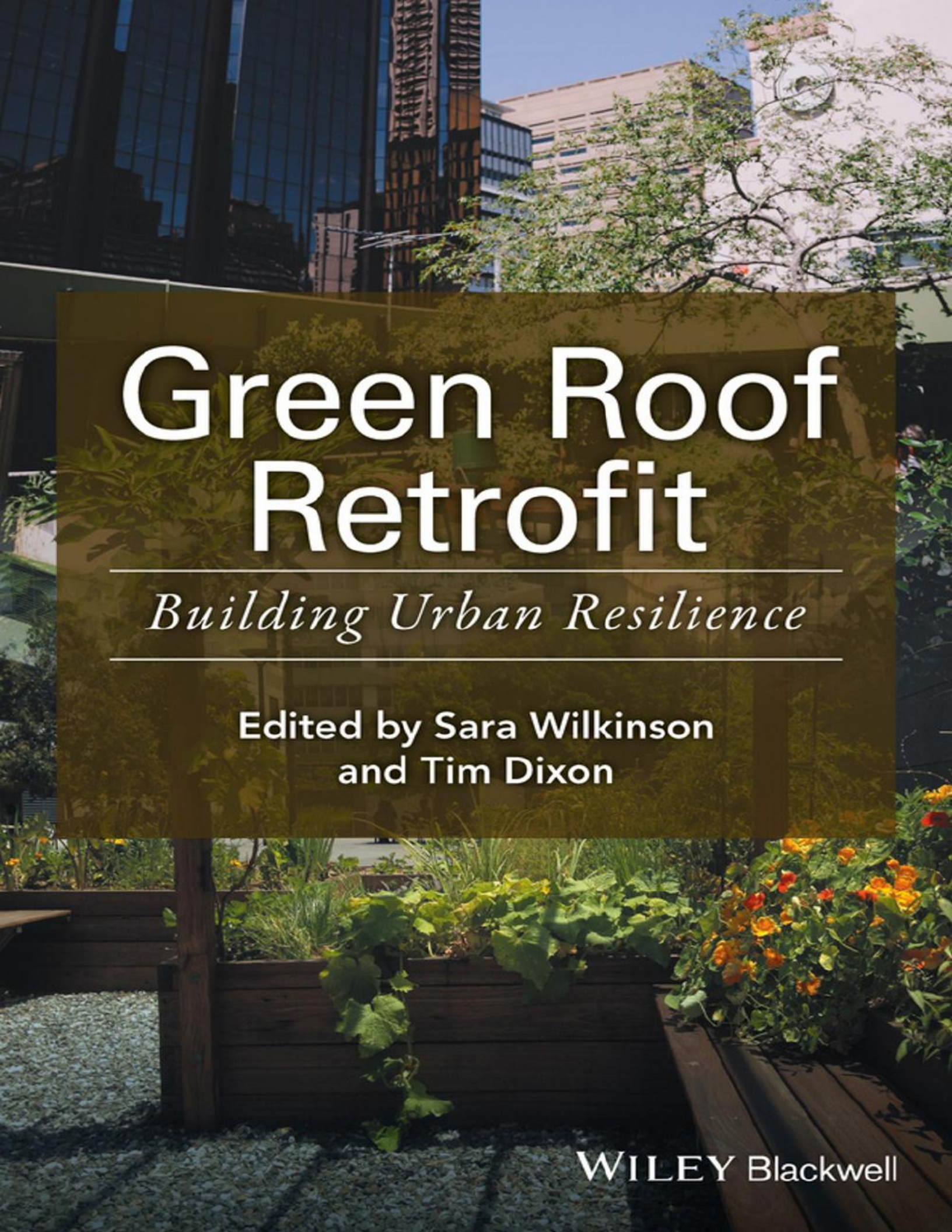
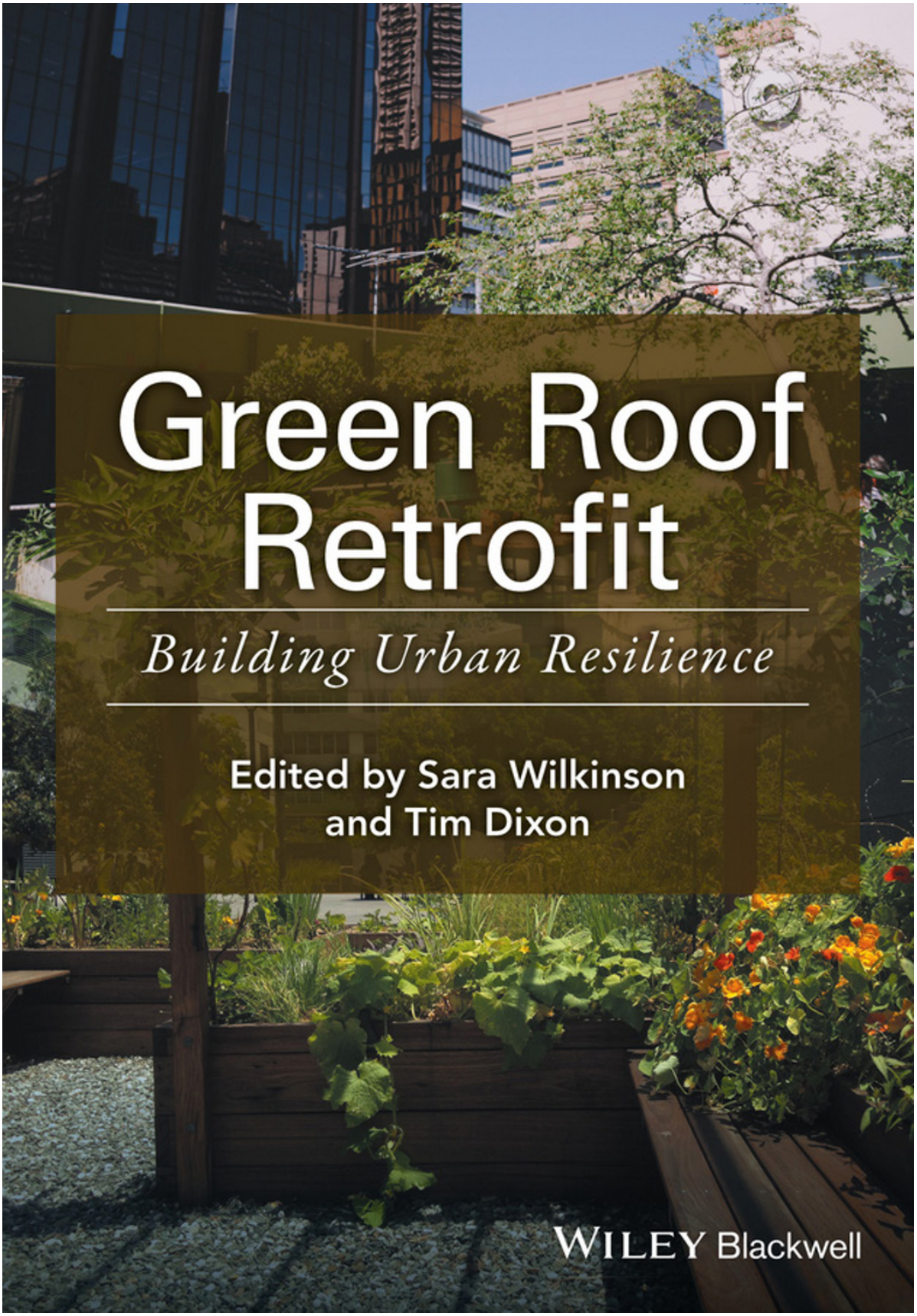


# Green Roof Retrofit

## *Building Urban Resilience*

Edited by Sara Wilkinson
and Tim Dixon

WILEY Blackwell


Green Roof Retrofit
Building Urban Resilience
Edited by Sara Wilkinson and Tim Dixon
WILEY Blackwell

**Green Roof Retrofit**

**Green Roof Retrofit:**

**Building Urban Resilience**

Edited by

**Sara Wilkinson**

Associate Head of School Research & External Engagement

Faculty of Design Architecture and Building

University of Technology Sydney

Australia

and

**Tim Dixon**

Professor of Sustainable Futures in the Built Environment

School of the Built Environment

University of Reading

UK

This edition first published 2016

© 2016 by John Wiley & Sons, Ltd.

*Registered Office*

John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom.

*Editorial Offices*

9600 Garsington Road, Oxford, OX4 2DQ, United Kingdom.

The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom.

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our

website at www.wiley.com/wiley-blackwell.

The right of the author to be identified as the author of this work has been asserted in accordance with the UK Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Designations used by companies to distinguish their products are often claimed as

trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author(s) have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If

professional advice or other expert assistance is required, the services of a competent professional should be sought.

*Library of Congress Cataloging-in-Publication data applied for*

ISBN: 9781119055570

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover Image: Courtesy of the Author

Set in 10/12pt Sabon by SPi Global, Pondicherry, India

1 2016

**Contents**

*Notes on Editors*

x

*Notes on Contributors*

xi

*Foreword*

xiv

*Acknowledgements*

xvi

**Chapter 1 Building Resilience in Urban Settlements**

**Through Green Roof Retrofit**

**1**

1.0 Introduction

1

1.1 Background and Context: Green Infrastructure

2

1.1.1 Green Roofs

4

1.2 Extensive and Intensive Systems

5

1.3 Valuing Green Infrastructure and Wider Economic Benefits

5

1.4 Measures of Greenness in Cities and the Growing Market for Green Roofs

7

1.5 A Growing Global Market for Green Roofs

7

1.6 Overview of the Structure of the Book

8

1.7 Conclusion

12

References 12

**Chapter 2 Technical and Engineering Issues in Green Roof Retrofit**

**14**

2.0 Introduction

14

2.1 Technical and Engineering Considerations

15

2.2 Roof Structure and Covering Typologies

15

2.2.1 Pitched Roof Structures

15

2.2.2 Pitched Roof Coverings

16

2.2.3 Flat Roof Structures

18

2.2.4 Flat Roof Coverings

19

2.2.5 Other Roof Designs

20

2.2.6 Green Roof Modular Systems

20

2.3 Available Space

21

2.4 Structural Capacity

21

2.5 Waterproof Membranes and Insulation

23

2.6 Drainage

24

2.7 Heritage

24

2.8 Green Roof Access

24

2.8.1 Access for Maintenance

25

2.8.2 Temporary or Permanent Access Strategies

25

2.8.3 Maintenance

Frequency 26

2.9 Other Issues

26

vi Contents

2.10 How to Determine Which Green Roof Type is Best Suited to Different Structures

26

2.11 Illustrative Case Studies

27

2.11.1 Australia – Surry Hills Library and Beare Park, Sydney

27

2.11.2 Brazil

30

2.11.3 1214 Queen St West, Toronto, Ontario, Canada

33

2.11.4 107 Cheapside, London, UK

34

2.12 Conclusions

35

References 36

**Chapter 3 Green Roof Retrofit and the Urban Heat Island**

**37**

3.0 Introduction

37

3.1

Defining the Urban Heat Island

37

3.1.1

UHI Impacts on Environment, Society and Economy

39

3.2

Microclimatic Effects of Rooftop Greening

40

3.3

Green Roof Cooling Mechanisms

43

3.4

Green Roof Retrofit for UHI Mitigation – Defining

the Boundaries 45

3.4.1

Roof Availability and Suitability

45

3.4.2

Design Considerations – Intensive Versus Extensive

46

3.5

Green Roof Retrofit for UHI Mitigation – Developing

the Model 47

3.5.1

Overview of Methods

47

3.5.2

Modelling Roof Availability and Suitability

48

3.5.3

Modelling Thermal Performance

49

3.6

Model Implementation – Evaluating Sydney's Surface

and Canopy-Layer Heat Islands

50

3.7

Green Roof Retrofit for UHI Mitigation – Model Implementation 55

3.8 Conclusions – Where to from Here? 57

3.8.1 Limitations of the Research and Opportunities for Further Work 58

References 59

**Chapter 4 Thermal Performance of Green Roof Retrofit 62**

4.0 Introduction 62

4.1 Green Roof Retrofit and Thermal Performance 63

4.2 Research Methodology 67

4.3

Case study: Rio de Janeiro and Sydney

68

4.3.1

Rio de Janeiro Case Study

69

4.3.2

Sydney Case Study

74

4.3.3

Evaluation of Rio de Janeiro and Sydney Cases

78

4.4 Conclusions

80

References 82

**Chapter 5 Stormwater Attenuation and Green Roof Retrofit**

**85**

5.0 Introduction

85

5.1

The Problem of Pluvial Flooding

86

5.2

Specifications for Stormwater Roofs and Issues for Retrofit

88

Contents vii

5.2.1 Technical and Physical Issues in Retrofit

88

5.2.2 Estimating Runoff Reduction

89

5.3 Modelling for City-Scale Stormwater Attenuation

90

5.3.1 Melbourne, Australia

92

5.3.2 Newcastle-upon-Tyne, UK CBD Database

95

5.3.3 Melbourne and Newcastle Runoff Estimation

97

5.4 Assessment of Retrofit at a Building Scale

99

5.4.1 Portland Ecoroof Programme

101

5.5 Conclusions – Where to Next?

102

References 103

**Chapter 6 Biodiversity and Green Roof Retrofit**

**106**

6.0 Introduction

106

6.1 What is Biodiversity?

108

6.2 Green Roofs for Vertebrate Conservation

109

6.3 Green Roofs for Invertebrate Conservation

110

6.4 Conclusions

112

6.4.1 Designing Biodiverse Green Roofs

113

References 115

**Chapter 7 Planting Choices for Retrofitted Green Roofs**

**118**

7.0 Introduction

118

7.1 Ecosystem Services Delivery By Green Roofs: The Importance of Plant Choice

120

7.2 Plant Species Choice and Building Cooling/Insulation

120

7.2.1 Plants and Cooling – Basic Principles

120

7.2.2 Plant Species Choice and Summer-Time Surface Cooling

123

7.2.3 Plant Species Choice and Winter-Time Insulation

129

7.3 Plant Species Choice and Stormwater Management

130

7.4 Greater Plant Variety can Enhance Urban Biodiversity

133

7.5 Plant Choices and Particle Pollution Mitigation

134

7.6 New Plant Choices and Adaptation of Current Green Roof Systems

134

7.7 Conclusions and Future Work

135

References 136

**Chapter 8 Green Roof Retrofitting and Conservation of Endangered Flora**

**140**

8.0 Introduction

140

8.1 Biodiversity Conservation – a Strategic Overview

141

8.2 A Review of Green Roofs in Habitat Conservation

143

8.3 Knowledge Gaps and Further Research

146

8.3.1 A Research Programme for Conserving Endangered Species on Green Roofs

147

8.3.2 The Endangered Community of the Eastern

Suburbs Banksia Scrub 147

8.4 A Model Research Design for Species Conservation

149

8.4.1 Extensive or Intensive Roofs?

149

8.4.2 Research Objectives

150



8.4.3

Guiding Principles for ESBS Regeneration

152

8.4.4

Preparatory Steps

152

8.4.5 Monitoring

153

8.4.6

Expected Outcomes

153

8.5 Conclusions

154

References 154

**Chapter 9 Urban Food Production on Retrofitted Rooftops**

**158**

9.0 Introduction

158

9.1

Green Roof Retrofit and Urban Food Production

159

9.2

Stakeholders and Urban Food Production

161

9.3

Contamination and Air-Quality Issues

162

9.3.1

Types of Pollutant

163

9.3.2

Most Urban Soils are Contaminated

164

9.3.3

Do Contaminants Accumulate in Urban Crops?

165

9.3.4

Mitigating Urban Crop Contamination

167

9.3.5

Urban Gardens and Air Quality

169

9.4

The Research Design and Methodology

170

9.4.1

Case Studies

171

9.4.2

Gumal Student Housing

171

9.4.3

Science Roof

173

9.4.4

Vertical Gardens

175

9.4.5

Results and Interpretation

176

9.4.6 Findings

180

9.5

The Carbon Footprint of Food Grown on Demonstration Beds

180

9.6

Potential Reductions in Carbon Footprint

181

9.7 Conclusions

183

References 183

**Chapter 10 Social Aspects of Institutional Rooftop Gardens**

**189**

10.0 Introduction and Objectives

189

10.1 Social Aspects, Productivity and Sustainability Potential

of Rooftop Gardens

190

10.2 Methodology

193

10.2.1 Comparative Analysis of Eight University Rooftop

Garden Case Studies 195

10.2.2 Semi-Structured Interviews with UTS Roof

Gardening Club

195

10.2.3 107 Projects Rooftop Garden: A Sensory Ethnography 196

10.3 Main Findings

197

10.3.1 Comparative Analysis of Eight Rooftop Gardens

in Universities 197

10.3.2 Qualitative Analysis of UTS Roof Gardening Club

Semi-Structured Interviews

198

10.3.3 107 Projects Rooftop Garden, Sydney

205

10.3.4 St Canice Kitchen Garden, Kings Cross, Sydney

208

10.4 Recommendations, Discussions and Conclusions

209

Acknowledgement 212

References 212



**Chapter 11 Cool Roof Retrofits as an Alternative to Green Roofs**

**216**

11.0 Introduction

216

11.1 What is a Cool Roof?

216

11.2 Background – How does a Cool Roof Work?

217

11.3 Cool Roof Studies and Measurements

217

11.4 The Experiments

218

11.4.1 Results

219

11.4.2 Other Residential Building Typologies

228

11.4.3 Impact of CRP on PV Energy Generation

231

11.5 Conclusions

232

11.5.1 Negative Impacts of Cool Roofs

232

11.5.2 Green Roofs Versus Cool Roofs

232

11.5.3 Cool Roofs and Retrofits

233

11.5.4 Barriers and Stakeholders

233

Acknowledgements 233

References 234

**Chapter 12 Looking to the Future**

**235**

12.0 Introduction

235

12.1 City-level Actions: Basel and Paris

235

12.2 City-level Actions: Requirements or Inducements?

237

12.3 Tools and Information Sources

240

12.4 Green Roofs: The Big Picture of GI and Future Developments
241

12.5 Recognising the Multiple Benefits of Green Roof Retrofit

243

12.6 Overall Conclusions

244

References 245

*Appendices*

247

*Appendix 1: A Checklist for Appraising the Suitability*

*of an Existing Roof for Green Roof Retrofit*

247

*Appendix 2: Checklist for Designers of Biodiverse Green Roofs*

250

*Appendix 3: Tools, Information Sources and mapping/GIS for*

*Green Roofs – Some Examples*

253

*Index*

257

**Notes on Editors**

**Associate Professor Sara Wilkinson**

Sara is Associate Head of the School of Built Environment for Research and

External Engagement, a Chartered Building Surveyor, a Fellow of the Royal

Institution of Chartered Surveyors (RICS) and a member of the Australian

Property Institute (API). She has worked in UK and Australian universities

over 25 years. Her PhD examined building adaptation, whilst her MPhil

explored the conceptual understanding of green buildings. Her research

focus is on sustainability, adaptation of the built environment, retrofit of

green roofs and conceptual understanding of sustainability. Sara sits on

professional committees for RICS to inform her research and to ensure

direct benefit to industry. She sits on the editorial boards of five leading

international journals and is Regional Editor for *Structural Survey* in

Australasia. Sara has published over 100 articles and books. Her research

is published in academic and professional journals, and mostly recently a

RICS Best Practice Guidance Note on Green Roofs and Walls for RICS

practitioners.

**Professor Tim Dixon**

Tim Dixon is Professor of Sustainable Futures in the Built Environment at

the University of Reading (School of the Built Environment). With more than

30 years' experience in education, training and research in the built environ-

ment, he leads the Sustainability in the Built Environment network at the

University of Reading and is co-director of the TSBE doctoral training centre

(Technologies for a Sustainable Built Environment). He led the Urban

Foresight Laboratory work package of EPSRC Retrofit 2050, and is currently

working with local and regional partners to develop a ‘Reading 2050’ smart

and sustainable city vision, which connects with the UK BIS Future Cities

Foresight Programme. He is working on a smart cities and big data project

for RICS Research Trust. Tim is a member of the Climate Change Berkshire

Group and a member of the All Party Parliamentary Group on Smart Cities.

He is also a member of the editorial boards of four leading international

real-estate journals; a member of the Advisory Board for *Local Economy*;

and a member of the review panel of the RICS Research Paper Series. He has

written more than 100 papers and books in the field. He is also a member of

the international scientific committee for the national ‘Visions and Pathways

2040 Australia’ project on cities.

**Notes on Contributors**

**Assistant Professor Lu Aye** has over 35 years of engineering experience in

university teaching, research, development, demonstration and commercial-

isation of renewable energy and energy efficiency technologies. He is a

leading expert in modelling, simulation and optimisation of energy systems.

**Dr John Blair** heads the Master of Sustainable Development course as part

of UNSW’s Sustainable Built Environment programme. He is currently

undertaking research on greening rail corridors to secure a range of benefits,

particularly carbon storage and sequestration.

**Dr Tijana Blanusa** completed a PhD in Plant Biology and joined the Royal

Horticultural Society where she is Principal Horticultural Scientist, based at

the University of Reading. Her research interests are in understanding the

provision of ecosystem services by urban vegetation. She runs projects inves-

tigating the contribution of green roofs, green walls, garden hedges and

other forms of green infrastructure to the moderation of air temperatures,

capture of rainwater and aerial particulate pollutants.

**Dr Ross Cameron** is a horticultural scientist who specialises in urban green

infrastructure and leads a research team covering various aspects of ecosys-

tem service delivery and climate change adaptation in landscape plants.

This includes research on green roof and green wall plants and their impact

on the thermal properties of built structures.

**Dr Renato Castiglia Feitosa** has a Civil Engineering degree from the State

University of Rio de Janeiro (1996), an MSc (2003) and a PhD (2007) in

Coastal and Oceanographic Engineering from the Federal University of Rio

de Janeiro. He is a lecturer at the University Estacio de Sa and a researcher

at the National School of Public Health (ENSP) – Oswaldo Cruz Foundation

(FioCruz).

**Dr Sumita Ghosh** is an academic, architect and urban planner who focuses

on responsive urban design and spatial planning in the School of Built

Environment at UTS. She has over 20 years' teaching, research and

professional experience for government, local councils, research organi-

sations and universities in Australia, New Zealand and India. Her research



focuses on urban sustainability and green infrastructure planning (urban

forestry and local food production).

**Dr Angela Giovanangeli** teaches in the School of International Studies at the

University of Technology Sydney. Her research examines cultural initiatives

and urban regeneration.

**Dr Dominique Hes** is an academic at the University of Melbourne specialis-

ing in multidisciplinary approaches to complex questions. Her recent book

*Designing for Hope: Pathways to Regenerative Sustainability* explores the

power of projects that provide social and ecological benefits; green infra-

structure is a key element of this.

**Dr Matthias Irger** is an architect and urbanist who specialises in climate-

responsive design and planning. His research interests focus on the effect of

the built environment on the urban microclimate to improve the heat resil-

ience and carbon footprint of cities.

**Chris Jensen** draws on his 12 years as an ESD consultant to provide indus-

try-relevant research in architectural science and construction innovation.

He has a particular interest in new technology for passive performance.

**Sarah Kemp** is undertaking a PhD in the School of Agriculture, Policy and

Development, where she is investigating the impact of plant species choice

on green roofs and the ability of green roofs to sequester rainwater.

**Dr Jessica Lamond** is Associate Professor in the Centre for Floods,

Communities and Resilience at the University of the West of England.

Jessica's research focuses on understanding the socio-technical aspects of

structural and non-structural responses to flood risk and climate adaptation

in the built environment. This includes work on the multiple benefits of blue

green infrastructure as a flood and stormwater management approach.

Jessica has published widely, including in leading journals such as *Housing*

*Studies*, *Urban Design and Planning* and *Journal of Risk Research*, and is co-author of the World Bank integrated handbook *Cities and Flooding*.

**Dr Tanya Latty** is an entomologist with a special interest in insect behaviour

and ecology. She has a BSc in Biology and Environmental Science from Trent

University (Canada) and a PhD in insect ecology from the University of

Calgary (Canada). Her highly interdisciplinary work involves local and

international collaborations with researchers in a broad range of fields

including mathematics, computer science, forestry and operations research.

**Dr Paul Osmond** is Director of the Sustainable Built Environment Programme

at the University of New South Wales in Sydney, Australia. His research

interests cross a range of topics in the broad domain of built environment

sustainability.

Notes on Contributors xiii

**Professor David Proverbs** began his academic career in 1994, following

10 years of project management experience in the UK construction sector.

He is Associate Dean – International in the Faculty of Computing,

Engineering and the Built Environment at Birmingham City University.

From 2013 to 2014 he was Co-Director, Centre for Flooding Communities

and Resilience, University of the West of England. He has published widely

on the topic of flooding and disaster prevention and management. David

chairs the UK Council of Heads of the Built Environment (CHOBE) and

co-edits *Structural Survey – Journal of Building Pathology and Refurbishment*.

**Dr Fraser Torpy** AssDipAppSc (STC), BSc (Hons) (UTS), PhD (UTS) started

at UTS in 1991 and currently lectures in the School of the Environment. He

has been undergraduate programme director for all environmental courses

since 2013. His research focuses on the relationship between plants and

urban environmental quality, with a current emphasis on several aspects

related to green wall technology and urban greening. He has over 15 years'

experience in horticultural biotechnology and has been instrumental in

broadening our understanding of how plants can contribute to improved air

quality in cities. He is director of the Plants and Environmental Quality

Research Group at UTS.

**Dr Ilaria Vanni** is a teacher and researcher in the School of International

Studies at the University of Technology Sydney. Her research is in the field

of cultural history, with a focus on urban activism.

**Dr Madalena Vaz Monteiro's** PhD investigated the impact of plant structure

and function on temperature regulation and the surface energy balance.

Currently, she is involved with research aiming to better understand ecosystem

services delivery by urban trees.

## Foreword

When British Land first started creating green roofs on various London

office buildings in 2004, it was challenging to take the idea from an ecolo-

gist's vision to the reality of a planted, healthy landscape. As a client, we

were testing a new idea. We often needed to introduce our architects, struc-

tural engineers, contractors and property management partners to the

concept – and then develop and test strategies together to deliver quality

natural habitats on commercial buildings.

Over the years, as we have installed different green roof styles and commis-

sioned studies, we have learned and shared many lessons. Today, we know

more, for instance, about drainage and the potential for (or, more often, lack

of) water retention. We understand the need for roof and terrace access to

align with internal floor levels. We know which substrates last through British

winters and how to plan for rooftop winds. We recognise issues and opportu-

nities relating to visibility from surrounding buildings, and more. Happily, we

have not been the only ones to recognise the benefits of green roofs and to

learn these lessons.

Green roofs have gone mainstream around the world over the past 10 years.

From London to Sydney, Hamburg to Istanbul, Singapore to Rio de Janeiro,

they are a recognised strategy for urban green infrastructure. In London, there

are now about 700 green roofs, covering 175,000 m2. I am pleased that British

Land has played a small but important part in this success story – creating

green roofs on 12 new buildings and retrofitting three on existing buildings,

with more on the way. Green roofs are no longer an unusual concept, and there

are standard design formats and green roof types that architects and others

understand and can design or install.

However, many of the technical benefits of green roofs remain to be ana-

lysed and understood. And so this book and the research it describes are

much needed, particularly at a time when strengthening urban resilience is a

critical policy issue.

Of particular relevance to cities and property owners are the prospects for

retrofitting green roofs and the infrastructure benefits that all green roofs

provide. Given the acres of existing roof space in cities around the world,

what kind of buildings are particularly suitable for the additional structural

load of retrofitting green roofs? With increasing incidence of flooding in

many areas, how much rainwater can a 50 cm soil substrate attenuate, and

can we make basement flood attenuation tanks correspondingly smaller?

Also, how can we deliver green roofs that fulfil multiple functions, such as

biodiversity, human enjoyment, aesthetics and food production?

Approaches to modelling urban heat island impacts are particularly useful

for policy-makers. As climate change increasingly affects city temperatures,

with knock-on effects on people's health and energy consumption, it is

important to be able to calculate the benefit of green roofs for temperature

management. Likewise, the proposed methodology for calculating the

attenuation potential of green roofs should be of immediate assistance in

factoring green roofs into strategies for our changing weather futures.

In addition, this book helpfully advances research on the social and

biodiversity functions of green roofs for organisations interested in strate-

gies to support human health, ecology and food production in urban areas.

An in-depth analysis of a range of case studies explores how green roofs

fulfil a range of functions – adding visual interest, creating garden spaces,

growing food, introducing habitats for animal biodiversity and contributing

to healthy environments through air-quality filtration, water management

and temperature control. My colleagues are particularly interested in this

social potential of green roofs. Following examples in the USA and Asia, we

are exploring how to use our roof spaces to further promote people's health

and wellbeing in the places we create.

I am delighted to recommend this book for its timely and substantial

contribution to industry practice, and for improving our understanding of

green roofs and their multiple benefits. The editors (Sara Wilkinson and Tim

Dixon) have drawn together a diversity of authors to provide technical anal-

ysis of the practical and policy advantages of green roofs for cities facing

climate change, with diverse case studies from Australia, the UK and Brazil.

The research insights can also be tapped by property owners and designers

to realise the commercial, social and environmental benefits of green

roofs – from improving resource management in our cities to creating

opportunities for bees, butterflies, birds and people to flourish in the built

environment.

Green roofs have enormous potential in urban areas around the world. I

hope that this book will aid cities and organisations in developing and

growing acres of delightful and valuable habitats for people and the planet.

Sarah Cary

Head of Sustainable Places

British Land

**Acknowledgements**

Multidisciplinary projects are always challenging, exciting and fun, and

working on this book together with our contributing authors has been no

exception. The starting point was an increasing recognition that green roofs

can really make an important difference in helping build ‘urban resilience’

(or the ability of our urban areas to be flexible and agile enough to bounce

back from the anticipated and unanticipated environmental shocks stem-

ming from rapid urbanisation, climate change and resource depletion).

This is at the heart of the book, and is one of the key reasons so many cities

globally are engaging with city-wide projects to green their environments –

particularly so that they can adapt and mitigate for climate change.

The inspiration for this book arose from Sara Wilkinson's membership of

the City of Sydney Technical Advisory Panel from 2012 to 2014. During

that time, Sara met with a multidisciplinary group of academics, practition-

ers and policy makers to work on ways to increase the uptake of green roofs

within the City of Sydney. Lucy Sharman was the City of Sydney Green

Roof & Green Walls Officer, and being a member of the group really raised

awareness of the multiple benefits of green roofs. Sara wishes to thank Lucy

for that. As a building surveyor she was well aware of the need to retrofit

our urban environments, but being part of the group increased the belief

that collectively, we can create and deliver change. Membership of the group

led to a number of new and exciting green roof research collaborations and

projects with mental healthcare professionals, disadvantaged groups and

sustainable urban agriculture entrepreneurs. Sara wishes to thank the RICS

Research Trust, City of Sydney and NSW Environmental Trust for funding

some of that research, which features in this book. Sara still works with

other academic members of the Technical Advisory Panel group, who have

contributed to this book. The Technical Advisory Panel has evolved and

broadened now into the National Green Infrastructure Network (NGIN),

comprising academics and practitioners from several Australian universities

and national research organisations as well as NSW state policy makers.

Writing a book is always a journey, and we were fortunate on this particu-

lar journey to have the company and wise counsel of a truly international

and multidisciplinary group of 20 academics. The geographical spread of

knowledge and expertise ranged from Brazil to the UK, Europe and Australia,

covering a wide range of climates and temperature zones. We really wanted

to create a resource that covered every type of green roof retrofit and as

many professional, technical, legal and stakeholder aspects as possible. The



disciplines that have contributed include Building Surveying, Horticultural

Science, Civil Engineering, Urban Planning, Architecture, Urbanism, Environ-

mental Sustainability Consultancy, Entomology, Flood & Disaster Prevention

Management, and Social Sciences. This is a rich and empowering environ-

ment in which to work, and we would like to thank all our contributing

authors for their expertise and inputs to the text. This is the first book we

are aware of that covers such a breadth of reasons to adopt green roofs from

the retrofit perspective, and our aim is to facilitate the retrofit of greater

numbers of green roofs as a result.

We also wish to personally thank the staff at Wiley Blackwell, Madeleine

Metcalfe and Viktoria Vida for their support and help in delivering the

book, and Sarah Cary of British Land for her foreword.

Finally, writing a book always takes time. Without the support and

encouragement of family and friends the task would be much harder, so

Sara would like to thank Ted, Ruskin, Maureen and Lindsay. Tim would

also like to thank his family for all their help and support during the editing

and writing process.

**Sara Wilkinson and Tim Dixon**

**1**

# Building Resilience in Urban Settlements Through Green Roof Retrofit

**Tim Dixon1 and Sara Wilkinson2**

1 University of Reading, UK

2 UTS, Australia

## 1.0 Introduction

The ‘challenge of achieving sustainable development in the 21st century

[will] be won or lost in the world’s urban areas’ (Newton and Bai, 2008: 4)

and a major issue is the contribution that the built environment makes to

greenhouse gas (GHG) emissions and global warming. Typically each year

1–2% of new buildings are added to the total stock; it follows that informed

decision-making in respect of sustainable adaptation of existing stock is

critical to deliver emissions reductions. Within cities, local government

authorities are encouraging building adaptation to lower building-related

energy consumption and associated GHG emissions. Examples include San

Francisco in the USA and Melbourne in Australia. For example, the City of

Melbourne aims to retrofit 1200 commercial central business district (CBD)

properties before 2020 as part of their strategy to become carbon neutral

(Lorenz and Lützkendorf, 2008). Office property contributes around 12%

of all Australian GHG emissions and adaptation of this stock is a vital part

of the policy (Garnaut, 2008). Whilst Australian cities date from the early

19th century, the concepts of adaptation and evolution of buildings and

suburbs are not as well developed or entrenched as in other continents

like Europe. However, the issue of the sustainable adaptation of existing

stock is a universal problem, which increasing numbers of local and state

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



governments will endeavour to address within the short to medium term. In

most developed countries we now spend more on building adaptation than

we do on new construction. Clearly there is a need for greater knowledge

and awareness of what happens to commercial buildings over time.

There are a range of definitions for ‘urban resilience’, and a marked lack of

agreement as to what the concept means. However, there is an underlying mean-

ing which covers the ability to bounce back from external shocks, and Meerow's

et al's (2016: 39) definition provides a comprehensive and up to date focus:

'Urban resilience refers to the ability of an urban system….to maintain or rap-

idly return to desired functions in the face of a disturbance, to adapt to change,

and to quickly transform systems that limit current of future adaptive capacity'.

Green roofs therefore not only offer an important element in developing urban

resilience across a range of scales (building, neighbourhood and city), but also

in helping create adaptive capacity to deal with future environmental distur-

bances, both of which are key themes explored throughout this book.

This book is intended to make a significant contribution to our under-

standing of best practice in sustainable adaptations to existing commercial

buildings in respect of green roof retrofit by offering new knowledge-based

theoretical and practical insights, and models grounded in results of empiri-

cal research conducted within eight collaborative construction project team

settings in Australia, the UK and Brazil (see Section 1.6 below). The results

clearly demonstrate that the new models can assist with informed decision-

making in adaptations that challenge some of the prevailing solutions based

on empirical approaches, which do not appreciate and accommodate the

sustainability dimension. Hence, the studies collectively offer guidance

towards a balanced approach to decision-making in respect of green roof

retrofit that incorporates sustainable and optimal approaches towards

effective management of sustainable adaptation of existing commercial

buildings; from strategic policy-making level to individual building level.

## 1.1

## Background and Context: Green Infrastructure

Green infrastructure (GI) is a term used to describe all green and blue spaces

in and around our towns and cities, and as such is very much a collective

term embracing parks, gardens, agricultural fields, hedges, trees, woodland,

green roofs, green walls, rivers and ponds (RTPI, 2013). The concept evolved

for thinking in the USA and the ‘greenway’ movement, which highlighted

the importance of using networks to manage green space and achieve

multiple aims and objectives (Roe and Mell, 2013). In the North American

context, therefore, GI was originally based around conservationist princi-

ples, and in Europe it has evolved into a holistic and cross-cutting agenda.

In the UK, GI principles have now flowed into a range of policy, practice

and guidance for built environment professionals. In England, national

planning policy (through the National Planning Policy Framework, NPPF)

(Communities and Local Government, 2012) places an emphasis on local

planning authorities to plan strategically for networks of green infrastruc-

ture, and to take account of the benefits of GI in reducing the risks posed

**Table 1.1** Examples of GI assets (TCPA, 2012)

| | |
|---|---|
| Natural and semi-natural | Including woodland and scrub, grassland (e.g., |
| rural and urban green | downland and meadow), heath and moor, wetlands, |
| spaces | open and running water, brownfield sites, bare rock |
| habitats (e.g., cliffs and quarries), coasts, beaches and | community forests. |
| Parks and gardens | Urban parks, country and regional parks, formal and |
| private gardens, institutional grounds (e.g., at schools | and hospitals). |
| Amenity green space | Informal recreation spaces, play areas, outdoor sports |
| facilities, housing green spaces, domestic gardens, | community gardens, roof gardens, village greens, |
| commons, living roofs and walls, hedges, civic spaces, | highway trees and verges. |
| Allotments, city farms, | |

orchards, suburban and

rural farmland

Cemeteries and

churchyards

Green corridors

Rivers and canals (including their banks), road verges

and rail embankments, cycling routes and rights of way.

Sites selected for their

Sites of Special Scientific Interest and Local Sites (Local

substantive nature

Wildlife Sites and Local Geological Sites); Nature

conservation value

Reserves (statutory and non-statutory).

Green space designations

Selected for historic significance, beauty, recreation,

wildlife or tranquillity.

Archaeological and

historic sites

Functional green space

Such as sustainable drainage schemes (SuDS) and flood

storage areas.

Built structures

Green (or living) roofs and walls, bird and bat boxes,

roost sites within existing and new-build developments.

by climate change. The NPPF defines GI as: ‘a network of multi-functional

green space, urban and rural, which is capable of delivering a wide range

of environmental and quality of life benefits for local communities’

(Communities and Local Government, 2012: 52). Similarly, the UK’s natural

environment white paper (HM Government, 2011) offers explicit support

for green infrastructure as an effective tool in managing environmental risks

such as flooding and heatwaves.

GI is seen very much as a multi-functional asset therefore and so relates

to making the best use of land to provide a range of valuable goods and

services (see Table 1.1). GI is also underpinned by the concept of ‘ecosystem

services’, which are provided by the range of GI assets. Work by the UK

National Ecosystems Assessment, for example, includes the following as

key ecosystem services:

■

Supporting services – those necessary for all other ecosystem services

such as soil formation and photosynthesis.

4

Green Roof Retrofit

■

Provisioning services – such as food, fibre and fuel.

■

Regulating services – including air quality and climate.

■

Cultural services – such as recreational activities and wellbeing, aesthetic

values and sense of place.

By thinking in this way about assets and services, it requires us to think

more closely about the overall costs and benefits of GI as a service-producing

infrastructure (UKGBC, 2015). One of the key attractions of GI is its multi-

functionality, or its ability to perform several functions and provide several

benefits on the same spatial area (EC, 2012). These functions can be envi-

ronmental, such as conserving biodiversity or adapting to climate change,

social, such as providing water drainage or green space, and economic, such

as jobs creation or increasing property prices for owners.

As the European Commission (EC, 2012) suggests, a good example of

this multi-functionality is provided by the urban GI of a green roof, which

reduces stormwater runoff and the pollutant load of the water, but also helps

reduce the urban heat effect, improves the insulation of the building and pro-

vides increased biodiversity habitat for a range of species. Thus it is this multi-

functionality of GI that sets it apart from the majority of its ‘grey’ counterparts,

which tend to be designed to perform one function, such as transport or drain-

age without contributing to the broader environmental, social and economic

context (Naumann *et al*., 2011; EC, 2012). In this way GI has the potential to

offer ‘no regrets’ solutions by dealing with a range of important problems and

producing the maximum number of cost-effective benefits.

GI has a wide range of health and wellbeing and environmental benefits,

through improved mental wellbeing and better physical activity, as well

as reduced exposure to pollution and high urban temperatures (POST,

2013). Although in the UK some local authorities (such as Birmingham,

London, Manchester and Plymouth) have developed GI strategies, this is

variable, and with the exception of SuDS, new GI is not *required* by national

legislation. In Australia, the adoption of GI is at state and city level and

varies between states and cities. Plans and strategies have been made and

adopted, only to be amended and moved to other agencies. As such, no

coherent national policy exists currently.

**1.1.1**

## Green Roofs

Green roofs are an important and growing element of GI. Green roofs have

existed throughout history. Some of the earliest examples include the

Hanging Gardens of Babylon in 500BC (Figure 1.1), the ziggurats of

Mesopotamia and early Roman architecture (Berardi *et al*., 2014). Early

Viking housing and mediaeval buildings also employed green roofs, with the

technique also popular during the settling of the American west and in the

vernacular tradition of Scandinavia. During the 20th century Le Corbusier

also included them in his five points of modern architecture before the tech-

nology gained a real foothold in Germany (from the 1880s), then latterly in

France and Switzerland (Magill *et al*., 2011; Berardi *et al*., 2014). In comparison, the UK is a relatively recent innovator in green roofs (although the




Building Resilience in Urban Settlements Through Green Roof Retrofit 5

**Figure 1.1** The mythical Hanging Gardens of Babylon.

*Source*: Wikimedia.

technology was used to camouflage airfield buildings during World War II)

with some good examples in London (St James Tube Station), Manchester

(Metropolitan University), Edinburgh (Royal Bank of Scotland) and Cardiff

(Interpretation Centre).

## 1.2

## Extensive and Intensive Systems

Green roofs (also known as vegetation or living roofs) are an example of

a ‘no regrets’ adaptation measure that can serve multiple societal goals

(Mees *et al*., 2013). For example, they can offer a number of improved

public ecosystem services (or benefits), such as increased biodiversity,

improved air quality and mitigation of the urban heat island effect, as well

as having the ability to harvest rainwater and reduce surface runoff.

Similarly, they offer additional private benefits to property owners through

improved energy savings, thermal comfort and aesthetics, and can poten-

tially increase property values.

## 1.3

## Valuing Green Infrastructure and Wider Economic Benefits

There are clearly a range of benefits that green infrastructure can bring to

bear in adapting to, and mitigating for, climate change. Often these may be

indirect, through reduced flooding risk, which can increase property values

6

Green Roof Retrofit

**Table 1.2** Potential benefits of green infrastructure in a retail centre (NRDC, 2013) Green infrastructure

40,000 sq. ft green roof with 90% green coverage

improvements

50 strategically planted medium-sized trees

Bioswales and rain gardens that manage an inch of runoff from

2000 sq. ft adjacent impervious area

72,000 sq. ft permeable pavement parking lot

Cisterns to capture runoff from 5000 sq. ft of roof area and use for

irrigation

Building assumptions

Area: 40,000 sq. ft

One storey with 40,000 sq. ft roof

Lot area: 128,000 sq. ft

Permeable area: 5000 sq. ft (covered in turf)

Number of storeys: 15

Annual rent: $17 per sq. ft

Annual retail sales: $2.182m per store

Potential benefits

Energy savings (reduced demand for heating/cooling): $3560 p.a.

Avoided costs for conventional roof replacement: $607,750 NPV over 40 years

Tax credit: $100,000 for installation

Increased retail sales: $1.2m p.a.

Stormwater fee reduction: $14,020 p.a. (with projected 6% increase)

Total benefits (over 40 years) > $24,202,000

Non-quantified benefits

Water conservation (increase in net benefits)

Increased property value (significant increase in net benefits)

Reduced infrastructure costs (possible increase)

Reduced crime (possible increase)

Improved health and employee satisfaction (increase in net benefits)

Reduced flooding costs (uncertain impacts)

(Molla, 2015), or perhaps contributing to, for example, a higher sustainability

assessment rating through BREAAM1 or LEED2 (Berardi *et al*., 2014). Perhaps

key to understanding how cities could create real change in the built environ-

ment to bring about more sustainable outcomes is the commercial property

sector, comprising offices, retail and industrial properties. Theoretically, at

least, GI (including green roofs) could help increase property values, sales, save

energy and increase workplace productivity. Research by NDRC (2013) high-

lights how, in an office building, the total present value of benefits can

approach $2m and in a retail centre, $24m (with $23m of this in increased

sales). In the case of the retail centre, present value benefits were calculated

over a 40-year period using a 6% discount rate, and projected inflationary

rates with the location assumed as being Philadelphia (Table 1.2).

GI can, in a general sense, also reduce lifecycle costs associated with pri-

vate property improvements. Green roofs do not need to be replaced as

1 Building Research Establishment Environmental Assessment Methodology.

2 Leadership in Energy and Environmental Design.



frequently as conventional roofs – they are typically considered to have a life

expectancy of at least 40 years, compared with 20 years for a conventional

roof. For example, in a midsize retail building (with a 40,000 sq. ft roof), a

green roof could avoid a net present value of over $600,000 in roof replace-

ment costs over 40 years; a medium-sized office building, with a roof half

that size, could save over $270,000. In some instances, green roofs can also

reduce air conditioning system capital costs by allowing for use of a smaller

heating, ventilation and air conditioning (HVAC) system.

## 1.4

## Measures of Greenness in Cities and the Growing Market for Green Roofs

The Inter-American Development Bank (2014) suggest that Latin American

and Caribbean cities need to measure and benchmark the amount of green

space within their boundaries. A key indicator is suggested as being the

amount of green space (in hectares) per 100,000 inhabitants, with a green

rating as >50 ha, orange as 20–50 ha and red as <20 ha. Similarly, the World

Health Organisation (WHO) has suggested that every city should have a

minimum of 9 m2 of green space per person. An ‘optimal’ amount would sit

between 10 and 15 m2 per person. Indeed, one of the greenest cities in the

world is thought to be Curitiba in Brazil, with 52 m2 per person, followed

by Rotterdam and New York (Karayannis, 2014).

This increasing focus on green space and its role within a specific meas-

ure of urban sustainability has come at a time when there has also been an

increasing focus on how cities can become more self-sufficient in terms of

food production. Urban agriculture, which focuses on the development of

localised food systems within and close to urban areas, has been a frequent

feature of sustainable thinking in many cities (Hui, 2011). This is not

surprising, given that cities occupy only 2% of the global land surface but

consume 75% of the world's resources (Giradet, 2008), although by the

same token cities can also be relatively efficient in terms of per capita con-

sumption and emissions. There are many examples of what has been

termed 'zero acreage farming' (Z farming), which implies the non-use of

land/acreage, and which is a subset of the wider term 'urban agriculture'

(Specht *et al*., 2013; Thomaier *et al*., 2014). Examples include open rooftop farms, rooftop greenhouses, productive façades and indoor farming.

Clearly, green roofs which produce food are a key example of this growing

phenomenon.

## 1.5 A Growing Global Market for Green Roofs

In contrast to other markets such as photovoltaics (PVs) or biofuels, the

growth of green roofs and green walls (building-integrated vegetation, BIV)

is often driven by city-level actions rather than national policies. Green roofs

tend therefore to be driven by building code requirements and mandates or

financial incentives (or both).

8

Green Roof Retrofit

Previous estimates (Ranade, 2013) suggest that the green roof market

globally will be $7bn, comprising a $2bn market for suppliers of polymetric

materials and the balance for vegetation, installation and operations. This

reflects falling costs, and also the use of incentives and regulation. By 2017,

costs for green roof installation are expected to be cut by 28%, from an

average of $38 per sq. ft in 2012 to $23 per sq. ft in 2017. Green wall

growth is expected to be $680m by 2017. Europe has led the growth of

the green roof market over the last 20 years: for example, Germany has

86 million m2 of green roofs out of a total of 104 million m2 and already

10% of flat roofs are green. Similar growth levels have occurred in

Switzerland, where for example in Basel 70% of its green roof target has

been met. Despite this, there is considerable opportunity for green roof

growth in other European cities, such as London and Copenhagen. Wilkinson

and Reed (2009) estimated that 15% of commercial office roofs in the

Melbourne CBD could be retrofitted as green roofs. Despite this growth,

the sector faces key challenges. Generally speaking, most green roofs globally

have used sedum or drought-friendly irrigation, but green thinking is mov-

ing towards greater diversity in species – with payback periods of 30 years.

## 1.6

## Overview of the Structure of the Book

As this chapter and the book as a whole emphasises, roofs can fulfil a mul-

titude of objectives: attracting biodiversity, improving thermal performance,

attenuating stormwater runoff, mitigating the urban heat island, providing

space for urban food production, providing space for social interaction

and engagement, and possibly space for the reintroduction of endangered

species of flora and fauna. In most climates, therefore, green roofs can make

a positive contribution to building resilience to climate change and help to

arrest the speed of that change.

Furthermore, in addition to the primary reason for the retrofit, other

benefits co-exist. For example, a green roof retrofit in northern Europe for

improving thermal performance and saving energy not only results in less

GHG emissions but also attracts biodiversity, reduces stormwater runoff,

mitigates the urban heat island, and could provide space for the reintro-

duction of endangered species of local flora and fauna. Where access is

provided, the roof could also provide space for urban food production

and/or space for social interaction and engagement. These multiple benefits

make it an attractive option.

In Chapter 2, structural issues are taken into account by Renato Castiglia

Feitosa and Sara Wilkinson. Retrofit of the existing stock of buildings is

vital, as only 1–2% is added annually to the total stock of buildings, and

around 87% of the buildings that we will have by 2050 are already built

(Kelly, 2009). With regard to green roofs, the overriding issue is one of struc-

tural capacity to accommodate the additional loads that a retrofit brings.

This chapter considers the technical and engineering considerations that

stakeholders need to consider when evaluating green roof retrofit potential.

For example, existing structure, load-bearing capacity, access, power and



water supply, orientation, exposure to sunlight and overshadowing, and

occupational health and safety. In short, how to determine what type of

green roof is suited to the structure.

Issues of urban heat islands are raised in Chapter 3 by Paul Osmond and

Matthias Irger. The global climate change and the urban heat island (UHI)

phenomenon – whereby cities absorb and release more heat than the

surrounding countryside – carry growing potential to make urban life at

particular times and places an exercise in low-grade misery. The mitigating

role of urban vegetation and green spaces, reflective materials and strategies

for reducing the release of heat from human activities like transport and air

conditioning are increasingly well understood. Green roofs have also been

widely recognised as playing a part in UHI mitigation. This chapter reviews

the literature around the microclimatic effects of green roof retrofitting and

presents a model based on detailed remote-sensing data for metropolitan

Sydney, Australia. We apply this model to explore the effects of installing

extensive green roofs on 100% and 50% of rooftops across the variety of

urban form typologies which characterise Sydney's built environment.

The results suggest a modest but real reduction in heat island effects.

Thermal performance is the focus of Sara Wilkinson and Renato Castiglia

Feitosa in Chapter 4. Green areas have diminished in big cities and with

increasing temperatures, deterioration of air quality is a common result.

Consequently, there is a rise in air pollution and GHG emissions, the costs

of air conditioning, and mortality and heat-related illness. Due to the lack

of space in urban areas, green roof retrofit is a feasible alternative to this

problem. Green roofs improve the insulating qualities of buildings, attenuat-

ing heat exchange through inadequately insulated and poorly sealed roof

structures. After a review of the literature, this chapter reports an experi-

ment on two small-scale metal roofs in Sydney (Australia) and Rio de

Janeiro (Brazil) to assess the thermal performance of portable green roof

modules. In each site, two identical roofs, one covered with modular light-

weight trays planted with succulents and the other not, had their internal

temperature recorded simultaneously and compared. Green roofs were

showed to attenuate housing temperatures, indicating that green roof

retrofitting could lower the cooling energy demand considerably.

In Chapter 5, Jessica Lamond, David Proverbs and Sara Wilkinson

describe research demonstrating the assessment of whether to retrofit with

green roofs as a means of attenuating stormwater runoff. The problem of

pluvial flooding in terms of financial costs and the impact on our urban set-

tlements is the starting point for a discussion on the potential of retrofitted

green roofs as a mitigating measure. A range of technical specifications

for stormwater roofs, and critical issues to consider in retrofit of existing

buildings, are evaluated. Theoretical frameworks of the distributed benefits

of green roofs are presented, and a methodology to estimate the potential

for stormwater attenuation of green roof retrofit at the city-scale level is

described in detail. The chapter reports on recent empirical research under-

taken in two cities with very different climatic conditions: Melbourne,

Australia and Newcastle, UK, at city-scale level. Having examined the

city-scale level, a second illustrative case study at an individual building

10

Green Roof Retrofit

scale outlines stormwater performance and the assessment process in

Portland, Oregon. The chapter concludes by describing how the stormwater

effectiveness of green roofs may be limited in certain conditions by the avail-

ability of suitable buildings and the source of floodwater. A summary of the

potential benefits of green roof retrofit for stormwater attenuation is made.

The focus of Chapter 6 is the changes to biodiversity associated with green

roof retrofit and based on work by Tanya Latty, an entomologist. Green roof

retrofits have the potential to increase urban biodiversity by providing animal

habitats within highly urbanised areas. Indeed, many municipalities explicitly

list ‘benefits to biodiversity’ as part of the rationale for building or retrofitting

green roofs. But do green roofs actually increase animal biodiversity? Although

green roofs can provide food sources for bats and birds, there is little evidence

that the presence of green roofs actually increases bird or bat populations; in

at least one case, green roofs appear to act as an ecological trap, attracting

birds to build nests in habitats that cannot support their offspring. In con-

trast, green roofs support a wide variety of invertebrate species, but at levels

that are usually below those of other urban green spaces such as parks or

bushland fragments. Nevertheless, green roofs may play a role in urban

conservation by creating corridors through urban areas, effectively connect-

ing otherwise isolated populations. Future retrofits can increase invertebrate

biodiversity by providing structurally complex habitats, providing a mixture

of pollen and nectar-producing plants, and by using diverse substrates.

Plant survival and green roof installation/maintenance costs will long

remain prime considerations in planting choices for green roofs, and this

is covered in Chapter 7 by Tijana Blanusa, Madalena Vaz Monteiro, Sarah

Kemp and Ross Cameron. If low levels of funding, lack of horticultural

knowledge/experience and the need for reduced maintenance limit the

options, then developing a roof with succulents and grasses might be a way

to introduce some ecosystem benefits. However, in scenarios where a semi-

extensive substrate depth can be afforded and an investment in sustainable

irrigation (recycled rainwater, greywater) is possible, considering and using

a wider range of low-growing perennial species with light-coloured leaves,

higher leaf area indices (LAIs) and evapotranspiration (ETp) rates would

likely provide more benefits. The total direct cost of roof installation may

well be higher in that case but the argument in support of a more diverse

plant choice should be linked to the direct and indirect savings and benefits

which this planting produces over and above the simple extensive green

roof. These benefits include building insulation and temperature reduction,

localised air cooling effects, greater rainfall capture, more pollutant capture

per square metre, greater biodiversity support, etc.

In Chapter 8, John Blair and Paul Osmond consider the potential for

green roof retrofit to provide space for reintroducing or increasing the

amount of indigenous or endangered species. The multiple environmental,

social and economic benefits of green roofs are increasingly well understood

among built environment practitioners and in the broader community.

However, the issue of biodiversity protection and conservation of endan-

gered flora in our densifying cities has received much less attention than

benefits such as stormwater detention or building energy savings. This chap-

ter provides a brief strategic overview of urban biodiversity conservation

Building Resilience in Urban Settlements Through Green Roof Retrofit 11

before examining the current state of play regarding the application of roof

greening in the protection of endangered flora, including the identification

of key knowledge gaps. The Eastern Suburbs Banksia Scrub – a threatened

plant community indigenous to the coastal zone of Sydney, Australia – is

introduced here as the focus for a proposed five-year research programme

aimed at evaluating the role of green roofs in the management of this par-

ticular community and, it is hoped, helping to address the more general

research gaps around roof greening as a viable flora conservation strategy.

Food security is an issue that we need to be conscious of, and in Chapter 9,

Sara Wilkinson and Fraser Torpy examine the potential of green roof retro-

fit for urban food production. Human populations are becoming increas-

ingly urbanised and thus distanced, both physically and psychologically,

from the sources of their food. Decentralising food production from remote

rural regions to within urban centres will address both the growing sense

of disconnect and the growing costs associated with food transport. This

chapter describes the social, environmental and economic aspects of local-

scale urban food production, as well as setting out typical specifications and

considerations in respect of bed systems, with a focus on the health and

safety, technical, environmental and economic aspects of larger-scale roof-

top food production. Our empirical observations demonstrate that there is

great potential in most cities for the expansion of urban rooftop farming,

and that many of the traditional barriers to growing food in cities – such as

fears over food safety – can be overcome in virtually all situations.

As well as environmental sustainability, green roofs can provide social sus-

tainability. Sumita Ghosh, Ilaria Vanni Accarigi and Angela Giovangeli report

on the social aspects of rooftop gardens in Chapter 10. Rooftop gardens have

a long history, dating back many centuries. In the contemporary context, the

rooftop garden reflects a concern for the natural and built environment in

terms of sustainability, community and food production. This chapter

explores the social aspects of rooftop gardens by examining mainly two

Sydney inner-city rooftop gardens in Australia: the University of Technology

Sydney, an educational institution in Ultimo and 107 Projects, a permaculture

garden that is part of a multidisciplinary creative space in Redfern. Eight

rooftop gardens in different universities from other parts of the world are

also considered. Through interviews, sensory ethnography and comparative

analysis, this chapter highlights that rooftop gardens in different types of

institutional settings revolve around shared interests in growing food as well

as a shared ethos in creating community links in the workplace and beyond.

In Chapter 11, Dominique Hes, Christopher Jensen and Lu Aye consider

an alternative to green roofs, where thermal performance and a reduction of

building-related GHG emissions is the goal; this option is the cool or white

roof. Cool roof paint (CRP) is a practical, low-cost and retrofit option for

improving the thermal performance where there are significant cooling

loads. This chapter looks at their viability in cool-temperate climates, where

there is a higher heating load. The chapter presents the results of four exper-

iments investigating a CRP roof retrofit of a 20-year-old metal roof; the

extension of this data through modelling to test the sensitivity of CRP to

changes in shading, roof pitch, insulation levels, insulation location and

building roof-to-surface area ratios; the testing of the CRP against a green

roof retrofit; and the benefit of white roofs on electricity production through

photovoltaics. There is a benefit to CRPs used in a residential sense in

Melbourne, reducing the cooling loads depending on ceiling insulation

levels. The research shows that the CRPs are most beneficial for the retrofit

of short (high roof area to overall surface area) industrial buildings. Other

effective retrofit scenarios are discussed. Compared with CRP retrofits, the

green roof reflected less energy back into the external environment and pro-

vided an additional reduction in internal temperature of up to 3°C on a hot

summer's day (based on the retrofit of a 20-year-old metal roof with insula-

tion of less than 1 R-value). CRP treatments have a valuable role to play in

adding to the retrofit options when a green roof may not be appropriate.

In Chapter 12, Sara Wilkinson and Tim Dixon review the preceding

chapters and highlight the importance of green roofs in the context of

cities, neighbourhoods and individual buildings.

## 1.7 Conclusion

This chapter has outlined the context in which green roof retrofit can be seen

to provide a means for reducing the environmental impact of the built envi-

ronment on climate change and global warming. The structure of the book

has been outlined to show how empirical research in three continents is being

developed and implemented to address a range of social, environmental and

economic issues related to sustainable development. For many practitioners

this is a new area of practice, and the aim of the book is to raise awareness of

the primary and related benefits that occur with green roof retrofit, as well as

increasing knowledge to reduce risk and increase uptake of the technology.

## References

Berardi, U., GhaffarianHoseini, A. H. and GhaffarianHoseini, A. (2014) ‘State of

the art analysis of the environmental benefits of green roofs’, *Applied Energy*, 115, 411–428.

Communities and Local Government (2012) *National Planning Policy Framework*.

Communities and Local Government: London.

EC (2012) *The Multifunctionality of Green Infrastructure*. European Commission: Brussels.

Garnaut, R. (2008) *Garnaut Climate Change Review*. Cambridge University Press:

Cambridge.

Giradet, H. (2008) *Cities, People, Planet: Urban Development and Climate Change*.

John Wiley & Sons: Chichester.

HM Government (2011) *The Natural Choice: Securing the Value of Nature*. HM

Government: London.

Hui, S. (2011) 'Green roof urban farming for buildings in high density urban cities',

Hainan China World Green Roof Conference, 18–21 March, Hainan, China.

Inter-American Development Bank (2014) *Annex 2: Indicators of the Emerging*

*Sustainable Cities Initiative*. Inter-American Development Bank: Washington D.C.

Building Resilience in Urban Settlements Through Green Roof Retrofit 13

Karayannis, G. (2014) 'Dissecting ISO 37120: Why shady planning is good for

smart cities', available at: smartcitiescouncil.com/article/dissecting-iso-37120-

why-shady-planning-good-smart-cities.

Kelly, M. J. (2009) 'Retrofitting the existing UK building stock', *Building Research & Information*, 37(2), 196–200.

Lorenz, D. and Lützkendorf, T. (2008) 'Sustainability in property valuation: theory

and practice', *Journal of Property Investment & Finance* 26(6), 482–521.

Magill, J., Midden, K., Groninger, J. and Therrell, M. (2011) *A History and Definition of Green Roof Technology with Recommendations for Future Research*. Research

Papers No. 91, available at: opensiuc.lib.siu.edu/gs_rp/91.

Meerow, S., Newell, J., Stults, M. (2016) 'Defining urban resilience: a review',

*Landscape and Urban Planning*, 147, 38–49.

Mees, H., Driessen, P., Runhaar, H. and Stamatelos, J. (2013) 'Who governs climate

change adaptation? Getting green roofs for stormwater retention off the ground',

*Journal of Environmental Planning and Management*, 56(6), 802–825.

Molla, M. (2015) 'The value of urban green infrastructure and its environmental

response in urban ecosystem: a literature review', *International Journal of*

*Environmental Sciences*, 4(2), 89–101.

Naumann, S., Davis, M., Kaphengst, T., Pieterse, M. and Ratment, M. (2011) *Design, Implementation & Cost Elements of Green Infrastructure Projects. Final Report*

*to the EU Commission*. Ecologic Institute and GHK Consulting.

NDRC (2013) *The Green Edge: How Commercial Property Investment in Green*

*Infrastructure Creates Value*. National Resources Defence Council: New York.

Newton, P. and Bai, X. M. (2008) 'Transitioning to sustainable urban development'.

In Newton, P. (ed.), *Transitions: Pathways Towards Sustainable Urban Development*

*in Australia*. CSIRO Publishing/Springer-Verlag: Berlin; pp. 3–19.

POST (2013) *Urban Green Infrastructure*. PostNote No. 448. POST: London.

Ranade, A. (2013) *Building Integrated Vegetation*. Available at: cityminded.org/

building-integrated-vegetation-mitigating-urban-environmental-challenges-with-

building-material-technologies-8238.

Roe, M. and Mell, I. (2013) 'Negotiating value and priorities: evaluating the demands

of green infrastructure development', *Journal of Environmental Planning and*

*Management*, 56(5), 650–673.

RTPI (2013) *Building on Green Infrastructure in the UK*. Available at: www.rtpi.

org.uk/media/499964/rtpi_gi_task_group_briefing_final.pdf.

Specht, K., Siebert, R., Hartmann, I., *et al*. (2014) 'Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings',

*Agriculture and Human Values*, 31, 33–51.

TCPA (2012) *Planning for a Healthy Environment: Good Practice Guidance for*

*Green Infrastructure and Biodiversity*. TCPA: London.

Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U. and

Sawicka, M. (2014) 'Farming in and on urban buildings: present practice and

specific novelties of zero-acreage farming (ZFarming)', *Renewable Agriculture*

*and Food Systems*, 30(1), 43–54.

UKGBC (2015) *Demystifying Green Infrastructure*. Available at: ww.ukgbc.org/

sites/default/files/Demystifying%20Green%20Infrastructure%20report%20

FINAL.pdf.

Wilkinson, S. J. and Reed, R. (2009) ‘Green roof retrofit potential in the central

business district’, *Journal of Property Management*, 27(5), 284–301.

**12**

# Technical and Engineering Issues in Green Roof Retrofit

**Sara Wilkinson1 and Renato Castiglia Feitosa2**

1 UTS, Australia

2 FioCruz, Rio de Janeiro, Brazil

## 2.0 Introduction

It is necessary to retrofit the existing stock of buildings as only 1–2% is

added annually to the total stock of buildings, and the result is that 87% of

the buildings we will have by 2050 are already built (Kelly, 2008). However,

the overriding issue here is one of structural capacity to accommodate the

additional live and dead loads that a retrofit brings. Live loads are loads

which move about or change, for example, the people in a building. Dead

loads, in contrast, are the intrinsic weight of a structure. This chapter con-

siders the technical and engineering considerations that stakeholders need to

consider when evaluating green roof retrofit potential. For example, existing

structure, load-bearing capacity, access, power and water supply, orienta-

tion, exposure to sunlight and overshadowing, and occupational health

and safety. In short, how to determine what type of green roof is suited to

the structure.

Using some typical building types, case studies show how to determine

whether an existing roof has sufficient load-bearing capacity to support a

retrofit green roof. Initially it may be worth considering whether the roof is

intended to have people using it regularly and spending extended periods of

time there. Equally, does the owner have a preference for a thermal or a

biodiversity or a stormwater roof, for example? If so, this will affect the roof

design and the depth of substrate, and hence the additional dead loads the

original roof will need to support.

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



**2.1**

## Technical and Engineering Considerations

This first section identifies the key factors to consider when evaluating the

green roof retrofit potential of existing buildings. When analysing an exist-

ing building to determine its structural and physical suitability for a green

roof retrofit, it is necessary to consider the following:

1. roof structure and covering typologies

2. available space

3. structural capacity

4. waterproofing membranes and insulation

5. drainage

6. heritage

7. green roof access

8. other issues

9. how to determine which green roof type is best suited to different

structures

10. access for maintenance.

## 2.2

## Roof Structure and Covering Typologies

Roofs can be either pitched or flat, and comprise a variety of impervious

coverings described below. Whatever the form of the roof structure and cov-

ering, it is essential to undertake a thorough visual inspection to ascertain

the condition of the structure and membrane and to identify any building

defects. Any defects must be taken into account with retrofit, as if left

untreated, they may undermine the integrity and/or lifespan of the green

roof. Some defects are minor and superficial and can be repaired in situ,

whereas others are more extensive and may involve substantial repairs and

additional costs.

### 2.2.1

### Pitched Roof Structures

Pitched roofs are often found on smaller, older and residential buildings.

In traditional forms of construction the roof structure is independent of the

structural frame (Riley and Cotgrave, 2014) and is usually of modest spans.

Another option is for the roof structure to be part of, or integral to, the struc-

tural frame – such as a portal frame. This type of construction is typically

found in industrial-type buildings. In domestic buildings, the structural mate-

rial may be timber, or sometimes steel or aluminium in locations such as

Queensland, Australia, where termites are an issue, for example. These mate-

rials have different physical qualities and age in different ways. For example,

timber may be affected by rot, which can weaken the structure and cause

deflection (Douglas, 2013). Some metals, however, can corrode and weaken

when exposed to moisture or sea breezes. Roof structures, whether they are

timber or metal, if covered adequately and if the building remains unaffected

by differential settlement, can last for many decades, if not centuries.

Pitches can be as much as 50°, however the maximum degree for

retrofitting extensive green roofs is said to be 35° (ZinCo, 2015), although

other studies concluded that shallower pitches of 32° were considered

maximum (Wilkinson and Reed, 2009). In intensive green roof systems, sur-

faces must be relatively flat. With pitched roofs, it is necessary to consider

the degree of pitch. Where the pitch is too steep, the substrate will move over

time and this will be exacerbated in heavy rain. Proprietary systems for

pitched roofs do include support brackets, known as ‘shear brackets’, which

are installed to prevent slippage of the substrates. The shear brackets are

anchored to the roof substrate and sealed separately. They sit slightly below

the surface, so that the vegetation is not visually interrupted. A similar

detail is provided at the eaves. Various details are available to accommodate

different eaves designs. Where applicable, snow loadings should also be

taken into consideration.

Other systems are manufactured from recycled polyethylene (HDPE)

and come in small 540 mm square units, which interlock. A benefit of this

system is that it is lightweight and speedily erected. With pitched green

roofs, irrigation may be integrated for use during dry periods to ensure that

erosion does not occur due to plants dying off. Finally, all designs have to

take into account that access for maintenance is more challenging.

### 2.2.2

### Pitched Roof Coverings

Profiled metal sheeting is typically provided as a roof covering to pitched

metal-framed roofs, and also to residential timber-framed roofs in some

locations (Figure 2.1). In some locations, a plastic coating is applied to

protect the metal from corrosion (Riley and Cotgrave, 2014). The metal

sheets are steel or aluminium and are fixed with self-tapping screws to the

50 – 200 mm

• Growing medium – mostly inorganic

• Geotextile

• Drainage layer

• Root barrier

• Metal/lightweight roof deck

**Figure 2.1** Extensive green roof on metal sheet roof deck.

*Source*: Your Home (2013).

Technical and Engineering Issues in Green Roof Retrofit 17

purlins (horizontal beams that span across the rafters). Different proprietary

systems are available with various profiles and fixings. For example, the

purlins can be ‘Z’, ‘C’ or ‘M’-shaped sections. In general, these roofs are

unable to support people walking across them, so any green roof system has

to take this into consideration with regard to planting selection and mainte-

nance access issues. Typically, the metal sheeting systems are designed for a

25-year lifespan. Some proprietary green roof systems are designed to fix

onto profiled metal sheet roofing systems (see Figures 2.2 and 2.3). Extensive

green roofs are more suited to this form of lightweight roof construction,

with the following characteristics:

■

Shallow growing medium – typically less than 200 mm.

■

Roof structure similar to conventional roof coverings.

■

Weight 60–200 kg/m2.

■

Vegetation generally limited to low, shallow-rooting and groundcover

plants that are tolerant of drought, wind exposure and temperature

fluctuations.

■

Not suitable for general access.

■

Relatively economical.

■

Some thermal and acoustic insulation benefits.

■

Relatively easy to retrofit on existing roofs.

■

Low maintenance.

In summary, pitched roofs are usually retrofitted with low-maintenance

extensive green roofs. The shear forces, which create a downward movement

Weight

Depth

kg/m2

mm

ed

y

aturat

Plug plants as per plant list “pitched/

Dr

S

steep pitched green roof”

yer

System substrate “rockery type plants”

Plant la

Floraset® FS 75

e

Protection mat BSM 64

75 105

Substrat er +

A root-resistant waterproofing

From 50

Shear transf

drainage yer

membrane is required.

Protection la

80

2

10

77

115

Roof pitch:

10–15° 15–20° 20–25°

Build-up height:

ca.

130

140

150

mm

Weight, saturated:

ca.

110

130

145

kg/m2

Water storage capacity:

ca.

38

40

44

l/m2

**Figure 2.2** Pitched green roofs, 10° to 25° pitches.

*Source*: ZinCo (2015).

Green Roof Retrofit

Weight

Depth

kg/m2

mm

ed

y

yer

aturat

Dr

S

Plant la

e

Substrat

er

yer

Shear transf

89

155

Protection la

120

Build-up height:

from 120 mm

Weight, saturated:

from 155 Kg/m2

Water storage capacity:

from 64 l/m2

**Figure 2.3** Steep pitched green roofs, 26° to 35° pitches.

*Source*: ZinCo (2015).

of the substrates, are channelled into stable eaves edgings and, where neces-

sary, into additional shear barriers using load-absorbing elements (see

Figure 2.3). On account of the faster runoff of rainwater on pitched roofs,

the substrate layer is increased and the possibility of additional irrigation

should be considered. Furthermore, to prevent erosion on pitched roofs,

plants should be applied in higher densities; where steep pitches exist, pre-

cultivated vegetation mats are recommended to prevent soil erosion. It is

said that the planting selection on pitched roofs is more important because

of the runoff issue (ZinCo, 2015). A final consideration on pitched roofs is

the orientation of the roof area (north/south depending on hemisphere) and

how this might affect vegetation development.

### 2.2.3

### Flat Roof Structures

The term ‘flat roof’ is a little misleading, as all roofs have some slope or

pitch to ensure the effective discharge of rainwater. Flat roofs are defined as

those who pitch is less than 10° (Riley and Cotgrave, 2014). In commercial



buildings, typically the construction of the roof structure is supported by the

building’s structural frame and the roof deck, which forms a base on which

the roof covering is applied. The roof structure provides support and trans-

fers the live and dead loads to the building structure. In commercial build-

ings, the structure is either reinforced concrete or steel, although some newer

sustainable buildings are using cross-laminated timber frames. In smaller,

and in residential buildings, timber-framed decks may also be used.

Where concrete roof decks are provided, they may be cast in situ, or com-

prise ‘pot and beam’ (where concrete beams sit between concrete pots with

flanges to support the beams), or they may be pre-cast concrete planks. An

alternative is to use woodwool slabs to support the covering, or timber or

profiled steel sheeting. The profiled metal sheeting can be covered with insu-

lation and timber decking prior to the application of the waterproof mem-

brane (see below), or it may be covered with reinforced concrete with the

sheeting acting as permanent shuttering. Each material can carry a different

amount of live and dead loads, and this is further influenced by the spacing

of the supporting structure (e.g., columns). Live loads are defined as a mov-

ing, variable weight added to the dead load or intrinsic weight of a structure,

whereas dead loads are defined as a constant load in a structure (such as a

building) that is due to the weight of the members, the supported structure,

and permanent attachments or accessories.

For both pitched and flat roofs, a structural engineer should be engaged

to determine the additional loads that the existing roof structure can sup-

port safely. At this point, these estimated loads of the retrofit roof should be

considered and then, a decision is made as to whether strengthening works

are required. Additional structural works can be expensive and may render

the retrofit not viable economically.

### 2.2.4

### Flat Roof Coverings

There are a number of options regarding coverings, such as bituminous felt,

or roofing felt, which is built up over multiple layers. This is an economical

covering, which has been widely used over many decades. It has a lifespan

of typically 20–25 years, depending on the degree of exposure and foot traf-

fic, and other issues such as building movement and differential movement

(which is where two or more different materials, in close proximity, move at

different rates when exposed to heat and cold) (Douglas, 2013). That is,

they expand and contract at different rates and the result is the formation of

cracks, splits or tears in adjoining materials. Typically, differential move-

ment is seen at junctions such as parapets (Douglas, 2013). Over recent

years, felt coverings have been replaced increasingly with a single-layer cov-

ering of polymer-based material, which has a longer lifespan and is more

able to cope with differential movement. Another traditional flat roof mate-

rial is asphalt, which has a long lifespan of up to 40 years in some cases, is

very durable and considered a good choice where foot traffic is expected.

It is applied in a liquid form and therefore does not have any joints,

which makes it a very good form of covering. However, it is expensive,



is affected by solar degradation and can creep around up-stands (Riley and

Cotgrave, 2104).

In terms of suitability for retrofit, it is necessary to determine the type of

covering, its age and condition. Again, an assessment of its remaining life is

undertaken to determine whether replacement is needed prior to the green

roof retrofit. It is stated that green roofs extend the life of the covering by

100%; that is, a felt roof with a typical lifespan of 25 years will last for

50 years. The lifespan is extended because the roof covering is no longer

exposed to the degrading effects of rainfall and water, ultraviolet (UV),

sunlight or the effects of temperature changes, cooling at night and getting

hot during summer months in daylight periods.

These, then, are the typical roof types, structures and coverings, which are

the basis on which a green roof may be retrofitted. The typical construction

of a green roof has six layers, on top of the structural roof and covering as

follows:

1. Root barrier (polyethylene sheeting, copper or copper compounds in

the membrane).

2. Insulation (optional).

3. Drainage layer (synthetic drainage mesh, granular aggregate).

4. Filter fabric (geotextile).

5. Growing medium – also known as planting medium or substrate (man-

ufactured soil, crushed brick or other inorganic material, which may be

supplemented with organic material such as coconut fibre or coir).

6. Vegetation (shallow rooted on extensive roofs, deeper rooted on inten-

sive roofs).

### 2.2.5

### Other Roof Designs

Green roofs can be retrofitted to other roof shapes or designs, for example

barrel roofs and curved roofs. Here the proprietary systems developed for

pitched roofs can be used in many cases. Roof coverings for barrel and

curved roof designs tend to be polymer and asphalt applications, which

are applied in liquid form, and the comments made above with respect to

lifecycle apply here also.

### 2.2.6

### Green Roof Modular Systems

In these systems (Figure 2.4), plants and substrate are gathered in trays or

boxes with a water storage system, which provides water to the soil through

evaporation, enhancing the plants' survival, even during extended dry peri-

ods. The soil is separated from the drainage system by a permeable fabric

(Geotextile), which allows water flow but prevents soil passage into the

water chamber.

As regards their applicability, modular systems are suited to either

pitched or flat roofs. These extensive modular systems enable a reduction





**Figure 2.4** Examples of modular systems applied in different types of profiled metal sheeting.

in maintenance and installation costs, since the soil and plants are previ-

ously planted offsite in containers made of plastic or any other recycled

material, which are then applied directly onto the roof covering – be it

existing slabs, profiled metal sheeting or tiles. Additionally, modular sys-

tems provide better initial conditions for plant growth than rooftops, due

to the possibility of green roof cultivation in plant nurseries (gardens) or

greenhouses (in cold climates).

## 2.3

## Available Space

Many rooftops accommodate mechanical equipment, such as air-handling

units and plant rooms. When retrofitting a green roof, it is necessary to

undertake a survey of the roof space to ascertain the amount of available

space for the green roof. Furthermore, some plant rooms vent emissions,

which may make the roof, or parts of it, unsuitable for a social amenity

space for building users. In this case, however, it may still be possible to

install a thermal or stormwater green roof. At this point, it may be worth-

while to determine whether any mechanical rooftop units can be reduced in

size or repositioned, as was the case with the UK case study described in this

chapter. Where a more extensive retrofit of the building and services is

occurring it may be possible, and economic, to reduce the size of the plant

and relocate it. This factor will have an impact on the type of green roof that

can be retrofitted.

## 2.4

## Structural Capacity

Before designing any green roof system, it is critical to first conduct a

structural investigation to determine the building’s existing structural load-

bearing capacity and to check for any damage. Damage would be in the



**Table 2.1** Extensive green roof

| Vegetation | Depth (mm) | Weight (kg/m2) |
|---|---|---|
| Extensive green roof with sedum, grass, moss, etc. | 50–100 | 10 |
| 70–140* | | |
| Extensive green roof with soil, plants and small shrubs | 100–150 | 15 |

(below 0.5 m tall)

140–225*

*Source*: RICS Green Roofs and Green Walls Best Practice Guidance Note, 2015.

* Dunnett and Kingsbury (2008) rain loaded but not including plants.

**Table 2.2** Intensive green roof

Vegetation

Depth (mm)

Weight (kg/m2)

Intensive green roof with larger plants and small shrubs

150–200

20

(below 1 m tall)

225–300*

Intensive green roof with larger plants and small shrubs

200–400

30

(below 3 m tall)

300–600*

Intensive green roof with larger plants and small trees

400–1000

60

(below 6 m tall)

600–1500 up to 2600

Intensive green roof with larger plants and small trees

Over 1000

150 when one tree is

(below 10 m tall); one tree weighs more than 150 kg

1000 kg/m2

*Source*: RICS Green Roofs and Green Walls Best Practice Guidance Note, 2015.

* Dunnett and Kingsbury (2008) rain loaded but not including plants.

form of deflection due to overloading of the structure. The building's

structural capacity will determine the type of vegetation and substrate depth

that can be grown. Also, the age of the building will influence the type of

construction methods adopted. If available, original drawings or building

information modelling data should be reviewed. This information, the thick-

ness of the structural slab and the span between columns gives an indication

of the load-bearing capacity of the roof structure.

Essentially there is a choice to be made between intensive and extensive

green roof systems, with each having different load-bearing implications.

Intensive green roofs are significantly heavier than extensive green roofs (see

Tables 2.1 and 2.2), and are therefore more challenging and expensive to

retrofit on existing roofs. If the structural capacity of the building is deemed

insufficient to support the proposed green roof system then structural rein-

forcements may be made, but these can be prohibitively costly and will

involve certification from the authorities responsible for building regula-

tions and codes. Tables 2.1 and 2.2 show typical loads/weights for extensive

and intensive green roofs, but caution must be exercised when designing a

green roof retrofit to consider the structure of the existing building. In all

cases, an independent analysis of the design loadings will need to be carried

out by a certified structural engineer. Furthermore, as well as the weight

of all additional structures, membranes, frames, walls, trellis, cables, mesh,

Technical and Engineering Issues in Green Roof Retrofit 23

finishes and so on, storm loading must be taken into account and the plants

at maturity and soil loads.

Based on a conservative perspective and considering a typical sandy loam,

it is estimated that the worst-case situation of loading on the roof would

occur at 2000 kg/m3 for soil depths varying from 5 to 100 cm. On this basis,

for green roofs with soil depths from 5 to 100 cm, the loading per square

metre would be equivalent to 100 and 2000 kg/m2, respectively. As the

design load of existing roofs varies between 50 and 200 kg/m2, it is expected

that a structural upgrade is not necessary for soil depths up to 10 cm (Liu,

2011). However, lightweight-substrate materials with depths slightly higher,

such as pumice and expanded clay, may reproduce the same loads as a single

soil component. As noted by Peck and Kuhn (2003), the 36 cm depth green

roof on the new library in Vancouver (Canada) weighs, under saturated

conditions, 293 kg/m2, and according to the British Columbia Building Code

does not require a structural upgrade. Comparatively, the same depth of

saturated sandy loam soil weighs 720 kg/m2. In most existing buildings, high

extra loads are not supported by the structure and thus, structural reinforce-

ments are necessary. This circumstance is leading to an initial trend in the

use of extensive systems for retrofits.

## 2.5

## Waterproof Membranes and Insulation

A thorough inspection of the existing roof waterproof membrane is needed

to assess its condition before considering retrofitting a green roof. At this

point, any damage should be repaired before retrofitting a green roof

(Wilkinson *et al*., 2015). The age and estimated remaining life of the roof

membrane is an important consideration. For example, if the roof mem-

brane is in poor condition and is due to be replaced within 2 years or so, it

could be worth either replacing the membrane prior to installing the green

roof, or deferring installation until the membrane is replaced. Depending

on the plant specification, and in consultation with the landscape architect

or horticulturalist, a root barrier membrane may be required to protect the

membrane from plant roots. This membrane is not required in extensive

green roof systems.

Where provided, the existing roof insulation should be checked to ensure

it has sufficient compressive strength to support the dead and live loads

of the new green roof system. Sometimes insulation is provided on top of

the structural slab, where in other cases it can be fixed below the slab. With

flat roof construction there are cold decks (where the insulation is placed

below the roof deck), warm decks (where insulation is placed over the deck

and below the waterproof membrane), and finally an inverted roof (where

insulation is placed over the roof deck and the membrane). Clearly, warm

and inverted roofs are susceptible to damage to the insulation. A final

consideration is that drainage must be designed to ensure water does

not get trapped between the existing roof and the new green roof, as this

will cause thermal cold spots, which will lead to building defects and a

shorter lifespan.



**2.6 Drainage**

Overall, until the saturation point of the substrate is reached in the green

roof, the flow of water entering the drainage system will be slower than if

no green roof existed. Pitched roofs drain to gutters fixed to the eaves of the

roof. The water is then discharged via drainpipes or downpipes, usually to a

below-ground drainage system. In some instances, rainwater may be diverted

to rainwater tanks for reuse. The aim is to prevent any materials, planting or

substrate entering the drainage system as this may cause a blockage. Where

water is able to accumulate, there may be problems with corrosion of metal

gutters and downpipes or fixings, which may in turn lead to leaks and

potential staining of the building façade if left unrepaired.

On flat roofs, the drainage can be external on the building façade or inter-

nal with downpipes located within the building envelope. There is similar

potential for blockages of the gutters and downpipes as with the pitched

roof design above. Where pipes are located internally, any building defects

are often harder to see, especially where pipes are concealed within vertical

ducting. By the time a defect, leak or stain is visible, considerable damage to

the building structure and fabric may have occurred.

Roof drains are strongly recommended in all types of roof, since the

existing domes in these types of drain provide efficient drainage of rainwater

and also prevent debris from entering the drainage system.

### 2.7 Heritage

This needs careful consideration, as the visual impact of historic buildings is

of primary importance. In summary, to satisfy the local authorities, heritage

buildings must be able to accommodate a green roof without negatively

altering the historic character of the building. All jurisdictions have slightly

different classifications of heritage and historic buildings, and also allow

different levels of intervention. Furthermore, guidelines are published by

groups such as the Society for the Protection of Ancient Buildings (SPAB) in

the UK, with similar guides existing in other countries. It may be that instal-

lations which can be removed easily, that are designed for disassembly or

deconstruction, without damage to the original fabric of the building, will

be preferable to some planning authorities. Finally, structural considerations

are a key factor with heritage buildings that may have been structurally

compromised – possibly by age, wear and tear, and/or previous adaptations.

**2.8**

## Green Roof Access

Green roof access must be considered and included in any green roof design.

Furthermore, the initial installation will be considerably cheaper if there is

good, safe access. If a green roof is intended to be used as an amenity space,

then how the space is accessed for this purpose (e.g., via lifts or stairs) needs

to be considered. Accessible roof amenity spaces need to meet all relevant



access and health and safety legislation, for example additional structures

may need to be added to existing parapets. Additional certifications to

prove compliance with building regulations and codes may be required in

some cases. A chartered building surveyor, building control surveyor or

other suitably qualified professional consultant will be able to advise on

these aspects.

When considering green roof access, the following three green roof

typologies are considered.

*Terrace.* This is defined as an external covered or uncovered garden space,

typically housing vegetation, such as planter boxes that can be accessed

internally by maintenance persons or externally by one of the following:

1. a building maintenance (BMU) system;

2. abseiling;

3. a cherry picker (depending on the height from the floor).

*Multi-terrace.* This is defined as an external covered or uncovered garden

space, with a minimum double height, housing vegetation such as planter

boxes and trees. Trees can be accessed internally via a monorail and

platform system or externally by one of the following:

1. a BMU system;

2. abseiling;

3. a cherry picker (depending on the height from the floor).

*Roof.* This is defined as a typically uncovered rooftop space comprising a

variety of vegetation such as lawns and trees. Access to trees on roof

spaces is via a ladder or temporary scaffolding, depending on the height

from the floor.

**2.8.1**

**Access for Maintenance**

Green roofs require regular monitoring and maintenance; this includes

pruning and weed control, plant nutrition, plant installation/replacement,

maintenance of supporting structure and waterproofing. As green roofs will

likely increase the ongoing maintenance requirements of the roof, additional

or improved access should be considered. Green roof access strategies should

consider the current or proposed façade access plan and integrate where

relevant.

**2.8.2**

**Temporary or Permanent Access Strategies**

During the construction or installation of a green roof, there are a number

of considerations. For external access of a terrace or multi-terrace system,

the maximum reach possible for a maintenance person is limited to 800 mm

(via a cherry picker or BMU), whereas rope access enables full access.

Where access is required to private property, it is advised that access is

written into all tenancy agreements. The installation and removal of trees



can be expensive, and the associated costs high, as these works typically

require a crane to be hired. Depending on the project scope and design

intention, avoiding the use of mature trees is preferred. Building code

requirements may apply to the design of planter boxes and trees, particu-

larly when located in close proximity to a balustrade. For example, in

Australia AS1657 Fixed Platforms, walkways, stairways and ladders are

relevant, and in AS1891 Fall, arrest systems. A minimum width of 600 mm

is recommended between balustrade and internal planter boxes for suffi-

cient access.

### 2.8.3 Maintenance

### Frequency

When specifying systems and horticulture, consideration of the frequency

and costs of maintenance is crucial. For example, to minimise mainte-

nance frequency, surveyors or consultants should identify and specify

low-maintenance systems. To estimate the ongoing costs associated with

the addition of a green roof system to a building lifecycle, it is recom-

mended that a cost analysis based on data from previous projects is

implemented where possible. Another consideration in some cases is the

option of integrating green roof access strategies with the current or

proposed façade access plan for cost-effective solutions. The planting

selection can also impact the amount of maintenance required.

## 2.9

## Other Issues

The orientation of the roof affects the amount of exposure to sun the roof

will get, and this affects the type of plants that will flourish there (Wilkinson

and Reed, 2009). Added to this, the surveyor also needs to consider any

overshadowing from surrounding buildings as this affects access to sunlight

for the plants. Finally, the height above ground will affect exposure levels to

high winds in particular. Some rooftop environments can be hostile in differ-

ent seasons, and planting specifications must take this into account (Williams

*et al*., 2010). A checklist for building surveyors to appraise the suitability for green roof retrofit is provided in Appendix 1.

## 2.10 How to Determine Which Green Roof Type is Best Suited to Different Structures

As previously mentioned, the choice of using either intensive or extensive

green roofs will depend on the structural characteristics of the buildings. In

most cases the use of extensive systems is imperative, since the existing

buildings were not designed to support significant extra loads. Where struc-

tural designs consider such loads, intensive green roofs are recommended

due to their adequacy for a wide variety of plants, including trees, and their



better performance in thermal and runoff aspects. However, it is important

to emphasise that this type of green roof is not preferred for pitched roofs.

In general, in terms of costs, setup, structural adequacy and maintenance,

extensive green roofs are more indicated. As far as maintenance frequency is

concerned, drought-tolerant plants are preferable. The choice of modular

systems additionally improves the setup and maintenance aspects, being

easily applied to any roof structure and covering. In addition, the need to

use containers (trays for planting) is offset by the absence of an anti-root

membrane. Table 2.3 summarises green roof types suitable for a range of

different structures.

**2.11**

## Illustrative Case Studies

This section uses four cases from different countries to illustrate how an existing building can be retrofitted successfully with a green roof for different purposes. However, it is important to highlight that the green roof design must meet the load-bearing capacity of the roof structure. In concrete structures, for example, such loads cannot be evaluated through a visual inspection, and thus a structural engineer must be consulted. As addressed in Section 2.4, it is expected that green roof soil depths lower than 10 cm will be acceptable for meeting the design loads of most of the roofs.

### 2.11.1 Australia – Surry Hills Library and Beare Park, Sydney

The City of Sydney intends to reintroduce greenery to homes as part of Sustainable Sydney 2030, where the mission is to make the local area as green as possible. The City of Sydney is committed to increasing the number of high-quality green roofs and walls, where, in April 2014, the city adopted

its green roofs and walls policy (City of Sydney, 2013). The two case studies

presented are the Surry Hills Library and Beare Park, Elizabeth Bay.

In the Surry Hills Library and Community Centre Building (Figure 2.5),

it was intended to improve the air-quality system using the natural filtering

properties of plants. The building was completed in 2009, comprises

2497 m2, and is three storeys high. In this case, air is naturally cooled under

the building, reducing by 50% the need for artificial cooling. The improve-

ment in the air quality is provided when it is drawn in at the top of the

atrium, passing through special plants that behave as passive filters. The

building is also designed to minimise energy consumption, since the green

roof reduces energy consumption due to its insulating properties (City of

Sydney, 2013). The soil depth on the extensive green roof is 300 mm and the

plant types are a mix of sedges and heath plants. Although it is a public

building, the green roof is not accessible to the public. The key driver for

sustainability features, including the green roof, was the objectives of

Sustainable Sydney 2030 and the desires of the local community. Irrigation

has been installed but is not routinely used for maintenance, and the water

source is recycled rainwater stored on site. The building won the Best New

28

Green Roof Retrofit

**Table 2.3** Green roof type best suited to different structures

Green roof types suited:

Intensive or

amenity (A), biodiversity (B),

Characteristic

Notes

extensive

stormwater (S), thermal (T)

Roof structure (flat)

Concrete (if able to support

Extensive

B, S, T

up to 225 kg/m2)

Roof structure (flat)

Concrete (if able to support

Intensive

A, B, S, T

more than 225 kg/m2)

Roof structure (flat)

Timber (if able to support

Extensive

B, S, T

up to 225 kg/m2)

Roof structure (flat)

Timber (if able to support

Intensive

A, B, S, T

more than 225 kg/m2)

Roof structure

Timber (if able to support

Extensive

B, S, T

(pitched) 35ůp to 225 kg/m2)

and lower

Roof structure

Metal (if able to support up

Extensive

B, S, T

(pitched) 35°

to 225 kg/m2)

and lower

Roof covering

Profiled metal sheeting

Extensive

B, S, T

(pitched or flat roofs)

Roof covering

Roofing tiles (pitched)

N/A

N/A

Roof covering

Bituminous felt

Extensive/

A, B, S, T

intensive

Roof covering

Asphalt

Extensive/

A, B, S, T

intensive

Roof covering

Polymer

Extensive/

A, B, S, T

intensive

Available space

If good

Extensive/

A, B, S, T

intensive

Available space

If not good

Extensive/

B, S, T

intensive

Structural capacity

If good

Extensive/

A, B, S, T

intensive

Structural capacity

If not good

Extensive/

B, S, T

intensive

Waterproofing

If poor condition, consider

N/A

N/A

membranes

repair or replacing

Waterproofing

If good condition

Extensive/

A, B, S, T

membranes

intensive

Drainage

If poor condition, consider

N/A

N/A

repair or replacing

Drainage

If good condition

Extensive/

A, B, S, T

intensive

Accessibility

If poor, consider plant

Extensive/

B, S, T

selection to avoid

intensive

maintenance access

Accessibility

If good

Extensive/

A, B, S, T

intensive

Heritage

If local laws preclude green

N/A

N/A

roof




**Table 2.3** ( *Cont'd*)

| Green roof types suited: | |
|---|---|
| Intensive or<br>amenity (A), biodiversity (B), | |
| Characteristic | Notes |
| extensive<br>stormwater (S), thermal (T) | |
| Heritage | |

If local laws permit, depends Extensive/

A, B, S, T

on structure type, condition

intensive

and load-bearing capacity

Access for

If good condition

Extensive/

A, B, S, T

maintenance

intensive

Access for

If poor, consider plant

Extensive/

B, S, T

maintenance

selection to avoid

intensive

maintenance access

Green roof access

If good, consider most

Extensive/

A, B, S, T

economic option

intensive

Green roof access

If poor, consider plant

Extensive/

B, S, T

selection to avoid

intensive

maintenance access

Frequency of

If good

Extensive/

A, B, S, T

maintenance

intensive

Frequency of

If poor, consider plant

Extensive/

B, S, T

maintenance

selection to avoid

intensive

maintenance

Orientation

If good, consider plant

Extensive/

A, B, S, T

selection

intensive

Orientation

If poor, consider plant

Extensive/

A, B, S, T

selection carefully

intensive

**Figure 2.5** Case study: Surry Hills Library and Community Centre Building, Sydney, Australia.

*Source*: Wilkinson, 2015.



30

Green Roof Retrofit

**Figure 2.6** Case study: Beare Park, Elizabeth Bay, Sydney, Australia.

*Source*: Wilkinson, 2015.

Global Design Award at the 2011 International Architecture Awards in

Chicago for public and sustainable design (City of Sydney, 2016).

As shown in Figure 2.6, the second case study comprises a retrofit or an

adaptive reuse of a single toilet in Beare Park, Elizabeth Bay, Sydney. The

project aimed to refurbish an existing 1950s toilet block, upgrading the

facility by making the building more sympathetic to the landscape using a

green roof (40 m2) and a green wall (10 m2). The design aims were to make

the building more sympathetic to the surrounding landscape through the

green roof and walls, to upgrade the facility and improve access and public

safety, and to retain as much of the original fabric as possible. The roof

works cost $1625/m2 when installed in 2007. There is irrigation, but it is

rarely used and is sourced from recycled water. The roof was planted out

with a variety of succulents and drought-resistant species suited to a shallow

soil depth of 100 to 160 mm substrate. The total area covered is 40 m2 and

the roof has a 1° pitch (Figure 2.7). After 8 years, the green roof is thriving

and has full coverage (City of Sydney, 2013).

### 2.11.2 Brazil

Two case studies are the Village Mall and Canal Saude Building (FioCruz

Campus) in Rio de Janeiro. In both examples an extensive modular system

was used. The green roof design in the Village Mall (Figure 2.8) comprised

an area of 860 m2, and had the main purpose of thermal and acoustic

insulation. It was developed as a system to meet the load-bearing capacity

40×40 PVC coated angle

1st Fall

Subsurface irrigation

Adhesive

system

1st Fall

50 mm+ soil depth

m

20-40 mm hydrocell

RG30 flaked foam

Geotextile

Min100m

20 mm drainage cell

Waterproof membrane

with protection

Hot air weld

sheet over

360

S-U bar

Fall in slab as per

S-welding cord PVC 4mm

structural engineers

details

Slab thickness

as per structural

engineers details

Column fixing plate

750

recessed in slab

Drip line

RHS column

Security screen

refer CD 506

Roof detail

**Figure 2.7** Case study: Beare Park, Elizabeth Bay, Sydney, Australia.

*Source*: City of Sydney (2013).





32

Green Roof Retrofit

**Figure 2.8** Case study: Village Mall, Rio de Janeiro, Brazil.

*Source*: Studio Cidade Jardim (2012).

**Figure 2.9** Case study: Oswaldo Cruz Foundation (FioCruz), Rio de Janeiro, Brazil.

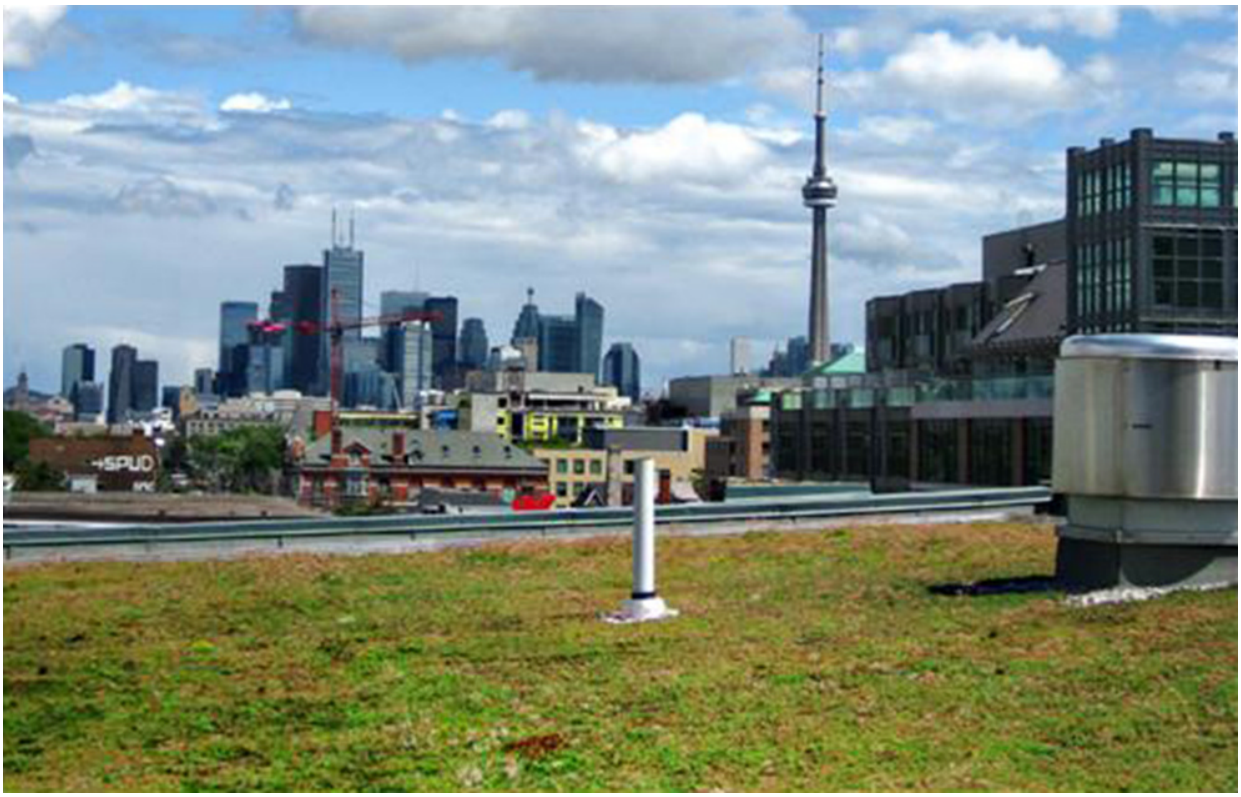
of the metallic roof underneath, so the load was not higher than 60 kg/m2.

Thus, the modules were designed with a drainage system that could allow a

fast flow of rainwater.

In the Canal Saude Building, located at FioCruz (Oswaldo Cruz

Foundation) Campus (Figure 2.9), a modular system composed of alveolar





plastic boxes has been used to cover an existing metallic roof. The main

reason for retrofitting is solar reflection towards the next building, which

has windows facing the existing roof.

This is a pilot design of a low-cost green roof technology, where previ-

ously disposable vaccine boxes with 4 cm depth are reused as planting

containers. Considering that the planting was carried out by FioCruz itself,

this could be called a zero-cost project, where the main goal was to find

alternatives to spread green roof use on a city-wide scale.

### 2.11.3 1214 Queen St West, Toronto, Ontario, Canada

In Toronto, a 540 m2 extensive green roof was installed in 2009 at the

Gladstone Hotel to reduce heating and cooling costs. The installation of the

green roof (Figure 2.10) also remedied the hotel's flooding issues, with an

estimated 264,585 litres per annum diverting much of the building's storm-

water runoff. The Gladstone Hotel comprises 2787 m2, built over four

storeys, with a tower on the fifth storey. The hotel was built in 1889 in the

Richardsonian Romanesque style and was refurbished in 1913, the 1950s,

the late 1980s, and in 2004–2005 after a change in ownership. The new

owners inherited many problems with the building, some of which were

difficult to solve with conventional construction techniques.

The extensive green roof has a shallow, light growing medium with the

landscaping designed to be self-sustaining, requiring minimal maintenance

and structural support.

**Figure 2.10** Case study: Gladstone Hotel, Toronto, Canada.

*Source*: Ecoroof (2011).





Green Roof Retrofit

The total cost of the roof was C$54,845, however C$27,000 was paid as

part of the Eco-Roof Incentive Programme (ERIP) funding to encourage

greater uptake of green roof technology in the city. The City of Toronto's

ERIP provides funds for green or cool roof retrofit projects on existing com-

mercial, industrial and institutional buildings. The programme also provides

funding for green roofs on new industrial buildings with a gross floor area of

2000 m2 (21,528 sq. ft) or greater, and new institutional and commercial

buildings of less than 2000 m2. Eligible green roof projects receive $50/m2 up

to a maximum of C$100,000. Eligible cool roof projects receive $2–5/m2 up to

a maximum of C$50,000. The cost was C$101/m2. The roof took 2 days

to install, after a 2-month design and lead-in period. The annual gas

saving, based on actual energy consumption, as indicated on pre- and post-

installation energy records, is 31,131.5 GJ. This equates to GHG emission

reductions of 59 kg of CO equivalent.

### 2.11.4 107 Cheapside, London, UK

Unilever House is an office headquarters building located in the St Paul's

area of the City of London (see Figure 2.11). It was constructed in 1929

prior to the implementation of the St Paul's height restrictions and, as a

result, some parts of the roof exceed this. During the 2007 retrofit, the roof

was rebuilt to create intensive roofs at Level 8 and Level 9, with a 200 mm

deep planter substrate. Of the total roof area of 2614 m2, 1825 m2 (or 70%

of the total area) was greened at a cost of £514,650, or £282/m2 (City of

**Figure 2.11** Case study: 107 Cheapside, London, UK.

*Source*: KPF.



London, 2011). The main aim was to provide an amenity space for users.

Biodiverse plant species have been planted within the cradle cleaning zones,

as these zones are less likely to be disturbed than in the general roof garden.

Although no specific species have been targeted for this roof, it is hoped that

with the variations in materials, substrate depths and plant species, the roof

will support biodiversity (City of London, 2011).

The keys to success for the green roof retrofit were enthusiastic architects

(KPF) with prior experience and a desire to return the roofscape to its origi-

nal profile. The roof had been taken over by mechanical plant. The provi-

sion of amenity space was a key issue, and the green roof achieves this with

views along the River Thames. The staff restaurant is co-located to provide

a social green roof space. It was important to the client for the building to

maintain importance and stature as the sustainable European headquarters

for the Unilever company (City of London, 2011). The benefits are heavy

use by the occupants as an amenity space, with accessibility from three

access stairs, as well as opening out from the canteen and meeting rooms.

Further, a sloping bed design allows for greater visibility of the planting and

creates shelter from the wind.

A key barrier faced was that the existing roof was not as structurally

sound as thought, and part of the roof had to be rebuilt to support the green

roof. A further challenge was accommodating services around the roof

garden plans, encouraging minimal plant on the roof and innovative design.

Much of the plant was relocated to the basement level to keep the roof area

as clear as possible. A small structure on the roof required planning permis-

sion, despite parts of the original roof being higher than the current height

restrictions (City of London, 2011).

## 2.12 Conclusions

This chapter has examined the technical and engineering considerations that

stakeholders need to take into account when evaluating green roof retrofit

potential. This has included appraising the type and condition of the exist-

ing structure, the existing load-bearing capacity, access, power and water

supply, orientation, exposure to sunlight and overshadowing, occupational

health and safety. Table 2.3 has illustrated how to determine what type of

green roof is suited to a given structure.

The illustrative case studies have shown how existing roofs have had suf-

ficient load-bearing capacity to support a retrofitted green roof across a

range of climate types and building types. The structural and waterproofing

elements of green roofs, properly installed, require little maintenance. As

with all aspects of building, good construction detailing reduces the risk of

failures and facilitates access for repairs (e.g., in the unlikely event of leaks).

Maintenance demands are reduced by integrated irrigation, but a small

green wall needs no more tending than more conventional indoor plant

arrangements. Larger installations may include programmable and auto-

mated watering systems. To date, there is a general preference to retrofit

extensive green roofs due to their lighter loads.



**References**

City of London (2011) *City of London Green Roof Case Studies*. Available at: www.

cityoflondon.gov.uk/services/environment-and-planning/planning/heritage-and-

design/Documents/Green-roof-case-studies-28Nov11.pdf.

City of Sydney (2013) *Green Roofs and Walls*. Available at: www.cityofsydney.nsw.

gov.au/vision/towards-2030/sustainability/greening-the-city/green-roofs-and-

walls.

City of Sydney (2016) 'Surry Hills Library crowned a world leader', available at:

www.sydneymedia.com.au/4647-surry-hills-library-crowned-a-world-leader/.

Douglas, J. (2013) *Understanding Building Failures*, 4th edn. Routledge: London.

Dunnett, N. and Kingsbury, N. (2008) *Planting Green and Living Walls*, 2nd edn.

Timber Press: Portland, OR.

Ecoroof (2011) *Gladstone Hotel*. Available at: www1.toronto.ca/City%20Of%20

Toronto/Environment%20and%20Energy/Programs%20for%20Residents/

PDFs/Eco-Roof/ecoroof_gladstone.pdf.

Liu, K. (2011) 'Retrofitting existing buildings with green roofs,' in *Construction Canada*. Construction Specifications Canada: Toronto.

Peck, S. and Kuhn, M. (2003) *Design Guidelines for Green Roofs*. Ontario

Association of Architects (OAA) and Canada Mortgage and Housing Corporation

(CMHC): Ontario.

Riley, M. and Cotgrave, A. (2014) *Construction Technology 2: Industrial and*

*Commercial Building*. Palgrave Macmillan: New York.

Studio Cidade Jardim (2012) *Village Mall – Rio de Janeiro*. Available at: www.

studiocidadejardim.com.br/#!Village-Mall-Rio-de-Janeiro/cv53/RoomsListItem0_

hvis0iyt667_0.

Williams, N. S., Rayner, J. P. and Raynor, K. J. (2010) 'Green roofs for a wide brown

land: opportunities and barriers for rooftop greening in Australia', *Urban Forestry*

*& Urban Greening*, 9(3), 245–251.

Wilkinson, S. J. and Reed, R. 2009. 'Green roof retrofit potential in the central

business district', *Journal of Property Management*, 27(5), 284–301.

Wilkinson, S. J., Lamond, J., Proverbs, D., Sharman, L. and Manion, J. (2015)

'Technical considerations and stakeholder awareness in green roof retrofit for

stormwater attenuation', *Structural Survey*, 33(1), 33–51.

Your Home (2013) *Green Roofs and Walls*. Available at: www.yourhome.gov.au/

sites/prod.yourhome.gov.au/files/pdf/YOURHOME-3-Materials-14-GreenRoofs

Walls-(4Dec13).pdf.

Zinco (2015) *Pitched Green Roofs*. Available at: www.zinco-greenroof.com/EN/

downloads/pdfs/ZinCo_Pitched_Green_Roofs.pdf.

**3**

## Green Roof Retrofit and the Urban Heat Island

**Paul Osmond and Matthias Irger**

UNSW, Sydney, Australia

## 3.0 Introduction

Global climate change and the UHI phenomenon – whereby cities absorb

and release more heat than the surrounding countryside – carry growing

potential to make urban life at particular times and places an exercise in

low-grade misery (Chindapol *et al*., 2014). The mitigating or temperature-

moderating role of urban vegetation and green spaces (Bowler *et al*., 2010),

reflective materials (Santamouris, 2014) and strategies for reducing the

release of heat from human activities like transport and air conditioning

are increasingly well understood. Green roofs have also been widely recog-

nised as playing a part in UHI mitigation (Rizwan *et al*., 2008). This chap-

ter reviews the literature around the microclimatic effects of green roof

retrofitting and presents a model based on detailed remote-sensing data for

metropolitan Sydney, Australia (Irger, 2014). This model is applied to

explore the effects of installing extensive green roofs on 100% and 50% of

rooftops across the variety of urban form typologies that characterise

Sydney's built environment. The results suggest a modest but real reduction

in heat island effects.

## 3.1

## Defining the Urban Heat Island

The notion that there is 'something different' about city air versus country

air has been understood since antiquity (e.g., Landsberg, 1981) – air *pollu-*

*tion* is nothing new. The idea that these differences could be extended to

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



properties such as air *temperature* arguably originated with Luke Howard,

Fellow of the British Royal Society, whose pioneering work on the climate

of London opened the way for the new science of urban climatology.

Howard was the first to document the UHI phenomenon, which in 1820

comprised a four-degree night-time difference in ambient temperature

between London and its rural surrounds, and which he attributed to the

heat generated by the burning of fuels (Howard, 1833).

Urban climates more generally are distinguished by the balance between

the gain of incident shortwave solar radiation and heat losses from long-

wave radiation re-radiated from walls, roofs and ground; by convective heat

exchange between ground, buildings and atmosphere; and by heat genera-

tion within the city itself (Givoni, 1998). The heat island phenomenon is

undoubtedly the most intensively studied feature of the urban climate

(Souch and Grimmond, 2006). Causative factors (Givoni, 1998; Coutts

*et al*., 2004; Grimmond, 2007) include:

■

The lower albedo (reflectivity) and higher heat capacities and conduc-

tivities of urban surfaces (roofs, walls, pavements) compared with those

of rural surfaces (crops, trees), leading to increased absorption of incom-

ing solar radiation, which is re-emitted, reflected and re-absorbed among

buildings and pavements.

■

The slower rate of radiant cooling (longwave radiation emission) at

night as a result of the physical characteristics and configuration of

urban form.

■

Reduced evapotranspirative cooling from vegetation, soil and water

bodies – less incoming solar radiation is dissipated as latent heat, so

more goes into sensible heat.

■

Nocturnal release of sensible heat stored in building mass during the

daytime (night-time air temperature differences between city and coun-

try are typically larger than during daylight hours).

■

Anthropogenic heat release from urban activities, including industry,

transport and space heating and cooling.

■

Reduced overall wind speeds (hence reduced heat transport) due to

increased friction.

The relative contribution of these causative factors varies between cities. For

instance, solar gain will be the dominant influence on diurnal heat island

formation during a cloudless day in the tropics, whereas anthropogenic heat

release may be the main cause of a nocturnal UHI in a dense, high-rise city

centre under a cloudy sky (Mirzaei and Haghighat, 2010).

Three types of heat island are recognised (Voogt, 2004): boundary layer,

canopy layer (CLUHI) and surface (SUHI) heat islands. The first two refer

to the warming of the urban atmosphere (see Figure 3.1); the last refers to

the warming of urban surfaces. The urban canopy layer is the layer of air

which extends from ground level to approximately the mean building height

(Voogt, 2004). The boundary layer is that part of the atmosphere which

interacts directly with the earth's surface – in this case, the 'rough' surface of

the city.

Green Roof Retrofit and the Urban Heat Island 39

Urban boundary layer

Wind

Rural boundary

layer

Rural

Urban

Rural

Urban canopy layer

**Figure 3.1** Urban boundary layer and canopy layer.

*Source*: Redrawn from Voogt (2004).

The annual average difference between the ambient temperature of a

large city and that of the surrounding countryside, or canopy layer UHI

*intensity*, typically averages about 1–3 °C (Oke, 1982), but can peak at

10–12 °C on still winter nights. The difference between urban and rural

temperatures ($\Delta T$) is generally greater at higher latitudes. However, the

u–r

variation from the average may be considerable depending on synoptic con-

ditions – for example, analysis of 19 years of Melbourne UHI data reveals a

range from −3.16 °C to +6 °C (Morris and Simmonds, 2000).

### 3.1.1

### UHI Impacts on Environment, Society and Economy

The effects of urban heat islands reach across the ‘triple bottom line’ –

environment, society and economy. Impacts include heat-related deaths,

illness and discomfort, worsened air pollution, greater electricity and water

consumption and additional GHG emissions, as described below.

An anticipated effect of global warming is an increase in the frequency

and intensity of heat waves and associated impacts on human health and

wellbeing through thermal stress (Meehl *et al*., 2001; Patz and Khaliq, 2002);

the elevated temperatures associated with the UHI will only exacerbate the

dangers to human health from climate change-induced heat waves. Higher

night-time temperatures and a decrease in the difference between average

minima and maxima – typical heat island phenomena – serve to prolong the

stress and delay relief. Many studies have linked heat waves with increased

morbidity and mortality, while others have modelled the persistent effects of

the UHI and climate change (e.g., Dessai, 2002; Bi *et al*., 2011). The elderly, the very young and the poor in the rapidly urbanising tropics and subtropics

are particularly at risk (Chindapol *et al*., 2014). One recent observational



project focused on a subtropical ‘megacity’ – Shanghai. Thirty years of mete-

orological records, together with mortality data, were analysed to ascertain

the relationship between UHI, heat waves and heat-related excess deaths

(Tan *et al*., 2010). The results indicate heightened heat-related mortality in

built-up inner areas of the city compared with the suburbs, and the authors

conclude that the UHI is directly responsible, acting to worsen adverse

health effects from exposure to extreme thermal conditions. In Australia, it

has been estimated that heat waves have claimed more lives than any other

natural hazard (Nicholls *et al*., 2008).

Hard, hot urban surfaces induce convection, which draws up city air

together with its burden of pollutants. Hence another distinctive feature of

the urban climate at city-wide scale, associated with the UHI, is what Piracha

and Marcotullio (2002) term the ‘urban dust-dome’, within which particu-

late and gaseous pollutants are trapped. Moreover, the increase in air tem-

perature inherent to the UHI accelerates the rate of formation of secondary

pollutants such as ozone (Sarrat *et al*., 2006; Fallmann *et al*., 2014), which can trigger and/or exacerbate a range of health problems. Finally, urban air

pollution can lead to greater cloud cover as pollutant particles provide

nuclei for condensation – which in turn helps to trap more heat.

Analysis of research from some 30 countries covering the world's main

climate zones showed that for each degree of temperature increase, the

growth in peak electricity load varies between 0.45% and 4.6% (Santamouris

*et al*., 2014). This rise in peak load both increases the prospect of power

outages and, being largely a consequence of air-conditioning use, generates

additional waste heat. Further, *total* electricity demand increases between 0.5%

and 8.5% per degree of temperature rise. Where fossil fuels are employed to

generate power, this will lead to a similar increment in electricity-related

greenhouse emissions.

Investigation of heat island influences on residential water use in Phoenix,

AZ found that a 1 °F (approximately 0.6 °C) rise in mean minimum tem-

perature resulting from the city's UHI was associated with a 1.7% increase

in water use in single-family homes. A fall of 1 °F in the difference between

mean minimum and maximum temperatures, reflecting warmer nights, saw

a 4% rise in water consumption (Guhathakurta and Gober, 2007). In addi-

tion to the immediate financial expense to householders, longer-term eco-

nomic implications include the cost of building and maintaining additional

water-supply infrastructure.

### 3.2

### Microclimatic Effects of Rooftop Greening

Before examining the UHI mitigation and broader microclimatic effects

of green roofs, it is helpful to review some fundamental concepts of urban

climatology. The *urban canyon* (i.e., the street as defined by the buildings on either side) is the key ‘unit’ of analysis, particularly at the micro (<102 m)

and local (102–103 m) scales. Urban canyons are characterised by four main

parameters: mean building height, canyon width, canyon length and orien-

tation (Figure 3.2). The ratio of height to width is known as the aspect ratio.

Green Roof Retrofit and the Urban Heat Island 41

O

L

H

W

**Figure 3.2** Properties of the urban canyon – length, width, height and orientation.

Together, these four geometric properties affect the solar exposure of build-

ings and open space, wind speed and direction, pollution dispersion and the

intensity of heat island effects. In turn, these microclimatic factors affect

building energy consumption for heating, cooling and lighting, and associ-

ated greenhouse emissions. They also influence outdoor comfort levels and

thus physical activity and behaviour patterns, and ultimately the health and

wellbeing of citizens.

As building density increases (either over time, or in space as we travel

from countryside to city centre), the radiatively active surfaces move upwards from ground plane to rooftops. So in densely built urban environments, roofs are where a considerable amount of absorption, reflection and emission of solar radiation occurs (Bruse and Skinner, 1999). The corollary of urban densification is that there is less space for greening at ground level, although the UHI mitigation benefits of ground-level street trees, parks and gardens are well established (e.g., Bowler *et al*., 2010). Hence, the option of retrofitting green roofs (and/or walls) becomes an increasingly logical response to moderating the effects of the UHI in densifying urban places.

So what degree of reduction in ambient and surface temperatures are we talking about? Research on UHI mitigation through rooftop greening falls into one or more of field measurement, simulation or remote sensing (Santamouris, 2014). It has expanded significantly since the initial studies of

the late 1990s,1 and the results in terms of projected temperature decreases

are generally fairly consistent. Before discussing the numbers though, it is

worth noting some general considerations (Alexandri and Jones, 2008),

which underpin the effects of green roofs and/or walls on UHI mitigation

across a variety of climate types:

■

The more solar radiation a roof or wall receives, the greater the decrease

in temperature when it is covered with vegetation.

■

Where wind speeds inside an urban canyon are low, the wind direction

has no significant effect on temperature decreases due to vegetation.

■

The wider the canyon, the weaker the effect green roofs and walls have

on temperatures.

1 A Google Scholar search on the terms ‘urban heat island’ plus ‘green roof’ on

30 August 2015 gave 3020 hits.

■

Green walls have a stronger effect than green roofs *within the canyon*.

■

Green roofs have a greater effect at roof level and thus *at urban scale*,

but predominantly with respect to the *surface* UHI.

Alexandri and Jones (2008) found that if applied to a single urban block, a

combination of green roofs and green walls could create a small local ‘cool

island’, or when applied at city scale, achieve more general UHI mitigation

benefits. The city-wide UHI is the combined result of heat production and/

or retention at the micro and local scales (see Figure 3.1) (Norton *et al*.,

2014). This highlights an important difference between the extreme varia-

bility of urban ambient and surface temperatures when measured at the

microscale, and the relative consistency of these properties when averaged

across the local neighbourhood or city wide. Anecdotally, this dichotomy

has led to misunderstandings among some end-users of urban climatology

research, since it is not possible simply to ‘scale up’ green roof findings at

building or block resolution to draw conclusions about UHI temperature

reductions at the scale of the whole city. Perhaps unsurprisingly, Stewart

(2011) points out that confusion of scales is also a common flaw in UHI

research itself. The simplifying assumptions introduced to integrate scale-

bound phenomena have been flagged as the main cause of discrepancies in

UHI results (Mirzaei and Haghighat, 2010).

While an *individual* green roof can reduce roof surface temperature

by 15–45 °C, near-surface air temperature by 2–5 °C and building energy

consumption by up to 80% (Peng and Jim, 2013), credible research indi-

cates quite modest city-wide UHI mitigation. For example, widely cited mes-

oscale (tens of kilometres) simulations identified city-wide cooling of

0.1–0.8 °C from retrofitting 50% of Toronto rooftops (Liu and Bass, 2005),

and 0.4–1.1 °C for 100% roof greening in New York (Rosenzweig *et al*.,

2006b). This of course does not discount potentially important *local* cooling

effects obtained through neighbourhood-scale green roof retrofitting

(e.g., Peng and Jim, 2013; see also Section 3.5.2).

In relation to *vertical* scale, Section 3.1 notes the three main heat island

types: surface, canopy layer and boundary layer. Norton *et al*. focus on

the role of green infrastructure in mitigating the *surface* heat island, argu-

ing that reduction of high urban surface temperatures represents a useful

target because they are easier to measure (e.g., through aerial thermal

photography) and compare accurately between areas (Norton *et al*.,

2014). The corresponding decrease in sensible heat flux to the atmosphere

can contribute both to reducing ambient air temperature and to UHI mit-

igation overall. In contrast, a decrease in roof surface temperature, even

with 100% rooftop greening, may not translate into a fall in ambient

temperature where buildings are tall, as was discovered by Ng *et al*.

(2012) in Hong Kong.

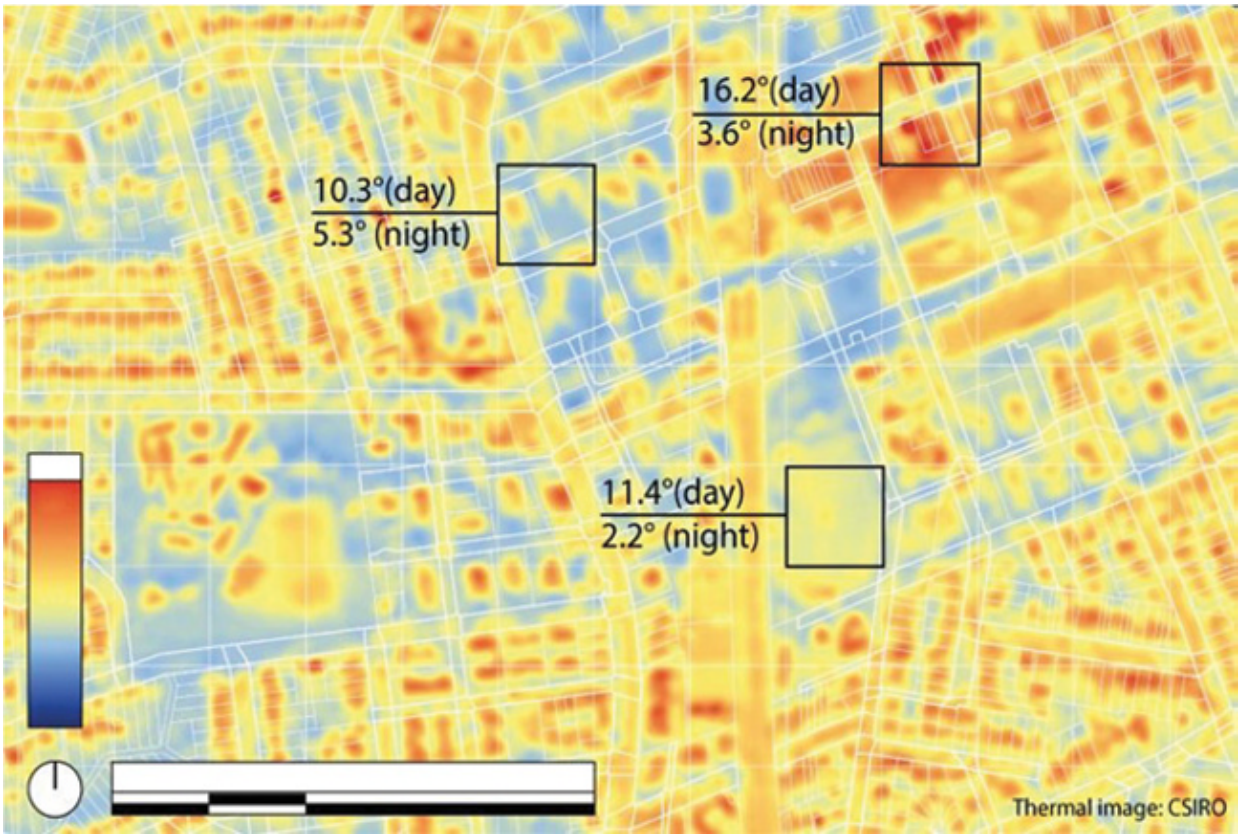
Figure 3.3 shows the surface thermal footprint of part of the Sydney sub-

urb of Chatswood, taken at approximately 12 p.m. on 6 August 2012, from

an aerial traverse of Sydney (Irger, 2014). Irger's model, explained in

Section 3.6, informs the green roof UHI mitigation methodology and calcu-

lations presented in this chapter.






°C

30

15

0

0

100

200

500 m

**Figure 3.3** Airborne thermal image of the Sydney suburb of Chatswood (Irger, 2014).

Indicated temperatures of grid cells show averages of night-time (approximately

12 a.m.) and daytime (approximately 12 p.m.) surface temperatures in degrees Celsius

based on imagery obtained 5 August 2012.

**3.3**

## Green Roof Cooling Mechanisms

The above-mentioned review by Santamouris (2014) compared the UHI

reduction potential of ‘cool’ (i.e., reflective) and green roofs2 (see also

Chapter 11). The former are designed to reflect solar energy – their cooling

capacity lies in their high albedo, or reflectivity. The mechanisms involved in

the UHI mitigation capacity of green roofs are more complex (see Table 3.1

and Figure 3.4). One of the acknowledged benefits of green roofs is their

ability to conserve building heating and cooling energy (Alexandri and

Jones, 2008), and thereby reduce the amount of waste heat from air condi-

tioning. This is attributable to a combination of insulation ( *U*-value), which

is determined by the thermal properties and thickness of the green roof,

latent heat release through evapotranspiration and shading by vegetation.

Plants also absorb solar energy to photosynthesise, which limits absorption

of the radiation by the soil and the roof structure, as well as reflection and

re-emission towards the sky and façades of taller buildings nearby. Perhaps

counter-intuitively, the energy conservation benefit of green roofs is strong-

est in poorly insulated buildings, while in modern, well-insulated buildings

the contribution is quite modest (Santamouris, 2014).

2 His conclusion was that in sunny climates, reflective roofs are more effective, while in moderate and cold climates, green roofs can offer greater benefits. Of course, this relates to UHI mitigation only; green roofs provide a wider range of co-benefits

compared with cool roofs.

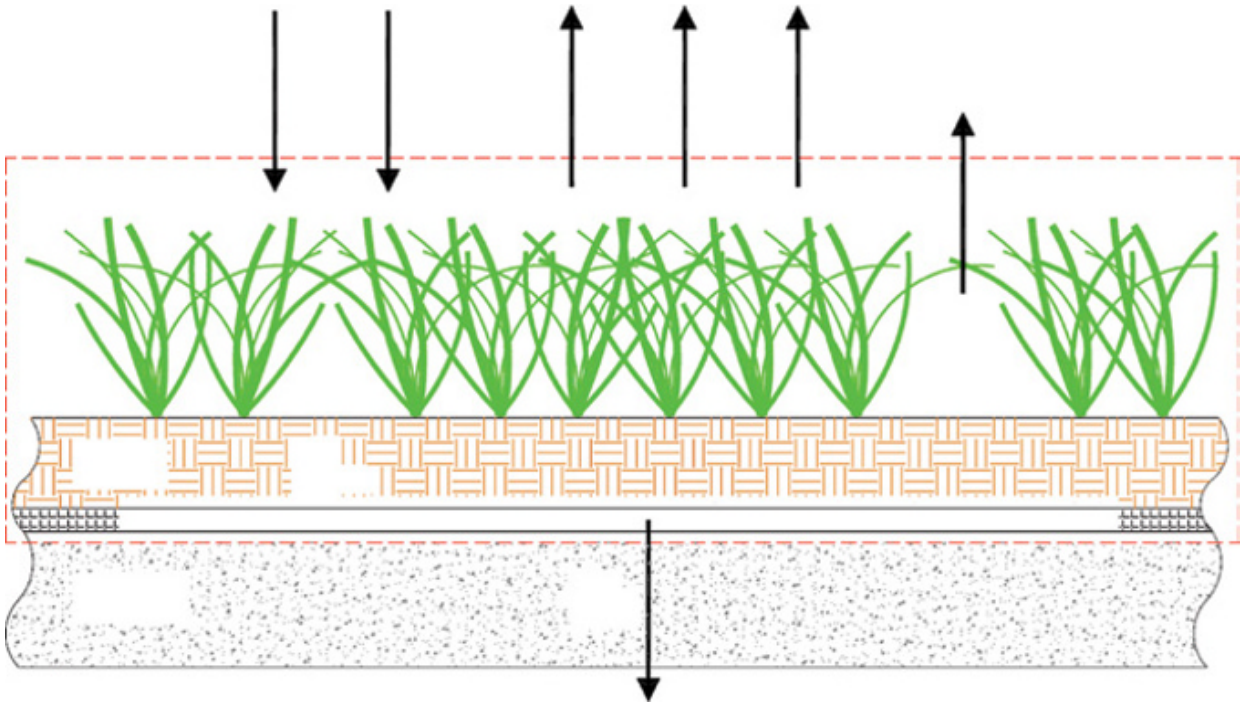




**Table 3.1** Key green roof properties which affect UHI mitigation

| Property | Relationship to UHI mitigation |
| --- | --- |
| Ambient | Determines the amount of sensible heat released by green roofs. |
| temperature | |
| Wind speed and | Determine sensible heat flux – high wind speeds increase both the flux of |
| turbulence | |

sensible heat and evapotranspiration.

Solar radiation

Largely determines the surface temperature of the roof, the amount of heat

intensity

transmitted to the building and evaporation from the roof.

Relative humidity

Interacts with rooftop vegetation – high relative humidity suppresses

evapotranspiration and reduces latent heat flux.

Precipitation and

Increase soil moisture and determine the latent heat flux.

irrigation

Effective albedo

Determined by type and density of rooftop vegetation – high albedo

decreases roof surface temperature and accumulation of heat, which means

lower sensible heat fluxes and higher mitigation potential.

Emissivity

Defines ability of roofs to dissipate heat through emission of infrared

radiation – higher emissivity means lower surface temperatures and higher

mitigation potential.

Leaf area index

The key parameter defining evapotranspirative losses – vegetation must be

dense to provide significant cooling.

Roof heat transfer

Determines the heat transferred to the building through the roof, which

coefficient

affects building cooling load.

*Source*: Based on Santamouris (2014).

qar

qsr

qtp

qev

qem

Environment

qep

Plants

System boundar

qsp

qrp

qps

q

y

Soil

ss

Drainage, root barrier, insulation, roof membrane (not to scale)

Roof

qtf

**Figure 3.4** Extensive green roof energy balance model.

*Source*: Adapted from Feng *et al*. (2010).

Table 3.1, adapted from Santamouris (2014), summarises the key physical

properties relating green roofs to UHI mitigation.

Fundamentally, the potential contribution of green roofs to UHI mitiga-

tion is defined by the gains, losses and storage of energy – the green roof



energy balance. A variety of models of varying degrees of complexity have

been advanced. Feng *et al*. (2010) propose a ‘simple but practical’ energy

balance model3 for extensive green roofs, which they have validated in

the field. The model may be expressed in the following equation and is

illustrated in Figure 3.4:

*q*

*q*

*q*

*q*

*q*

*q*

*q*

*q*

*q*

*q*

0 (3.1)

*sr*

*lr*

*cv*

*em*

*tp*

*ep*

*sp*

*ss*

*tf*

*ps*

*rp*

where:

$q$ = heat gain from solar radiation

*sr*

$q$ = heat gain from longwave radiation

*lr*

$q$ = heat transferred by convection

*cv*

$q$ = heat loss by emission

*em*

$q$ = heat loss by transpiration

*tp*

$q$ = heat loss by evaporation

*ep*

*q* = heat storage by plants

*sp*

*q* = heat storage by soil

*ss*

*q* = heat transferred into the building

*tf*

*q* = solar energy converted by photosynthesi

*ps*

*q* = heat generation by respiration.

*rp*

The units are W/m2 (Feng *et al*., 2010).

**3.4**

**Green Roof Retrofit for UHI Mitigation – Defining the Boundaries**

As proposed in Section 3.3, the model applied to calculate green roof UHI

mitigation potential (i.e., city cooling) is that which was developed through

a combination of remote sensing and field measurement by Matthias Irger

in his PhD thesis: ‘The effect of urban form on urban microclimate’ (Irger,

2014). However, the first task is to identify the extent, availability and suit-

ability of roof space for retrofitting, focusing on our case study city, Sydney.

### 3.4.1

### Roof Availability and Suitability

Urban cooling through green roof retrofitting is dependent on three4 main

factors: roof area as a proportion of a city's overall horizontal surface area;

the proportion of rooftops available and suitable for greening; and the

design of the green roofs themselves (design aspects are briefly canvassed in

Section 3.5.2). Roof area as a percentage of urban surface area obviously

3 Precipitation and irrigation inputs are excluded in this model.

4 The role of building *height* in attenuating cooling effects is raised in Section 3.3 and should not be underestimated, especially in relation to city centres. However, height

can be incorporated into building suitability analysis, discussed in this section, so is not considered here as a separate factor.



varies with building density. While rooftops comprise 45% of land surface

for mid-Manhattan west, the figure for New York City as a whole is just

18% (Rosenzweig *et al*., 2006a). Jacobson and Ten Hoeve (2012) have

estimated that roofs make up 28% of urban land surface area globally.

Using an adapted version of Stewart and Oke's (2012) local climate zone

(LCZ) model, Irger (2014) found that in Sydney, roof area varied from

more than 70% for the densest zone (**1e:** *compact high rise, mostly paved*) to near zero (**C:** *bush, scrub*). The most common LCZ (**6e:** *open low rise, mostly paved*), which takes in a sizeable part of Sydney suburbia, has a roof

coverage of 34%.

An evaluation of buildings in the Melbourne CBD by Wilkinson and Reed

(2009) established a set of benchmarks for assessing suitability for green roof

retrofit. These criteria included roof pitch (those pitched above 30° and below

2% were rejected), structural criteria (concrete-framed construction was

deemed most suitable because minimum structural alterations are required),

presence of rooftop plant and equipment (retrofit was rejected where plant/

equipment comprised ≥40% of roof area) and overshadowing by taller build-

ings. The authors found that 39.3% of CBD buildings were overshadowed

and 36.3% were partially overshadowed, limiting suitability for green roof

retrofit on the basis that there would be insufficient sunlight for planting to

flourish. They concluded it was possible that greater potential for retrofitting

existed in the suburbs or regional towns, where lower-rise buildings could

reduce the amount of overshadowing found in city centres (Wilkinson and

Reed, 2009). Wong and Lau, working in subtropical Hong Kong, took a more

tolerant approach to overshadowing. Applying 3D modelling to the densely

built Mongkok district, they identified that close to 94% of rooftops would

receive at least three hours of direct sunlight per day, which they argued was

adequate to support plant growth (Wong and Lau, 2013).

On the contrary, if the objective is to maximise UHI mitigation potential, it

is those buildings that are more likely to overshadow than be overshadowed

which may be less suitable for greening for purposes of lowering ambient

temperature, as suggested by the conclusions in Ng *et al*. (2012), introduced

in Section 3.3 above. Roof greening in the hot humid tropics may be effective

with building heights of less than 10 m (Wong *et al*., 2003), but an Australian study found that semi-intensive roof gardens modelled at 15 and 24 m height

had little cooling influence beyond their immediate environs (Osmond, 2004).

This suggests that the building height limit for useful mitigation of the urban

canopy heat island (as distinct from the surface heat island) via roof greening

may be as modest as three or four storeys. However, the pitfalls of generalising

findings from building or block scale to precinct or city scale and vice versa,

as mentioned in Section 3.3, are worth re-emphasising.

### 3.4.2

### Design Considerations – Intensive Versus Extensive

Most research on UHI mitigation through roof greening has unsurprisingly

focused on extensive green roofs, as building structural and financial

considerations preclude broad-scale retrofitting of intensive roof gardens.

Green Roof Retrofit and the Urban Heat Island 47

Analysis of the thermal insulation performance of an experimental ‘sky

woodland’ in Hong Kong revealed that the 1 m deep substrate was acting

as a heat sink; heat stored during the day was dissipated by transforming to

sensible and convective heat at night (Jim and Tsang, 2011), suggesting

minimal or even negative night-time UHI mitigation.

There has been very little research directly comparing the performance of

the two green roof types. However, another Hong Kong project designed to

investigate local-scale thermal comfort established that extensive green

roofs reduced pedestrian-level air temperature by 0.4–0.7 °C, and intensive

roofs by 0.5–1.7 °C, with maximum effects in more open low-rise sites (Peng

and Jim, 2013). Building massing and heights reduced the movement of cool

air generated by the green roofs. Significantly, the authors' research indicated

a reduction in the diurnal duration of high heat stress of 6–9 hours for the

extensive scenario, and 9–11 hours for the intensive scenario.

Research such as the above suggests that practical neighbourhood-scale

retrofitting could perhaps combine a matrix of mainly extensive green roofs

with a scattering of intensive roof gardens, where structural criteria and

budgets permit. The latter could potentially even form useful nodes within a

rooftop biodiversity network (see Chapter 8).

## 3.5

## Green Roof Retrofit for UHI Mitigation – Developing the Model

As noted above, UHI research includes three distinct methods: fieldwork,

numerical modelling and remote sensing. Each of these comes with strengths

and weaknesses.

### 3.5.1

### Overview of Methods

Field measurement typically involves assessment of the spatial distribution

and intensity of the heat island using a combination of fixed and/or mobile

stations. Usually this will require interpolations and approximations, given

the inevitable limitations on the number of measurement locations, times

and parameters measured (Mirzaei and Haghighat, 2010).

Field measurement is also employed to parameterise simulation models.

Numerical modelling approaches can be classified according to scale.

Mesoscale climate models applied in city-wide studies may extend over

hundreds of square kilometres with a resolution (grid cell size) of

1 km – parameters such as building height and albedo are averaged for each

cell (Burian *et al*., 2004; Masson, 2006). At the other extreme, microscale

computational fluid dynamics (CFD) models can simulate flow processes in

buildings or outdoor spaces to a resolution of centimetres. For urban climate

applications the horizontal extent is usually of the order of a few hundred

metres with a resolution of one or two metres. Whatever the scale, these

models by definition simplify the complex processes of the UHI; at the

microscale, there is the additional issue of establishing realistic boundary

conditions to initialise the model (Mirzaei and Haghighat, 2010).



Satellite or aerial remote sensing involves acquisition of surface temperature

data through thermal (infrared) imaging. Other sections of the electromag-

netic spectrum may be employed to identify the spectral signatures of par-

ticular materials, vegetation, etc. Surface temperatures integrate the effects

of several radiative and thermodynamic properties, including surface mois-

ture, emissivity, albedo and interactions with the near-surface atmosphere.

However, surface UHI differs from the canopy-layer UHI, where wind veloc-

ity and turbulence affect ambient air temperature (Mirzaei and Haghighat,

2010). Also, of course, vertical surfaces5 as well as horizontal surfaces

obscured by, for example, vegetation cannot be imaged.

The methodology discussed below combines remote sensing through

aerial photogrammetry with mobile (vehicle transect) field measurement.

### 3.5.2

### Modelling Roof Availability and Suitability

Three-dimensional information on buildings and their roof surface proper-

ties is a prerequisite for estimating the effect of rooftops on urban tempera-

tures. While data on the height, roof area and slope of individual buildings

is rarely readily accessible and is too time consuming to obtain manually

for large areas, airborne remote sensing allows rapid morphological and

radiative mapping at city-wide scale. Lidar, for instance, can obtain highly

accurate 3D information on buildings and vegetation, while thermal and

hyper- or multispectral sensors6 can reveal detailed surface temperature,

albedo and materiality data at the microscale.

A lidar system transmits a pulsed laser beam and records reflected signals

as a set of points in space, often referred to as point clouds. The lidar point

cloud data can be classified into vegetation, buildings and ground surface

according to the signature of the return pulse. As lidar registers not only the

geographic coordinates but also the altitude above sea level for each recorded

point, the height of buildings and vegetation can be derived relative to the

ground.

Lidar processing software such as LP360 (QCoherent, 2013) can trace

outlines around clusters of similar points to generate building footprints.

Roof heights relative to the ground can be derived by subtracting a digital

*elevation* model created from points classified as buildings from a digital

*terrain* model based on points identified as ground surface. A resolution of

multiple points per square metre allows the calculation of individual roof

slopes by triangulating the height information of individual points within

each building's footprint.

5 Walls may account for 47% of the total surface area in a city's 'urban core' (Ellefsen, 1990/91).

6 Hyperspectral and multispectral imaging capture reflected electromagnetic radia-

tion across a wide region of the electromagnetic spectrum. The main difference is the

number and width of the wavelength bands – multispectral imaging involves fewer

and wider bands vs more and narrower for hyperspectral imaging.



The spatial information derived from these remote-sensing techniques can

be further analysed in a geographic information system (GIS) environment.

This allows the researcher to estimate roof surface availability and suitabil-

ity for a specific area or spatial unit, derive morphological parameters

such as volumetric building density and urban canyon properties (see

Figure 3.2), and facilitates automated urban classification into local climate

zones (Irger, 2014).

### 3.5.3

### Modelling Thermal Performance

The air and surface-temperature profile in a precinct or street is the result

of a range of different interacting physical factors (see Section 3.3). To be

able to estimate the mitigating potential of roof greening on canopy layer

and surface heat island intensity, we need access to highly detailed spatial

information and a comprehensive understanding of the complex interplay

among the various factors that influence the urban microclimate in a

given location.

With resolutions of up to 0.5 m/pixel, airborne remote thermal sensing

is now able to provide surface-temperature mapping suitable for building-

scale analysis. In combination with lidar-derived data, this level of detail

allows broad-scale thermal assessment of rooftops across a variety of

urban areas.

Multiple linear regression (MLR) analysis can quantify the contribution

of individual urban form parameters such as roof area per LCZ or per hec-

tare to the average air or surface temperature for the relevant spatial unit.

An ordinary least squares MLR model estimates the best fit (correlation)

between predicted and recorded variables for a number of observations

within a data set. The resulting correlation coefficients approximate the

effect of each independent variable on the dependent variable of interest – in

this case, air or surface temperature. These coefficients can be expressed in

an equation and used to predict the dependent variable for similar locations

where the predictors are known.

When working with spatial data it is important to recognise that indi-

vidual observations are generally affected by those in neighbouring areas

(Tobler, 1970), a phenomenon known as spatial autocorrelation. One can

imagine that clustering of similar LCZs in a given location could influence

the thermal performance of a particular urban setting, for instance. Without

controlling for spatial autocorrelation, a regression model becomes unstable

and the correlation coefficients become inaccurate. The freely available soft-

ware GeoDa, which can analyse GIS-based shape files, provides a number of

statistical tests to identify the most appropriate model to deal with such

spatial interdependencies (Anselin, 2013).

In Irger's research, the spatial error model (SEM) was successfully

employed to manage this kind of autocorrelation between multiple variables

and improve overall model performance. The SEM introduces the spatial

error term $\lambda$ in a global linear regression equation to improve the correctness of correlation coefficients by removing spatially related errors in individual



variables (Anselin, 2003; Ward and Gleditsch, 2008). The model applied in

this research can be expressed in the following equation:

*y*



*x*

*w*

(3.2)

*i*

0

*p*

*ip*

*p*

*i i*

*i*

where:

*y* is the dependent variable for spatial units indexed by *i*

*i*

*β* represents the model *constant* or *intercept*

0

*β* are the *parameter vectors* or *regression coefficients* for *p* independent *p* variables

*x* are the independent variables or *predictors*

*ip*

*λ* is the *spatial error parameter* indicating the extent of the spatial correla-

tion

*w* represents the *vector of connectivity* indicating the closeness of spatial *i* units

*ξ* is the *spatial component* of the *error term*

*i*

*ε* is the *error term* of the regression (Ward and Gleditsch, 2008).

*i*

**3.6**

**Model Implementation – Evaluating Sydney's Surface**

**and Canopy-Layer Heat Islands**

The above model was developed as part of Matthias Irger's (2014) PhD

thesis and successfully applied in a case study of the Sydney metropolitan

area. Irger's research analysed the morphology of different urban settings

in relation to surface and urban canopy-layer heat island intensity at sub-

precinct and street scale. The research centred on the question: How much

do individual urban form parameters including volumetric building density,

urban canyon geometry and orientation, vegetation content and structure

and surface albedo modify overall air and surface temperatures?

High-resolution airborne remote sensing was used to record diurnal SUHI

intensity and quantify the above-mentioned range of morphological param-

eters over an area of approximately 160 km2, from the City of Sydney and

Chatswood CBD in the east to the outer western suburbs. The airborne data

collection was funded by the Climate Adaptation Research Flagship of the

Commonwealth Scientific and Industrial Research Organisation (CSIRO),

who commissioned two flights around midnight and noon in August 2012

to capture lidar, thermal and hyperspectral imagery under clear and calm

conditions. Two simultaneous automobile transects recorded in-situ meas-

urements of air temperature and relative humidity along the flight path.

Hyperspectral imagery with spectral range from visible light to shortwave

infrared were used to derive albedo values for the urban surfaces by

averaging the reflectivity of individual spectral bands. The same data were

utilised to create a normalised difference vegetation index (NDVI)7 image to

7 NDVI is an index of vegetation ‘greenness’, representing photosynthetic activity.



help distinguish between impervious and vegetated ground surfaces. Lidar

data were employed to generate roof outlines and building shapes, and to

identify surfaces covered by low (<0.5 m), medium (0.5–2 m) and high

(>2 m) vegetation.

The case study area was organised in a generic grid of 1 ha squares, which

was found to be the smallest spatial unit able to represent distinctly recog-

nisable urban settings. Averages of horizontal surface temperature and

albedo were calculated for each grid cell, as well as the areas represented

by roofs, trees, shrubs, low vegetation and impervious ground surfaces, the

urban canyon aspect ratio and average building height. These parameters

enabled the classification of each grid cell into LCZ subgroups as combi-

nations of ‘built’ and ‘natural’ types via an automated GIS-based process.

Table 3.2 provides an overview of selected morphological parameters

including averages of day and night-time air and surface temperatures for

each LCZ (per hectare) as well as roof surface temperatures.

The overwhelming majority (more than 90%) of the case study area

consisted of suburbs with low or very low urban densities, namely ‘open

low rise’ (LCZ 6) and ‘sparsely built’ (LCZ 9) with roof surfaces covering

22–34% and around 7–10%/ha, respectively. These precincts featured

largely uniform roof heights averaging 4.2 to 6.7 m (generally one to two

storeys).

‘Open midrise’ (LCZ 5) was the third commonest LCZ, with 1.4% of the

case study area and building heights of 11–14 m. ‘Open high rise’ (LCZ 4)

areas with average building heights of more than 40 m were slightly less

common and concentrated in city centres. While overall roof coverage is

comparable across all ‘open’ LCZs, the variation of neighbouring roof levels

or ‘surface roughness’ increases with average building height. ‘Compact’ low

or high-rise urban settings with more than 50% roof coverage per hectare

were very rare, just 0.1% of the study area.

Comparative analysis of thermal performance illustrated that SUHI inten-

sity varies significantly within short distances even in winter with minimal

solar radiation: the difference between average surface temperatures of indi-

vidual LCZs reached up to 13.7 °C during the day and 7.7 °C at night.

The highest daytime average surface temperatures of around 19 °C were

recorded in completely paved large low-rise developments with a high pro-

portion of exposed rooftops (LCZ 8e), while densely forested areas (LCZs

A and 9a) were up to 11.5 °C cooler. In general, SUHI intensity was greatest

in low-rise suburban developments, and increased with the proportion of

impervious ground and roof surfaces, and limited shade due to low building

heights and distinct lack of trees.

At night, SUHI intensity is reversed, with the highest average surface tem-

peratures recorded in compact urban settings and areas with dense vegeta-

tion, where closely set buildings and extensive tree canopies obstruct

night-time cooling. Open and sparsely built low-rise developments with pre-

dominantly low plants (LCZ 6b and 9b) featured the coolest night-time

surface temperatures.

As expected, roof surface temperatures appeared to be predominantly

governed by material-specific thermal properties and the amount of

e

y

CZ @ da

L

NA

18.3

18.4

NA

18.9

17.5

18.3

20.1

NA

19.1

17.5

ir

atur

)

A

(°C

t

CZ @ nigh

L

temper

NA

12.3

12.1

NA

9.2

9.8

7.3

4.2

NA

8.6

NA

y

ops @ da

t

oof

R

14.7

12.6

13.8

14.5

14.0

11.1

6.8

15.1

14.7

10.0

16.1

)

e

y

CZ @ da

L

fac

e (°C

14.0

12.1

13.0

12.0

13.1

11.9

12.8

14.4

13.1

13.9

12.1

atur

t

nigh

ean sur

ops @

t

oof

R

M

3.8

4.1

3.4

4.0

3.1

3.5

4.0

5.3

2.7

3.5

4.5

temper

t

CZ @ nigh

L

4.2

4.4

4.0

4.5

3.8

4.0

4.5

5.5

3.1

4.0

4.7

t (m)

ean building heigh

M

92.9

18.7

41.5

11.4

14.0

5.5

4.7

4.2

4.6

4.7

5.8

ops (%)

t

oof

R

57.8

56.5

35.4

24.7

36.7

26.4

27.8

22.5

22.9

34.2

27.1

ees (%)

r T

3.1

7.5

4.4

28.7

6.3

57.4

28.3

8.7

6.9

11.5

52.5

e and air)

Shrubs (%)

fac

0.3

0.6

2.0

2.0

1.6

7.3

4.6

6.3

8.4

CZ/ha)

11.6

13.9

es (sur

ass (%)

Gr

3.9

3.0

11.3

28.7

11.9

3.7

17.8

32.0

42.9

15.2

14.3

atur

rea (% LA

oad (%)

R

emper

25.4

21.8

26.5

25.5

25.6

17.0

19.0

19.7

17.3

24.4

9.5

ound (%)

r g

es and t

vious

mper

l

26.0

25.1

34.1

11.1

32.1

12.9

20.0

24.8

20.6

31.0

12.9

turea

7

9

7

2

*N*

25

120

89

464

12

15

istic f

3022

terac

ees

ved

ees

, char

ved

ees

ts

ees

ved

ed tr

ed tr

er

ved

er

ved

roups

tt

tt

w plan

, mostly pa

, mostly pa

ise

ise

, mostly pa

, mostly pa

, mostly pa

LCZ subg

ise

ise with sca

ise with shrubs

ise with lo

ise

ise with dense tr

ise with sca

ise

ise with dense tr

t high r

t midr

w r

w r

w r

w r

w r

w r

roups

Z

ge lo

**Table 3.2**

LC

subg

**LCZ 1e:** Compac **LCZ 2e:** Compac **LCZ 4e:** Open high r **LCZ 5b:** Open midr **LCZ 5e:** Open midr **LCZ 6a:** Open lo **LCZ 6b:** Open lo **LCZ 6c:** Open lo **LCZ 6d:** Open lo **LCZ 6e:** Open lo **LCZ 8a:** Lar

NA

18.4

18.7

17.9

18.2

18.1

18.7

18.6

NA

18.4

NA

NA

NA

NA

8.2

7.1

8.8

8.6

5.0

8.3

8.3

NA

5.8

NA

NA

NA

14.4

14.8

15.0

8.9

8.6

NA

6.3

10.2

NA

NA

9.7

NA

14.3

11.8

12.7

14.5

10.7

11.6

11.1

11.9

13.2

9.9

9.6

9.4

10.3

14.5

2.9

2.8

2.8

3.9

3.5

4.6

3.1

2.9

5.1

4.2

3.7

3.6

3.4

3.6

3.8

3.6

4.6

4.0

4.6

3.1

3.6

5.4

3.9

2.6

2.5

4.1

7.7

4.8

6.7

6.0

5.4

4.2

5.4

6.7

9.6

6.6

5.1

4.6

10.4

31.1

25.7

49.0

11.7

10.2

9.8

7.1

11.5

3.1

2.7

0.9

1.1

3.6

22.0

3.2

6.6

63.1

24.5

5.7

4.6

8.7

87.6

36.6

6.2

4.2

1.3

1.7

1.4

1.3

7.6

6.5

17.4

2.5

3.3

35.4

17.6

16.6

3.3

0.9

29.5

51.7

14.9

9.0

35.3

45.3

61.4

25.1

4.8

45.8

70.8

87.5

3.5

0.1

7.0

10.9

14.6

19.3

21.1

16.0

26.2

6.6

12.0

11.2

13.6

20.5

14.1

16.9

25.8

11.0

20.0

24.8

21.3

46.9

3.4

7.6

1.7

3.0

89.4

3

5

74

191

72

60

13

21

1057

604

1225

234

113

ees

ees

ts

ts

ed tr

ees

ed tr

er

ved

ved

tt

er

w plan

tt

w plan

, mostly pa

, mostly pa

ise with sca

ise with lo

ise

ees

ved

w r

w r

w r

ees

ts

ed trer

ge lo

ge lo

ge lo

tt

ense tr

**LCZ 8b:** Lar **LCZ 8d:** Lar **LCZ 8e:** Lar **LCZ 9a:** Sparsely built with dense tr **LCZ 9b:** Sparsely built with sca **LCZ 9c:** Sparsely built with shrubs **LCZ 9d:** Sparsely built with lo **LCZ 9e:** Sparsely built **LCZ A:** D **LCZ B:** Sca **LCZ C:** Shrubs **LCZ D:** Low plan **LCZ E:** Rock or pa



overshadowing by tall buildings and trees. As the proportion of roof area

increases with rising compactness while vegetation content declines, the

influence of roof characteristics on the average surface temperature of LCZs

naturally becomes more pronounced.

The application of the above-mentioned SEM (equation (3.2)) allows us

to go beyond descriptive trends and estimate the individual contribution

of relevant urban form parameters on SUHI intensity, while controlling for

situational factors such as the distance to the ocean and the average altitude

of the location, as well as the effect of surrounding neighbours. The devel-

oped models predict average day and night-time surface temperatures

as dependent variables ( *sT* and *sT*

) and can be expressed in the follow-

*Day*

*Night*

ing equations:

*sT*

*A*

*A*

*A*

*Day*

0

1 *VEG _ high*

2 *IMP _ ground*

3 *IMP _ roof*

4

*IMP _ grounnd*

5 *IMP _ roof*

*HD*

*D*

(3.3)

6

*7 coast*

*sT*

*A*

*A*

*A*

*Night*

0

1 *VEG _ high*

2 *IMP _ ground*

3 *IMP _ roof*

4

*IMP _ groound*

5 *IMP _ roof*

*HD*

*ALT*

*D*

*t*

(3.4)

6

*7*

8

*coast*

9 *Night*

where:

*sT* and *sT*

are the mean day and night-time surface temperatures of

*Day*

*Night*

LCZs

*β* represents the model constant

0

$\beta$ are the correlation coefficients of significant independent variables

$n$

$A$

, $A$

and $A$

are the percentage fractions of LCZ area

*VEG_high*

*IMP_ground*

*IMP_roof*

covered by high vegetation, impervious ground and impervious roof sur-

faces, respectively

$\alpha$

and $\alpha$

are the mean albedo values of impervious ground and

*IMP_ground*

*IMP_roof*

roof surfaces, respectively

*HD* is the height-to-distance ratio of buildings

*ALT* is the altitude in metres above sea level

*D*

is the distance to the coast in metres

*coast*

*t*

represents the time since first measurement during the night in seconds

*Night*

*λ* is the spatial error term

*ε* is the error term of the regression.

Based on the regression coefficients for the above equation, Table 3.3

illustrates the magnitude of change in average night and daytime surface

temperatures of LCZs caused by the respective variable (°C) with all other

factors held constant.

The statistical analysis confirmed that roof surfaces are indeed the most

significant single contributor to overall SUHI intensity during the day.

While their albedo appeared to be irrelevant, a 10% increase in the area of

rooftops as a proportion of the overall surface area was responsible for an

increase of almost 0.6 °C in the average daytime surface temperature of a

given LCZ. The fact that this is nearly twice as high as the contribution of

Green Roof Retrofit and the Urban Heat Island 55

**Table 3.3** The effect of individual independent variables on night and daytime

surface temperature of LCZs (°C)

Effect on mean surface

temperature

Variable

Change

Night

Day

Area of high vegetation

+10%

↑ +0.13 °C

↓ −0.15 °C

Area of impervious ground surface

+10%

↑ +0.15 °C

↑ +0.32 °C

**Area of roofs**

**+10%**

↔ **−0.04 °C**

↑ **+0.57 °C**

Albedo of impervious ground surfaces

+0.1

↓ −0.22 °C

↑ +0.18 °C

**Albedo of roofs**

**+0.1**

↔ **+0.02 °C**

**Insignificant**

Building height to distance ( *H*/ *D*) ratio

+0.1

↔ +0.05 °C

↓ −0.15 °C

Altitude

+10 m

↑ +0.16 K

Insignificant

Distance to coast

Insignificant

impervious ground surfaces indicates that the physical properties of surface

materials, such as thermal inertia and emissivity,8 in combination with the

extent of solar exposure are the main drivers for SUHI intensity. Shading by

trees and buildings appears to be largely responsible for lowering surface

temperatures by 0.15 °C/10% increase in high vegetation and 0.1 in the

height-to-distance ratio of buildings, respectively.

At night, roof surfaces had no influence on overall SUHI intensity, while

a moderate effect of material-specific thermal properties was noticeable in

the rate of surface warming of 0.15 °C/10% increase in impervious ground

surfaces. The presence of trees had a similar warming effect due to sky-view

reduction and heat trapping, but this was interestingly not the case for volu-

metric building density, the effect of which was insignificant at night.

## 3.7

## Green Roof Retrofit for UHI Mitigation – Model Implementation

Apart from identifying and quantifying the factors responsible for local climate change, the main benefit of spatial regression modelling is its predictive capability. When the urban parameters for a given area are introduced into equation (3.2), we can simulate the average surface temperature of any urban setting with similar background climate. We can also model scenarios of potential green roof retrofit programmes, which can be compared with the baseline case. Table 3.4 illustrates by how much the average surface temperature of each LCZ would change if buildings were covered 50% and 100% by green roofs.

The above example demonstrates that it is possible to significantly reduce the average surface temperatures of a neighbourhood even in winter through green roof retrofits. As the main factor for SUHI intensity is the area of roofs

8 The speed with which the temperature of an object approaches that of its surround-

ings, and the efficiency of a surface in emitting thermal energy, respectively.



**Table 3.4** Observed versus predicted mean surface temperatures of LCZs (°C) modelled for mitigation scenarios with 50% and 100% extensive green roof retrofit, assuming 0% baseline green roof coverage in the case study area

Predicted mean surface temperature (°C) of LCZ

0% green roofs

50% green roofs

100% green roofs

LCZ subgroups

@ night

@ day

@ night

@ day

@ night

@ day

**LCZ 1e:**

+0.1

−1.7

+0.3

−3.3

Compact high rise, mostly paved

4.2

14.0

4.4

12.3

4.5

10.7

**LCZ 2e:**

+0.1

−1.6

+0.3

−3.2

Compact midrise, mostly paved

4.4

12.1

4.5

10.5

4.6

8.8

**LCZ 4e:**

+0.1

−1.0

+0.2

−2.0

Open high rise, mostly paved

4.0

13.0

4.1

12.0

4.1

11.0

**LCZ 5b:**

+0.1

−0.7

+0.1

−1.4

Open midrise with scattered trees

4.5

12.0

4.6

11.3

4.6

10.6

**LCZ 5e:**

+0.1

−1.0

+0.2

−2.1

Open midrise, mostly paved

3.8

13.1

3.9

12.0

4.0

11.0

**LCZ 6a:**

+0.1

−0.8

+0.1

−1.5

Open low rise with dense trees

4.0

11.9

4.1

11.2

4.2

10.4

**LCZ 6b:**

+0.1

−0.8

+0.1

−1.6

Open low rise with scattered trees

4.5

12.8

4.5

12.0

4.6

11.2

**LCZ 6c:**

+0.1

−0.6

+0.1

−1.3

Open low rise with shrubs

5.5

14.4

5.6

13.8

5.7

13.2

**LCZ 6d:**

+0.1

−0.7

+0.1

−1.3

Open low rise with low plants

3.1

13.1

3.2

12.4

3.2

11.8

**LCZ 6e:**

+0.1

−1.0

+0.2

−2.0

Open low rise, mostly paved

4.0

13.9

4.1

12.9

4.2

11.9

**LCZ 8a:**

0.1

−0.8

+0.1

−1.6

Large low rise with dense trees

4.7

12.1

4.7

11.3

4.8

10.5

**LCZ 8b:**

0.1

−0.9

+0.1

−1.8

Large low rise with scattered trees

3.6

11.8

3.7

10.9

3.7

10.0

**LCZ 8d:**

+0.1

−0.7

+0.1

−1.5

Large low rise with low plants

3.8

12.7

3.8

12.0

3.9

11.3

**LCZ 8e:**

+0.1

−1.4

+0.2

−2.8

Large low rise, mostly paved

3.6

14.5

3.7

13.1

3.8

11.7

**LCZ 9a:**

0.0

−0.3

0.1

−0.7

Sparsely built with dense trees

4.6

10.7

4.6

10.4

4.6

10.1

**LCZ 9b:**

0.0

−0.3

0.0

−0.6

Sparsely built with scattered trees

4.0

11.6

4.1

11.3

4.1

11.0

**LCZ 9c:**

0.0

−0.3

0.0

−0.6

Sparsely built with shrubs

4.6

11.1

4.6

10.8

4.6

10.5

**LCZ 9d:**

0.0

−0.2

0.0

−0.4

Sparsely built with low plants

3.1

11.9

3.1

11.7

3.1

11.5

**LCZ 9e:**

0.0

−0.3

0.1

−0.7

Sparsely built, mostly paved

3.6

13.2

3.6

12.8

3.6

12.5



as a proportion of LCZ, the mitigation potential is greatest during the day

in compact high and midrise as well as large low-rise developments. With

100% extensive green roof coverage, daytime SUHI intensity in these LCZs

would be reduced by about 3°C. Predominantly paved areas would benefit

the most, with average surface cooling of 2°C or more, while the presence

of trees appears to reduce this effect slightly.

In a scenario where half the conventional roof surfaces are greened, SUHI

intensity during the day would still decline between 0.6 and 2 °C in most

urban settings. At night, however, both scenarios would have a marginal

warming effect.

A preliminary street-scale statistical analysis of urban canyons revealed

no significant correlation between surface and air temperatures, which

could mean that green rooftop retrofits would not necessarily lead to sub-

stantial urban microclimate modification in winter, particularly if roof levels

were more than 10 m above ground. This is consistent with a detailed analy-

sis of existing simulation studies (Santamouris, 2014), which suggests that

100% green roof retrofitting applied on a city scale may reduce the average

ambient temperature between 0.3 and 3°C.

This may be entirely different in summer, when surfaces frequently become

more than 40°C hotter than ambient air and consequently contribute sig-

nificantly more to local urban warming. Considering that the vast majority

of urban development outside city centres is made up of buildings 4–7 m

high with roof slopes generally less than 30°, the heat mitigation potential

of green roof retrofits may be substantial during the warmer months of the

year. However, it is important to note that the efficacy of mitigation is

related to water availability for efficient photosynthesis and evapotranspira-

tion to extract energy which otherwise would end up as sensible heat.

## 3.8

## Conclusions – Where to from Here?

Thermal, lidar and hyperspectral data from aerial remote sensing were com-

bined with mobile (vehicle transect) field measurements and analysed in a GIS

environment using multiple linear regression to support the morphological

classification, evaluation and prediction of the thermal performance of urban

settings. Our research provides evidence that the specific morphological com-

position of precincts, in particular the proportion of roof surface per hectare,

is responsible for significantly different SUHI intensities at local scale.

The automated LCZ classification comprehensively describes the compo-

sition of the actual urban fabric and provides insights into the availability of

roof surfaces across the metropolitan region of Sydney.

By analysing observations of urban form indicators in relation to surface

temperature, the spatial error regression model permits us to estimate the

effect of rooftops on urban microclimate, while allowing for hidden, inter-

dependent relationships between other contributing factors such as urban

canyon geometry and orientation, the presence of vegetation and its struc-

ture, surface cover and albedo, volumetric building density of precincts, as

well as geographical factors such as altitude or proximity to the ocean.



Detailed knowledge of these quantities is a prerequisite for this kind of

microscale analysis. Airborne remote-sensing products can support efficient

spatial and thermal analysis of rooftops in a city-wide application, while

aggregation of manually collected data in individual locations is also possi-

ble but time consuming. Once evidence-based models have been developed

for a given region, outcomes are transferable to other settlements with

similar climate.

The combination of LCZ subgroup classification with spatial regression

analysis allowed us to make assumptions about the effect of roof surfaces on

overall surface temperature, albeit limited to winter conditions. The next

obvious step is to expand this framework to include maximum summer

temperatures and verify results in other cities across the country to develop

a comprehensive understanding of the potential of green roof retrofit to

mitigate local heat phenomena in all climate zones.

While the benefits of green roofs may be greatest in relation to aspects

such as stormwater management, the potential for urban cooling may be

significant when taking low plants and shrubs as indicator for surface

temperatures of green roofs. Roof surface and road corridors are the main

areas of interest for the implementation of effective mitigation strategies in

existing suburbs most exposed to extreme temperatures.

### 3.8.1

### Limitations of the Research and Opportunities for Further Work

In the absence of empirical data on rooftop vegetation, this study used low

ground vegetation (<0.5 m) as a proxy. Given that the majority of roofs in

the study area are less than 10 m high, this is not seen as a major source of

error, but as with all models, this one is a simplification of reality. Factors

such as plant species, substrate depth and seasonal water availability will

have a significant impact on the diurnal thermal performance of green roofs

and require thorough investigation.

The automobile collection of air temperature measurements was limited

to streets and thus not considered representative of the complete LCZ.

Further research is also needed to determine the temperature distribution

across the air column within the urban canopy layer under maximum sum-

mer conditions in order to evaluate the mitigating effect of green roofs on

CLUHI intensity, ideally also considering the effects of building façades

(including green walls). Indeed, the effect of the *angle* of the greened surface from vertical to horizontal would seem a useful avenue to pursue.

Oke (1982) points out that the most significant meteorological variable

governing heat island intensity is wind speed, followed by cloud cover.

Hence, another aspect warranting investigation (e.g., via simulation) is the

interaction between wind and surface temperature with and without green

roofs for different LCZs.

The effect of building height on green roof UHI mitigation potential was

flagged in Section 3.3 and remains an area of potential research interest,

as does evaluation of the resilience and efficacy of green roofs during dry

spells and heat waves. This latter issue raises the question of the relative



performance of extensive versus intensive green roofs, including vegetation

structure and water storage and retention capacities.

Finally, the *multi-functionality* of green roofs has been emphasised

throughout this book, and opportunities for flora and fauna conservation,

urban farming and other green roof retrofit benefits – which can co-exist

with UHI mitigation – are addressed in other chapters.

## References

Alexandri, E. and Jones, P. (2008) 'Temperature decreases in an urban canyon due

to green walls and green roofs in diverse climates', *Building and Environment*, 43, 480–493.

Anselin, L. (2003) *GeoDa 0.9 User's Guide*. Spatial Analysis Laboratory, Center for Spatially Integrated Social Sciences, University of Illinois.

Anselin, L. (2013) *GeoDa*. Available at: geodacenter.asu.edu/software.

Bi, P., Pisaniello, D., Hansen, A., et al. (2011) 'The effects of extreme heat on human mortality and morbidity in Australia: implications for public health', *Asia-Pacific Journal of Public Health*, 23, 27S–36S.

Bowler, D. E., Buyung-Ali, L., Knight, T. M. and Pullin, A. S. (2010) 'Urban greening

to cool towns and cities: a systematic review of the empirical evidence', *Landscape and Urban Planning*, 97, 147–155.

Bruse, M. and Skinner, C. J. (1999) 'Rooftop greening and local climate: a case

study in Melbourne'. 15th International Congress of Biometeorology/International

Conference on Urban Climatology, Sydney, pp. 21–25.

Burian, S. J., Brown, M. J., Ching, J., *et al*. (2004) 'Urban morphological analysis for mesoscale meteorological and dispersion modeling applications: current issues'.

Fifth Symposium on the Urban Environment, Vancouver, Canada.

Chindapol, S., Blair, J., Osmond, P., King, S., and Prasad, D. (2014) 'Thermal stress

and comfort in elderly people's housing in tropical climates: the need for policy'.

World Sustainable Building Conference WSB14, Barcelona.

Coutts, A. M., Berlinger, J., Tapper, N. J. and Cleugh, H. (2004) 'The influence of

housing density and urban design on the surface energy balance and local climates

of Melbourne Australia and the impact on Melbourne's 2030 Vision'. Fifth

Symposium on the Urban Environment, Vancouver, Canada.

Dessai, S. (2002) 'Heat stress and mortality in Lisbon. Part I. Model construction and validation', *International Journal of Biometeorology*, 47, 6–12.

Ellefsen, R. (1990/91) 'Mapping and measuring buildings in the urban canopy

boundary layer in ten US cities', *Energy and Buildings*, 15/16, 1025–1049.

Fallmann, J., Emeis, S. and Suppan, P. (2014) 'Modeling of the urban heat island and

its effect on air quality using WRF/WRF-Chem – assessment of mitigation strate-

gies for a Central European city'. In Steyn, D. and Mathur, R. (eds), *Air Pollution Modeling and its Application XXIII*. Springer-Verlag: Berlin; pp. 373–377.

Feng, C., Meng, Q. and Zhang, Y. (2010) 'Theoretical and experimental analysis of

the energy balance of extensive green roofs', *Energy and buildings*, 42, 959–965.

Givoni, B. (1998) *Climate Considerations in Building and Urban Design*. John

Wiley & Sons: Chichester.

Grimmond, S. (2007) ‘Urbanization and global environmental change: local effects

of urban warming’, *Geographical Journal*, 173, 83–88.

Guhathakurta, S. and Gober, P. (2007) ‘The impact of the Phoenix urban heat island on

residential water use’, *Journal of the American Planning Association*, 73, 317–329.



Howard, L. (1833) *Climate of London Deduced from Meteorological Observations*.

Harvey Darton: London.

Irger, M. (2014) ‘The effect of urban form on urban microclimate’. Faculty of Built

Environment, University of New South Wales.

Jacobson, M. Z. and Ten Hoeve, J. E. (2012) ‘Effects of urban surfaces and white

roofs on global and regional climate’, *Journal of Climate*, 25, 1028–1044.

Jim, C. Y. and Tsang, S. W. (2011) ‘Biophysical properties and thermal performance

of an intensive green roof’, *Building and Environment*, 46, 1263–1274.

Landsberg, H. E. (1981) *The Urban Climate*. Academic Press: New York.

Liu, K. and Bass, B. (2005) ‘Performance of green roof systems’. National Research

Council Canada Report, Toronto, Canada.

Masson, V. (2006) ‘Urban surface modeling and the meso-scale impact of cities’,

*Theoretical and Applied Climatology*, 84, 35–46.

Meehl, G. A., Zwiers, F., Evans, J., Knutson, T., Mearns, L. and Whetton, P. (2001)

‘Trends in extreme weather and climate events: issues related to modeling extremes

in projections of future climate change’, *Bulletin of the American Meteorological*

*Society*, 81, 427–436.

Mirzaei, P. A. and Haghighat, F. (2010) ‘Approaches to study urban heat island –

abilities and limitations’, *Building and Environment*, 45, 2192–2201.

Morris, C. J. G. and Simmonds, I. (2000) ‘Associations between varying magnitudes

of the urban heat island and the synoptic climatology in Melbourne, Australia’,

*International Journal of Climatology*, 20, 1931–1954.

Ng, E., Chen, L., Wang, Y. and Yuan, C. (2012) ‘A study on the cooling effects of

greening in a high-density city: an experience from Hong Kong’, *Building and*

*Environment*, 47, 256–271.

Nicholls, N., Skinner, C., Loughnan, M. and Tapper, N. (2008) ‘A simple heat alert

system for Melbourne’, *International Journal of Biometeorology*, 52, 375–384.

Norton, B., Bosomworth, K., Coutts, A., *et al*. (2014) ‘ *Planning for a cooler future: green infrastucture to reduce urban heat*’. Victorian Centre for Climate Change Adaptation Research (VCCCAR): Melbourne.

Oke, T. R. (1982) ‘The energetic basis of the urban heat island’, *Quarterly Journal of the Royal Meteorological Society*, 108, 1–24.

Osmond, P. (2004) ‘Rooftop “greening” as an option for microclimatic amelioration

in a high-density building complex’. American Meteorological Society, 5th

Conference on the Urban Environment, Vancouver.

Patz, J. A. and Khaliq, M. (2002) ‘Global climate change and health: challenges for

future practitioners’, *Journal of the American Medical Association*, 287, 2283–2284.

Peng, L. L. and Jim, C. Y. (2013) ‘Green-roof effects on neighborhood microclimate

and human thermal sensation’, *Energies*, 6, 598–618.

Piracha, A. L. and Marcotullio, P. J. (2002) ‘Urban ecosystem analysis: identifying

tools and methods'. UNU/IAS Report, United Nations University Institute of

Advanced Studies.

QCoherent (2013) LP360 for ArcGIS.

Rizwan, A. M., Dennis, L. Y. and Chunho, L. I. U. (2008) 'A review on the generation,

determination and mitigation of Urban Heat Island', *Journal of Environmental*

*Sciences*, 20, 120–128.

Rosenzweig, C., Solecki, W. and Slosberg, R. (2006a) Mitigating New York City's

Heat Island with Urban Forestry, Living Roofs, and Light Surfaces: A Report to

the New York State Energy Research and Development Authority.

Rosenzweig, C., Solecki, W. and Slosberg, R. (2006b) 'Mitigating New York City's

heat island with urban forestry, living roofs and light surfaces'. American

Meteorological Society, 6th Symposium on the Urban Environment, Atlanta, GA.

Green Roof Retrofit and the Urban Heat Island 61

Santamouris, M. (2014) 'Cooling the cities – a review of reflective and green

roof mitigation technologies to fight heat island and improve comfort in urban

environments', *Solar Energy*, 103, 682–703.

Santamouris, M., Cartalis, C., Synnefa, A. and Kolokotsa, D. (2014) 'On the impact

of urban heat island and global warming on the power demand and electricity

consumption of buildings – a review', *Energy and Buildings*, 98, 119–124.

Sarrat, C., Lemonsu, A., Masson, V. and Guedalia, D. (2006) 'Impact of urban

heat island on regional atmospheric pollution', *Atmospheric Environment*, 40,

1743–1758.

Souch, C. and Grimmond, S. (2006) 'Applied climatology: urban climate', *Progress*

*in Physical Geography*, 30, 270–279.

Stewart, I. D. (2011) 'A systematic review and scientific critique of methodology in

modern urban heat island literature', *International Journal of Climatology*, 31, 200–217.

Stewart, I. D. and Oke, T. R. (2012) 'Local climate zones for urban temperature

studies', *Bulletin of the American Meteorological Society*, 93, 1879–1900.

Tan, J., Zheng, Y., Tang, X., *et al*. (2010) 'The urban heat island and its impact on heat waves and human health in Shanghai', *International Journal of*

*Biometeorology*, 54, 75–84.

Tobler, W. (1970) ‘A computer movie simulating urban growth in the Detroit region’,

*Economic Geography*, 46, 234–240.

Voogt, J. A. (2004) ‘Urban heat islands: hotter cities’, available at: www.actionbio

science.org/environment/voogt.html?newwindow=true.

Ward, M. D. and Gleditsch, K. S. (2008) *Spatial Regression Models*. Sage Publications: London.

Wilkinson, S. J. and Reed, R. (2009) ‘Green roof retrofit potential in the central

business district’, *Property Management*, 27, 284–301.

Wong, J. K. W. and Lau, L. S. K. (2013) ‘From the “urban heat island” to the “green

island”? A preliminary investigation into the potential of retrofitting green roofs

in Mongkok district of Hong Kong’, *Habitat International*, 39, 25–35.

Wong, N. H., Chen, Y., Ong, C. L. and Sia, A. (2003) ‘Investigation of thermal

benefits of rooftop garden in the tropical environment’, *Building and Environment*, 38, 261–270.

**14**

**Thermal Performance of Green Roof Retrofit**

**Sara Wilkinson1 and Renato Castiglia Feitosa2**

1 UTS, Australia

2 FioCruz, Rio de Janeiro, Brazil

## 4.0 Introduction

Green areas have decreased considerably in the urban environment due to

uncontrolled growth of buildings and roads, resulting in an increase of air

temperature and the worsening of air quality. As a result, urban areas have

experienced an increase in air temperature, mostly by trapping thermal

energy, which leads to much warmer temperatures compared with country

areas (Lamond *et al*., 2014). This is described as the UHI effect, and according to the EPA (2015), the annual mean air temperature of a city can be 1–3°C

warmer than the surrounding areas. In the evening, the temperature difference can reach 12°C. Heat islands can increase GHG emissions, the cost of air conditioning, mortality and heat-related illness, and water quality. An

alternative to reduce building-related GHG emissions, for cooling or heating environments, is to retrofit buildings with green roofs, which also have other social, economic and environmental benefits.

The social gain is the creation of spaces where people can have more

contact with natural aspects. The ‘biophilia’ effect describes the phenomenon

by which humans experience positive feelings due to a connection to the

natural environment (Kellert and Wilkinson, 1993). Unfortunately, access to

the natural environment is limited and diminishing for many city residents.

For instance, it is estimated that there are less than 22 m2 per resident in

Sydney, and that the urban canopy coverage is only about 15.5% (City of

Sydney, 2012). The city aims to increase this level of urban greenery, for the

health and wellbeing of the community, by 20% before 2020 (Green, 2014),

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



and the application of green roofs would be a way of contributing to this

target. Owing to population growth and the lack of space in Rio de Janeiro,

the amount of green areas has decreased substantially (Agência Brasil,

2014). No plans have been adopted yet to deal with this problem.

Economically, roof maintenance costs are reduced, since green roofs

increase the lifespan of the waterproofing system (Castleton, 2010). There

are erroneous perceptions, however, among the practitioner community that

green roofs lead to higher maintenance costs – for example clearing blocked

drainage outlets (Wilkinson *et al*., 2013) – which is resulting in less application of green roof technology in buildings than could otherwise occur.

The environmental benefits comprise potential reductions in operational

carbon emissions, attenuation in the urban heat island, increases in biodiversity, housing temperature attenuation and reductions in stormwater runoff (Castleton, 2010). An improvement in air quality is provided, since plants

remove carbon dioxide and harmful pollutants from the atmosphere. In addition, green roofs provide habitats for insects, birds and reptiles, as shelter, a source of food and water (Williams *et al*., 2010).

Thermally, green roofs improve the insulating qualities of the building by

reducing heat gain or loss through inadequately insulated and poorly sealed

roof structures. Some authors have evaluated the role of green roofs' cooling

and warming potential in energy savings and the potential for retrofitting, based

either on modelling or experimental data (Castleton, 2010; Langston, 2015).

This chapter reports an experiment on two small-scale profiled metal

sheet roofs in Sydney (Australia) and Rio de Janeiro (Brazil) to assess thermal performance. Metal roof coverings are fairly common in Brazilian and Australian housing design and have less load-bearing capacity than other

coverings. Thus, a lightweight, low-cost, easily installed module is tested.

In each city, two identical roofs, one covered with modular lightweight

trays planted with succulents and the other not, had their internal

t emperature recorded simultaneously and compared. Data collection was

performed by using thermal data loggers over a summer and autumn season.

In this chapter the findings for temperature attenuation and the potential

for retrofitting residential stock with lightweight trays planted with

s ucculents are discussed.

**4.1**

## Green Roof Retrofit and Thermal Performance

Many cities have been experiencing rapid urban expansion and/or densification, which contributes to the creation of urban canyons, where heat is trapped between buildings, leading to negative human health impacts and

even fatalities during excessively hot days (Oke, 1982; Harlan *et al*., 2006).

Recently, high temperatures have been observed. During February 2014,

high-temperature records were registered in Rio de Janeiro (Portal G1,

2014). In the same year, Melbourne experienced four to five days in January

with temperatures higher than 45°C, and more than twice the average rate

of mortality was experienced. These deaths related to the extreme heat

conditions, and were even more intense in the city centre, where heat was



trapped between buildings and under tree cover in an urban canyon (ABC,

2014). In a scenario of predicted climate change impacts and an ageing

population, these figures look likely to increase. On this basis, the focus for

climate change mitigation is through adaptation and sustainable retrofitting

of existing buildings based on viable solutions.

Green roofs can be classified as either extensive or intensive systems.

According to Berndtsson (2010), in intensive systems soil depths are more

than 10 cm, providing for the growth of small plants to trees. In contrast,

extensive green roof systems comprise thinner soil layers and lighter vegetation, and thus can be retrofitted to most existing buildings without additional structural strengthening.

One of the points to be highlighted is that the majority of cities worldwide

have buildings that can accommodate extra loads. In many countries there

is little space available for planting, unless existing rooftops are considered.

Stovin (2010) estimated that 40–50% of all horizontal surfaces in cities are

rooftops. A viable solution for retrofitting housing must meet load-bearing

capacity requirements, which tends to favour a lightweight green roof technology. The extra load applied per square metre to an existing

structure is related to the soil depth. Under a conservative estimate, a typical saturated

soil density of 2000 kg/m3 is expected so that a load limit of 100 and 2000 kg/m2

should be applied for green roof soil depths from 5 to 100 cm, respectively.

As the design load of existing roofs varies between 50 and 200 kg/m2, it is

anticipated that soil depths up to 10 cm do not require a structural upgrade

(Liu, 2011). However, using lightweight substrate material with slightly

greater depths, such as pumice and expanded clay, may reproduce the same

loads as a single soil component. As cited by Peck and Kuhn (2003), the

36 cm depth green roof on the new library in Vancouver, B.C., Canada

weighs 293 kg/m2 under saturated conditions, and based on the local building code does not require a structural upgrade. In comparison, the same depth of saturated sandy loam soil weighs 720 kg/m2.

Green roof applications have been observed worldwide. For instance, 260

green roofs have been created in Toronto from 1 February 2010 to 1 March

2015, comprising a total green roof area of 196,000 m2. In total, 444 green

roofs exist in the City of Toronto (City of Toronto, 2015). Additionally,

London, UK presents many examples of living roofs, including at Canary

Wharf, Bishops Square, the Laban Centre, Deptford and Offord Street,

Islington (Greater London Authority, 2008). In the USA, many communities

have been taking action by encouraging or sponsoring green roof projects,

and some cities such as Chicago, Portland and Seattle have developed more

coordinated programmes and policies to promote green roofs (EPA, 2014).

Although green roofs have become a topical subject nowadays, in

Scandinavian countries such as Norway there are examples of buildings

with green roofs that are hundreds of years old. According to Herman

(2003), there were about 13.5 km2 of existing green roofs in Germany.

In the context of the urban environment as a whole, due to the lower

temperatures observed in green roofs there is a lower heat transfer to the air

above the roof, which helps to maintain the air at cooler temperatures compared with conventional roofs. According to EPA (2014), studies performed

in Chicago (USA) compared summer-time surface temperatures on a green

roof with a non-vegetated neighbouring building. The temperature of the

conventional roof reached 76°C, whereas the green roof surface temperature ranged from 33°C to 48°C. A similar study performed in Florida observed a difference of 27°C comparing a green roof and an adjacent light-coloured roof surface.

A modelling approach performed for the City of Toronto (Canada)

p redicted that if green roofs were applied to 50% of the roof surfaces available, this would reduce the temperature of the city between 0.1°C and 0.8°C. Under well-irrigated conditions, these roofs could reduce the temperature further by about 2°C (Liu and Bass, 2005). A similar modelling study performed for New York City modelled a green roof application to

all available roofs, and found for the whole city an air temperature reduction of 0.2°C, 2 m above the roof surface, was possible. However, it is important to highlight that temperature reduction is averaged over all

times of the day. At three o'clock in the afternoon, the temperature would

be 0.4°C cooler.

In addition, green roofs can reduce the energy used to cool and heat buildings. Under wet conditions, they reduce temperature fluctuations by absorbing and storing considerable amounts of heat. During dry periods, green roofs provide an insulating feature, attenuating the heat flux through the

roof and reducing energy consumption for cooling or heating environments.

According to a modelling study carried out in Canada (Liu and Bass,

2005), a green roof provided an energy saving of 6% and 10%, respectively,

for cooling and heating a one-storey commercial building in Toronto

(2980 m2). This study also pointed out that the energy savings for cooling

would be even higher for lower latitudes (Lui and Bass, 2005). As an additional simulation example, considering a building location in Santa Barbara, CA, the cooling savings increased to 10% (Bass *et al*., 2003). A comparison

between a green roof and an adjacent light-coloured roof performed in

Florida (USA) showed that the heat flux through the former was more than

40% less than the latter. The reduction in heat flux is estimated to lower

summer-time energy consumption of a 1000 m2 building by 2.0 kWh/day

(Cummings *et al*., 2007). Under winter conditions with external temperatures less than 13°C, the heat flux through the green roof is 50% less than the conventional roof (Sonne, 2006).

In non-insulated buildings, which are common in Rio de Janeiro, Brazil

and Sydney, Australia, green roofs can improve the insulating properties

and reduce annual energy consumption. According to Castleton (2010),

several studies have shown that green roofs act, not only in summer cooling,

but also in winter heating reduction. Niachou *et al*. (2001) showed an

annual energy saving potential of green roofs on non-insulated buildings for

heating of 45–46% and for cooling of 22–45%. Wong *et al*. (2003) found

an annual energy saving of 10.5% comparing an uninsulated extensive

green roof covered in turf with a non-greened uninsulated roof. However,

the energy savings occur only on floors near to the roof. Alcazar and Bass

(2005) state that, because of the tall nature of the buildings, roofs comprise

around 16% of the total building envelope, and the largest reductions in



energy consumption were seen in rooms directly below the green roof.

Energy savings were found up to three floors below the roof (Alcazar

and Bass, 2005).

Green roofs lead to numerous environmental benefits in urban settlements concerning enhanced thermal performance. The decision to retrofit a green roof has multiple variables and should not be evaluated on one variable alone, but on the multiple benefits that are delivered (Wilkinson *et al*., 2013). For example, a thermal green roof will also attract biodiversity,

improve air quality, reduce the urban heat island and attenuate stormwater

flow to the drainage system. It may also provide an attractive view for

adjoining and overlooking building occupants. Traditional air-conditioning

systems can provide thermal comfort, reducing housing temperatures

mechanically. However, these systems basically transfer the heat from internal to external environments. As a result, they contribute to an increase in external air temperature as a whole. In the case of thermal load attenuation,

green roofs avoid the increase in temperature of internal environments and

external surfaces.

Green roofs work in temperature attenuation by shading roof surfaces,

increasing thermal insulation and promoting evapotranspiration. Plants

reduce the surface temperature below by shading. These cooler surfaces

decrease the heat transmission to the building or the re-emission to the

atmosphere (EPA, 2014). Evapotranspiration absorbs heat from the air to

evaporate water. Owing to shading, insulating properties and evapotranspiration processes, green roof surfaces remain cooler than conventional roofs during summer conditions.

However, barriers to the adoption of retrofitted green roofs include perceptions of structural adequacy, risk of water damage, high installation and maintenance costs, as well as access and security issues (Wilkinson and

Reed, 2009). Some locations, such as London, will require thermal insulation against external low temperatures, whereas for other locations, such as Sydney and Rio de Janeiro, the intent will be to reduce heat gain. The ability

to meet these demands will depend on the available budget and physical

characteristics. Although the technology to design and retrofit green roofs

exists, the uptake and demand have not been high because of the lack of

governmental incentives and high commercial costs provided by green roof

suppliers. Overall, the gains have not been deemed sufficient, and in both

cities the existing numbers of residential and commercial green roofs confirm this observation. The City of Sydney adopted the first green

roofs and walls policy for Australia in 2014, setting out a commitment to increase the

number of high-quality green roofs and walls (City of Sydney, 2015). The

policy includes a three-year implementation plan to ensure its understanding, adoption and integration. Sydney currently has 59 green roofs, which serve a variety of purposes, including enhancing thermal performance (City

of Sydney, 2012). Rio de Janeiro has not adopted any policy to date.

Many Australian and Brazilian residential buildings have rooftop systems

with little or no insulation to offset the high heat gains. Thus, green roofs

may become an imperative solution to deal with the increasingly high

temperatures experienced during the summer periods.



## 4.2

## Research Methodology

The methodology adopted is based on the employment of simple technologies to mitigate the problems created by increasing urban densification, which exacerbates urban heat islands and contributes to uncomfortably

high internal housing temperatures. Many technologies are available to

conduct this research. However, in this case, the researchers aimed to use

adaptive techniques to minimise initial costs and maintenance costs. Thus,

this project used lightweight removable modules of vegetation (rectangular

containers) of a low thickness, which enables planting, cultivation and

maintenance off-site to be undertaken. This is an exploratory study to assess

the thermal performance and feasibility of retrofitting with low-cost,

lightweight roofing modules for any type of roof.

The authors evaluated the thermal performance of a green roof retrofit

system, which could be widely used in metropolitan areas. At this point,

there is a lack of empirical evidence on the performance of green roofs in

Australia and South America, with most data coming from the USA and

European countries, where climatic conditions are quite different (Mentens

*et al*., 2006).

Succulent plants, such as variegated sedum, *Echeveria glauca* and

*Kalanchoe quicksilver* were selected on the basis of their higher drought

resistance qualities and a lower risk of fire. Furthermore, these species can

develop easily in shallow soils and, therefore, no structural reinforcement of

existing roofs is necessary. Additionally, due to the modular characteristics

of the planting containers, the modules can be applied directly onto the roof

covering, be it existing slabs, profiled metal sheeting or tiles. The modular

systems comprise containers with a water storage system, which provides

water to the soil through evaporation, enhancing the plants' survival, even

during extended dry periods.

The soil is separated from the drainage system by a permeable fabric

(Geotextile), which allows water flow but prevents soil passage into the

water chamber. For the plant species used in this research, a soil with good

drainage and low organic content was used. A composition of two parts of

sand to one part of loam was employed.

Green roof performance in temperature attenuation is measured by the

comparison between two small-scale housing prototypes with vegetated and

non-vegetated roofs. Owing to financial limitations and because of the

exploratory nature of the research, it was not possible to use full-scale housing for the experiment.

A simultaneous comparison between the records of temperature inside

the vegetated and non-vegetated structures was made using data loggers

that collect continuous temperature records over long periods of time. The

temperature measurements were carried out every 30 minutes, using Extech

TH10 temperature USB data loggers.

The data loggers were positioned at the same height inside each of the

prototypes. Thus, the temperature differences observed are attributed only

to the influence of heat incidence on the structures, given the identical

weather conditions between the vegetated and non-vegetated prototypes.





68

Green Roof Retrofit

**4.3**

**Case study: Rio de Janeiro and Sydney**

Two sets of experiments were performed in Brazil (Rio de Janeiro) and in

Australia (Sydney). The Brazilian site is located on the roof of an existing

building at the Oswaldo Cruz Foundation (FioCruz), and the Australian

location is on the roof of a building at the University of Technology in

Ultimo, Sydney.

Rio de Janeiro is geographically located at S 23°, W 43° and has a tropical

wet and dry or savannah climate with dry winters (Aw); Sydney (S 33.9°, W

151.2°) has a humid subtropical climate (Cfa). The high and low annual

average temperatures in Rio de Janeiro are 27.3°C and 21°C, respectively. In

Sydney, these temperatures range from 21.7°C to 13.9°C. However, according to IPCC (2013), extreme higher temperatures are more commonly observed in Sydney (39.8–48.8°C) rather than in Rio de Janeiro (37.7–39°C).

Figure 4.1 shows the rectangular plastic containers or modular systems

used on each site (Rio de Janeiro, 400

mm

× 500 mm and Sydney,

190 mm × 330 mm).

The experimental setup for each site is illustrated in Figure 4.2. The Rio

de Janeiro tests were carried out using small blockwork houses covered with

metal sheeting, whereas in Sydney, metallic sheds were employed. In

Australian housing, profiled metal sheet roofs are typically specified, and for

this reason, the metal sheds were selected. The Rio de Janeiro data set comprised two different periods: 194 days, from 17 October 2012 to 29 April 2013 (spring to autumn, southern hemisphere); and 180 days, from 22 May

2014 to 18 November 2014 (autumn to spring). Sydney trial tests comprised a 134-day period from 11 December 2013 to 23 April 2014. The position of the temperature data loggers in Rio de Janeiro and Sydney

housing prototypes is, respectively, 250 mm and 50 mm below the top of the

roof structure.

(a)

(b)

**Figure 4.1** Rectangular plastic containers used in the temperature experiments. (a) Brazilian module, provided by Cidade Jardim Institute. (b) Australian module.







**Figure 4.2** Housing thermal experiments. Left: Rio de Janeiro. Right: Sydney.

The results concerning the green roof cooling potential for the two experimental sites (Rio de Janeiro and Sydney) are shown in Figures 4.3–4.10.

Notwithstanding some basic differences in the experimental setups (that is,

block work in Rio de Janeiro and metal sheeting in Sydney), the tendency for

temperature attenuation is evident. The measurements performed in both cities

show that green roofs are able to attenuate daily variations of temperature.

### 4.3.1

### Rio de Janeiro Case Study

Figure 4.3 presents a comparison between the non-green and green roofs'

internal temperatures, during the 194-day data collection period, which

comprises for the Brazilian site from the spring to the autumn period. Some

of this work was partially reported in Feitosa (2012). Additional measurements from May to November 2014 (180 days) are presented in Figure 4.4.

Besides, being collected in a different year, these complementary data cover

part of autumn, winter and part of the spring period. In total, more than one

year of data collection was performed for this site.

Based on daily variations of temperature, from the spring to the autumn

period (2012–2013), the daytime temperatures for non-green and green

roofs varied from 23.9°C to 41.4°C and from 23.2°C to 39.3°C, respectively. The minimum values that occurred during the night-time varied from 20.1°C to 31.8°C for the non-green roof and from 20.3°C to 31.8°C for the

green roof. Considering the second set of data, comprising the autumn to

spring (2014) period, the daytime temperatures ranged from 16.6°C to

29.7°C and from 15.9°C to 29.7°C for green and non-green roofs, respectively. The maximum, minimum and average temperatures for the entire two sets of data are presented in Table 4.1.

Comparing the simultaneous temperature differences between green and

non-green roofs, these values varied from −1.7°C to 5.6°C. Positive values

mean a higher non-green roof temperature and negative values indicate the

opposite (a higher green roof temperature). From the first set of data,

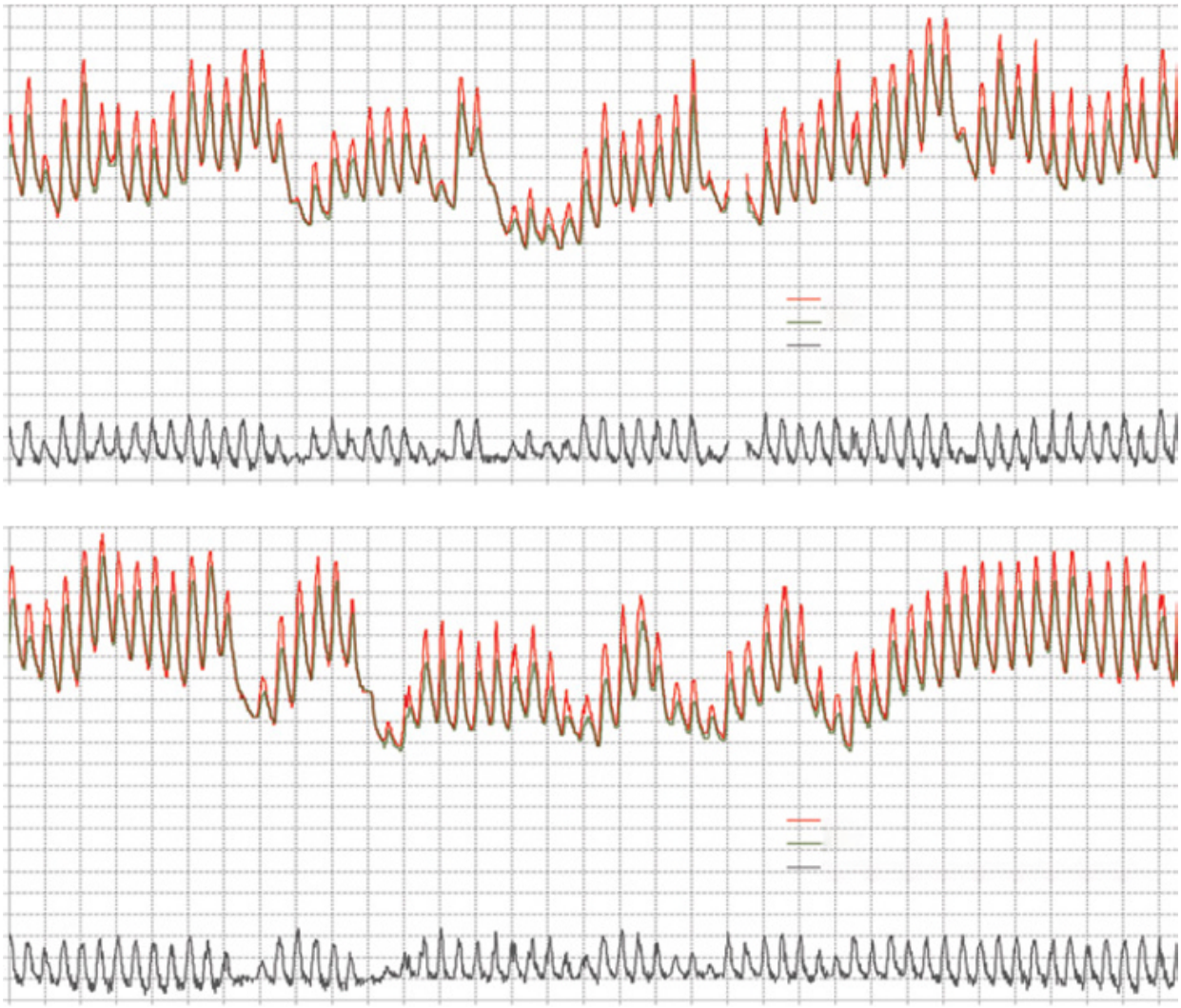
Figure 4.5 shows a typical detail of the temperature comparison between non-

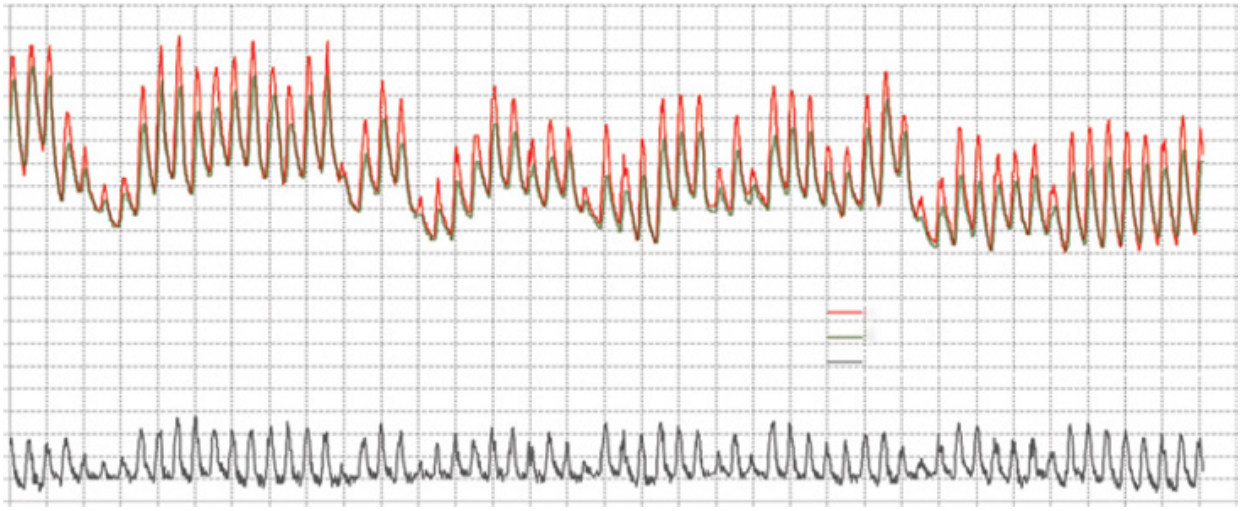
green and green roofs. It is evident that basically, positive differences occur

during the daytime, while negative differences can be seen during the night-

time and in the early morning. Additionally, from the same figure a delay is

observed between the temperature peaks of non-green and green roofs.





42

40

38

36

34

32

30

28

26

24

e °C 22

20

18

Temperatur 16

Bare roof

14

Green roof

12

10

Temperature difference

8

(green roof - bare roof)

6

4

2

0

–2

:00

:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

:00

2:00

2:00

2:00

2:00

2:00

12

12

1

1

1

1

1

1

1

1

1

1

12

1

1

1

1

1

1

1

1

1

1

12

1

12

12

12

12

12

12

12

12

12

12

12

12

12

2 1

2 1

2 1

2 1

2 1

2 1

2 1

2 1

01

01

01

01

12

12

12

12

12

12

12

12

12

12

12

01

01

01

01

12

0/20

0/20

0/20

0/20

0/20

0/20

0/20

0/20

1/20

1/20

1/20

1/20

1/20

1/2

1/2

1/2

1/2

1/20

1/20

1/20

1/20

1/20

1/20

1/20

2/20

2/20

2/20

2/20

2/20

2/2

2/2

2/2

2/2

2/20

/1

/1

/1

/1

17

19

21/1

23/1

25/1

27/1

29/1

31/1

02/1

04/1

06/1

08/1

10

12/1

14/1

16/1

18/1

20/1

22/1

24/1

26/1

28/1

30/1

02/1

04/1

06/1

08/1

10

12/1

14/1

16/1

18/1

20/1

Date

42

40

38

36

34

32

30

28

26

24

e °C

22

20

18

Temperatur

16

14

Bare roof

12

Green roof

10

Temperature difference

8

(green roof - bare roof)

6

4

2

0

–2

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

12

12

12

12

12

12

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

2/20

2/20

2/20

2/20

2/20

2/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

/02/20

21/1

23/1

25/1

27/1

29/1

31/1

02/0

04/0

06/0

08/0

10/0

12/0

14/0

16/0

18/0

20/0

22/0

24/0

26/0

28/0

30/0

01/02/20

03/02/20

05/02/20

07/02/20

09/02/20

11

13/02/20

15/02/20

17/02/20

19/02/20

21/02/20

23/02/20

Date

42

40

38

36

34

32

30

28

26

24

e °C

22

20

18

Temperatur

16

Bare roof

14

Green roof

12

Temperature difference

10

(green roof - bare roof)

8

6

4

2

0

–2

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

1

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

13

/04/20

24/02/20

26/02/20

28/02/20

02/03/20

04/03/20

06/03/20

08/03/20

10/03/20

12/03/20

14/03/20

16/03/20

18/03/20

20/03/20

22/03/20

24/03/20

26/03/20

28/03/20

30/03/20

01/04/20

03/04/20

05/04/20

07/04/20

09/04/20

11

13/04/20

15/04/20

17/04/20

19/04/20

21/04/20

23/04/20

25/04/20

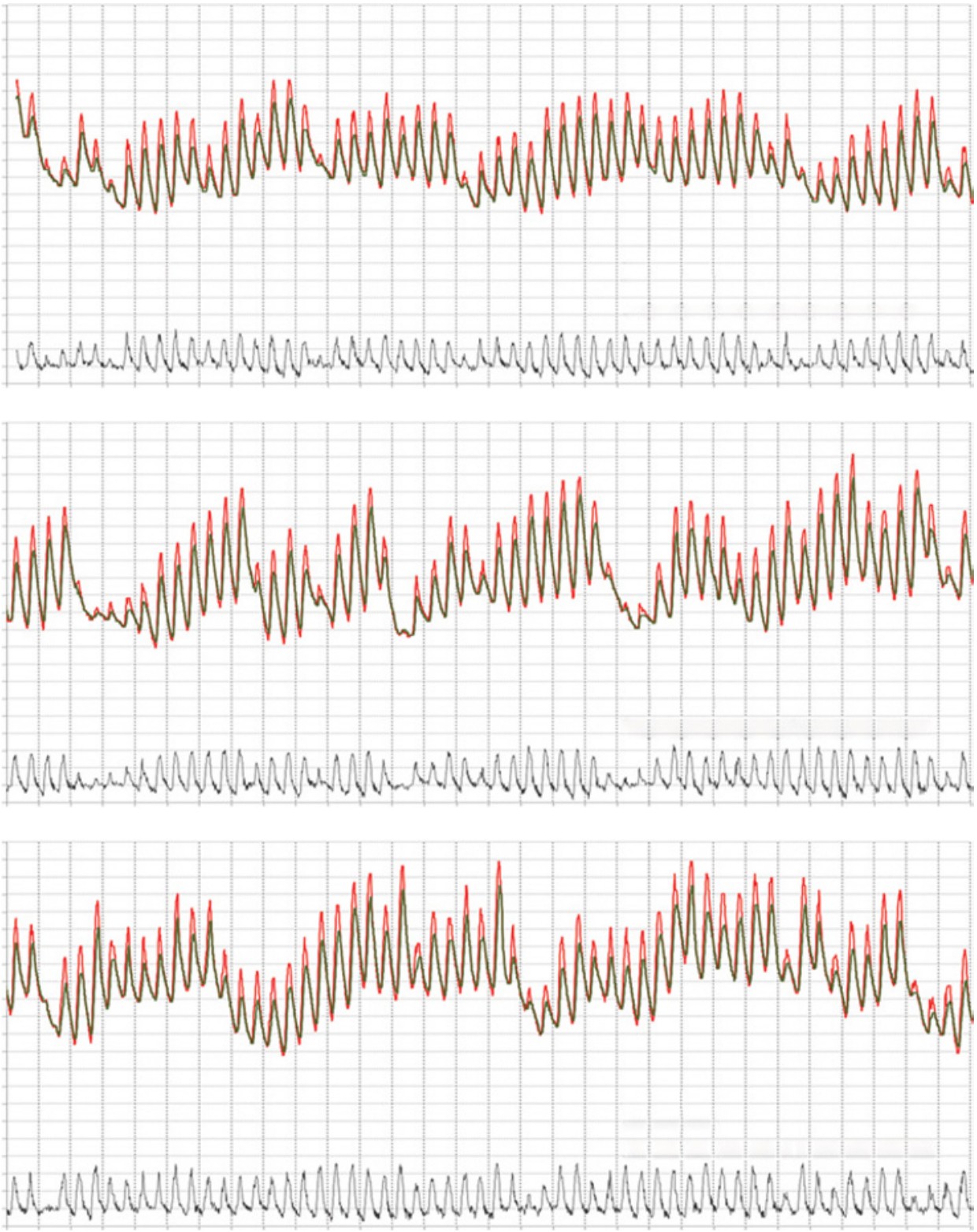
27/04/20

29/04/20

01/05/20

Date

**Figure 4.3** Comparison between non-green and green roofs' internal temperature, Rio de Janeiro, Brazil (first set of data: 17/10/2012–29/04/2013).



40

38

36

34

32

30

28

26

24

e °C 22

20

18

16

Temperatur 14

12

Bare roof

10

Green roof

8

6

Temperature differednce (green roof - bare roof)

4

2

0

–2

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

/06/20

/07/20

22/05/20

24/05/20

26/05/20

28/05/20

30/05/20

01/06/20

03/06/20

05/06/20

07/06/20

09/06/20

11

13/06/20

15/06/20

17/06/20

19/06/20

21/06/20

23/06/20

25/06/20

27/06/20

29/06/20

01/07/20

03/07/20

05/07/20

07/07/20

09/07/20

11

13/07/20

15/07/20

17/07/20

19/07/20

21/07/20

Date

42

40

38

36

34

32

30

28

26

24

e °C 22

20

18

16

Temperatur 14

12

Bare roof

10

Green roof

8

6

Temperature differednce (green roof - bare roof)

4

2

0

–2

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

01

01

01

01

01

01

01

01

01

01

01

14

14

14

14

01

01

01

01

01

01

01

01

01

01

01

01

14

14

14

14

14

/08/2

/09/2

21/07/2

23/07/2

25/07/2

27/07/2

29/07/2

31/07/2

02/08/2

04/08/2

06/08/2

08/08/2

10

12/08/20

14/08/20

16/08/20

18/08/20

20/08/2

22/08/2

24/08/2

26/08/2

28/08/2

30/08/2

01

03/09/2

05/09/2

07/09/2

09/09/2

11/09/20

13/09/20

15/09/20

17/09/20

19/09/20

Date

42

40

38

36

34

32

30

28

26

24

e °C 22

20

18

16

Temperatur 14

12

Bare roof

10

Green roof

8

6

Temperature differednce (green roof - bare roof)

4

2

0

–2

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

00:00

14

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

4 00:00

01

01

01

01

01

01

01

01

01

01

14

14

14

14

14

01

01

01

01

01

01

14

14

14

14

14

01

01

01

01

0/2

0/2

0/2

0/2

0/2

0/20

0/20

0/20

0/20

0/20

0/2

0/2

0/2

0/2

0/2

0/2

1/20

1/20

1/20

1/20

1/20

1/2

1/2

1/2

1/2

/1

/1

19/09/20

21/09/2

23/09/2

25/09/2

27/09/2

29/09/2

01

03/1

05/1

07/1

09/1

11/1

13/1

15/1

17/1

19/1

21/1

23/1

25/1

27/1

29/1

31/1

02/1

04/1

06/1

08/1

10

12/1

14/1

16/1

18/1

Date

**Figure 4.4** Comparison between non-green and green roofs' internal temperature, Rio de Janeiro, Brazil (second set of data: 22/05/2014–18/11/2014).

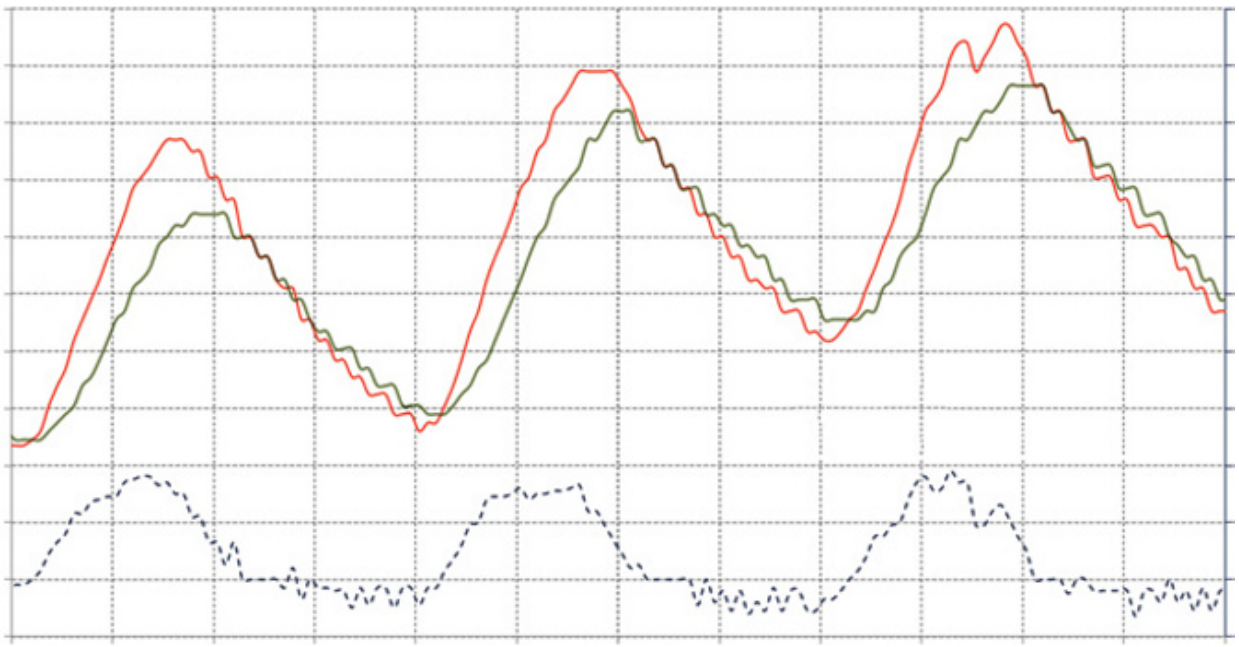


**Table 4.1** Maximum, minimum and average temperatures for the two sets of data,

Rio de Janeiro site

Non-green roof

temperatures (°C)

Green roof temperatures (°C)

Period

Max.

Min.

Average

Max.

Min.

Average

17/10/2012–29/04/2013

41.4

20.1

28.8

39.3

20.3

27.7

spring to autumn

22/05/2014–18/11/2014

39.8

15.9

25.3

37.0

16.6

24.5

autumn to spring

42

20

40

18

38

16

36

14

34

12

nce (°C)

e (°C)

re

32

10

fe

30

8

e dif

Bare roof

28

Green roof

6

Temperatur

Temperature difference (green roof - bare roof

26

4

Temperatur

24

2

22

0

20

–2

2:00

8:00

2:00

8:00

2:00

8:00

06:00

1

1

00:00

06:00

1

1

00:00

06:00

1

1

00:00

06:00

12

12

12

12

12

12

12

12

12

12

12

12

12

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

24/1

24/1

24/1

25/1

25/1

25/1

25/1

26/1

26/1

26/1

26/1

27/1

27/1

Date

**Figure 4.5** Typical detail of the temperature records between green and non-green (bare) roofs, Rio de Janeiro site.

In addition to this overall analysis of the temperature data, Figure 4.6

presents the maximum, minimum and average daily temperatures, as well as

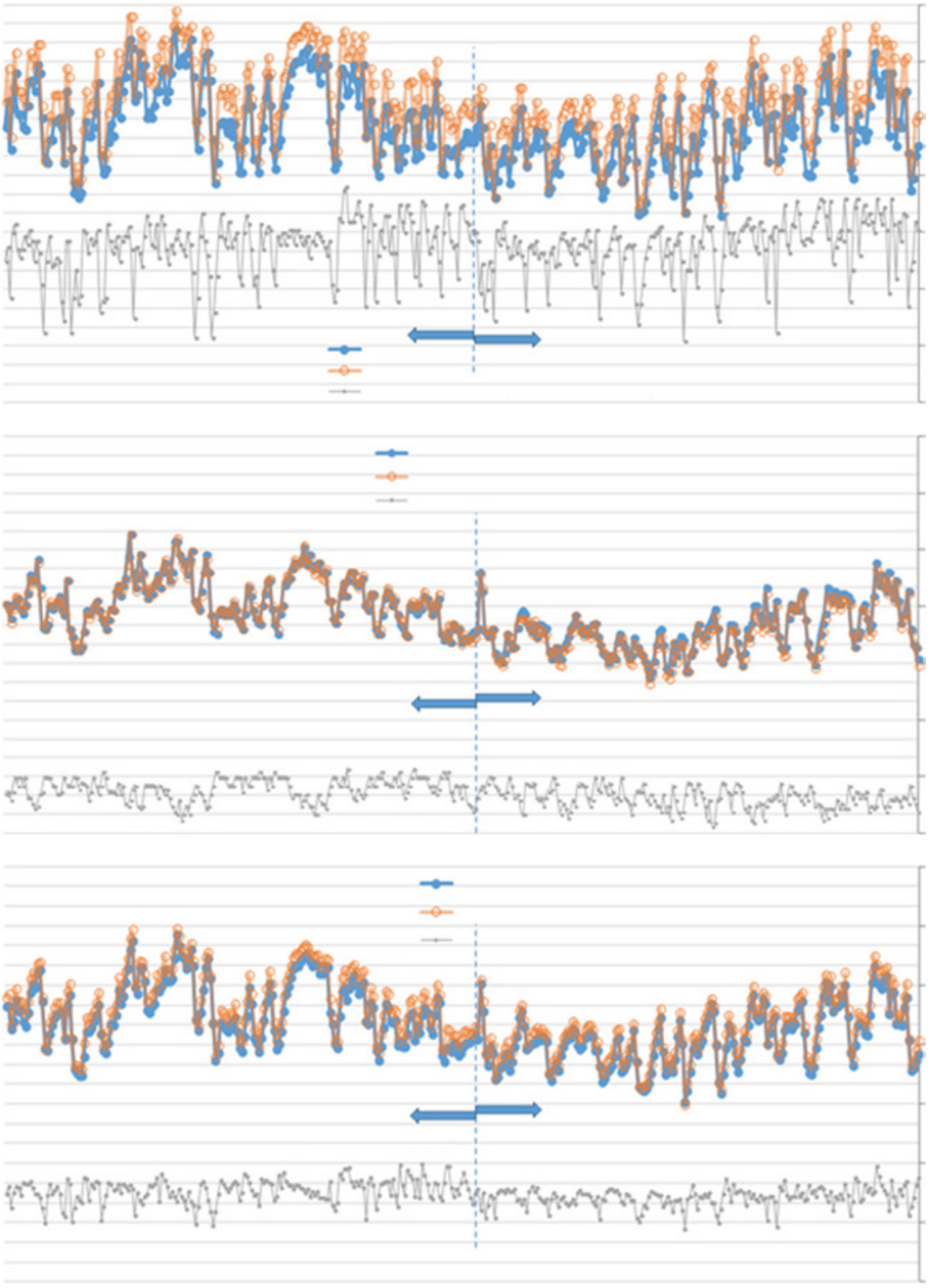
their differences, observed for non-green and green roofs. These values calculated for each of the 374 days (194 – first data set; 180 – second data set) are based on 48 records (30 minutes of sampling).

Compared with non-green roofs, the green roofs were capable of flattening the differences between maximum and minimum temperatures.

Maximum temperatures were always higher for the non-green roof, whereas

minimum temperatures were higher practically for all sets of data for the

green roof. This fact is evidenced by the positive differences between maximum temperatures of non-green and green roofs and by the negative differences between their minimum temperatures. In all of 374 days, the average temperatures of the non-green roof were higher than those of the green roof.



Thermal Performance of Green Roof Retrofit 73

Maximum daily temperatures

42

12

40

38

36

10

34

32

30

8

28

26

24

6

22

20

18

4

16

Temperature °C

14

12

2

108

First set of data

6

Green roof

0

4

Second set of data

Non-green roof

2

Temperature difference (Non-green - green roof)

0

–2

Temperature difference °C(Non-green - green roofs)

1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239 246 253 260 267 274 281 288 295 302 309 316 323 330 337 344 351 358 365 372

Day

Minimum daily temperatures

42

12

40

Green roof

38

Non-green roof

36

10

34

Temperature difference (Non-green - green roof)

32

30

8

28

26

24

6

22

20

18

4

16

Temperature °C

14

12

2

First set of data

10

Second set of data

86

0

420

–2

Temperature difference °C(Non-green - green roofs)

1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239 246 253 260 267 274 281 288 295 302 309 316 323 330 337 344 351 358 365 372

Day

Average daily temperatures

42

12

40

Green roof

38

Non-green roof

36

10

34

Temperature difference (Non-green - green roof)

32

30

8

28

26

24

6

22

20

18

4

16

Temperature °C

14

First set of data

Second set of data

12

2

1086

0

420

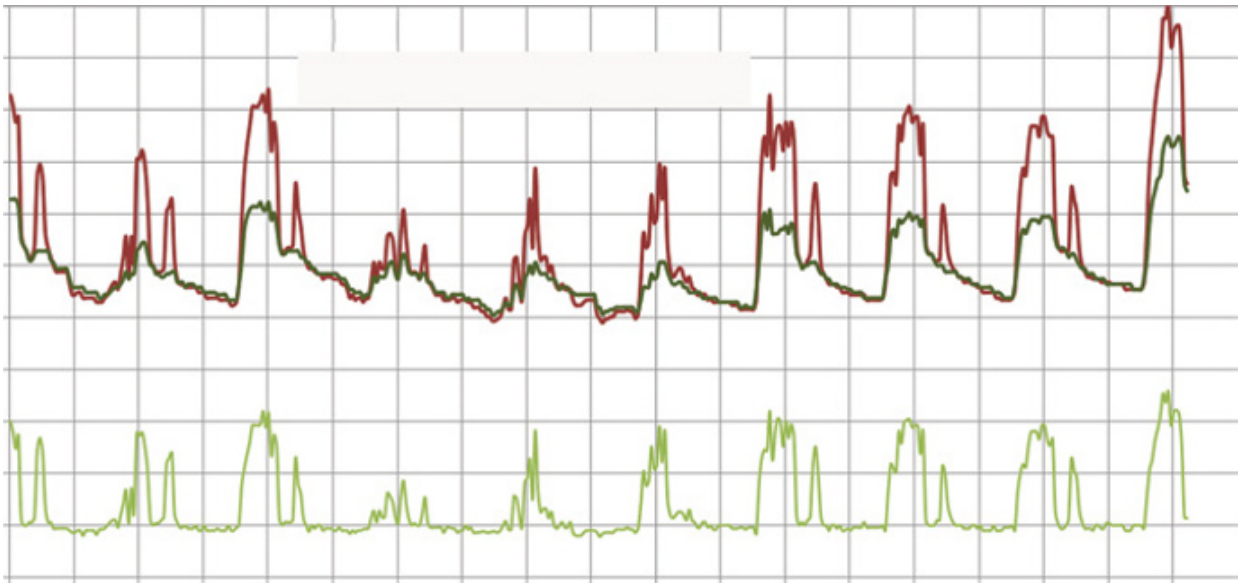
–2

Temperature difference °C(Non-green - green roofs)

1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113 120 127 134 141 148 155 162 169 176 183 190 197 204 211 218 225 232 239 246 253 260 267 274 281 288 295 302 309 316 323 330 337 344 351 358 365 372

Day

**Figure 4.6** Maximum, minimum and average daily temperatures and their differences for non-green and green roofs, Rio de Janeiro.





Only five events occurred where the green roof’s average temperatures were

insignificantly higher than those of the non-green roof. In these cases, the

differences observed between non-green and green roof temperatures were

less than 0.2°C.

**4.3.2**

**Sydney Case Study**

Despite the shorter period of data compared with Rio de Janeiro, a significant temperature difference was observed in Sydney tests between non-green and green roof prototypes. However, based on the characteristics of the site

where the experiments were performed, a particular pattern in temperature

registers can be observed. As highlighted in Figure 4.7, a sudden reduction

in temperature occurs both for non-green and green roofs around 3 p.m.,

due to the shading created by near buildings. This figure shows attenuation

in temperature variation for green roofs, which is consistent with their insulating properties. The results are different compared with the Rio de Janeiro site, as a second set of data is not available due to technical problems in the

data loggers.

Figure 4.8 presents a comparison between non-green and green roof inner

temperatures, for 134 days from summer to the autumn period. For all sets of

data, non-green roofs presented maximum, minimum and average temperatures equal to 50.3°C, 14.2°C and 25.4°C, respectively. The values observed for the green roof were 37.4°C, 14.8°C and 23.0°C.

Compared with the brick wall prototypes used in Rio de Janeiro experiments, as expected, the metal sheds used in Sydney show a faster response in terms of thermal exchange.



Bare roof

45

Green roof

40

Temperature difference

(green roof - bare roof)

35

30

e (°C)

25

20

Temperatur

15

10

5

0

–5

2:00

:00

:00

:00

:00

:00

:00

:00

:00

12

13

12

12

12

12

12

12

12

2:00

3 1

3 0:00

3

3

3

3 0:00

3

3 0:00

3

3 0:00

3

3 0:00

3

3 0:00

3

3 0:00

3

3 0:00

3 1

3 0:00

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

2/1

11/1

12/1

12/1

13/1

13/1

14/1

14/1

15/1

15/1

16/1

16/1

17/1

17/1

18/1

18/1

19/1

19/1

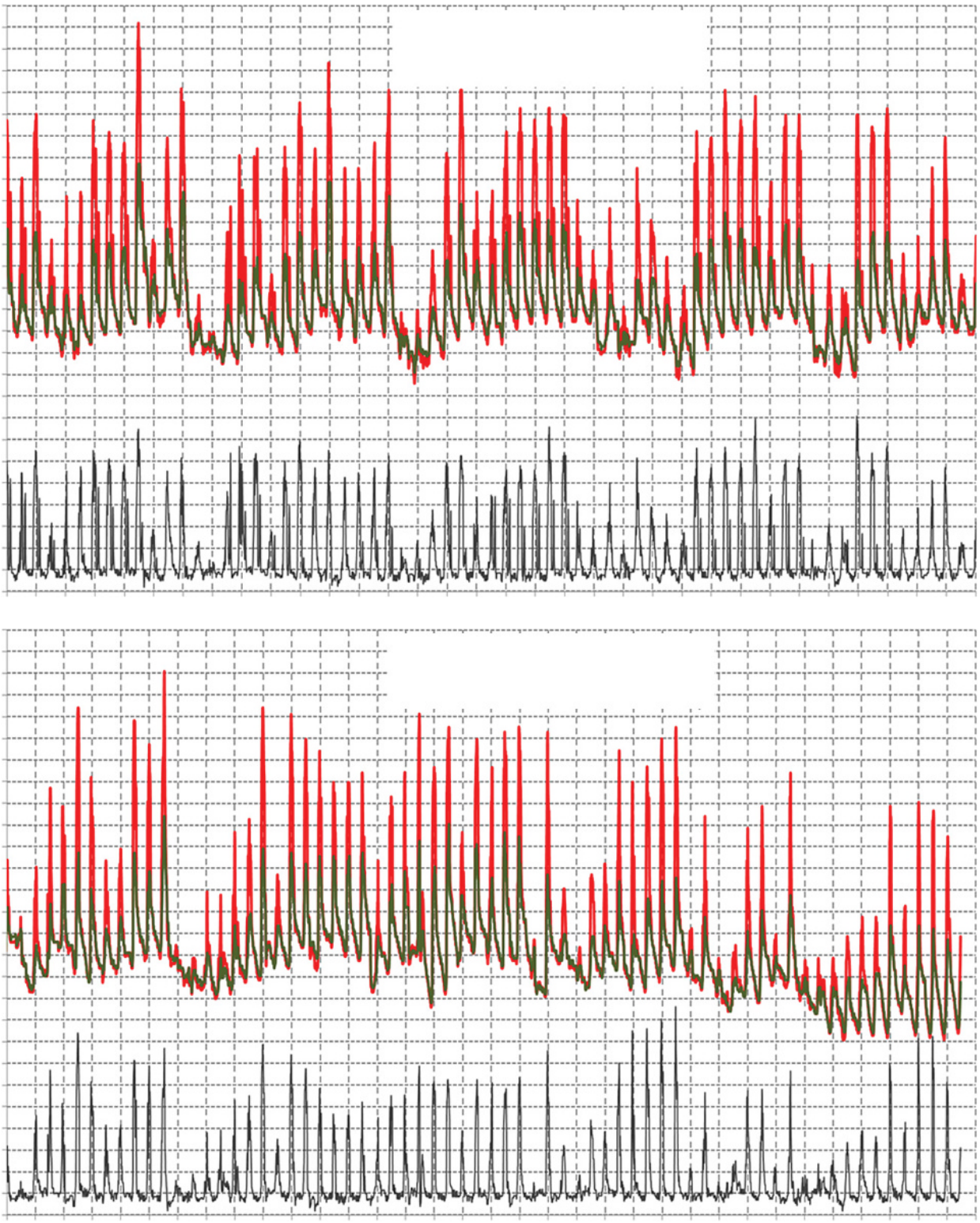
20/1

20/1

21/1

**Figure 4.7** Influence of shadows on temperature caused by adjacent buildings for Sydney exper-

imental roofs.



50

Bare roof

48

Green roof

46

Temperature difference (green roof - bare roof)

44

42

40

38

36

34

32

30

28

e (°C) 26

24

22

mperatur 20

Te

18

16

14

12

108

64

2

0

–2

:00

:00

:00

:00

:00

:00

:00

:00

:00

2:00

2:00

2:00

2:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

12

1

1

1

1

12

12

12

12

12

12

12

12

12

12

12

1

1

1

1

1

12

12

12

12

12

12

12

1

1

1

1

1

12

12

13

13

13

13

13

13

13

13

13

13

13

14

14

14

14

14

14

14

14

14

14

13

14

14

14

14

14

14

14

14

14

14

14

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

2/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

1/20

/0

11/1

13/1

15/1

17/1

19/1

21/1

23/1

25/1

27/1

29/1

31/1

02/0

04/0

06/0

08/0

10

12/0

14/0

16/0

18/0

20/0

22/0

24/0

26/0

28/0

30/0

01/02/20

03/02/20

05/02/20

07/02/20

09/02/20

11/02/20

13/02/20

15/02/20

Date

52

50

Bare roof

48

Green roof

46

Temperature difference (green roof - bare roof)

44

42

40

38

36

34

32

30

28

e (°C) 26

24

22

mperatur 20

Te

18

16

14

12

108

64

2

0

–2

:00

:00

:00

2:00

2:00

2:00

2:00

:00

2:00

2:00

2:00

2:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

2:00

12

12

12

1

1

1

1

12

1

1

1

1

1

12

12

12

12

1

1

1

1

1

1

1

12

12

12

12

12

12

12

12

12

12

12

12

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

14

4

4

4

4

01

01

01

01

14

14

14

/04/20

/04/2

/04/2

/04/2

/04/2

15/02/20

17/02/20

19/02/20

21/02/20

23/02/20

25/02/20

27/02/20

01/03/20

03/03/20

05/03/20

07/03/20

09/03/20

11/03/20

13/03/20

15/03/20

17/03/20

19/03/20

21/03/20

23/03/20

25/03/20

27/03/20

29/03/20

31/03/20

02/04/20

04/04/20

06/04/20

08/04/20

10

12

14

16

18

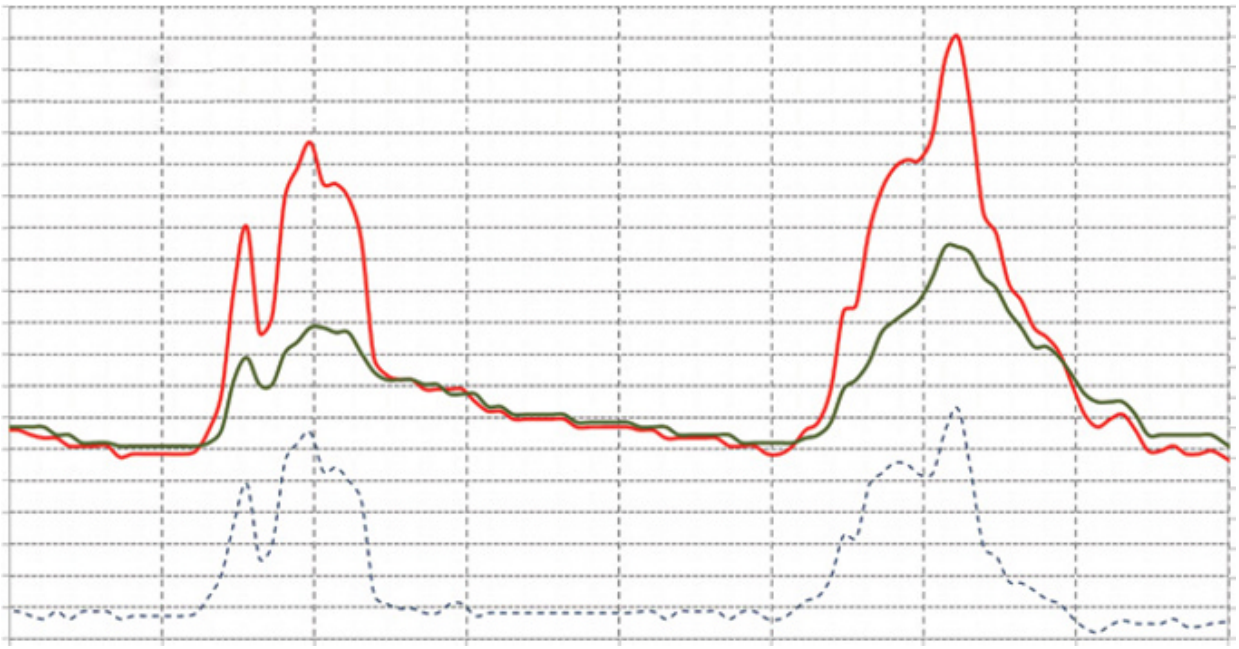
20/04/20

22/04/20

24/04/20

Date

**Figure 4.8** Comparison between non-green and green roofs' internal temperature, Sydney, Australia.



76

Green Roof Retrofit

50

40

48

Bare roof

38

46

Green roof

36

44

Temperature difference (green roof - bare roof)

34

42

32

30

40

28

38

26

36

24

34

22

e (°C)

rence (°C)

32

20

fe

30

18

e dif

28

16

26

14

Temperatur 24

12

22

10

20

8

Temperatur

18

6

16

4

14

2

12

0

10

–2

2:00

8:00

2:00

8:00

00:00

06:00

1

1

00:00

06:00

1

1

00:00

14

14

14

14

14

14

14

14

14

25/02/20

25/02/20

25/02/20

25/02/20

26/02/20

26/02/20

26/02/20

26/02/20

27/02/20

Date

**Figure 4.9** Typical detail of the temperature records between green and non-green roofs, Sydney, Australia.

Figure 4.9 depicts a two-day detail of the whole set of data presented in

Figure 4.8. As at the Rio de Janeiro site, the highest differences in temperature

between green and non-green roofs were also detected around noon. Negative

differences were evident practically throughout the whole night and early

morning periods, additionally corroborating the efficiency of the green roof in

attenuating high and relatively low temperatures. Another point to be highlighted in Figure 4.9 is related to the observed delay between temperature peaks of non-green and green roofs. In comparison with the Rio de Janeiro

experiments (Figure 4.5), a lower delay in the Sydney prototypes was observed,

in all likelihood due to the poor insulating properties of the metal walls.

Analogous to the Rio de Janeiro experiments, Figure 4.10 presents the

maximum, minimum and average daily temperatures, as well as their differences, observed for non-green and green roofs in Sydney. These values calculated for each of the 134 days are based on 48 records (30 minutes of sampling). Compared with the non-green roof, the green roof also showed

attenuation of the differences between the maximum and minimum temperatures. Maximum temperatures were always higher for the non-green roof, and minimum temperatures were higher for all sets of data for

green roofs. This fact is evidenced by the positive differences between non-

green and green roof maximum temperatures (0.9°C to 17.2°C) and by the

negative differences between their minimum temperatures (−1.6°C to −0.3°C).

The average temperatures of non-green roofs were higher than those of green

roofs, except for seven events where the green roof average temperatures

were insignificantly higher (0.06–0.2°C).

Thermal Performance of Green Roof Retrofit 77

Maximum daily temperatures

52

50

48

Green roof

46

Non-green roof

44

Temperature difference (non-green - green roofs)

42

40

38

36

34

32

30

28

26

24

22

Temperature (°C)

20

18

16

14

12

1086420

1

5

9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133

Day

Minimum daily temperatures

52

50

48

Green roof

46

Non-green roof

44

Temperature difference (non-green - green roofs)

42

40

38

36

34

32

30

28

26

24

22

20

Temperature (°C)

18

16

14

12

1086420–2

1

5

9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133

Day

Average daily temperatures

52

50

48

Green roof

46

Non-green roof

44

Temperature difference (non-green - green roofs)

42

40

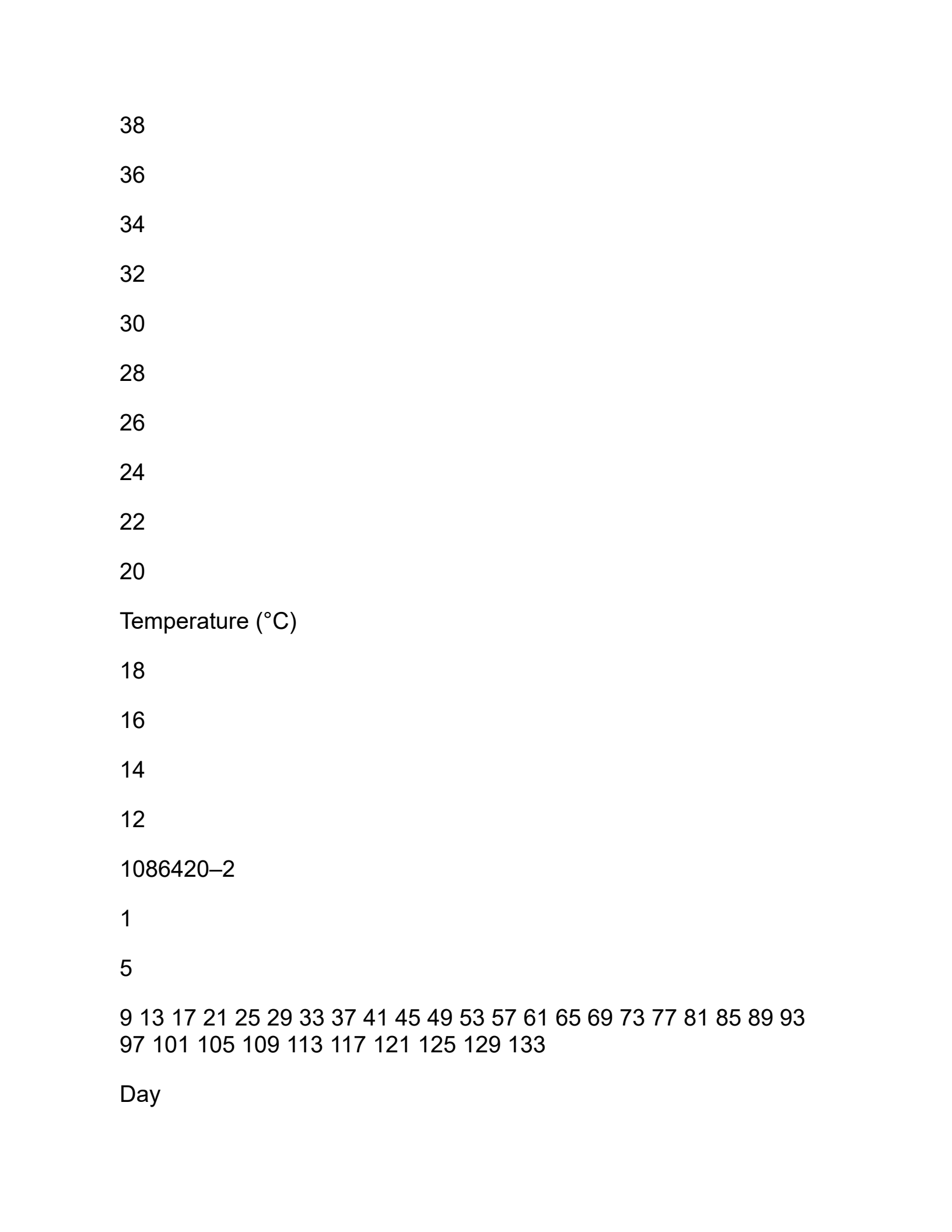

38
36
34
32
30
28
26
24
22
20
Temperature (°C)
18
16
14
12
1086420–2
1
5
9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77 81 85 89 93 97 101 105 109 113 117 121 125 129 133
Day

**Figure 4.10** Maximum, minimum and average daily temperatures and their differences for non-green and green roofs, Sydney, Australia.

78

Green Roof Retrofit

**Table 4.2** Experimental temperature comparison between the Sydney and Rio de Janeiro sites Rio de Janeiro

Sydney

Simultaneous

Simultaneous

Temperatures

Non-green

Green

temperature

Non-green

Green

temperature

(°C)

roof

roof

difference

roof

roof

difference

Maximum

41.4

39.3

5.6

50.3

37.4

17.2

Minimum

15.9

16.6

−1.7

14.2

14.8

−1.6

Average

27.0

26.0

–

24.4

23.0

–

### 4.3.3

### Evaluation of Rio de Janeiro and Sydney Cases

This section does not compare Sydney and Rio de Janeiro experiments, but

rather evaluates the green roofs' potential to attenuate housing temperature.

Green roof tests performed in Rio de Janeiro and Sydney showed improvement in the insulating properties of the roof, due to heat influx reduction in the prototypes and, consequently, temperature attenuation compared with

the non-green roof. That is to say, the vegetation increases the thermal performance of the roof quantified by the *U*-value, which indicates the heat gain or loss through a surface, and is also known as the overall heat transfer

coefficient. A decrease in this parameter means an improvement in thermal

performance due to the attenuation of heat transfer into the buildings. Wong

*et al*. (2003) indicated that in a non-thermally insulating building, a green

roof coverage with turf could reduce the *U*-value from 2.39 to 1.19 W/m2K.

Table 4.2 depicts, for the Rio de Janeiro and Sydney sites, the maximum,

minimum and average temperatures of the non-green and green roofs, as

well as their higher and lower differences. The green roof cooling potential

in Sydney seemed to be greater than that in Rio de Janeiro, most likely due

to the positioning of the temperature data loggers. These devices were placed

50 mm and 250 mm below the roof in Sydney and Rio de Janeiro, respectively. As already mentioned, the goal of this work is not direct comparison between the two sites. Surrounding buildings overshadowed the Sydney site

for parts of the day, and the amount and duration of overshadowing changes

with time as the sun's height increases or decreases. The study sought to

evaluate the insulating properties of green roofs based on different scenarios. This can be corroborated at the Sydney site by the temperature differences (up to 17.2°C) taken close to the inner roof surface, composed of a good thermal conductor (metal sheet).

Compared with non-green roofs, besides insulation, green roofs also add

thermal mass, which is the material capacity to absorb and store energy, and

thus provide inertia against temperature fluctuation, resulting in a temperature peak delay (Castleton, 2010). However, analogous to Castleton (2010), in relation to non-green roofs, the green roof internal temperature peak

delay observed is not much relevant. In the present work, Figures 4.5 and 4.9

show a slight time delay between green and non-green roof temperatures in

both Rio de Janeiro and Sydney. The higher observed delays mostly ranged

from 30 minutes (in Sydney) to 90 minutes (in Rio de Janeiro), showing



more the insulating rather than the thermal mass property of the green roofs.

Owing to its high heat capacity, water has a high thermal mass, since it gains

and loses heat slowly. Thus, it is expected that the thermal mass will increase

when the soil on the green roof is under well-watered conditions.

Besides the insulating properties, it is believed that neighbourhood shading conditions and different roof side conditions may affect green roofs'

effects in temperature attenuation and, consequently, energy savings in

urban environments.

Another aspect to consider is related to the amounts of water in the soil

and storage systems. Owing to its high specific heat, water is supposed to

provide inertia against temperature fluctuations. Although water levels have

not been monitored in the current study, previous works have evaluated this

effect (Del Barrio, 1998; Wong *et al*., 2003; Alcazar and Bass, 2005; Lazzarin, 2005; Castleton, 2010). Alcazar and Bass (2005) revealed that the thermal

performance decreases for wetter soils, since water is a better conductor

than air, while oppositely, Del Barrio (1998) indicates that water promotes

insulation. The results presented by Wong *et al*. (2003) concur with those of

Niachou *et al*. (2001), Alcazar and Bass (2005) and Castleton (2010), where

higher *U*-values (heat gain) are observed for higher water soil content.

Lazzarin *et al*. (2005) presented an evaluation of passive cooling and the

role of evapotranspiration, under wet and dry soil conditions of the green

roofs. According to these authors, compared with a traditional roof, green

roofs reduce the incoming heat flux by 60%, even under dry conditions.

However, in a wet green roof, the additional evapotranspiration acts as a

heat sink in buildings. The water effect in the green roofs' cooling potential

seems to be dependent simultaneously on the soil water content and the

evapotranspiration process. According to Castleton (2010), the moisture

levels in the soil influence the heat loss through evapotranspiration. Wet

soils can promote heat removal from the building when evapotranspiration

effects are considerable.

Different studies have assessed the evapotranspiration effect of succulents

in extensive green roofs. According to Berghage *et al*. (2007), it has previously been hypothesised that, compared with evaporation from bare substrate, transpiration from succulents is not significant. However, these authors stated that the transpiration has a relevant role in the evapotranspiration process under well-watered soil conditions; during dry conditions, these plants stop transpiring, leading to similar levels of evapotranspiration

and evaporation. Evapotranspiration processes are shown to be dependent

on seasonal conditions. Planted plots with succulents transferred, for winter

and summer, respectively, 34% and 51% more water to the atmosphere

compared with bare soil (Rezaei *et al*., 2005). The results from experiments

performed by Voyde *et al*. (2010) challenge the hypothesis that succulent

plants hold water all the time. In a lightweight modular system, their results

indicated that when the water supply is not limited, transpiration contributes approximately 48% of the evapotranspiration.

Alcazar and Bass's (2005) studies revealed that water storage systems

could improve the thermal performance of green roofs. Even without water

level monitoring, their results showed a reduction in *U*-values compared



with systems without water storage. Owing to water's thermal mass, it was

expected in the Sydney and Rio de Janeiro results that there would be a

delay between temperature peaks greater than those observed. The modular

systems adopted in these studies were simply supported on top of the roof,

and thus promote airflow, which is believed to enhance the thermal insulation. It is also important to highlight that solar radiation levels were not collected in the two exploratory studies presented. Thus, it is believed that

the temperature attenuation provided by green roofs is directly related to

solar radiation levels, and under cloudy conditions this effect tends to be less

pronounced. It is considered that lightweight modules, similar to those

adopted here, could easily be retrofitted to many existing houses with sheet

metal roofs, increasing the thermal comfort of occupants, lowering energy

bills and reducing GHG emissions.

### 4.4 Conclusions

Experimental setups in Rio de Janeiro and Sydney have demonstrated the

potential of portable green roof modules for cooling buildings, reducing

carbon emissions and contributing towards zero carbon targets. However,

the exploratory experiments carried out in Sydney seem to have better green

roof performance in temperature attenuation, most likely due to the closer

positioning of the data loggers in relation to the roof.

Different types of green roof technology exist, from extensive to intensive

systems. It is expected that different substrate composition, soil depths, soil

moisture content, types of plant and water retention layer have a particular

role in heat transmission, thermal inertia and evapotranspiration. The low

cost, modular green roof systems adopted at both sites comprised an extensive system, where all the components are gathered in a single module. In this system, the existing space between modules and the underlying roof

provides some air circulation and an extra insulating effect. However, considering the partial contact between the modules and the roof, some effect on inertia was observed, and the time shifts when the inner temperatures of

the non-green and green roofs are compared. Similar results from experiments with modular systems (Lin and Lin, 2011) show the same trend observed in the present exploratory study.

The *U*-value parameter quantifies the heat exchange through a surface. In

addition to Wong *et al*. (2003), who evaluated this parameter from exposed

roofs to covered roofs with different types of vegetation and soil substrate,

Niachou *et al*. (2001), Alcazar and Bass (2005) and Castleton (2010) evaluated this parameter, especially for extensive green roofs with depths from 50

to 100 mm. These authors, besides corroborating the role of the green roofs

in reducing *U*-values compared with non-green roofs, revealed the effects of

thermal inertia, evapotranspiration, soil moisture content and water storage. Besides insulation, green roofs add thermal mass and provide inertia against temperature fluctuation (Castleton, 2010). A green roof may work

as a passive cooler. Under conditions of high external temperatures, not only

is the heat influx cancelled, but a slight outflux is also produced due to the



evapotranspiration cooling effect. The soil water content affects the extent

of heat loss due to the evapotranspiration process, and also influences the

thermal conductivity, since drier soils offer better thermal insulation.

As an alternative to green roofs, a common practice adopted in some

Mediterranean countries is the cool roof, which consists of painting the roof

surface white. This lowers the air and surface temperature, and the heat

influx to the building. Cool roofs are covered in Chapter 11 of this book.

According to Diep (2014), cool, or white, roofs have an extreme capacity to

reflect sunlight and heat. Green roofs do not reflect as well as white roofs.

However, both roofs manage to cool buildings on hot days. During summer

periods, green roofs have a major role in energy savings, due to the cooling

effect of evapotranspiration, while in the winter, they are able to reduce heat

loss because of their more pronounced insulating properties. Green roofs

have a major role in energy savings. In the summer, due to the cooling effect

of evapotranspiration and in the winter, reducing the heat loss because of

their more pronounced insulating properties. Despite the aforementioned

benefits, white roofs may negatively affect neighbouring buildings, due to

the solar radiation reflected towards windows facing these roofs.

Water levels were not monitored in this feasibility study. However, it is

noted that due to the delay between the temperature peaks observed, the

water levels do not seem to have a predominant role in green roof thermal

performance. Furthermore, the passage of air is allowed in the modular system adopted, due to the existing space between the planted trays and the underside of the roof. This characteristic seems to enhance the insulating

properties of the system and/or mitigate the effects of the water storage.

Even though the present study did not monitor the water levels in the storage system, it could be seen, due to the delay between temperature peaks, that these levels do not seem to play a predominant role in the thermal performance of green roofs. In addition, the modular system adopted allows the air flux between the planted trays and the roof surface. This characteristic seems to enhance the insulating properties of the system and/or mitigate the effects of the water storage.

Even though no temperatures lower than 14°C have been measured, the

negative differences observed (green roof temperature higher than non-

green roof temperature) might indicate the green roofs' potential, due to

their insulating properties, for attenuating extremes of temperature. It is

probable that different substrate compositions will provide different results,

and can be the object of further research.

Previous literature emphasises significant temperature differences between

urban centres and green areas. Green roofs attenuate heat exchanges

between the internal and external environments of buildings, and thus promote thermal comfort improvement. Additionally, according to a modelling study performed in Canada, if green roofs are adopted for new buildings

and as retrofitting for existing buildings, it is expected that an attenuation

of the urban heat islands will occur (see Chapter 3).

The research has demonstrated that roof structures planted with succulents are viable, as the plants survive well and could provide a low-cost, drought-tolerant, lightweight option to reduce heat gain and heat loss



through roof structures. However, regarding the thermal aspect, the adoption of green roofs in urban centres is a partial solution only, due to the contribution of the building façades in the overall heating. Thus, a combination of green walls and green roofs could be an optimum solution for this problem. Furthermore, in terms of energy saving, considering that buildings

comprise the most part of big cities, green roof adoption would only be

relevant in top floors, which reinforces the combination of green roofs and

green walls in urban environments.

Additional experiments with structures that more closely emulate typical

Australian housing specifications in terms of wall construction would be

very useful to consolidate the preliminary results found here. One of the

limitations of this exploratory research is that the walls of the shed are profile metal sheeting, which is not typically specified in housing, although it does exist. In the Rio de Janeiro experiments, brick walls comprise a common type of solution adopted in the majority of housing. However, additional procedures, such as green walls, are the subject of current research to mitigate the rates of thermal transfer through walls.

The lightweight modular green roof system adopted in Rio de Janeiro prototypes has been subject to testing for approximately 2.5 years, during which time no maintenance has been required. The succulent plants have shown

extreme resistance to intense heat, drought periods and atmospheric pollutants. The Sydney experiment has been underway for 1.5 years, and no maintenance of the plants has been required. The present study is based on new adaptive techniques, where the green roof setup costs have been substantially

reduced using reusable materials. Currently, testing is underway in Rio de

Janeiro at the FioCruz campus using cellular plastic boxes, which are commercially available at a low cost. This new modular system has been shown to be applicable to roofs and comprises a portable green patch solution that

is intended for widespread use on a large scale in urban environments.

**References**

ABC (2014) ‘Heatwave blamed for large spike in the number of deaths in Victoria

last week’, available at: www.abc.net.au/news/2014-01-23/heatwave-death-toll-

expected-to-top-almost-400/5214496.

Agência Brasil (2014) ‘Área verde por habitante cai 26% no Rio com avanço de

favelas e especulação imobiliária’, available at: memoria.ebc.com.br/agenciabrasil/

noticia/2012-06-02/area-verde-por-habitante-cai-26-no-rio-com-avanco-de-favelas-

e-especulacao-imobiliaria.

Alcazar, S. and Bass, B. (2005) ‘Energy performance of green roofs in a multi storey

residential building in Madrid’. *Greening Rooftops for Sustainable Communities*, Green Roofs for Healthy Cities Conference, Washington D.C.

Bass, B., Liu, K. K. Y. and Baskaran, B. A. (2003) ‘Evaluating rooftop and vertical

gardens as an adaptation strategy for urban areas’, National Research Council, Canada.

Berghage, R. D., Jarrett, A. R., Beattie, D., *et al*. (2007) *Quantifying Evaporation and Transpirational Water Losses from Green Roofs and Green Roof Media Capacity*

*for Neutralizing Acid Rain*. National Decentralized Water Resources Capacity

Development Project, Penn State University, State College, PA.

Thermal Performance of Green Roof Retrofit 83

Berndtsson, J. C. (2010) 'Green roof performance towards management of run-off

water quantity and quality: a review', *Ecological Engineering*, 36, 351–360.

Castleton, H. (2010) 'Green roofs; building energy savings and the potential for

retrofit', *Energy and Buildings*, 42, 1582–1591.

City of Sydney (2012) *Greening Sydney Plan*. Available at: www.cityofsydney.nsw.

gov.au.

City of Sydney (2015) *Green Roofs and Walls Policy*. Available at: www.cityofsydney.

nsw.gov.au/vision/towards-2030/sustainability/greening-the-city/green-roofs-and-

walls.

City of Toronto (2015) *Green Roofs*. Available at: www1.toronto.ca/wps/portal/con

tentonly?vgnextoid=3a7a036318061410VgnVCM10000071d60f89RCRD.

Cummings, J., Withers, C., Sonne, J., Parker, D. and Vieira, R. (2007) *UCF*

*Recommissioning, Green Roofing Technology, and Building Science Training. Final*

*Report*. Available at: www.fsec.ucf.edu/en/publications/pdf/FSEC-CR-1718-07.pdf.

Del Barrio, E. P. (1998) 'Analysis of the green roofs cooling potential in buildings', *Energy and Buildings*, 27, 179–193.

Diep, F. (2014) 'White roofs keep cities cooler than "green" ones, study finds', avail

able at: www.popsci.com/article/science/white-roofs-keep-cities-cooler-green-ones-

study-finds.

EPA (2014). *Reducing Urban Heat Islands: Compendium of Strategies. Green Roofs*.

Available at: www.epa.gov/heatislands/resources/pdf/GreenRoofsCompendium.

pdf.

EPA (2015) *Heat Island Effect*. Available at: www.epa.gov/heatisland/index.htm.

Feitosa, R. C. (2012) 'Telhados verdes reduzem temperatura interna de casas', avail

able at: oglobo.globo.com/ciencia/telhados-verdes-reduzem-temperatura-interna-

de-casas-5173467.

Greater London Authority (2008) *Living Roofs and Walls Technical Report*.

Supporting London Plan Policy, London, UK.

Green (2014) *202020 Vision*. Available at: greenmagazine.com.au/202020-vision/.

Harlan, S., Brazer, A. J., Prashad, L., Stefanov, W. L. and Larsen, L. (2006)

'Neighbourhood microclimates and vulnerability to heat stress', *Social Science & Medicine*, 63, 2847–2863.

Herman, R. (2003) *Green Roofs in Germany: Yesterday, Today and Tomorrow*.

Greening Rooftops for Sustainable Communities, Chicago, IL.

IPCC (2013) *Climate Change 2013: The Physical Science Basis*. Available at: www.

ipcc.ch/report/ar5/wg1/.

Kellert, S. R. and Wilson, E. O. (1993) *The Biophilia Hypothesis*. Island Press: Washington D.C.

Lamond, J., Wilkinson, S. and Rose, C. (2014) 'Conceptualizing the benefits of green

roof technology for commercial real estate owners and occupiers', Proceedings of

Pacific Rim Real Estate Conference, Christchurch, New Zealand.

Langston, C. (2015) 'Green roof evaluation: a holistic "long life, loose fit, low

energy” approach’, *Construction Economics and Building*, 15(4), 76–94.

Lazzarin, R. M., Castellotti, F. and Busato, F. (2005) ‘Experimental measurements

and numerical modelling of a green roof’, *Energy and Buildings*, 37, 1260–1267.

Lin, Y.-J. and Lin, H.-T. (2011) ‘Thermal performance of different planting substrates and irrigation frequencies in extensive tropical rooftop greeneries’, *Building and Environment*, 46, 345–355.

Liu, K. (2011) *Retrofitting Existing Buildings with Green Roofs*. Construction

Canada: Toronto.

Liu, K. and Bass, B. (2005) *Performance of Green Roof Systems*. National Research Council Canada Report, Toronto.



Mentens, J., Raes, D. and Hermy, M. (2006) Green roofs as a tool for solving the

rainwater runoff problem in the urbanized 21st century? *Landscape and Urban*

*Planning*, 77, 217–226.

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A. and

Mihalakakou, G. (2001) ‘Analysis of the green roof thermal properties and

investigation of its energy performance', *Energy and Buildings*, 33, 719–729.

Oke, T. R. (1982) 'The energetic basis of the urban heat island', *Quarterly Journal of the Royal Meteorological Society*, 108, 1–24.

Peck, S. and Kuhn, M. (2003) *Design Guidelines for Green Roofs*. Ontario

Association of Architects (OAA) and Canada Mortgage and Housing Corporation

(CMHC), Ontario.

Portal G1 (2014) 'Rio tem novo recorde de calor e dia mais quente do ano chega a

41,4°C', available at: www.climatempo.com.br/destaques/tag/recorde-de-calor/.

Rezaei, F., Jarrett, A. R., Berghage, R. D. and Beattie, D. J. (2005) 'Evapotranspiration rates from extensive green roof plant species', Proceedings of the 2005 ASAE

Annual International Meeting, Tampa, FL.

Sonne, J. (2006) 'Energy performance aspects of a Florida green roof', Fifteenth

Symposium on Improving Building Systems in Hot and Humid Climates,

Orlando, FL.

Stovin, V. (2010) The potential of green roofs to manage Urban Stormwater. Water

and Environment Journal 24, 192–199.

Voyde, E., Fassman, E., Simcock, R. and Wells, J. (2010) ‘Quantifying evapotranspiration rates for New Zealand green roofs’, *Journal of Hydrologic Engineering*, 15, 395–403.

Wilkinson, S. J. and Reed, R. (2009) ‘Green roof retrofit potential in the central

business district’, *Journal of Property Management*, 27, 284–301.

Wilkinson, S. J., Ghosh, S. and Page, L. (2013) ‘Options for green roof retrofit and

urban food production in the Sydney CBD’, Proceedings of RICS COBRA

Conference, New Delhi.

Williams, N., Raynor, J. and Raynor, K. (2010) ‘Green roofs for a wide brown land:

opportunities and barriers for rooftop greening in Australia’, *Urban Forestry & Urban Greening*, 9, 169–272.

Wong, N. H., Cheong, D. K. W., Yan, H., Soh, J., Ong, C. L. and Sia, A. (2003) ‘The

effects of rooftop garden on energy consumption of a commercial building in

Singapore’, *Energy and Buildings*, 35, 353–364.

**5**

## Stormwater Attenuation and Green Roof Retrofit

**Jessica Lamond1, Sara Wilkinson2 and David Proverbs3**

1 University of the West of England, UK

2 University of Technology, Sydney

3 Birmingham City University, UK

## 5.0 Introduction

This chapter describes research demonstrating how to make an assessment

of whether to retrofit with green roofs as a way of attenuating stormwater

runoff. The problem of pluvial flooding in terms of financial costs and the

impact on our urban settlements is the starting point for a discussion on the

potential of retrofitted green roofs as a mitigation measure. A range of tech-

nical specifications for stormwater roofs and critical issues to consider in

retrofitting existing buildings are evaluated.

Theoretical frameworks of the distributed benefits of green roofs are pre-

sented, and a methodology to estimate the potential for stormwater attenu-

ation of green roof retrofit at city-scale level is described in detail. The

chapter reports on recent empirical research undertaken in two cities with

very different climatic conditions: Melbourne, Australia and Newcastle, UK,

at city-scale level. Having examined the city-scale level, a second illustrative

case study at an individual building scale outlines stormwater performance

and the assessment process in Portland, OR. The chapter concludes by

describing how the stormwater effectiveness of green roofs may be limited

in certain conditions by the availability of suitable buildings and the source

of floodwater. A summary of the potential benefits of green roof retrofit for

stormwater attenuation is made.

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



## 5.1

## The Problem of Pluvial Flooding

Flooding in all forms causes severe problems for urban areas worldwide.

For example, in 2010 alone, 178 million people were affected by floods. The

total losses in exceptional years, such as 1998 and 2010, exceeded US$40bn.

Many of these disasters are caused by extreme weather events at a large

scale, rainfall events that cause rivers to swell and burst their banks (fluvial

flooding), and storm events that result in coastal surge and flooding. Pluvial

flooding, also called surface water flooding, or flooding from intense rainfall

events is caused directly by rainfall that has not yet reached watercourses or

drainage systems, particularly in dense urban areas with low permeability,

and results in overland flows of water that can often be characterised by

sudden onset and high velocity. Among the predicted changes in weather

patterns consistent with a warming global climate (Met Office Hadley

Centre for Climate Research, 2007; Solomon and Qin, 2007), consensus

exists that the frequency of intense rainfall events is rising even where average

rainfall is decreasing.

Pluvial flooding can be one of the most unpredictable forms of urban flooding, and this adds to the problems associated with preparing for and protecting against it. In some circumstances, pluvial flooding can be the most dangerous due to rapid onset and velocity of water taking communities by surprise. Equally, some pluvial flooding can be seen as nuisance flooding, affecting properties on a regular basis with shallow flood characteristics for a relatively brief period of time. Nevertheless, for those communities affected, the effect of frequent inundation can be very corrosive in the long term, affecting their ability to repair and insure their assets. For example, in the UK, 3.8 million properties in England are estimated to be at risk from surface water flooding alone (Environment Agency, 2013).

Disruption associated with pluvial flooding can also be very detrimental to the functioning of businesses and the wider infrastructure network, even if the damage in terms of individual properties is limited due to low depths.

Within the CBD of cities, arguably, the impact of disruption and long-term

impacts due to recovery time are at least as important as the direct damages

caused to property and contents during the flood (Bhattacharya-Mis *et al*.,

2015). Floods in city centres are disruptive to all who live, work and pass

through them, particularly if transport networks are involved, resulting in

long-lasting cost to local economies if businesses fail to recover (BMG

research, 2011; Ingirige and Wedawatta, 2011; Wedawatta *et al*., 2011).

Causes of increased pluvial flooding are not limited to changes in weather,

but also driven by increased development pressures and urbanisation (Jha

*et al*., 2011). Urban densification policies and practice in the UK and

Australia have increased the concentration of impermeable surfaces in cities

(White and Howe, 2002). Stormwater runs swiftly off these surfaces and in

many business districts, piped drainage systems have not been updated to

accommodate the increased runoff (French *et al*., 2011). As an alternative to

the expensive and disruptive business of retrofitting extra capacity into the

piped drainage, measures designed to increase infiltration and evapotran-

spiration within urban areas have been suggested. Within existing business







**Figure 5.1** Overviews of the building styles in Newcastle-upon-Tyne's CBD (left) and Melbourne (right).

*Source*: J. Lamond and S. Wilkinson.

districts, this approach could include the widespread retrofit of green roofs

according to many authors including Charlesworth and Warwick (2011).

However, the viability of such a retrofit from a structural and functional

point of view, and the associated reduction of flood risk and delivery of

other multiple benefits, is yet to be fully explored (Wilkinson and Reed,

2009; Lawson *et al*., 2014).

The cities selected for the research described here (Newcastle, UK and

Melbourne, Australia – shown in Figure 5.1) represent historic cities that

have expanded and densified over time. Furthermore, the cities are on the

banks of major watercourses and contain streets that have been built over

culverted watercourses, further reducing the permeability and flow poten-

tial within them. It is not surprising, then, that pluvial flood risk exists in

both cities and, in fact, they have both recently been subject to severe pluvial

flood events.

In 2012, Newcastle experienced a severe rainfall event in which the whole

of the expected total rainfall for June fell within a two-hour period

(Environment Agency – Yorkshire & North East Region, 2012). In their sur-

vey, Newcastle City Council determined that temporary closure was experi-

enced by around 40% of non-residential properties in the CBD. This

included the Central Railway Station (Total Research and Technical Services

Newcastle City Council, 2013).

Similarly, the Melbourne area experienced a severe storm in 2010, during

which almost a month’s rain fell in a single 24-hour period (Bureau of

Meteorology (Australia), undated). Massive disruption included a number

of roads in the CBD rendered impassable for several hours, flooding of

Flinders Street railway station and disruption of the trams. An even more

intense storm occurred in February 2011 when, during a 20-minute cloud-

burst, 17 mm fell in the CBD (News.com, 2011). A further flood occurred in

June 2015, causing extensive damage to the city (City of Melbourne, 2015).

The City of Portland in the USA, also the subject of research referred to in

Section 5.4.1, has been subject to nuisance flooding over many decades and

instituted a green infrastructure policy that included the encouragement of

green roof installation. Many acres of green roofs have been installed under

the programme; a roof garden is visible in Figure 5.2(a), including one on





88

Green Roof Retrofit

(a)

(b)

**Figure 5.2** Roofscapes of Portland, OR taken from two vantage points: (a) the heart of the city with views of green roofs; (b) across the Williamette from the green roof of the Multnomah building.

what is now the Apple building opposite Pioneer Place, which has a brand

new green roof. However, it is clear that there is still considerable untapped

potential in the rooftops of Portland.

**5.2**

## Specifications for Stormwater Roofs and Issues for Retrofit

Modelling of the impact of green roofs on stormwater and other benefits is

carried out at different spatial scales and for different purposes. This chapter

describes modelling at two different spatial scales contextualised within the

perspectives of stakeholders involved in the decision-making process.

For new developments and retrofit installations there are software

resources available to aid in calculating the impact of sustainable drainage

on runoff. Some have a green roof feature, for example ‘SWMM’ software

(US EPA) and ‘xpdrainage’ (XP Solutions). These software packages require

or assume design features, climate and rainfall patterns. At a feasibility and

design stage, more detailed local monitoring and detailed structural calcula-

tions can be made at an individual building scale. However, at a larger spa-

tial scale, and for the formulation of policy and incentive schemes to

encourage uptake, a less detailed methodology is needed. At whatever spa-

tial scale, it is contended that two critical factors are the criteria for assess-

ment of the suitability of buildings for green roof retrofit and the estimate

of runoff reduction assumed or modelled.

### 5.2.1

### Technical and Physical Issues in Retrofit

When retrofitting a green roof it is useful to undertake a survey of the roof

space to determine the available space for vegetation. Many rooftops accom-

modate mechanical equipment (such as air-handling units). Before designing

a green roof it is vital to undertake an investigation to determine the build-

ing's existing structural load-bearing capacity and to check for damage,

and this may be undertaken by a surveyor. The building's structural capacity



determines the type of vegetation that can be grown. An inspection of the

existing roof membrane determines its condition, and any damage should be

repaired. Green roofs require regular maintenance, therefore safe access

must be provided. If a green roof is to be used as an amenity space, then how

the space is accessed for this purpose (e.g., via lifts/stairs) needs to be

considered. Accessible roof amenity spaces need to meet access and health

and safety legislation; additional structures may need to be added to existing

parapets. Considering the visual impact of historic buildings is of primary

importance. Heritage buildings must be able to accommodate a green roof

without negatively altering the historic character of the building. Green

roofs require regular monitoring and maintenance; this includes pruning

and weed control, plant nutrition, plant installation/replacement, mainte-

nance of supporting structure and waterproofing. The orientation of the

roof affects the amount of exposure to sun the roof will get, and this affects

the type of plants that will flourish there (Wilkinson and Reed, 2009). Added

to this, the surveyor needs to consider any overshadowing from surrounding

buildings as this affects access to sunlight for the plants. Finally, the height

above ground will affect exposure levels to high winds in particular. Some

rooftop environments can be hostile in different seasons, and planting

specifications must take this into account (Williams *et al*., 2010).

### 5.2.2

### Estimating Runoff Reduction

In designing or planning for green roof retrofit, a sensible choice of runoff

performance is needed and this can be gained from theory and modelling

or from analysis and monitoring of other similar roofs. Using the data

from previous measurement of the retention or runoff reduction from

green roofs is complicated by the variety of performance measures used by

researchers. Researchers may measure the percentage of annual rainfall

retained, the average percentage retained during a given storm size or the

reduction in peak flow during a storm. In their meta-analysis, Rose and

Lamond (2013) note that reported performance ranged from 42–90% of

annual rainfall, whilst average retention during storm events varied from

30–100%.

According to Mentens *et al*. (2006), the stormwater performance of green

roofs relies on three actions: absorption by the substrate delays runoff from

the roof during a storm event until it is saturated; storage of this water

throughout the storm reduces total flow and is likely to reduce peak flow;

water stored by the roof is released back into the atmosphere through evap-

otranspiration, thereby reducing the total load on the ground-level drainage

and treatment systems. There are therefore several factors that can impact

on the performance by influencing the quantity of water stored and the

speed with which it is released. For example, design features like the grow-

ing medium, presence and size of reservoir storage (Wilkinson and Reed,

2009) and choice of vegetation can each affect interception rates by 50–60%

(Nagase and Dunnett, 2012). Slope, or roof pitch, is also a factor (Wilkinson

and Reed, 2009).

Non-design factors that can potentially have an impact include regional

climatic variation and expected rainfall patterns. For example, subtropical

Mediterranean climates (Fioretti *et al*., 2010) place different demands on

vegetation, including roofs, with the result that the performance of roofs

varies from that in temperate maritime climates (MacIvor and Lundholm,

2011). Most measurements have been taken under northern US climate con-

ditions with very little data available for subtropical Mediterranean-type

climates. In a retrofit scenario, roof characteristics such as overshadowing

(which can inhibit vegetation growth) and the degree of pitch of the roof

(Wilkinson *et al*., 2009) may also be fixed characteristics of the urban envi-

ronment that can impact on runoff reduction.

Advice previously given for ‘rule of thumb’ estimates for the design and

installation of vegetated roofs include the San Francisco toolbox, which

gives figures of 50–65% of annual rainfall and 50% of peak events (Sanfran,

2010) and Groundwork Sheffield (2011) citing, for the UK, 50–70% in

summer and 25–40% in winter. However, it should be noted that relying on

measured performance limits the technical considerations to a small range

of installations, often designed for a specified storm event. This runs the risk

of underestimating the potential to design roofs to a higher specification if

peak attenuation is a major goal for the roof.

## 5.3

## Modelling for City-Scale Stormwater Attenuation

Estimation of reduced runoff (that is, the reduction in the quantity of sur-

face water that flows off a surface), which results from the retrofitting of

SuDS features, is useful for a number of different purposes and at different

scales. For example, on an individual building basis the reduction in runoff

from a green roof could result in savings in wastewater disposal or it could

be used to determine the appropriate size for ground-level SuDS (Ma *et al*.,

2012). At a city-wide level it could be used to determine the reduction in

flood hazard and the resultant decrease in expected flood damage (Gordon-

Walker *et al*., 2007). This type of assessment may be carried out by city or

local authorities (among others) while formulating policy or during the

planning cycle. Roofs can represent a high proportion of impermeable sur-

faces in urban areas, for example Stovin (2010) estimated 40–50% of the

impermeable surfaces in urban locations were roofs. These surfaces offer

mitigation potential without the need for land-take, however the area and

location of suitable roofs will have a large influence on the quantity and

pattern or attenuation and therefore hazard reduction. The perspective of

different agencies or authorities in determining the benefits of retrofit has

been discussed by Abbott *et al*. (2013) in the UK context. As adapted for

green roof benefits, the match between investment and benefit is shown in

Figure 5.3. In the UK, where lead local flood authorities bear a large part of

the responsibility for the management of surface water flooding and also

much of the cost of clearing up after a flood, runoff for flood reduction

purposes is strongly within the remit of the local authority. However, in

other contexts the responsibility may fall on other bodies, for example in

Stormwater Attenuation and Green Roof Retrofit 91

Reduced need for drainage infrastructure

Other actors and

wider society

Acoustic damping

Extended roof life/manitenance costs

Reduced erosion/stream degradation

Easier planning

Thermal buffering

consent

Biodiversity

Amenity

Reduced UHI

Carbon/nitrogen sequestration

Water quality

Aesthetic improvement

Local authority

investment in

Air quality

incentives for

green roof

Peakflow/

flood control

**Figure 5.3** Distribution of benefits from local authority investment in green roofs.

*Source*: After Abbott *et al*. (2013).

Australia, responsibilities are shared between local authorities, State and

Federal authorities. In this framework, flood prevention is one of the key

quantifications that a public body may focus on.

On a city-wide scale, any assessment of retrofit potential will need to

make generalised assumptions about the type and design of green roofs to

be retrofitted. Of the two main types of green roof, the extensive roof (incor-

porating shallow-rooted species in a relatively thin substrate) is regarded as

more suitable for retrofit because there will be a lower load superimposed

on existing structures. Therefore, it was assumed in this study that an exten-

sive roof would be the preferred option in modelling runoff. Choosing a

runoff percentage is still challenging given that the cities were in different

climate zones and that the percentage rates of runoff retention vary for dif-

ferent storm scales. The view that green roofs are unlikely to prevent flood-

ing in the most severe events led to the decision to look at average annual

retention as this is the most measured and is relevant for stormwater man-

agement and nuisance flooding. Based on the meta-analysis described in

Section 5.2.2, an estimate of 60% was chosen.

Green Roof Retrofit

Databases of buildings suitable for green roof retrofit were established for

Melbourne and Newcastle using a desk-based approach that drew on evi-

dence from the literature as summarised in Section 5.2.1. This was used to

determine criteria for whether a building could be deemed suitable for ret-

rofit. Information from existing databases of building characteristics was

first accessed. The next stage involved a visual inspection of each identified

roof using the Google Earth and Google Map software (Google Earth 6.0,

2008). An evaluation of the potential of each roof for retrofitting with green

roof technology was undertaken, resulting in one of three classifications,

namely (a) ‘yes’, (b) ‘no’ or (c) ‘don’t know’ with regards to retrofitting. The

evaluation was based on roof pitch (i.e., those pitched above 30° and below

2% were deemed unsuitable). The amount of rooftop plant, especially

equipment which vents air from the building, and the provision of rooftop

window-cleaning equipment, safety handrails and PV units was taken into

account; where coverage exceeded 40% of the roof area, the roof was

deemed unsuitable for retrofit. Roofs with listed or conservation status,

overshadowing or lightweight construction were deemed unsuitable.

### 5.3.1

### Melbourne, Australia

Using this approach, 526 buildings in the Melbourne CBD database were

evaluated in terms of suitability for green roof retrofit. The analysis also

considered other characteristics that might affect the ease and likelihood of

retrofit in the near future, and the type of planting suitable.

An age profile analysis of the buildings gave an average property age of

61 years, with a range of construction dating from 1853 to 2005 (although

some buildings have been completed since 2005 they were not in the data-

base, which covered the time period from 1850 to 2005). The data reflects

considerable post-war construction in the Melbourne CBD with 302 (or

60.4%) new commercial CBD buildings built during this era. 237 Melbourne

CBD buildings date from the 1960s, therefore a large amount of stock is due

for adaptation and retrofitting green roofs could be considered.

The site and the location of the building were also considered (Kincaid,

2003) and within the CBD, locations were categorised as ‘prime’ (the best

location), ‘low prime’, ‘high secondary’, ‘secondary’ and the lowest grade

‘fringe’. 7.6% of all buildings were located in the prime zone, 15.2% in the

low prime area, and 7% in the high secondary area – thus 29.8% of all prop-

erties were located in the higher-grade location zones. The highest proportion

(43.2%) was in the low secondary area and nearly a quarter (24.7%) was

located in the fringe area at the periphery of the CBD grid. Wilkinson (2014)

has examined attributes which make Melbourne offices more or less likely to

be retrofitted and found that higher-grade stock typically has more activity.

Building height and overshadowing are important considerations in green

roof retrofit, and most buildings are low rise (three storeys) and often par-

tially or totally overshadowed. Overall, 68.1% of the stock is 10 storeys high

or less, 24.5% between 10 and 20 storeys, while only 7.4% is above 20

storeys high. A definition of a high-rise building refers to metres in height



80

70

60

50

40

30

20

10

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43

Frequency 24 69 73 41 38 34 20 15 17 19 31 36 14 10 10 6 11 10 3 3 3 5 2 3 1 3 3 1 1 1 1 3 1 1 2 1 1 2 1 1 1 2 1

Number of storeys

**Figure 5.4** Number of storeys in Melbourne CBD buildings.

*Source*: Wilkinson and Reed (2009).

rather than number of storeys. According to some definitions, buildings over

approximately 7 storeys (or 23 m high) are in the high-rise category and those

over 80 m (approximately 20 storeys) are deemed skyscrapers. Figure 5.4

shows that a minority of all buildings are high rise or skyscrapers, which cast

shadows over adjoining lower buildings as the sun moves across the sky

during the day. Such an arrangement of buildings could mean that existing

buildings with adequate structural strength to accommodate green roof retrofit

may be unsuitable due to overshadowing adversely affecting planting.

Orientation also has an influence on how much exposure to sunlight a roof

may benefit from. In the southern hemisphere, exposure to sunlight will be

greatest for north-facing properties and this will affect the type of plants spec-

ified and/or whether green roof retrofitting is viable. Analysis of a sample of

72 buildings in the database revealed that the highest number (41.17%) faced

east followed by west-facing (30.88%), south-facing (16.17%) and finally

north-facing buildings, which comprised 11.76% of the sample (see Figure 5.5).

Therefore, it appears that a large proportion of CBD buildings will only have

partial exposure to sunlight, even before overshadowing is considered.

Ease of access for construction and attachment to neighbours was consid-

ered, because cost/disruption and the need to interface with neighbouring

property can be a further constraint in the uptake of green roof retrofitting.

In the Melbourne CBD sample, the highest number of properties were

bounded on two sides (47.4%), 21.9% were bounded on one side only and

18% bounded on three sides. Only 12.1% were free-standing. This shows

that access is not an issue for the majority of properties, however, most

properties in the sample might need to consider the views and/or co-operation

of their neighbours.

94

Green Roof Retrofit

North facing buildings

11.76%

East facing

West facing buildings

buildings 41.17%

30.88%

South facing buildings

16.17%

**Figure 5.5** Building orientation in Melbourne CBD.

*Source*: Adapted from Wilkinson and Reed (2009).

**Table 5.1** Green roof option

Frequency

Valid (%)

Valid

Yes

78

15.0

No

418

80.2

Don’t know

25

4.8

Total

521

100.0

Missing

System

5

Total

526

*Source*: Adapted from Wilkinson and Reed (2009).

The structural capacity of a building affects the feasibility and ease of retrofit of a green roof. The majority (60.6%) of commercial buildings in the Melbourne CBD sample have framed structures, with concrete framing preferred over steel. The remaining 39.4% of properties are of traditional load-bearing brickwork and/or stone construction. Using remote visual inspection and information from the database, this analysis concluded there was good potential for retrofit (on the basis of structural strength), with minimal structural changes required for most of the CBD buildings. It should be noted that a full structural appraisal (noted above) would be required on an individual building basis to determine structural suitability for retrofit.

The results in Table 5.1 show that, using this approach, 15% of the buildings were judged suitable for retrofit with green roof technology. A relatively low 4.8% of buildings were classed as ‘don’t know’, and a significant per-

centage (80.2%) were not considered suitable for retrofit based on the crite-

ria above – such as having pitched roofs, being overshadowed substantially

or with no access and so on.



### 5.3.2

### Newcastle-upon-Tyne, UK CBD Database

An analysis of the 507 commercially rateable buildings in three postcodes in

the Newcastle CBD was undertaken using similar characteristics as for

Melbourne. Slight differences in the availability of information within UK

databases and a different type of building stock meant the analysis empha-

sised different limitations.

The precise age of buildings was not available for all buildings in the

Newcastle database. However, a general picture emerges of a preponderance

of historic buildings, for example many are listed, with 30 grade 1 and 189

grade 2 listings. The centre of Newcastle is also designated with multiple

conservation areas. For the sample this encompassed 386 (76%) of the

buildings. Clearly the potential to retrofit listed buildings may be limited,

but it will be important to establish the feasibility of retrofitting on non-

listed buildings within the conservation area. Although the conservation

areas contain historic buildings, there is also significant amounts of more

modern development that is not listed, some constructed as recently as 2012.

There is very little potential for massive overshadowing from skyscrapers

in Newcastle as the tallest building in the database has 18 storeys. The

average number of storeys for the Newcastle sample is 4, and 98% of the

buildings would be regarded as low rise with only 2% of buildings identi-

fied as having 10 storeys or more. In Figure 5.6, buildings over 10 storeys

are grouped together.

When considering access and the need for disruption during retrofit and

maintenance, it was seen that nearly half of the buildings (47.3%) have

street access only, raising concerns about any extra disruption required

when retrofitting and maintaining the roofs. The properties in the Newcastle

CBD were predominantly bounded on two sides or more. This comprised

37.7% bounded on two sides, 30.8% bounded on three sides and 14%

bounded on four.

250

200

150

100

50

0

1

2

3

4

5

6

7

8

9

10

Frequency

8

47

102

217

58

20

11

4

1

10

Number of storeys

**Figure 5.6** Histogram of building heights in storeys for Newcastle study area.



Green Roof Retrofit

Construction type, as might be expected, was significantly related to the

age of buildings, with a shift over time from load-bearing masonry to framed

buildings. The visual inspection estimated that most buildings in the study

area are load-bearing brick or stone (80.7%), with 13.4% steel or concrete

frame construction, the rest indeterminate. There was also a strong correla-

tion between construction type, listing and conservation area (see Table 5.2).

This means that the majority of the steel or concrete-framed buildings are

outside the conservation area and not listed.

From visual inspection of roof pitch it appears that only 99 buildings have

the slight pitch most suitable for green roof retrofitting (see Table 5.3).

Among those with a slight pitch, about half are steel or concrete with the

other half load-bearing brick or stone. It is also apparent that roof pitch is

highly associated with the age of buildings. The majority of older buildings

have been constructed with a steep pitch considered unsuitable for green

roof retrofitting. Given the high correlation between historic listing and pitch,

it is not necessary to include historic listing separately in the assessment of

retrofit suitability for this sample in Newcastle.

Car parking is at a premium in the centre of Newcastle, and several large

roofs have parking on them. Examining the coverage of the roof by plant or

**Table 5.2** Cross tabulation of conservation area, construction type and historic listing Historic listing status

Grade 1

Grade 2

Not listed

Total

Inside conservation area

Load-bearing brick or stone

26

176

136

338

Steel or concrete frame

0

6

20

26

Unknown/other

4

4

14

22

Total

30

186

170

386

Outside conservation

Load-bearing brick or stone

3

68

71

area

Steel or concrete frame

0

42

42

Unknown/other

0

5

5

Total

3

115

118

Total

Load-bearing brick or stone

26

179

204

409

Steel or concrete frame

0

6

62

68

Unknown/other

4

4

19

27

Total

30

189

285

504

**Table 5.3** Cross tabulation of pitch and construction type for Newcastle study area Construction type

Load-bearing

Steel or

Unknown/

brick or stone

concrete frame

other

Total

Pitch of roof okay;

Yes

49

45

5

99

and building not

No

359

22

8

389

listed

Unknown

1

1

17

19

Total

409

68

30

507



car-parking spaces further reduces the potential space available for a green

roof retrofit, as shown in Table 5.4. Plant was naturally more common on

rooftops with low pitch (see Table 5.4), and using a cut-off point of 40%

plant reduces the number of suitable rooftops to 76, representing 15% of

the CBD buildings.

If construction type is also considered, there are 30 potential retrofit roof-

tops that could take extra heavy loading; including access and site bounda-

ries brings the number judged suitable down to only 20, as shown in

Table 5.5. Therefore, if intensive roofs were considered, the potential for

retrofit would be less than 4%.

**5.3.3**

**Melbourne and Newcastle Runoff Estimation**

526 office buildings were examined in the Melbourne CBD for their

potential for green roof retrofit, compared with 507 buildings in Newcastle.

The Melbourne stock ranged from 9 years to 161 years, with an average age

of 61 years, whereas no age data was available for the Newcastle stock.

76.13% was located in conservation areas, with 43.19% listed, which

suggests the Newcastle stock is older than the Melbourne stock. Melbourne

is a new city compared with Newcastle, and the CBD was laid out in a grid

formation by the military surveyor Robert Hoddle in 1837. Table 5.6 sum-

marises the main similarities and differences for the two databases.

For both cities, the majority of buildings were low rise; on average, three

storeys in Melbourne and four storeys in Newcastle. However, the distribu-

tion of taller buildings across the two locations was much more contrasted.

Melbourne had more potential for overshadowing from high-rise stock than

Newcastle, with buildings up to 66 storeys. The highest Newcastle building

was 18 storeys high. Melbourne stock was more likely to be concrete framed,

whereas load-bearing masonry construction predominated in the Newcastle

**Table 5.4** Roofs judged suitable for extensive green roof retrofit based on pitch, historic listing and percentage coverage by plant in the Newcastle study area

Frequency

Percentage

Suitable

76

15.0

Not suitable

410

80.9

Unknown

21

4.1

Total

507

100.0

**Table 5.5** Roofs potentially suitable for intensive green roof retrofit in the Newcastle study area Frequency

Percentage

Valid (%)

Valid

Yes

20

3.9

3.9

No

479

94.5

94.5

Unknown

8

1.6

1.6

Total

507

100.0

database. As reflects the grid-planned layout of Melbourne, the buildings

here were less likely to be attached to others compared with Newcastle, where

most buildings were attached to others on more than one side. The degree

of attachment of other buildings affects the ease of retrofit and access for

contractors and maintenance.

In summary, Melbourne buildings are more likely to be overshadowed

but are structurally more suited to green roof retrofitting. The Newcastle

stock is likely to have good exposure to sunlight but is less structurally

suited to retrofitting, especially with the heavier types of green roof design.

Despite these differences, both cities had 15% of their stock found suitable

for green roof retrofitting. To calculate the total potential average runoff

performance, the assumption is that 15% of rooftops will be suitable.

Runoff calculations were made based on three assumptions, as shown in

Table 5.7. The calculation takes into account the percentage of the CBD

**Table 5.6** Melbourne and Newcastle stock compared for green roof retrofit

Green roof criterion

Melbourne stock

Newcastle stock

Age

Newer

More listed and older stock

Height

Low rise

Low rise

Overshadowing

Higher levels

Lower levels

Construction type

More suited – more flat

Less suited – more pitched roof

concrete roofs

construction

Adjoining buildings and

Fewer attached to other

Most attached to other buildings

accessibility for retrofit

buildings

Percentage of roofs suited

15

15

**Table 5.7** Runoff calculations for Melbourne and Newcastle showing estimated percentage of total rainfall falling on the CBD managed by potential retrofit under three scenarios Assume suitable roof

Assume half of suitable

Assume all roof retrofit

retrofit

roof retrofit

Melbourne

Newcastle

Melbourne

Newcastle

Melbourne

Newcastle

Total study

2150.0

853.0

2150.0

853.0

2150.0

853.0

area (1000 m2)

Area of

1150.0

388.0

172.5

58.2

86.3

29.1

selected roof

(100%)

(15%)

(15%)

(7.5%)

(7.5%)

(1000 m2)

Percentage of

53%

45%

8%

7%

4%

3.5%

CBD covered

by selected

roofs

Runoff

32.1%

27.3%

4.8%

4.1%

2.4%

2.0%

reduction

roof (% of

total rainfall)1

1 Assume 60% runoff reduction over the area of the green roof.



area covered by roofs to estimate the reduction in total CBD rainfall that

may be intercepted by roofs. In the case of these two cities, the coverage by

roofs is 53% for Melbourne and 45% for Newcastle, slightly high in com-

parison with the 40–50% average mentioned by Stovin (2010), but within

expectations. It also assumes a runoff percentage reduction of 60% to represent

the average capture by a retrofit extensive green roof to those rooftop

spaces. The maximum runoff reduction achievable if all roofs are considered

suitable for retrofit is the first scenario. The second scenario assumes that all

of the roofs deemed suitable are retrofitted with green roofs and the third

scenario recognises that other constraints may prevent retrofit and that only

half of suitable roofs are retrofit.

According to the research findings, a 10% reduction in runoff to the

sewer system has the potential to prevent 90% of flood incidents (Gordon-

Walker *et al*., 2007). The analysis of retrofit potential summarised in

Table 5.7 indicates that the retrofitting of roofs to intercept stormwater

could be a significant mitigation factor for both Newcastle and Melbourne,

but that limitations on the availability of roofs deemed suitable for retrofit

has reduced the estimates significantly from the all-roof retrofit scenario.

Despite the limitations of the analysis in terms of simplifying assumptions to

deal with the city-wide spatial scale, the findings are revealing in that they

demonstrate the importance of the assessment of rooftop suitability because

it can make a sizeable difference to the estimates of potential. Without building-

characteristic assessment, cities may overestimate the benefits of a green

roof incentive programme. However, if assumptions for roof suitability are

relaxed, for example retrofitting roofs with higher pitch or specifying plants

that are tolerant of overshadowing, the potential for runoff reduction

changes. Therefore, the databases can be used in sensitivity analysis as a

basis for informed discussion to determine the parameters for any policy

drivers or technical improvements that may increase the potential for green

roof retrofit in a city. For the specific case studies of Newcastle and

Melbourne, these findings imply that further detailed feasibility studies and

modelling are warranted.

**5.4**

**Assessment of Retrofit at a Building Scale**

When considering retrofit at a building scale, different stakeholders become

involved, namely the building owners and occupiers. Lamond *et al*. (2014)

considered the motivation for building owners and occupiers to install green

roofs, deriving a conceptual model for distributed benefits (Figure 5.7). This

model reveals that, as for the local authority, the distribution of benefits is

much wider than the investor and, in this case, few of them affect the inves-

tor directly. In particular, the stormwater management benefits accrue to the

neighbourhood and perhaps beyond rather than to the property owner or

occupier. The cost of installing a green roof is, however, likely to be incurred

by the owner or occupier of the building (unless specific incentive schemes

exist). It follows that unless regulation is in place, or specific charges are

made for runoff, or discounts offered for a reduction of discharge into

100 Green Roof Retrofit

Wider society/

ecosystem

Reduced erosion/stream

Carbon/nitrogen

degradation

sequestration

Neighbourhood

Biodiversity

Water quality

/societal

beneficiaries

Reduced need for drainage

infrastructure

Aesthetic improvement

Amenity

Occupiers,

Air quality

(customers

Reduced UHI

of occupier)

Acoustic damping

Image of

Reduced

Increased

corporate social

Thermal buffering

maintenance

property value

responsibility

costs

Owners/

Peak flow/

Extended

investors

flood control

roof life

Easier planning

consent

**Figure 5.7** Conceptual model of distributed benefits of green roof technology from the perspective of owners and occupiers of commercial buildings.

*Source*: Lamond *et al*. (2014).

drainage networks, the stormwater features of green roofs do not benefit the

installer. For example, in Australia, green roofs are not recognised as a

feature that can be used in complying with development requirements for

runoff reduction.

The model posits that there are, however, additional reputational and

operational factors that affect the value of a commercial site to owners and

occupiers. The perceived wider societal benefits have the potential to feed

back into the value of a building and affect the owners or investors. The

installation of a green roof may, for example, be seen as socially responsible,

as it contributes to stormwater management. The benefit of this corporate

social responsibility may accrue to the owner and investor and also the occu-

pier in terms of reputational benefit, regardless of the actual performance of

the roof. It may be enhanced or reduced by accessibility, publicity and visibil-

ity of the roof, as well as any status applied through labelling and marketing.

In some instances, measureable direct benefits (such as reduced heating

and cooling costs) can offset the cost of green roof installation over time.

Therefore, at a building level it is highly important to estimate the multiple

benefits that may be offset against the cost of retrofit. This model suggests

that the business case for retrofit of green roofs must be predicated on the

consideration of multiple direct benefits, as well as recognising feedback

from wider societal and ecological beneficiaries. This kind of approach is

exemplified below by considering the work of the Bureau of Environmental

Services (BES) and others in Portland when developing and implementing

the Portland Ecoroof programme.



### 5.4.1

### Portland Ecoroof Programme

The Portland Ecoroof programme is one example of a city's effort to increase

the uptake of green infrastructure in order to manage stormwater. In

Portland, the incentive to improve stormwater management has been driven

by the level of nuisance flooding and the need to avoid overextending the

municipal drainage and water treatment facilities while improving water

quality in the Williamette River through greater infiltration. In their 2008

study (Bureau of Environmental Services – City of Portland, 2008), the BES

evaluated the city-wide benefits of extensive green roof retrofit but also

recognised the difference between private and public benefits of stormwater

and other multiple benefits of vegetated roofs.

Using estimates of the cost to the city of managing stormwater, the study

estimated that a discount of 35% on stormwater fees could be offered to

owners that effectively reduced the impervious area on their site via instal-

lation of an Ecoroof. At 2008 rates this would generate a saving of $2.77/

sq. ft of roof. For a 40,000 sq. ft roof this could result in a monthly saving

of $110.74 (Bureau of Environmental Services – City of Portland, 2008).

Monitoring of two specific buildings that had been retrofitted with green

roofs was also carried out by Bureau staff (Kurtz, 2010), finding higher

average performances than predicted by benefits transfer estimates, with

precipitation retention being calculated at 69% on average and almost

100% during dry-period storm events.

Recognising the need to understand the multiple benefits, the Bureau also

estimated other owner benefits such as those identified in the conceptual

model above. Reduced heating and cooling costs were calculated based on

an average R-valued building being converted to a rye grass green roof. The

resulting improvement in thermal efficiency could save 0.156 kWh annually

per square foot, making the 40,000 sq. ft roof amass a saving of 6240 kWh.

Studies suggest that a green roof can extend the life of the roof membrane

from 20 to 40 years, saving the cost of one replacement out of two. The

Bureau estimated this as a saving of $600,000 and a saving of $21,000 on

HVAC equipment over 20 years. The findings from the study are summarised

in Table 5.8, and show that over 40 years the private owner has a net benefit

from the factors considered but that over a 5-year timeframe the installation

is not cost beneficial.

Amenity/aesthetics of green roofs was assessed by a follow-up study

(Entrix, 2010) and found to depend on the level of access or visibility of the

green roof. The well-publicised green roof atop the Multnomah building, for

example, provides public access for visitors, educative displays and is visible

to several neighbouring buildings. However, for the property owner the most

relevant question may relate to increased rental potential. Rental uplift from

green roof installation has not been widely measured in the commercial prop-

erty market, but many authors suggest that the recreational amenity value of

a green roof can be extrapolated from values for landscaping or parks and

could represent massive capital uplifts on large CBD offices if predicated on

a 7% increase in rental value (Clements *et al*., 2013). However, if a city-wide programme is successful, it may be argued that the differential benefit of

**Table 5.8** Summary of Ecoroof costs and benefits for private owner/investor

Costs

Benefits

Summary

One-time

Annual

One-time

Annual

5-year

40-year

Focus area

($)

($)

($)

($)

(2008$)

(2008$)

Stormwater management

1,330

6,992

45,866

volume reduction

Cooling energy reduction

680

3,424

19,983

Heating energy reduction

800

4,028

23,509

Construction cost

230,000

(230,000)

(230,000)

Avoided stormwater costs

69,000

69,000

69,000

Increased operation/

600

(3,077)

(20,677)

maintenance costs

Roof longevity

600,000

474,951

HVAC sizing

21,000

21,000

21,000

Total

230,000

600

690,000

2,810

(128,803)

403,632

*Source*: Adapted from BES (2008).

having a green roof would be much lower than 7%. More research into this

is warranted, because of the potential incentive such benefits could provide.

## 5.5

## Conclusions – Where to Next?

This chapter has described recent research towards assessing the contribu-

tion of green roof retrofit to attenuating stormwater runoff as a means of

mitigating pluvial flooding within the CBD. The challenges posed by pluvial

or surface-water flooding have been identified and characterised by their

unpredictability, sudden onset and high velocity; the frequency of pluvial

flooding is likely to increase in the future due to changes in weather patterns

caused by a warming climate and the concentration of impermeable surfaces

in cities caused by urban densification. The disruption and damage caused

by pluvial flooding in the CBD have been highlighted, including the direct

damage to buildings and contents caused by floodwater as well as the long-

term impact on local communities and economies.

One study reported the development of a novel methodology to estimate

the potential benefits of green roof retrofit. The methodology developed

uses a desk-based approach to the development of a database of buildings,

Google maps to gauge the suitability of existing buildings for green roof

retrofit and the latest green roof stormwater attenuation modelling to establish

the potential impacts and benefits of a green roof retrofit at a city scale.

The methodology is not without its limitations, but this study has demon-

strated the benefits of such an approach.

The two contrasting cities selected for this research (Newcastle, UK and

Melbourne, Australia) have been described, and their vulnerability to severe

pluvial flood events has been observed. The two cities have contrasting build-

ing stocks in the CBD, with Newcastle being characterised by generally older,

low-rise buildings, many of historic importance within conservation areas,

albeit with some more modern developments. By contrast, the building stock



in Melbourne is more modern, with an average age of 61 years and being of

frame construction. Other considerations – such as the orientation of build-

ings, roof pitch, access for installation and maintenance purposes and the

shadowing caused by neighbouring buildings – have also been highlighted

as factors that might make buildings unsuitable for green roof retrofit.

Despite these contrasts, it was observed that approximately 15% of the

existing building stock in both Melbourne and Newcastle was regarded as

suitable for green roof retrofit.

A conceptual model of the distributed benefits of green roof technology

has highlighted the direct and indirect benefits to owners and occupiers of

commercial buildings. The model recognises that the measurable direct ben-

efits may not be sufficiently attractive (i.e., in financial terms) to convince

property owners to commit to green roof retrofit. However, the multiple

direct benefits – including those to wider societal and ecological beneficiar-

ies – are likely to provide a compelling case. Further research into the impact

on property values in response to pro-environmental behaviour and com-

pany reputation is needed, so that suitable incentives and other interven-

tions that would support such adaptations can be called for.

The findings indicate that retrofit could be a significant mitigating factor

for both Newcastle and Melbourne if high levels of retrofit could be

achieved. However, achieving this high level will be challenging unless ways

can be found to render more buildings suitable for retrofit – for example,

careful choice of planting that can survive overshadowing.

The chapter draws on lessons from the Portland Ecoroof programme in

the USA, as a good-practice example of how a city's efforts to increase the

uptake of green infrastructure can be effectively implemented. The Portland

Ecoroof programme highlighted the multiple benefits afforded by green roof

retrofit, including reduced heating and cooling costs and the savings pro-

vided by extending the life of the roof membrane from 20 to 40 years.

The work discussed in this chapter highlights that the benefits of retrofit

at the individual building scale are unlikely to be suitably attractive to con-

vince building owners and occupiers to invest in green roof retrofit, unless

specific incentive schemes exist or more compelling evidence of indirect ben-

efits is generated. It is posited here that there exist perceived wider social

benefits (such as corporate social responsibility and potential reputational

gains) that could be attractive to owners and occupiers. That is, the model

suggests that the business case for retrofit of green roofs must be predicated

on the consideration of multiple direct benefits, as well as recognising the

wider societal and ecological benefits.

**References**

Abbott, J., Davies, P., Simkins, P., Morgan, C., Levin, D. and Robinson, P. (2013)

*Creating Water Sensitive Places – Scoping the Potential for Water Sensitive Urban*

*Design in the UK*. CIRIA: London.

Bhattacharya-Mis, N., Joseph, R., Proverbs, D. and Lamond, J. (2015) 'Grass-root

preparedness against potential flood risk among residential and commercial prop-

erty holders', *International Journal of Disaster Resilience in the Built Environment*, 6, 44–56.

104 Green Roof Retrofit

BMG Research (2011) *Cumbria Business Survey 2010*. Cumbria Intelligence

Observatory.

Bureau of Environmental Services – City of Portland (2008) *Cost Benefit Evaluation of Ecoroofs 2008*. City of Portland, Portland, OR.

Bureau of Meteorology (Australia) (undated) *Melbourne Metropolitan Area and*

*Environs in March 2010*. Available at: www.bom.gov.au/climate/current/month/

vic/archive/201003.melbourne.shtml#records RainTtlRecenthigh.

Charlesworth, S. M. and Warwick, F. (2011) 'Adapting to and mitigating floods using

sustainable urban drainage systems'. In Lamond, J., Booth, C., Hammond, F.

and Proverbs, D. (eds), *Flood Hazards: Impacts and Responses for the Built*

*Environment*. CRC/Taylor & Francis: Boca Raton, FL; pp. 207–234.

City of Melbourne (2015) http://www.melbourne.vic.gov.au/about-council/vision-

goals/eco-city/pages/adapting-to-climate-change.aspx.

City of San Francisco (2010) *San Francisco Stormwater Design Guidelines: Appendix A*: *BMP Factsheets*. San Francisco: City of San Francisco, Public Utilities Commission, Port of San Francisco.

Clements, J., St. Juliana, A., Davis, P. and Levine, L. (2013) *The Green Edge: How Commercial Property Investment in Green Infrastructure Creates Value*. Natural

Resources Defense Council: New York.

Entrix (2010) *Portland's Green Infrastructure: Quantifying the Health, Energy, and Community Livability Benefits*. City of Portland, Bureau of Environmental

Services, Portland, OR.

Environment Agency – Yorkshire & North East Region (2012) *Hydrology of the*

*Tyneside*, June 2012 Flood Environment Agency.

Environment Agency (2013) *Flooding in England – A National Assessment of Flood Risk* Environment Agency: Bristol.

Fioretti, R., Palla, A., Lanza, L. G. and Principi, P. (2010) 'Green roof energy and water related performance in the Mediterranean climate',

*Building and Environment*, 45, 1890–1904.

French, L., Samwinga, V. and Proverbs, D. (2011) 'The UK sewer network: percep-

tions of its condition and role in flood risk'. In Lamond, J. E., Proverbs, D. G.,

Booth, C. A. and Hammond, F. N. (eds), *Flood Hazards, Impacts and Responses*

*for the Built Environment*. CRC/Taylor & Francis: Boca Raton, FL.

Gordon-Walker, S., Harle, T. and Naismith, I. (2007) *Cost–Benefit of SUDS Retrofit in Urban Areas*. Science Report No. SC060024. Environment Agency: Bristol.

Groundwork (2011) *Green Roof Developer's Guide*. Groundwork: Sheffield.

Ingirige, B. and Wedawatta, G. (2011) 'Impacts of flood hazard on small and medium sized companies strategies for property level protection and business continuity'. In Lamond, J. E., Proverbs, D. G., Booth, C. A. and Hammond, F. N. (eds), *Flood Hazards, Impacts and Responses for the Built Environment*. CRC/Taylor & Francis: Boca Raton, FL.

Jha, A., Lamond, J., Bloch, R., *et al*. (2011) *'Five feet high and rising – cities and flooding in the 21st century*'. Policy Research Working Paper No. 5648. The World Bank: Washington, D.C.

Kincaid, D. (2003) *Adapting Buildings for Changing Uses: Guidelines for change of*

*use refurbishment*. Routledge: London.

Kurtz, T. (2010) 'Ecoroof performance monitoring in Portland, Oregon', 2010

International Low Impact Development Conference – Redefining Water in the City,

11–14 April. American Society of Civil Engineers: San Francisco, CA; pp. 1234–1246.

Lamond, J. E., Wilkinson, S. and Rose, C. (2014) ‘Conceptualising the benefits of

green roof technology for commercial real estate owners and occupiers’. *Resilient*

*Communities: Providing for the Future. 20th Annual Pacific Rim Real Estate*

*Conference (PRRES)*: Christchurch, New Zealand.

Stormwater Attenuation and Green Roof Retrofit 105

Lawson, E., Thorne, C., Ahilan, S., *et al*. (2014) *Delivering and Evaluating the Multiple Flood Risk Benefits in Blue–Green Cities: An Interdisciplinary Approach*.

Flood Recovery Innovation and Response IV. WIT Press: Southampton.

Ma, L., Qin, B. and Zuo, C. (2012) ‘Performance of urban rainwater retention by

green roof: a case study of Jinan’, 2nd International Conference on Civil

Engineering, Architecture and Building Materials (CEABM 2012), 25–27 May.

Trans Tech Publications: Yantai, China; pp. 295–299.

MacIvor, J. S. and Lundholm, J. (2011) ‘Performance evaluation of native plants

suited to extensive green roof conditions in a maritime climate', *Ecological*

*Engineering*, 37, 407–417.

Mentens, J., Raes, D. and Hermy, M. (2006) 'Green roofs as a tool for solving the

rainwater runoff problem in the urbanized 21st century?', *Landscape and Urban*

*Planning*, 77, 217–226.

Met Office Hadley Centre for Climate Research (2007) *Climate Research at the Met*

*Office Hadley Centre – Informing Government Policy into the Future*. Available

at: www.metoffice.gov.uk/research/hadleycentre/pubs/brochures/clim_res_had_

fut_pol.pdf.

Nagase, A. and Dunnett, N. (2012) 'Amount of water runoff from different vegeta-

tion types on extensive green roofs: effects of plant species, diversity and plant

structure', *Landscape and Urban Planning*, 104, 356–363.

News.com (2011) 'Severe storms, flash floods hit Melbourne and parts of Victoria'.

Available at: www.news.com.au/national/storm-to-move-south-and-soak- victoria/

storye6frfkvr-1226000442820.

Rose, C. and Lamond, J. (2013) ‘Performance of sustainable drainage for urban

flood control, lessons from Europe and Asia’, International Conference on Flood

Resilience: Experiences in Asia and Europe, 5–7 September, Exeter, UK.

Solomon, S. and Qin, D. (2007) *Climate Change 2007: The Physical Science Basis*.

Contribution of Working Group 1 to the Fourth Assessment Report of the Inter-

governmental Panel on Climate Change. Cambridge University Press: Cambridge.

Stovin, V. (2010) ‘The potential of green roofs to manage urban stormwater’, *Water and Environment Journal*, 24, 192–199.

Total Research and Technical Services Newcastle City Council (2013) *Summer 2012*

*Flooding in Newcastle-upon-Tyne*. A report on the experiences of residents and

non-residential property managers. Newcastle City Council: Newcastle-upon-Tyne.

Wedawatta, G., Ingirige, B., Jones, K. and Proverbs, D. (2011) ‘Extreme weather

events and construction SMEs: vulnerability, impacts and responses’, *Structural*

*Survey*, 29, 106–119.

White, I. and Howe, J. (2002) ‘Flooding and the role of planning in England and

Wales: a critical review’, *Journal of Environmental Planning and Management*, 45, 735–745.

Wilkinson, S. J. (2014) ‘The preliminary assessment of adaptation potential in exist-

ing office buildings’, *International Journal of Strategic Property Management*, 18(1), 77–87.

Wilkinson, S. J. and Reed, R. (2009) ‘Green roof retrofit potential in the central

business district’, *Property Management*, 27, 284–301.

Wilkinson, S. J., Reed, R. and James, K. (2009) ‘Using building adaptation to deliver

sustainability in Australia’, *Structural Survey*, 27, 46–61.

Williams, N. S., Raynor, J. P. and Raynor, K. J. (2010) ‘Green roofs for a wide brown

land: opportunities and barriers for rooftop greening in Australia’, *Urban Forestry and Urban Greening*, 9, 245–251.

**16**

## Biodiversity and Green Roof Retrofit

**Tanya Latty**

University of Sydney, Australia

### 6.0 Introduction

The conversion of pristine habitat and agricultural lands into urbanised

landscapes is increasing. By 2030, 60% of the population is expected to be

living within a city (Ksiazek *et al*., 2014). It is clear that the explosive

growth of cities has had tremendous effects on animal life; indeed, urbani-

sation is recognised as a leading threatening process to global biodiversity

(deGroot *et al*., 2010). Although there are many indirect effects (e.g., the

heat island effect, introduction of non-native species, changes to soils and

biogeochemical cycles; Kowarik, 2011), the major consequence of urbani-

sation is the conversion of continuous native vegetation into a patchwork

of habitats interspersed with a matrix of impervious surfaces (pavement

and buildings) and grassy lawns (McGuire *et al*., 2013). As the urbanisation

process progresses, some habitats are lost entirely, while the remaining

habitats are fragmented. Habitat fragmentation acts to isolate individual

habitat patches, thereby isolating organisms with limited mobility and

eliminating species that require large patches of habitat. Urbanisation also

decreases the structural complexity of vegetation, since landscaping typi-

cally involves the removal of shrubs and woody debris. The formerly com-

plex vegetation is then replaced with simpler grasses and forbs. Since the

biodiversity of many animal groups is positively correlated with vegetation

complexity (e.g., see Langellotto and Denno, 2004), habitat simplification

can lead to declines in biodiversity.

Although urbanisation generally leads to declines in biodiversity, cities are

also able to support high numbers of particular species. These animals

(‘urban adaptors’) possess behaviours or physiological adaptations that

allow them to thrive in urban environments; pigeons, the Australian white

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.

Ibis and some cockroach species are excellent examples. The role of urban

green spaces in protecting and conserving biodiversity is increasingly being

recognised by ecologists and urban planners (Ishimatsu and Ito, 2013). For

example, the City of Sydney has an Urban Ecology Action Plan designed to

enhance and protect biodiversity within its heavily urbanised city core

(Sydney, 2014b). In many developed countries, there are initiatives aimed at

increasing biodiversity in urban gardens (Goddard *et al*., 2010). In the USA,

for example, the National Wildlife Federation (www.nwf.org/) grants

'Certified Wildlife Habitat' status to homeowners who can demonstrate that

their yard provides five key habitat elements: the provision of food, the

provision of water, the provision of cover, places to raise young, and the use

of no or low-chemical sustainable gardening techniques, including the use of

native plants.

Arguably, the most effective way to mitigate habitat loss and fragmentation

is to increase the number of native vegetation patches within cities. In most

cases this is logistically infeasible, as competing land uses often preclude the

conversion of commercial or residential spaces into parklands. The urbani-

sation process is therefore difficult to reverse; for example, due to land

values and ownership patterns, apartment blocks are rarely replaced with

parks, and shopping centres rarely give way to native meadows. Green

roofs, and retrofitted green roofs, offer a potential solution to the dilemma

of urban biodiversity by converting otherwise unused roof space into habitat

for native species. At the same time, these habitat patches can increase

habitat connectivity, thus providing a potential antidote to habitat fragmen-

tation. Finally, the relative inaccessibility of green roofs might create havens

where species can grow and multiply undisturbed by human activity.

The exciting potential of green roofs has already led some municipal

governments to include them in their biodiversity plans. For example, the

cities of Toronto (Canada) and Basel (Switzerland) have published guide-

lines for enhancing biodiversity on green roofs (Toronto, 2013; Gunnarsson

and Federsel, 2014).

Although the potential biodiversity benefits of green roofs are exciting,

some scepticism is warranted because there are several important factors

which might make green roofs unsuitable for the conservation of biodiversity.

First, green roofs are generally small, so they are unable to support animals

that have larger range requirements (most mammals). As such, the habitat

provision benefit of green roofs is probably limited to small animals like

insects and other arthropods. Second, green roofs tend to be spatially isolated

and are inaccessible to all but the most mobile of animals. Third, green roofs

provide a very harsh environment, with higher temperatures and higher wind

velocities than ground-level habitats. Thus, they are unsuited for many species.

Given these potential difficulties, what role can retrofitted and new green

roofs play in the conservation of animal biodiversity? This chapter will review

current literature on the effectiveness of green roofs as tools for supporting

urban biodiversity, starting with a brief introduction to the concept and

measurement of biodiversity. The chapter will discuss research focused on the

impact of green roofs on vertebrate and invertebrate biodiversity, and will

conclude with recommendations for supporting biodiversity on green roofs.



## 6.1

## What is Biodiversity?

Enhancing or creating biodiversity is often cited as an objective of building

a green roof retrofit: but what does ‘biodiversity’ actually mean? How is it

measured? Biologists generally describe three kinds of biodiversity (Box 6.1),

of which ‘species diversity’ is the type most applicable to green roofs. When

designing a biodiverse green roof, it is worth considering exactly what kind

**Box 6.1 Biological Diversity**

Biologists delineate three distinct types of biodiversity: species diversity,

genetic diversity and ecological diversity. ***Species diversity*** is the most relevant for green roofs, as it refers to the species within an area. It is commonly

assessed as ‘species richness’, which is simply the total number of species

within a given area. Species richness does not take into account the number

of representatives of each species; thus, a region with 1000 individuals of

species A and only 1 representative of species B would have the same rich-

ness (2) as would a site that had 50 individuals of species A and 50 individu-

als of species B. Ecologists use a measure called ‘ *species evenness*’ to account for the different sizes of species populations. Communities where the number of individuals in each species is similar (our second example) are scored

as being more ‘even’ than communities in which there is a big difference in

the population sizes of the species present. Other indices, such as the Shannon

index, take into account both the number of species and the evenness of the

sample.

***Genetic diversity*** refers to the amount of genetic variation within a particular species. Species with low genetic diversity often suffer from an inability to

adapt to changing environments. Other effects, such as reduced reproduction

due to inbreeding depression, can also have serious negative consequences for

populations. Habitat fragmentation tends to decrease genetic diversity by

isolating populations, which then have no choice but to mate amongst them-

selves. This can be mitigated to some extent by providing corridors that allow

individuals to move from one fragment to another. The potential of green roofs

to increase genetic diversity has not been explored directly, although a recent

study (which will be discussed in detail later in this chapter) found that green

roofs can act as ‘corridors in the sky’, effectively linking otherwise isolated

populations (Dunnett, 2006).

***Ecosystem diversity*** refers to the number of ecosystems in an area, and at first appears to be irrelevant to the study of green roofs. However, green roofs tend

to have higher temperature and lower rainfall than ground-level sites; as a

consequence, green roofs might support ecosystems quite different from the

ecosystems present at ground level. For example, the presence of green roofs

could result in the co-existence of Mediterranean-type ecosystems on roofs and

temperate ecosystems at ground level. Green roofs could therefore have the

potential to increase ecosystem diversity.



of biodiversity we are hoping to enhance or increase. It is also important to

clearly define a reference habitat, so that the success of the green roof can be

assessed. For example, one might build a green roof with the goal of

increasing the total number of species (‘species richness’) that live on the

roof, relative to the surrounding area. Alternatively, we may wish to target

species of particular conservation concern, such as an endangered bird.

In that case, the appropriate measure of biodiversity might be the number of

chicks that successfully fledge from the green roof relative to the fledging

success of birds nesting on the ground.

A second consideration, often overlooked, is to determine the taxonomic

level of biodiversity that is being targeted. Are we interested only in bird

species? Soil-dwelling species? Bee species? While many green roof strategies

aim towards ‘biodiversity’, in practise, collecting and identifying all the species

present in a given area is a massive and logistically infeasible task. Different

groups, for example, require very different sampling regimes. Identifying bird

and mammal species can usually be done by non-specialists, while identifying

invertebrates such as insects generally requires extensive training. Indeed,

some species of insect are indistinguishable from one another without the use

of microscopes or even dissections. Finally, as we will discuss below, different

animal groups have different requirements, and so the techniques used to

encourage biodiversity need to reflect the target group.

## 6.2

## Green Roofs for Vertebrate Conservation

Attempts to increase vertebrate biodiversity typically target birds and/or

bats (with birds reviewed in Fernandez-Canero and Gonzalez-Redondo,

2010). This makes sense, since the inaccessibility of rooftops suggests that

only highly mobile winged species will be able to access them. Vertebrates

are relatively large, and it is unlikely that a single green roof can provide all

necessary resources for them. For example, a bat needs not only food

resources, but also adequate nest sites and access to water; all of these

resources must be within the animal's flight range. Thus, green roofs usually

support vertebrates by providing one or a few critical resources.

One of the simplest ways a green roof can support vertebrate fauna is by

providing food. As we will see later in this chapter, green roofs can serve as

a habitat for invertebrates, which may in turn attract predatory birds and

bats. Seeds, berries, nectar and other plant matter can also provide food

resources for birds (Fernandez-Canero and Gonzalez-Redondo, 2010).

Pearce and Walters (2012) investigated the value of conventional roofs and

two types of green roofs (biodiverse and sedum based) on the feeding

behaviour of bats in Greater London (UK). Three bat species were recorded

feeding over biodiverse roofs, and their feeding activity was significantly

greater than over conventional or sedum roofs. While there are reports of

birds feeding on or around green roofs (Fernandez-Canero and Gonzalez-

Redondo, 2010), surprisingly few peer-reviewed studies have explicitly

tested the hypothesis that green roofs can provide valuable food resources

for vertebrates.

110 Green Roof Retrofit

The idea that green roofs might provide nesting sites for birds has been

investigated by Baumann (2006), who found that Northern Lapwings, an

endangered species, used rooftop gardens as nesting sites. They found

evidence of old nesting sites, suggesting that the lapwings had been using the

rooftops over multiple seasons. However, in 2005 and 2006, not one of the

broods was successful. In most cases chicks hatched, but later died.

Improvements to the roof's vegetation improved chick life expectancy,

although no chicks survived to adulthood. This study raises the important

point that simply observing the presence of a species on a green roof does

not mean that the green roof is necessarily benefiting the animal in question.

In some cases green roofs may act as 'ecological traps', diverting wildlife

away from appropriate habitat into habitat that cannot support it. It is

absolutely crucial that studies investigating the biodiversity value of green

roofs do not stop at simply observing the presence of key species, but that

they also investigate the eventual reproductive success of individuals using

the habitat relative to those using other urban habitats.

To date, the available evidence on the conservation value of green roofs to

vertebrates is mixed at best. At least some literature suggests we should be

cautious about assuming that the creation of habitat will necessarily have a

positive influence on species. In addition, none of the studies to date have

actually assessed biodiversity per se; in all cases, the authors were interested

in measuring the abundance of only one or a few vertebrate species, with no

real attempt to quantify species richness. One could argue that, since each

free-living vertebrate probably harbours a multitude of parasites – both

internal and external – anything that benefits a single species necessarily

benefits a veritable universe of species. However, the fact that we have not

yet quantified vertebrate species richness on green roofs means that we still

know very little about the actual role green roofs play in conserving biodi-

versity. The studies above focus primarily on birds, but there has been at

least one effort to create green roofs for reptiles. For example, deGroot *et al*.

(2010) investigated the potential of green roofs as habitat for an endemic

New Zealand skink species. While they found that the roofs would likely

meet the skinks' habitat requirements, no experiments that test the survivor-

ship and reproduction of skinks on rooftop habitats have yet been reported.

## 6.3

## Green Roofs for Invertebrate Conservation

Invertebrate animals such as insects are generally much smaller than

vertebrates; as such, it is possible for all of their habitat needs to be met on

a single green roof. In addition, many invertebrate taxa are highly mobile

and so can access spatially isolated roofs. Insects, for example, often have

wings, which allow them to travel large distances. Despite lacking wings,

spiderlings can ‘fly’ by ballooning along on a fine piece of silk. Green roofs

therefore have great potential in the conservation of invertebrate taxa.

Several studies have reported the presence of large numbers of invertebrates

on green roofs. Nagase and Nomura (2014) reported 46 invertebrate species

representing 11 different orders on a green roof in Japan, while other



research identified 26 bee species on 7 green roofs in Chicago (Ksiazek *et al*., 2014). Kadas (2006) found that 10% of the species captured on green roofs

had received the designation ‘nationally rare or scarce’, suggesting that green

roofs can serve as refuges for threatened invertebrate taxa. Interestingly, a

large proportion (50%) of the invertebrates captured were snails; this is

surprising, as snails are not particularly mobile and would not be amongst

the taxa normally expected to rapidly colonise rooftops. However, Kadas

(2006) points out that snails are abundant on the farms where green roof

plants are grown, and so they may have ‘hitch hiked’ in on the vegetation.

Once established, it is likely that snail populations expanded due to the

absence of mammalian predators. Thus, it is worth remembering that the

ecosystems which emerge on green roofs can include not only high-mobility

animals, but also those capable of ‘hitch hiking’ on plants or other animals.

It is clear that green roofs are capable of supporting large numbers of

invertebrates. But how does the biodiversity of green roofs compare with

similarly sized ground-level sites? MacIvor (2011) found no difference

between the number of species or the number of individual insects found on

green roofs compared with ground-level sites. Tonietto *et al*. (2011), however, found that while many native bee species were present on green roofs, the

number of individuals and the number of bee species was lower than observed

in traditional parks, or in areas of remnant tall grass prairie. Similarly,

Ksiazek *et al*. (2014) found fewer individuals and species on green roofs

compared with ground-level sites. Based on this small number of studies, it

appears that green roofs usually contain less biodiversity than ground-level

sites, although there are exceptions. Care must therefore be taken when

assuming that rooftop sites can simply replace equivalent ground-level sites.

The specific composition of green roofs has a strong effect on invertebrate

biodiversity. In general, invertebrate diversity increases with increasing veg-

etation complexity; the same appears to be true on green roofs. Madre *et al*.

(2013) found that green roofs with the most structurally complex vegetation

had the highest arthropod abundance. Similarly, Schindler *et al*. (2011)

found a positive relationship between arthropod abundance and vegetation

cover; indeed, vegetation cover was more important than plant diversity.

Planting a variety of structurally complex plants is therefore a good strategy

for maximising biodiversity on green roofs.

There is evidence that the hot, dry environment on green roofs favours

species that are pre-adapted to similarly arid conditions. It has been

suggested that urban environments favour cliff-dwelling species, which

are already adapted to life on hot, rocky surfaces (Lundholm, 2006).

For example, Madre (2013) noted an abundance of dry, heat-loving

species on green roofs, while Rumble and Gange (2013) noted that the

soil microarthropod community of green roofs was dominated by heat

and drought-tolerant species. Moisture-sensitive species such as annelids

and millipedes were completely absent.

In addition to increasing the number of species in the urban environment,

green roofs can act as ‘stepping stones’ connecting distant areas together

and increasing the ‘permeability’ of the city (Braaker *et al*., 2013). Small-

bodied bee species, for example, are typically restricted to flight ranges of



less than 500 m. Both the nesting site and all flower resources must be

located within this 500 m radius. If areas of habitat are isolated, then the

offspring of our hypothetical small bee will not disperse across the land-

scape; they will be limited to the 500 m radius of their forefathers, leading to

inbreeding. However, if habitat patches are connected, perhaps by green

roofs, then dispersing offspring can hop to a new patch. Over time, this

allows for increasing ranges and, more importantly, connects isolated

populations. This connectivity is crucial for conservation as well-connected

populations are thought to be more resilient to disturbance, since areas can

be recolonised after local extinction events (Braaker *et al*., 2013). The ben-

efits of better connectivity extend to the plants pollinated by insects, as these

will now have access to a pollinator whose range may have previously been

restricted by lack of connectivity.

## 6.4 Conclusions

The study of green roofs as habitat is in its infancy, and as yet there are too few

studies from which to draw strong conclusions. As Williams *et al*. (2014) point out in their excellent review, there is still a tremendous paucity of data about

the impact of green roofs on biodiversity. In particular, more studies that com-

pare green roofs to ground sites are needed. It is not enough to simply observe

that certain species are present on green roofs; we need to know the extent to

which green roofs contribute to urban biodiversity compared with other types

of urban green space. There seems to be little evidence that green roofs outper-

form ground-level sites in terms of biodiversity (Williams *et al*., 2014). This is not surprising, given that the harsh conditions and general inaccessibility of

green roofs probably act as a ‘filter’, screening for species that are capable of

colonising and surviving in these novel environments. Future research would

do well to study the filter effect in greater detail. Few studies have examined

the dynamics of green roof communities, so we have little understanding of

how green roof ecosystems change over time. Some work in this direction has

already occurred. For example, Schrader and Böning (2006) found slightly

higher collembolan (small soil-dwelling arthropods) diversity on older green

roofs than on younger green roofs, and observed that older roofs had more

stable environments due to the formation of mature soils.

Although vertebrate conservation is typically better funded than inverte-

brate conservation, the evidence for a strong role of green roofs in increasing

vertebrate biodiversity is weak. While green roofs can provide some resources

(i.e., insects as food for bats and birds), there is currently no evidence that they

provide high-quality breeding habitats. Indeed, studies which show breeding

failure in roof-breeding birds serve as a strong caution against assuming that

the provision of habitat will necessarily increase abundance or biodiversity.

Future research will need to determine if roofs purposely built to fulfil the

needs of particular vertebrate species are capable of supporting appreciable

populations, and importantly, whether these sites are equivalent or superior to

ground-level conservation efforts. Given the aridity of roof-top gardens, a

useful approach might be to focus on vertebrates from similar habitats.

Biodiversity and Green Roof Retrofit 113

Invertebrates are typically overlooked in conservation efforts, despite the

fact that they make up 98% of animal life and are absolutely crucial in

the provision of many ecosystem services such as pollination. In addition,

building green roofs that have greater invertebrate biodiversity can increase

the amount of food available for vertebrates. Supporting insect pollinators

can in turn have positive effects on plant diversity. Indeed, it is suggested

that in terms of maximising conservation value, green roof designers would

do well to focus on providing pollinator habitat. Pollinators are ecologically

important, well loved by the public and highly mobile. Studies that have

investigated bees and insects on rooftops suggest that many species are able

to use green roofs as habitat, and their ability to fly might allow green roofs

to serve as ecological corridors in the sky, connecting otherwise disconnected

pieces of habitat together.

At present, the study of green roof biodiversity suffers from a lack of

methodological consistency. Studies use vastly different trapping regimes

(from pitfall traps, to intercept traps, to pan traps, to direct observations).

This has a tremendous impact on the results and makes comparisons

between studies difficult. It is therefore important that green roof researchers

adopt some of the standard assessment protocols that have been developed

for particular groups. For example, there is an established, widely used

protocol for sampling bees (Bee Inventory Protocol; Droege *et al*., 2003).

Invertebrate-focused studies vary tremendously in their degree of taxonomic

resolution, with some studies identifying insects to species, several only

identifying to order, and others simply using ‘morpho-species’ to refer to

groups of individuals that look different from one another and are thought

to be members of the same species. This is hugely problematic, as each insect

order, for example, can contain upwards of 100,000 species, each with

differing ecology. In none of the papers referenced here did the authors

mention the existence of a reference collection. The deposition of a reference

collection, which contains examples of all the insects collected during a

project, is a standard practice in insect ecology. Reference collections ensure

that identifications can be double-checked by other researchers. Invertebrates

are notoriously difficult to identify, with specialist help often being required.

Since the number of trained insect taxonomists is declining rapidly, it is not

surprising that most studies struggled with their identifications. Nevertheless,

correct identification is absolutely crucial to understanding how green roofs

effect invertebrate diversity. Therefore, future researchers need to collaborate

with university or museum-based taxonomists who can help ensure that

identifications are correct.

### 6.4.1

### Designing Biodiverse Green Roofs

How do we go about increasing the biodiversity value of green roofs

(Appendix 2)? As we have seen throughout this chapter, greater vegetative

complexity equals more species in greater abundance. This is unsurprising,

given that research from ground-level sites consistently shows a strong pos-

itive relationship between vegetation complexity and biodiversity. Greater



complexity means more niches, and this leads to greater diversity. For

pollinators, ensuring a diversity of floral resources with differing flowering

times is likely key to increasing diversity. Different plants provide different

insects with different resources. For example, some flowering plants serve as

excellent nectar sources; many animals – including wasps, beetles, bees,

butterflies and some birds – use nectar as a source of carbohydrates. Other

plants provide nutritious pollen, which is a source of protein for animals

including bees, beetles, flies and butterflies. Planting a mixture of nectar and

pollen-producing plants helps to ensure that the food requirements of a

larger variety of animals are met. Along similar lines, planting flowers that

have different flowering periods ensures a continuous supply of pollen and

nectar throughout the season.

In addition to vegetative complexity, we should also consider diversity in

both the substrate and the topology of green roofs. Large rocks can provide

shelter for a variety of invertebrates, while altering stone sizes can create an

array of different microclimates for soil-dwelling microarthropods. Small

piles of sticks, wood and pine cones can add structural complexity and pro-

vide homes for more invertebrate species. In addition, adding small slopes,

hills and piles can change the microhydrology of the site, creating areas of

varying moisture. Recently, many ground-level gardens have started using

‘insect hotels’ to boost invertebrate diversity by providing nesting sites, pri-

marily for bees and wasps. Insect hotels typically consist of combinations of

drilled wood blocks, hollow reeds and clay blocks. The ability of insect

hotels to attract and maintain insect populations has been noted by several

authors (Gathmann *et al*., 1994; Tscharntke *et al*., 1998; Steffan-Dewenter, 2002). However, a recent study of more than 300 insect hotels found that

they housed a high number of invasive species, and that they tended to act

as accumulators for parasitoid species (MacIvor and Packer, 2015).

Therefore, the use of insect hotels as a conservation tool should proceed

with caution, as they may have a negative impact on overall bee popula-

tions. This study highlights the importance of careful, well-replicated studies

to assess the impacts of various habitat modifications on conservation.

While all the studies referenced here have focused on measures of ‘species

diversity’, there is tremendous scope for green roofs to increase genetic diver-

sity by acting collectively as stepping stones connecting otherwise isolated

animal communities. Increasing habitat connectivity through green roofs

requires a city-wide approach to green roof management. The City of Toronto,

for example, provides an excellent case study for developing city-wide guide-

lines for increasing biodiversity (Box 6.2). If designers follow the guidelines

set out by the City of Toronto, then green roofs no longer act in isolation;

rather, they become part of an interconnected habitat corridor. In addition,

taking a landscape view that incorporates not just the green roof but also the

surrounding habitat can lead to more successful attempts to increase or

enhance biodiversity. For example, if a roof is within flying distance of a pond

(or other water source), a roof aiming to increase bird biodiversity may not

need to provide a water source. In contrast, a roof that provides nesting

spaces for solitary bees, but which is surrounded by a concrete jungle, will

need to provide flowers if the bees are to survive and prosper.



**Box 6.2 Case study: City of Toronto guidelines for biodiverse green roofs.**

The City of Toronto, Canada was the first city in North America to require the

construction of green roofs on new developments (Toronto, 2013). By law, new

developments must include green roofs that cover between 20% and 60% of the

roof area. As part of the green roof programme, the City of Toronto also

publishes a set of guidelines which lay out best practices for the creation of roofs

that increase biodiversity through the creation of habitat. A positive feature of

the City of Toronto's guidelines is their clear distinction between creating

generally biodiverse habitats and creating habitat for specific target specimens.

They aim to increase biodiversity using several design strategies:

■

Varying the composition of the substrate to promote diverse arthropod

communities.

■

Providing topographic variety using slopes, different heights of edging,

planter boxes and modules.

■

Providing shady microclimates using rocks, plants and building elements.

■

Maximising the diversity of plants.

■

Providing a variety of nesting opportunities such as bird houses, logs and

branches, open soil areas and bee hotels.

■

Providing water sources such as basins, bird baths, pitted rocks and water

features.

■

Providing perching habitats such as branches, rocks, shrubs and logs.

The city's guidelines also incorporate a landscape perspective by providing

specific design strategies for rooftops adjacent to particular habitats. For example, it is suggested that rooftops adjacent to lakeside habitat be planted with seed-producing plants, which can provide food for early spring migratory birds.

The city also encourages the planting of diverse flowers, which bloom at

different times of the year. The guidelines provide a list of plants that support

caterpillars and butterflies.

In summary, carefully designed green roofs have the potential to alleviate

some of the biodiversity loss associated with urbanisation. We are, however,

in dire need of more well-designed studies to assess and monitor the novel

ecosystems created atop green roofs.

**References**

Baumann, N. (2006) 'Ground-nesting birds on green roofs in Switzerland: preliminary

observations', *Urban Habitats*, 4(1), 37–50.

Braaker, S., Ghazoul, J., Obrist, M. K. and Moretti, M. (2013) ‘Habitat connectivity

shapes urban arthropod communities: the key role of green roofs’, *Ecology*, 95, 1010–1021.



deGroot, C., Boult, M., Ussher, G., Toft, R., Simcock, R. and Davies, R. (2010)

‘Elevated enclaves – living roof biodiversity enhancement through prosthetic

habitats’.

Droege, S., Griswold, T., Minckley, R. and LeBuhn, G. (2003) A Standardized

Method for Monitoring Bee Populations – The Bee Inventory (BI) Plot. Available

at: online.sfsu.edu/~beeplot/pdfs/Bee%20Plot%202003.pdf.

Dunnett, N. (2006) ‘Green roofs for biodiversity: reconciling aesthetics with ecol-

ogy’. Fourth Annual Greening Rooftops for Sustainable Communities Conference,

Boston.

Fernandez-Canero, R. and Gonzalez-Redondo, P. (2010) ‘Green roofs as a habitat

for birds: a review’, *Journal of Animal and Veterinary Advances*, 9, 2041–2052.

Gathmann, A., Greiler, H.-J. and Tscharntke, T. (1994) ‘Trap-nesting bees and wasps

colonizing set-aside fields: succession and body size, management by cutting and

sowing’, *Oecologia*, 98, 8–14.

Goddard, M. A., Dougill, A. J. and Benton, T. G. (2010) ‘Scaling up from gardens:

biodiversity conservation in urban environments’, *Trends in Ecology & Evolution*, 25, 90–98.

Gunnarsson, B. and Federsel, L. M. (2014) ‘Bumblebees in the city: abundance,

species richness and diversity in two urban habitats’, *Journal of Insect Conservation*, 18, 1185–1191.

Ishimatsu, K. and Ito, K. (2013) ‘Brown/biodiverse roofs: a conservation action for

threatened brownfields to support urban biodiversity’, *Landscape and Ecological*

*Engineering*, 9, 299–304.

Kadas, G. (2006) ‘Rare invertebrates colonizing green roofs in London’, *Urban*

*Habitats*, 4, 66–86.

Kowarik, I. (2011) ‘Novel urban ecosystems, biodiversity, and conservation’,

*Environmental Pollution*, 159, 1974–1983.

Ksiazek, K., Tonietto, R. and Ascher, J. S. (2014) ‘Ten bee species new to green roofs in the Chicago area’, Michigan Entomological Society 47: 87.

Langellotto, G. A. and Denno, R. F. (2004) ‘Responses of invertebrate natural ene-

mies to complex-structured habitats: a meta-analytical synthesis’, *Oecologia*, 139, 1–10.

Lundholm, J. T. (2006) ‘Green roofs and facades: a habitat template approach’,

*Urban Habitats*, 4(1), 87–101.

MacIvor, J. S. and Packer, L. (2015) ‘“Bee hotels” as tools for native pollinator

conservation: a premature verdict?’, *PloS ONE*, 10(3), e0122126.

Madre, F., Vergnes, A., Machon, N. and Clergeau, P. (2014) ‘Green roofs as habitats

for wild plant species in urban landscapes: first insights from a large-scale

sampling’, *Landscape and Urban Planning*, 122, 100–107.

McGuire, K. L., Payne, S. G., Palmer, M. I., *et al*. (2013) ‘Digging the New York City skyline: soil fungal communities in green roofs and city parks’, *PLoS ONE*, 8(3), e58020.

Pearce, H. and Walters, C. L. (2012) ‘Do green roofs provide habitat for bats in

urban areas?’, *Acta chiropterologica*, 14(2), 469–478.

Rumble, H. and Gange, A. C. (2013) ‘Soil microarthropod community dynamics in

extensive green roofs’, *Ecological Engineering*, 57, 197–204.

Schindler, B. Y., Griffith, A. B. and Jones, K. N. (2011) ‘Factors influencing arthropod diversity on green roofs’, *Cities and the Environment (CATE)*, 4(1), 5.

Schrader, S. and Böning, M. (2006) ‘Soil formation on green roofs and its contribu-

tion to urban biodiversity with emphasis on Collembolans’, *Pedobiologia*, 50,

347–356.



Steffan-Dewenter, I. (2002) ‘Landscape context affects trap-nesting bees, wasps, and

their natural enemies’, *Ecological Entomology*, 27, 631–637.

Sydney (2014a) Green Roofs and Walls Implementation Plan. City of Sydney.

Sydney (2014b) Urban Ecology Strategic Action Plan. City of Sydney.

Tonietto, R., Fant, J., Ascher, J., Ellis, K. and Larkin, D. (2011) ‘A comparison of bee communities of Chicago green roofs, parks and prairies’, *Landscape and Urban*

*Planning*, 103(1), 102–108.

Toronto (2013) City of Toronto Guidelines for Biodiverse Roofs.

Tscharntke, T., Gathmann, A. and Steffan-Dewenter, I. (1998) ‘Bioindication using

trap-nesting bees and wasps and their natural enemies: community structure and

interactions', *Journal of Applied Ecology*, 35, 708–719.

Vitiello, D., Nairn, M. and Planning, P. (2009) Community Gardening in Philadelphia:

2008 Harvest Report. Penn Planning and Urban Studies, University of Pennsylvania.

Williams, N. S., Lundholm, J. and MacIvor, J. S. (2014) 'Do green roofs help urban

biodiversity conservation?', *Journal of Applied Ecology*, 51, 1643–1649.

**17**

## Planting Choices for Retrofitted Green Roofs

**Tijana Blanusa1,2, Madalena Vaz Monteiro2, Sarah Kemp2 and**

**Ross Cameron3**

1 RHS Wisley, Woking, UK

2 School of Agriculture, Policy and Development, University of Reading, UK

3 Department of Landscape, University of Sheffield, UK

### 7.0 Introduction

Several parameters currently determine which plant species are chosen for a

particular green roof type and location. These include the ability of plants to

survive and grow on a given roof depth, in given substrate and climatic

conditions, the cost of plant installation and maintenance and, to a degree,

the aesthetic appeal of chosen species. Designing a green roof with the deliv-

ery of the ecosystem services in mind is still not a mainstream consideration.

Irrespective of the local climate, currently most widely used species on shal-

lower (extensive/semi-extensive) green roofs, which have a tendency to

quickly dry out, are various *Sedum* (e.g., *S. album*, *S. acre*, *S. sexangulare*, *S.*

*spurium*, etc.) (Kolb and Schwarz, 1999; Monterusso *et al*., 2005; Köhler, 2006; Dunnett and Kingsbury, 2008). *Sedum* establish rapidly, provide good

surface coverage, survive in a range of environmental conditions and require

low maintenance. Bulbs and grasses are also frequent choices (Pahlke, 1989;

Liesecke, 2001) as well as the perennial forbs (Lundholm *et al*., 2010;

Nagase and Dunnett, 2010). In the last few years, however, in scientific

research (if not so widely in practice), a wider range of species is being

considered due to their potential to provide more environmental benefits/

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.








(a)

(b)

**Figure 7.1** Conventional plant species choice on green roofs could include (a) *Sedum* mixes, grasses and bulbs, while a wider range can be considered to include (b) herbaceous perennials and sub-shrubs where additional irrigation is possible.

ecosystem services (Figure 7.1). Consequently, a broader choice of substrate

depths (Savi *et al*., 2013) and compositions (Molineux *et al*., 2009;

Mickovski *et al*., 2013; Graceson *et al*., 2014) are also being considered in order to support this wider range of plant species.



**7.1**

## Ecosystem Services Delivery By Green Roofs: The Importance of Plant Choice

Ecosystem services have been defined as the benefits that humans derive,

either directly or indirectly, from the functioning of (healthy) ecosystems

(Costanza *et al*., 1997). Green roofs are increasingly being considered as one

such ecosystem, with the ability to contribute to regulating ecosystem ser-

vices (such as water cycling, pollutant trapping, temperature moderation

and carbon storage) as well as provisioning (e.g., rooftop food production)

and cultural/social ecosystem services (e.g., recreation areas) (Oberndorfer

*et al*., 2007; Rowe, 2011). The contribution of green roofs to ecosystem

services delivery had been studied particularly in the urban environment

context; the turn of the 21st century saw a surge in green roof (and ecosys-

tem services) research, focusing on describing green roofs' support of urban

biodiversity (Brenneisen, 2006; Kadas, 2006), their ability to contribute to

stormwater retention and circulation (Stovin, 2010), air temperature regula-

tion and thermal comfort of urban residents (Wong *et al*., 2003) and air

pollution (Speak *et al*., 2012). With the increasing number of published

studies covering a range of ecosystem services (Ascione *et al*., 2013; Speak

*et al*., 2014; Volder and Dvorak, 2014; Poë *et al*., 2015), it is becoming increasingly clear that plant species choice will significantly affect the extent

of ecosystem services provision of green roofs.

In this chapter we present a case for considering a wider range of herba-

ceous plants for semi-extensive green roofs to enhance the roofs' ability to

support a number of ecosystem services, using examples from our own

research on (1) plants' cooling and building insulation capacity and (2)

water sequestration. We will also highlight some more recent studies on the

contribution of green roofs to biodiversity support and air pollution mitiga-

tion, and explore the significance of widening planting choices to improve

the delivery of these services.

## 7.2

## Plant Species Choice and Building Cooling/Insulation

### 7.2.1

### Plants and Cooling – Basic Principles

Urban landscapes are typically warmer than the adjacent rural areas (Oke,

1987; Grimmond, 2007); this leads to a reduction of residents' (thermal)

comfort and the need for buildings cooling (Grimmond, 2007). It has been

suggested that when maximum daily temperatures are above a threshold of

15°C, a further rise of 1°C in the air temperature will increase the peak

air-conditioning energy consumption by 2–4% (Akbari *et al*., 1997, 2001).

Thus, strategically positioned vegetation on/around a building's envelope,

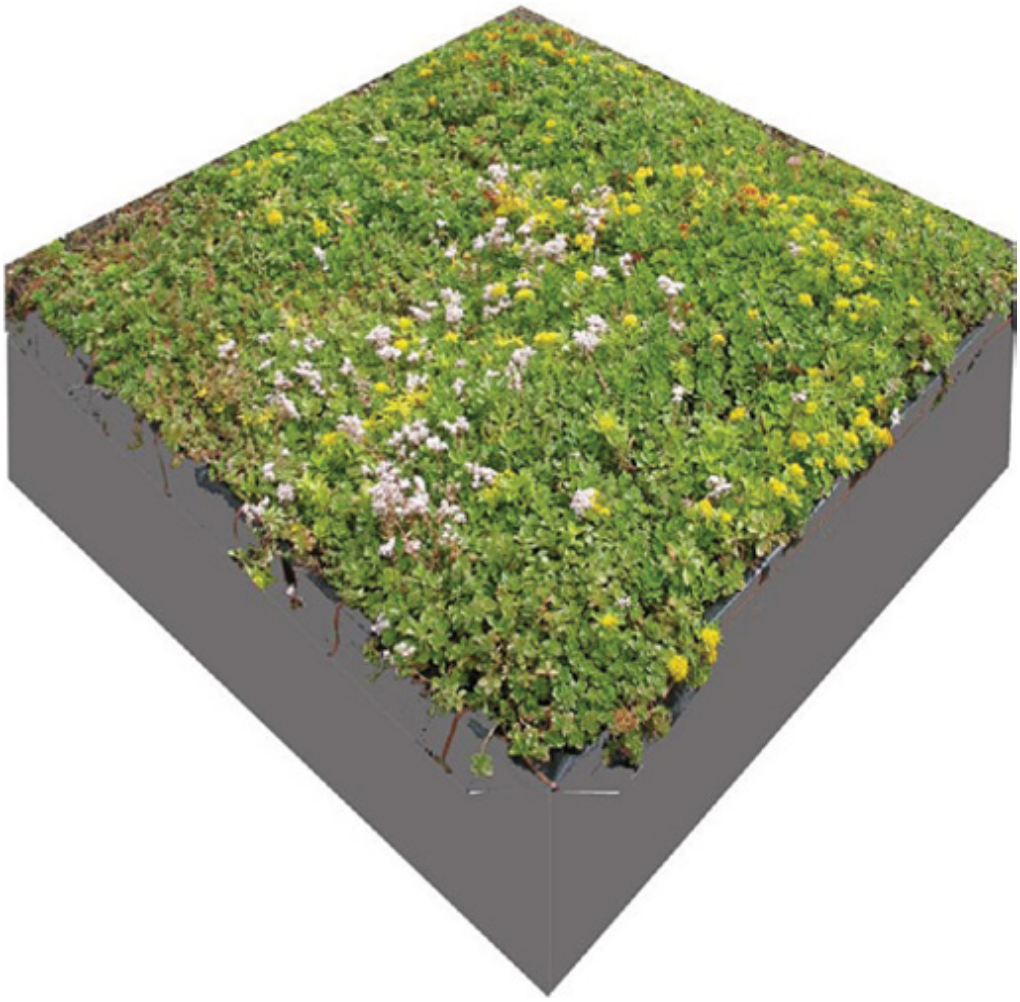
which can reduce the energy load on the building during summer, decreasing

reliance on artificial air conditioning and saving energy (McPherson *et al*.,

1988; Akbari *et al*., 2001; Saiz *et al*., 2006), can be part of the solution.

Energy exchange processes within a green roof have been summarised in

Figure 7.2. Energy inputs include long and shortwave radiation, which may



be immediately (a) reflected away from the building and (b) transmitted into

the building. The remaining radiation is absorbed and dissipated as:

1. emitted longwave radiation;

2. sensible heat though convection (when plants are cooler than the sur-

rounding environment);

3. latent heat through evapotranspiration (Figure 7.2).

Additionally, a small proportion (3–6% of the photosynthetically active

radiation, i.e., radiation in the visible spectrum) of incoming irradiance is

converted to chemical energy through the process of photosynthesis, and

this can be subject to further energy losses through chlorophyll fluorescence

and non-photochemical quenching (Taiz and Zeiger, 2010). The cooling

benefits of plants are thus provided via three main mechanisms:

1. reflecting the incoming light energy;

2. shading the surface;

3. evapotranspiration (i.e., controlled water loss through leaf stomata)

(Akbari *et al*., 2001; Lazzarin *et al*., 2005).

Convective

Radiation reflected

Longwave radiation

Longwave emitted

Shortwave radiation

Evapotranspiration

Heat conducted

Radiation transmited

to the building

to the building

**Figure 7.2** Representation of energy exchange processes on a green roof.

*Source*: Vaz Monteiro (2015).



Cooling by energy reflection is not plant-specific and can be achieved

using a range of materials and structures. So-called ‘cool roofs’ (light-

coloured, unvegetated roofs, where albedo can be increased to 0.4 compared

with conventional roofs with albedo of 0.1; Saiz *et al*., 2006) are also able

to provide effective surface and building cooling by energy reflection (Coutts

*et al*., 2013) (see also Chapter 10). However, compared with dark urban

materials such as roof felt, bitumen and asphalt, plants can also absorb less

heat, due to canopies' higher albedo (e.g., in the range of 0.15–0.30) (Taha

*et al*., 1988). Although cooling by shading is not plant-specific either, plants (in addition to structures such as pergolas) can intercept some of the solar

irradiance, thus reducing the radiation load to the building fabric (McPherson

*et al*., 1988; Shashua-Bar *et al*., 2009). For example, a 500 W/m2 reduction in the summer solar radiation reaching a concrete building façade located in

Athens was observed in areas where the wall was shaded by deciduous trees

and thus contributed to less heat reaching the buildings; areas of wall

protected by the trees had temperatures up to 8°C lower than those measured

on areas where the wall was unshaded (Papadakis *et al*., 2001). Another, UK,

summer-time study showed that the leaves of *Prunus laurocerasus* shrubs

screening a brick wall were up to 6.3°C cooler than bare, exposed wall

when temperatures were assessed around 15:00 h on a sunny summer day

(Cameron *et al*., 2014).

However, it is the cooling through evapotranspiration that is particularly

important, as it is an effective way of *consuming* heat, without warming up

the surrounding surfaces (Gates, 1966). Transpiration is specific to plants

and thus puts them in a unique position compared with other, artificial

materials. The physical process involved in the change of liquid water to

vapour absorbs 585 calories per gram (i.e., ml) of water (Monteith, 1965).

Therefore, this process of latent heat loss reduces the energy available to be

dissipated as sensible heat. A reduction in the ratio of local sensible heat to

latent heat fluxes during the daytime (described as the Bowen ratio) will

lead to an ‘oasis’ effect, lowering air temperatures overall (Taha *et al*., 1988), with higher plant evapotranspiration rates potentially leading to greater

cooling. The range of inherent transpiration rates in various plant taxa

under optimal substrate moisture conditions varies several-fold: from, for

example, 110 mol/m2/s in succulent species such as *Sedum* to 320 mol/m2/s

in *Salvia* (Vaz Monteiro, 2015). This, therefore, suggests that the extent of

cooling that different plant species can provide is likely to vary too.

For example, the most widely used *Sedum* (and similar succulent species

in the *Crassulaceae* family) are unlikely to offer substantial evapotranspira-

tional cooling and a reduction in air temperature when the weather is hot

and the substrate is dry. This is because their metabolism under water defi-

ciency switches from daytime CO uptake and fixation to night-time (the

2

so-called CAM pathway), when water is limiting. Consequently, the stomata

close during the light period, thus conserving water (Kluge and Ting, 1978).

This encourages survival of such species in harsh environmental conditions

(including those of dry and exposed rooftops), but it does not allow plants

to exploit daytime transpirational cooling as a key strategy, and restricts

cooling the surrounding environment (Vaz Monteiro, 2015).

Planting Choices for Retrofitted Green Roofs 123

### 7.2.2

### Plant Species Choice and Summer-Time Surface Cooling

The focus of our research was therefore on understanding which species

exhibit sufficient evapotranspiration to provide measurable (roof) surface

and aerial cooling, but are also robust enough to tolerate the adverse

conditions associated with roofs and façades, and have acceptable

ecological properties (e.g., promotion of urban biodiversity and ability to

capture particle air pollutants while being low emitters of biogenic vola-

tile organic compounds, reducing the likelihood of negative interaction

with gaseous air pollutants such as nitrogen dioxide, NO and ozone, $O_3$,

etc.). More broadly, we were interested in establishing basic principles on

which leaf/plant structural and functional traits should be considered when designing green roofs to provide maximal cooling and building insulation. The research was set in the context of the mild temperate climate of southeast England, where the annual rainfall averages around 600 mm (and >40 mm per month in the period June–August) (www.metoffice.gov.uk/climate/uk/regional-climates/so). Our initial hypothesis was that broad-leaved, relatively vigorous perennial plants would likely provide better transpirational cooling, substrate insulation and shading than small-leaved succulents, due to higher evapo-transpiration (ETp) rates and larger leaf area indices (LAI). However, as a degree of water-saving strategies in chosen plants would be required even on UK green roofs, we focused on species with relatively large leaf diameters, but which are known to have effective water use efficiency indices (Cameron *et al*., 2006) and a high degree of drought tolerance (Cameron *et al*., 2008). These may be appropriate for green roofs, especially if semi-exten-

sive systems (20 cm substrate depth) are employed to improve anchorage

for root systems and increase the water storage of the green roof.

In a series of glasshouse and field experiments, an industrial standard

*Sedum* species mix ('Enviromat' matting system, Q Lawns, Hockwold,

Norfolk, UK; a random mix of *S. album*, *S. spurium*, *S. acre* and *S. sexangulare)* was compared with a number of other potential planting options

( *Bergenia cordifolia*, *Stachys byzantina*, *Hedera hibernica*) and bare substrate (Blanusa *et al*., 2013) (Figure 7.3).

Plants were chosen on the basis of differences in canopy leaf areas, tran-

spiration rates and presence or absence of leaf hairs and grown in substrate

depths of 20 cm initially, but then reducing the depth to 10 cm for final

outdoor experiments. We examined how *Sedums*' ability to cool their own

leaves as well as the surrounding spaces (i.e., substrate 10 mm below surface

and air 10 cm above bare or vegetated surface) compared with that of other

broad-leaf species. This was complemented by a range of detailed biological

measurements of leaf stomatal conductance and transpiration, leaf tempera-

ture and LAI (Blanusa *et al*., 2013).

In this study, *Stachys byzantina* outperformed the other tested species in

terms of leaf surface cooling, cooling the substrate beneath its canopy and

even – during short intervals over the hottest still periods – the air above

the canopy, when the soil moisture was not limited (Blanusa *et al*., 2013).

For example, we found on one of the hottest days of the experiment





124 Green Roof Retrofit

(a)

(b)

**Figure 7.3** Images of plant species used in the experiment: (a) *Sedum*; (b) *Bergenia*; (c) *Stachys*; (d) *Hedera*.







(c)

(d)

**Figure 7.3** (Continued)

(maximum air temperature 28°C), on the outdoor plots, that the tempera-

ture of the substrate below *Stachys* was 12°C cooler than under *Sedum* and 15°C cooler than for bare, uncovered ground. This could have significant

implications for the temperature of the building, as well as a reduced need

for summer-time air-conditioning use, if these plants were installed on the

roof. *Stachys* is unlikely to be as resilient as *Sedum* in terms of survival in the most droughty, extensive green roofs (e.g., ≤10 cm deep), but is a

drought-adapted species in its own right, capable of survival and persis-

tence in semi-extensive systems.



This research confirmed our hypothesis about plants differing in their ability

to provide a cooling service. Consequently, we expanded the range of species

under investigation, extending the range of studied plant traits (all of which

could contribute to temperature regulation). The light leaf colour and hairi-

ness of the species that cooled best in our early experiments, along with the

succulence as a feature of many drought-adapted species, prompted us to

consider these leaf traits in more detail in a subsequent study. All of these

traits contribute to the regulation of leaf temperature (Vaz Monteiro, 2015;

Vaz Monteiro et al., 2016) and thus potentially to the environmental and

building cooling. We were interested in understanding the mechanisms which

enable plants with these traits to regulate leaf temperature and therefore

indirectly the temperature of the surrounding surfaces and the environment.

Chosen species included *Heuchera* (four cultivars representing a range of leaf

colours – from purple to yellow), *Salvia* (three cultivars with different leaf col-

ours and hair length), *Sempervivum* (three cultivars representing different leaf thicknesses, as well as colour and hairiness) (Vaz Monteiro, 2015) (Figure 7.4)

alongside *Stachys* and *Sedum* used in a previous study (Blanusa *et al*., 2013).

Experiments included both the glasshouse and controlled environment

work with all chosen species and cultivars, but also outdoor field work

with a subset of selected species, representing the widest range of responses

detected in controlled environments. Outdoors, plants were grown in

1.5 m × 1.5 m × 0.1 m plots (Figure 7.5), on the experimental grounds at the

University of Reading (UK), over two growing seasons. Each plant cultivar

was represented by two plots; within each plot, a number of parameters

were measured. The measurements included continuous monitoring (and

logging) of substrate temperature (at 10 mm and 60 mm depth) and leaf

temperature as well as regular discrete measurements of substrate moisture,

leaf stomatal conductance (used via the Penman–Monteith equation to esti-

mate plant transpiration) and albedo. Leaf area indices were determined

twice in each season.

In some of the experiments we also attempted to compare plant-induced

cooling of the ground (through shading, transpiration and reflection) with

the use of artificial shade (pergola) or by applying white paint to the sub-

strate surface to increase reflectance.

In the summer-time experiments in both experimental years (2012 and

2013), we found that the presence of thinner-leaved plants improved sub-

strate cooling (at two depths, 10 and 60 mm), particularly on the hottest

days of the experiments (maximum daytime temperature >24°C) compared

with the artificial shade (Table 7.1, showing 2013 data), but the presence of

succulents (particularly *Sempervivum*) did not.

Herbaceous plants insulated the substrate best; *Salvia* cultivar ( *Salvia*

*officinalis* ‘Berggarten’, with longest leaf hair length in our experiments) and *Stachys* provided most cooling and potential insulation (Table 7.1). This

was because they offered more substrate shading (through having a greater

LAI) and protection, and had the lowest leaf and canopy temperatures, lead-

ing to lower heat release towards the substrate underneath (and therefore

the lowest substrate heat fluxes) (data not shown). On the contrary, the

succulent *Sempervivum* even warmed up the substrate underneath on the





Planting Choices for Retrofitted Green Roofs 127

(a)

(b)

**Figure 7.4** Plant species/cultivars used in the experiments: (a) *S. officinalis*; (b) *Sempervivum*; (c) *Heuchera* 'Obsidian' – yellow and 'Electra' – purple).

hottest days during some parts of the day (data not shown). *Sedum*

performed intermediately between the best and worst 'coolers'.

Our research showed that water loss by evapotranspiration was the

main mechanism that contributed to better cooling of leaves, substrate and

air. Therefore, choosing plants which transpire more and keeping them







128 Green Roof Retrofit

(c)

**Figure 7.4** (Continued)

**Figure 7.5** Plots with sensors in use in summer 2013 at the experimental grounds of the University of Reading (UK). General view of the experimental site (left), unvegetated/

bare substrate shaded by netting (right).

(sustainably) watered is important for the reduction of temperatures. Using

canopies with a greater LAI and presence of light-coloured leaf hairs also

had a small positive influence on lowering leaf, surface and air tempera-

tures (Vaz Monteiro, 2015).

The importance of diversity and complexity of plant structure (i.e.,

larger LAIs and bigger canopies) as well as higher ETp rates for the

provision of insulation and cooling by green roofs can also be inferred

from other green roof species studies in different climatic conditions

(Huang *et al*., 2008; Liu *et al*., 2012; Blanusa *et al*., 2013), and similar examples have been found in green walls too (Cameron *et al*., 2014).



**Table 7.1** Substrate temperatures at 10 mm and 60 mm below the surface

Substrate temperature (°C)

below surface, 13:00–17:00 h

Treatment

At 10 mm

At 60 mm

Bare substrate

32.5 g

27.4 f

Shaded bare substrate

25.0 cd

23.4 cd

*S. officinalis*

20.7 a

19.8 a

*Stachys byzantine*

23.3 bc

21.9 bc

*Heuchera*, yellow*

29.0 ef

25.1 de

*Heuchera*, purple

21.9 ab

21.3 ab

*Sedum* mix

26.8 de

23.9 d

*Sempervivum*, green

29.1 f

26.4 ef

Least significant difference between the means, LSD

2.25

1.86

* Substrate coverage of yellow *Heuchera* was significantly lower than for other plant treatments (40% vs 100%) due to the frost damage to plants between 2012 and 2013 growing seasons.

*Note*: Temperatures were measured every 10 minutes in the period 13:00–17:00 h on 10 days when the maximal daily temperature was >24°C, in the period 15 July–31 August 2013. Values are means of two plots per treatment, averaged hourly. Statistical analysis was carried out with a residual maximum likelihood estimation and different letters next to the temperatures indicate means which are statistically significantly different ( $p = 0.05$)

**7.2.3**

**Plant Species Choice and Winter-Time Insulation**

Although the focus of our research was on detecting the species' differences

to provide summer-time cooling, and understanding which plant structural

and functional traits are the key to supporting those differences, we were

able to make observations relating to the species' potential for winter-time

insulation as well. We hypothesised again that extending the range of species

away from just succulents will be beneficial for improving winter-time insu-

lation, particularly in cold and overcast weather. Our winter-time outdoor

experiments showed that in the climate of southern UK, in the relatively

colder weather conditions (represented by maximal daytime temperatures

<3°C and when snow cover was present), plant species' choice influenced

surface insulation (as measured by substrate temperatures at 10 and 60 mm).

For example, in a snow-covered scenario, substrate 60 mm underneath

*Stachys byzantina* was 1.8°C warmer than bare, unvegetated (but snow-cov-

ered) substrate, with *Sedum* cover being second best, warming up a surface

by 1.4°C (Table 7.2). *Sempervivum* performed least well of all the studied

plant covers, still significantly warming the substrate compared with bare

substrate though (by 0.7°C, Table 7.2). This suggests that in those weather

scenarios, the presence of vegetation on the roofs would be beneficial as it

would act to increase roof insulation and building temperatures.

On warmer days (maximal air temperature >10°C), however, there

were no species differences, but the presence of vegetation reduced the

substrate temperature (by up to 2.9°C compared with bare, unvegetated

surface) (data not shown). The difference in insulation on mild winter

days is likely to be linked to the shading effect created by the plants,



**Table 7.2** Substrate temperatures 60 mm below the surface in two types

of winter scenario (Vaz Monteiro et al., 2016b)

| Substrate temperatures at 60 mm from 13:00 to 16:00 h | |
|---|---|
| Treatments | |
| Days with maximum air temperature <3°C | |
| Snow covered | |
| Bare substrate | |
| 2.4 a | |
| 0.5 a | |
| *Salvia* | |

2.5 abc

1.5 c

*Stachys*

2.8 bc

2.3 3

*Heuchera* yellow

2.8 abc

1.7 d

*Heuchera* purple

2.6 abc

1.4 c

*Sedum*

2.9 c

1.9 d

*Sempervivum*

2.5 ab

1.2 b

LSD

0.39

0.24

*Note*: Temperatures were measured every 10 minutes in the period 13:00–16:00 h on 9 days when plots were covered by snow and 10 days when maximal daily temperature was <3°C in January 2013.

Values are means of two plots per treatment, averaged hourly. Statistical analysis was carried out with a residual maximum likelihood estimation and different letters next to the temperatures indicate means which are statistically significantly different ( $p = 0.05$)

which reduced the radiation reaching the substrate on sunny winter days

(Sailor, 2008; Jaffal *et al*., 2012).

In climates such as that of the UK, winter-time insulation by green roofs

is likely to be in the balance (i.e., vegetation providing warming of the

surface on some days, while acting to cool on others). As the summer-time

benefits can be significant, we suggest that the overall annual service of

green roof vegetation will be a positive one (i.e., more benefits from sum-

mer-time cooling and insulation and winter-time insulation than from the

additional winter-time temperature reduction due to the blocking of solar

radiation). This is in agreement with recent findings (Cameron *et al*., 2015)

on a model mini building system clad with vegetation, suggesting that

21–37% reduction in winter heating could be achieved.

## 7.3

## Plant Species Choice and Stormwater Management

Surface flooding in urban areas is likely to become more common due to

further increases in urbanisation, as the replacement of vegetation with

impervious surfaces will lead to drainage systems being under increased

pressure (Nagase and Dunnett, 2012). Additionally, a likely increase in the

frequency of intense precipitation events in many parts of the world is

predicted by climate change models (IPCC, 2013). Sufficiently deep green

roofs with viable, diverse vegetative cover may help to alleviate flood risk by

delaying runoff and reducing its volume. Green roofs provide this service

through direct interception of rainfall by green roof vegetation, infiltration

and storage of water in the green roof substrate and subsequent uptake of

water by the vegetation (Stovin *et al*., 2012). Water taken up by plants

may be stored in plant tissues or transpired back to the atmosphere



(Razzaghmanesh *et al*., 2014). The majority of studies focused on measuring

the ability of simple, extensive green roofs to reduce runoff (Van Woert

*et al*., 2005; Carter and Rasmussen, 2006; Graceson *et al*., 2013), impact of substrate type and depth on runoff volume, and the change in runoff quality

and chemical properties (Berndtsson, 2010; Speak *et al*., 2014). Only a small

number of studies investigated the impact of plant species selection on

runoff volume (Nagase and Dunnett, 2012; Poë *et al*., 2015). Differences in

plant structure, including canopy size and leaf morphologies, will influence

the volume of water that can be intercepted (Nagase and Dunnett, 2012).

This study investigated functional groups of plants (forbs, grasses and

*Sedum*) on shallow, extensive green roofs and found that grasses as a group

reduced the runoff most of all studied species; larger canopy and root system

size correlated with better water retention within the system (Nagase and

Dunnett, 2012).

In our recent experiments we aimed to understand in more detail the

mechanisms that enable different plants (situated on green roofs or in other

forms of greening) to perform stormwater management to a greater or lesser

degree. We also aimed to identify if some of the mechanisms associated with

good provision of the cooling service could also be linked with the provision

of other ecosystem services by chosen plants (including runoff reduction).

For the experiments we chose plants which in our previous studies enabled

the best surface cooling and insulation (Vaz Monteiro, 2015) and also have

leaf/canopy properties (e.g., presence of hairs, large LAI, range of transpira-

tion rates) which should enable them to be effective at runoff reduction, but

also potentially improving other services such as particle pollutant trapping

(Freer-Smith *et al*., 2005; Blanusa *et al*., 2015).

Previous studies have identified that the green roof substrate, rather than

vegetation, is the main store for rainwater. The retention capacity of green roof

substrates depends on substrate type and depth, together with the antecedent

substrate moisture conditions (Stovin, 2010; Berretta *et al*., 2014). The ability of vegetation to restore a substrate's retention capacity following a rainfall

event, through uptake and removal of water from the substrate, is therefore

crucial as it determines the potential of the green roof system to retain water

in subsequent rainfall events. Water uptake from the substrate will vary

depending on each species' evapotranspiration rate, so we hypothesised that

species' ETp differences would be the main factor contributing to the improve-

ment of water retention within the plant/substrate system. Additionally,

however, we were interested in understanding what proportion of the applied

water (in a simulated rainfall event) would be directly intercepted and retained

within a plant canopy (i.e., what is the additional contribution of the intercep-

tion by canopy to overall water storage of a green roof system?).

Three low-growing perennial species with varying leaf and canopy char-

acteristics ( *Salvia officinalis*, *Stachys byzantina* and *Heuchera* 'Obsidian') that have shown potential for use on green roofs (Vaz Monteiro, 2015) were

used in the experiments, along with a typical succulent green roof mix

(industrial *Sedum* mix). Plants were grown in an industrial green roof sub-

strate (Meadow Roof Medium, Vital Earth GB Ltd, Ashbourne, Derbyshire,

UK). The amount of rainfall captured on the canopy was measured by



applying simulated rainfall to individual plants (eight replicates per species)

in 2 litre containers where the substrate was saturated with water to full

capacity, so any weight change of the plant/substrate system would be due

to the 'rainfall' retained on the canopy. We also assessed how species dif-

fered in their capacity to restore the substrate's water-holding capacity after

a fixed period of time (3 days in our glasshouse-based experiments), due to

the differences in their ETp rates, canopy and root system sizes or any com-

bination of those factors.

We found that succulent *Sedum* lost least water in a 3-day experimental

period (just under 130 ml on average), with three herbaceous species hav-

ing relatively similar extent of water losses per container ( *Heuchera* and

*Salvia* around 250 ml on average followed by *Stachys* with about 220 ml) (Table 7.3). This resulted in substrate moisture content dropping from a

full container/substrate capacity of 0.25 m3/m3 at the start of experimenta-

tion to about 0.10 m3/m3 after a 3-day drying period in herbaceous species;

however, in the substrate with *Sedum*, substrate moisture was significantly

higher after 3 days of drying (Table 7.3), linked to low rates of water loss.

*Salvia* also captured most water within the canopy (about 5% of that

applied) (Table 7.4). Consequently, when the system's ability to retain

water was re-tested after 3 days of drying, *Salvia* retained most ‘rainfall’

(about 50% of the applied water volume) within the plant/substrate

system (closely followed by *Heuchera* and *Stachys*) (Table 7.4). *Sedum* retained only about 30% of ‘rainfall’ in comparison, the same as bare

unvegetated substrate (Table 7.4). Experiments have also shown that

depending on the leaf and canopy shape and structure, varying amounts of

water slide off the leaves. For example, as much as 20% of the applied

water slid off the *Heuchera* canopy, compared with under 3% in *Salvia*.

We are conducting further tests to confirm this and understand the detail,

but we believe that it is the smooth epidermis and large, umbrella-like

structure of the *Heuchera* canopy that contributes to the greater propor-

tion of rainfall sliding off the canopy, in contrast with *Salvias*’ hairy,

upward-angled leaves and dense canopy.

**Table 7.3** Mean substrate moisture content (SMC) of a water-saturated substrate and a substrate after 3 days of drying; cumulative water lost from individual plant

containers after 3 days of drying

Species/

Saturated SMC

Water loss,

SMC 3 days post-

substrate

(m3/m3)

cumulative (ml)

watering (m3/m3)

Bare substrate

0.241

134.9

0.175

*Heuchera*

0.231

249.8

0.093

*Salvia*

0.254

262.8

0.111

*Sedum*

0.264

127.3

0.180

*Stachys*

0.250

217.4

0.097

LSD (d.f.)

0.0215 (35)

27.49 (35)

0.0154 (35)

Data are mean of eight replicates per treatment with the associated LSD and degrees of freedom (d.f.).

Planting Choices for Retrofitted Green Roofs 133

**Table 7.4** Mean percentage of water captured on a plant canopy (A) when soil is saturated or (C) after 3 days post-saturation; (B) mean percentage of water sliding off a plant canopy

Saturated substrate

After 3 days of drying

Species/

(A) % water

(B) % water

(C) % water captured in

substrate

captured on canopy

sliding off canopy

substrate and on canopy

Bare substrate

0.4

3.7

28.6

*Heuchera*

1.7

20.5

46.1

*Salvia*

5.1

2.8

50.7

*Sedum*

3.4

7.1

30.8

*Stachys*

1.8

6.6

42.7

LSD (d.f.)

2.01 (15)

17.25 (15)

4.42 (35)

Data are mean of eight replicates per treatment with the associated LSD and degrees of freedom (d.f.).

In our minds, this highlights the importance of understanding the biological

(i.e., structural and functional) differences between plants that can be used

on green roofs and more generally green spaces, because of the impact that

those differences can have on the delivery of ecosystem services. Owing to

the fact that plants simultaneously perform a number of ecosystem services,

success or ‘failure’ to deliver a single service should not be a reason to exclude

a plant from a planting list. However, depending on the main drivers for

a plant’s installation at a particular location (i.e., cooling of the south side

of a building in the northern hemisphere, stormwater retention, abatement

of noise or pollution of a building near a busy road), some plant traits might

be preferable.

**7.4**

## Greater Plant Variety can Enhance Urban Biodiversity

Early research dealing with the issue of biodiversity was focused primarily

on extensive, low-maintenance roofs; it described in depth the ability of spe-

cies (such as grass mixtures) adapted to dry, exposed conditions and shallow

substrates to attract particularly birds and small invertebrates in urban

areas (Brenneisen, 2006; Kadas, 2006). Even a relatively simple mixture of

grass and succulent cover on the roof, with some variation in substrate

depth and the presence of sheltering habitats (e.g., log piles), would serve to

increase the biodiversity support of roof spaces (Kadas, 2006). More recent

research, however, suggests that increasing the complexity of species'

mixtures and encouraging planting that encompasses a range of plant

structures will improve a roof's ability to provide biodiversity support

(Madre *et al*., 2013). In this study, for example, roofs composed of a combi-

nation of mosses, low-growing succulent plants ( *Sedum sp*.), grass mixes,

but also woody shrubs such as *Lavandula angustifolia*, *Cotoneaster fran-*

*chetii* or *Pinus mugo*, were characterised by a significantly increased species



richness and the abundance of four arthropods' taxa (spiders, beetles, true

bugs and hymenopterans) compared with simpler roofs where no shrubs

were present (Madre *et al*., 2013).

## 7.5

## Plant Choices and Particle Pollution Mitigation

Elevated concentrations of both gaseous and particle pollutants in urban

areas can in part be mitigated by urban greening interventions, including

green roofs. Concentrations of particulate pollutants are greater at ground

level than at roof level (Mitchell and Maher, 2009), so the potential for direct

impact of green roofs on particles' mitigation service is proportionally less

than their contribution to services such as building insulation/cooling

and runoff reduction. The contribution of simple extensive green roofs to

direct sequestration of particle pollutants (through dry deposition) has been

modelled and shown to be in the range of 100 g of particles/m2 of roof

annually, equating to the average annual emissions of one car (Rowe, 2011).

There is, however, a potential indirect contribution of green roofs to pollution

reduction through reduced coal use (and thus fewer particles released from

burning) for energy generation for air-conditioning in situations where build-

ing temperatures are lowered by the use of green roofs and walls (Rosenfeld

*et al*., 1998; Rowe, 2011). Extrapolation from a range of plant studies char-

acterising largely tree species' ability to sequester particulate pollutants (e.g.,

Beckett *et al*., 2000; Freer-Smith *et al*., 2005; Blanusa *et al*., 2016) suggests that there are significant species differences in the ability for pollutants cap-

ture, due to leaf or canopy property differences (e.g., larger LAIs usually cor-

relate with better particle capture, as does the presence of structures such as

trichomes). Canopy size and structure have an impact on surface roughness

and resultant wind turbulence, so plants with larger and more complex cano-

pies create greater surface roughness and more turbulence, and more particles

are thus deposited (Speak *et al*., 2012). Traditional *Sedum* would thus be unlikely to sequester as many particles per unit leaf area as well as per unit

area of the roof as a species with larger LAI and rougher leaves (Mitchell *et*

*al*., 2010). In a study on two in situ roofs in Manchester (UK), for example, it was found that the grasses ( *Agrostis stolonifera* and

*Festuca rubra*) were more effective than broad-leaved *Plantago lanceolata* and succulent *Sedum album*

at the capture of particles in the PM10 range (Speak *et al*., 2012).

## 7.6

## New Plant Choices and Adaptation of Current Green Roof Systems

Plant survival and green roof installation/maintenance costs will long remain

prime considerations in planting choices for green roofs. If the low levels of

funding, lack of horticultural knowledge/experience and need for reduced

maintenance limit the options, then developing a roof with succulents and

grasses might be a way to introduce some ecosystem benefits. These plant

groups might not excel in many aspects of ecosystem services provision, but

for a number of services (including some biodiversity support, pollutant and



noise abatement) would be an improvement on unvegetated, often impervious

surfaces. Drought-adapted grass species and succulents will thus remain of

interest as green roof planting choices in certain situations.

However, in scenarios where a semi-extensive substrate depth can be

afforded and an investment in sustainable irrigation (recycled rainwater,

greywater) is possible, then considering and using a wider range of low-

growing perennial species with light-coloured leaves, higher LAIs and ETp

rates would likely provide more benefits. The total direct cost of roof instal-

lation may well be higher in that case, but the argument to support a more

diverse plant choice should be linked to the direct and indirect savings and

benefits which this planting produces over and above the simple extensive

green roof (temperature reduction, more pollutant capture per square

metre, etc.).

The change of species from more succulent to more herbaceous, low-

growing, sub-shrub and vigorous planting choices would affect roof loads

and potential retrofitting costs (at the outset), then water management and

maintenance costs of green roofs. This will necessitate the use of sustainably

sourced water (e.g., collected rainwater, greywater), extending the substrate

depth to increase its water-holding capacity and considering the use of sub-

strate amendments such as biochar (Karhu *et al*., 2011), silicate granules

and hydrogels (Farrell *et al*., 2013; Savi *et al*., 2014).

## 7.7 Conclusions and Future Work

Work within our and other groups is beginning to paint a picture of the

importance of plant species' choice to maximise the provision of multiple

ecosystem services by green roofs and other forms of green infrastructure.

Often it is a similar set of leaf/canopy/plant traits that correspond to better

delivery of several services (i.e., large LAI, presence of light-coloured hairs,

high ETp rates with a degree of drought adaptation). Using a wider range of

plants on green roofs will improve the delivery of a number of ecosystem

services. Thus, the scientific and practical challenges will lie in elucidating

further issues, such as:

1. The impact of greywater on plants' functioning (and thus the potential

for the delivery of services such as cooling) by long-term greywater use.

It is clear that irrigation is required for many of those species to pro-

vide maximum benefits; however, to do it sustainably, greywater reuse

might be an option, but its impact on plant functioning needs to be

investigated.

2. Understanding the composite contribution to multiple services by

chosen plants. Most of the studies to date focus on one particular service

by plants, when it is evident that plants simultaneously perform

numerous roles that should now come into focus.

3.

Devising simplified tools to enable end users (landscape designers, private

owners, policy makers) to choose the most effective plant combina-

tions depending on cost and other constraints.

136 Green Roof Retrofit

The challenges for retrofitted green roofs lie additionally in the issues

relating to buildings' load-bearing capacities and limited options for instal-

lation of water supply. Many of the plants we studied, which exhibit a high

capacity for ecosystem services provision, also require additional watering

and at least 10–20 cm substrate depth. Thus, adapting existing lightweight

systems and developing new systems which are capable of supporting such

plants will be required.

**References**

Akbari, H., Kurn, D. M., Bretz, S. E. and Hanford, J. W. (1997) 'Peak power and

cooling energy savings of shade trees', *Energy and Buildings*, 25, 139–148.

Akbari, H., Pomerantz, M. and Taha, H. (2001) 'Cool surfaces and shade trees to

reduce energy use and improve air quality in urban areas', *Solar Energy*, 70,

295–310.

Ascione, F., Bianco, N., de' Rossi, F., Turni, G. and Vanoli, G. P. (2013) 'Green

roofs in European climates. Are effective solutions for the energy savings in

air-conditioning?', *Applied Energy*, 104, 845–859.

Beckett, K. P., Freer-Smith, P. H. and Taylor, G. (2000) 'Particulate pollution capture by urban trees: effect of species and windspread', *Global Change Biology*, 6,

995–1003.

Berndtsson, J. C. (2010) 'Green roof performance towards management of runoff

water quantity and quality: a review', *Ecological Engineering*, 36, 351–360.

Berretta, C., Poë, S. and Stovin, V. (2014) 'Moisture content behaviour in extensive

green roofs during dry periods: the influence of vegetation and substrate charac-

teristics', *Journal of Hydrology*, 511, 374–386.

Blanusa, T., Vaz Monteiro, M. M., Fantozzi, F., Vysini, E., Li, Y. and Cameron, R. W. F.

(2013) 'Alternatives to Sedum on green roofs: can broad leaf perennial plants offer

better "cooling service"?', *Building and Environment*, 59, 99–106.

Berndtsson, J. C. (2010) 'Green roof performance towards management of runoff

water quantity and quality: a review', *Ecological Engineering*, 36, 351–360.

Blanusa, T., Fantozzi, F., Monaci, F., Bargagli, R. (2015) 'Leaf trapping and retention of particles by holm oak and other common tree species in Mediterranean urban

environments', *Urban Forestry & Urban Greening* 14(4), 1095–1101.

Brenneisen, S. (2006) 'Space for urban wildlife: designing green roofs as habitats in

Switzerland', *Urban Habitats*, 4, 27–36.

Cameron, R. W. F., Harrison-Murray, R. S., Atkinson, C. J. and Judd, H. L. (2006)

'Regulated deficit irrigation – a means to control growth in woody ornamentals',

*Journal of Horticultural Science and Biotechnology*, 81, 435–443.

Cameron, R. W. F., Harrison-Murray, R. S., Fordham, M., Wilkinson, S., Davies,

W. J., Atkinson, C. J. and Else, M. A. (2008) 'Regulated deficit irrigation of woody

ornamentals to improve plant quality and precondition against drought stress',

*Annals of Applied Biology*, 153, 49–61.

Cameron, R. W. F., Taylor, J. E. and Emmett, M. R. (2014) 'What's "cool" in the

world of green façades? How plant choice influences the cooling properties of

green walls', *Building and Environment*, 73, 198–207.

Cameron, R. W. F., Taylor, J. E. and Emmett, M. R. (2015) 'A Hedera green

facade – energy performance and saving under different matirime-temperate,

winter weather conditions', *Building and Environment*, 92, 111–121.

Carter, T. L. and Rasmussen, T. C. (2006) 'Hydrologic behavior of vegetated roofs',

*Journal of the American Water Resources Association*, 42, 1261–1274.

Planting Choices for Retrofitted Green Roofs 137

Costanza, R., d'Arge, R., de Groot, R., *et al*. (1997) 'The value of the world's ecosys-

tem services and natural capital', *Nature*, 387, 253–260.

Coutts, A. M., Daly, E., Beringer, J. and Tapper, N. J. (2013) 'Assessing practical

measures to reduce urban heat: green and cool roofs', *Building and Environment*, 70, 266–276.

Dunnett, N. and Kingsbury, N. (2008) *Planting Green Roofs and Living Walls*.

Timber Press: Portland, OR.

Fantozzi, F. (2013) ' *The mitigation of air pollution by urban trees*', University of Siena, Siena.

Farrell, C., Ang, X. Q. and Rayner, J. P. (2013) ‘Water-retention additives increase plant available water in green roof substrates’, *Ecological Engineering*, 52, 112–118.

Freer-Smith, P. H., Beckett, K. P. and Taylor, G. (2005) ‘Deposition velocities to

Sorbus aria, Acer campestre, Populus deltoides × trichocarpa “Beaupré”, Pinus

nigra and × Cupressocyparis leylandii for coarse, fine and ultra-fine particles in the urban environment’, *Environmental Pollution*, 133, 157–167.

Gates, D. M. (1966) ‘Transpiration and energy exchange’, *The Quarterly Review of*

*Biology*, 41, 353–364.

Graceson, A., Hare, M., Monaghan, J. and Hall, N. (2013) ‘The water retention capa-

bilities of growing media for green roofs’, *Ecological Engineering*, 61, 328–334.

Graceson, A., Monaghan, J., Hall, N. and Hare, M. (2014) ‘Plant growth responses

to different growing media for green roofs’, *Ecological Engineering*, 69, 196–200.

Grimmond, S. (2007) ‘Urbanization and global environmental change: local effects

of urban warming’, *Geographical Journal*, 173, 83–88.

Huang, L., Li, J., Zhao, D. and Zhu, J. (2008) ‘A fieldwork study on the diurnal

changes of urban microclimate in four types of ground cover and urban heat

island of Nanjing, China', *Building and Environment*, 43, 7–17.

IPCC (2013) Summary for Policymakers. Climate Change 2013: The Physical

Science Basis. Contribution of Working Group I to Stocker, T. F., Qin, D., Plattner,

G.-K., *et al*. (eds), *Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press: Cambridge.

Jaffal, I., Ouldboukhitine, S.-E. and Belarbi, R. (2012) 'A comprehensive study of the impact of green roofs on building energy performance', *Renewable Energy*, 43,

157–164.

Kadas, G. (2006) 'Rare invertebrates colonizing green roofs in London', *Urban*

*Habitats*, 4, 66–86.

Karhu, K., Mattila, T., Bergström, I. and Regina, K. (2011) 'Biochar addition to

agricultural soil increased CH uptake and water holding capacity – results from



a short-term pilot field study', *Agriculture, Ecosystems & Environment*, 140, 309–313.

Kluge, M. and Ting, I. P. (1978) *Crassulacean Acid Metabolism: Analysis of an eco-*

*logical adaptation*. Springer-Verlag: New York.

Köhler, M. (2006) ‘Long-term vegetation research on two extensive green roofs in

Berlin’, *Urban Habitats*, 4, 3–26.

Kolb, W. and Schwarz, T. (1999) *Dachbegrünung – intensiv und extensiv*. Eugen Ulmer: Stuttgart.

Lazzarin, R. M., Castellotti, F. and Busato, F. (2005) ‘Experimental measurements

and numerical modelling of a green roof’, *Energy and Buildings*, 37, 1260–1267.

Liesecke, H. J. (2001) ‘Zwiebel- und Knollenpflanzen fuer extensive dachbegruenun-

gen’, *Stadt+Gruen*, 50, 133–139.

Liu, T. C., Shyu, G. S., Fang, W. T., Liu, S. Y. and Cheng, B. Y. (2012) ‘Drought toler-

ance and thermal effect measurements for plants suitable for extensive green roof

planting in humid subtropical climates’, *Energy and Buildings*, 47, 180–188.



Lundholm, J., MacIvor, J. S., MacDougall, Z. and Ranalli, M. (2010) ‘Plant species

and functional group combinations affect green roof ecosystem functions’, *PLoS*

*ONE*, 5(3), e9677.

Madre, F., Vergnes, A., Machon, N. and Clergeau, P. (2013) ‘A comparison of 3 types

of green roof as habitats for arthropods’, *Ecological Engineering*, 57, 109–117.

McPherson, E. G., Herrington, L. P. and Heisler, G. M. (1988) ‘Impacts of vegetation

on residential heating and cooling’, *Energy and Buildings*, 12, 41–51.

Mickovski, S. B., Buss, K., McKenzie, B. M. and Sökmener, B. (2013) ‘Laboratory

study on the potential use of recycled inert construction waste material in the

substrate mix for extensive green roofs’, *Ecological Engineering*, 61(C), 706–714.

Mitchell, R. and Maher, B. A. (2009) ‘Evaluation and application of biomagnetic

monitoring of traffic-derived particulate pollution’, *Atmospheric Environment*, 43, 2095–2103.

Mitchell, R., Maher, B. A. and Kinnersley, R. (2010) ‘Rates of particulate pollution

deposition onto leaf surfaces: temporal and inter-species magnetic analyses’,

*Environmental Pollution*, 158, 1472–1478.

Molineux, C. J., Fentiman, C. H. and Gange, A. C. (2009) ‘Characterising alternative

recycled waste materials for use as green roof growing media in the U.K.',

*Ecological Engineering*, 35, 1507–1513.

Monteith, J. L. (1965) 'Evaporation and environment'. *Symposia for the Society of*

*Experimental Biology*, Vol. 19, pp. 205–223.

Monterusso, M. A., Rowe, D. B. and Rugh, C. L. (2005) 'Establishment and persis-

tence of Sedum spp. and native taxa for green roof applications', *HortScience*, 40, 391–396.

Nagase, A. and Dunnett, N. (2010) 'Drought tolerance in different vegetation types

for extensive green roofs: effects of watering and diversity', *Landscape and Urban Planning*, 97, 318–327.

Nagase, A. and Dunnett, N. (2012) 'Amount of water runoff from different vegeta-

tion types on extensive green roofs: effects of plant species, diversity and plant

structure', *Landscape and Urban Planning*, 104, 356–363.

Oberndorfer, E., Lundholm, J., Bass, B., *et al*. (2007) 'Green roofs as urban ecosys-

tems: ecological structures, functions, and services', *BioScience*, 57, 823–833.

Oke, T. R. (1987) *Boundary Layer Climates*, 2nd edn. Methuen: New York.

Pahlke, K. (1989) ‘Establishing an extensive green cover on roofs – a comparison

under practical conditions. Results of a model experiment carried out over three

years’, *Rasen-Turf-Gazon*, 20, 37–41.

Papadakis, G., Tsamis, P. and Kyritsis, S. (2001) ‘An experimental investigation of the effect of shading with plants for solar control of buildings’, *Energy and Buildings*, 33, 831–836.

Poë, S., Stovin, V. and Berretta, C. (2015) ‘Parameters influencing the regeneration of a green roof’s retention capacity via evapotranspiration’, *Journal of Hydrology*, 523, 356–367.

Razzaghmanesh, M., Beecham, S. and Kazemi, F. (2014) ‘Impact of green roofs on

stormwater quality in a South Australian urban environment’, *Science of the Total*

*Environment*, 470, 651–659.

Rosenfeld, A. H., Akbari, H., Romm, J. J. and Pomerantz, M. (1998) ‘Cool commu-

nities: strategies for heat island mitigation and smog reduction’, *Energy and*

*Buildings*, 28, 51–62.

Rowe, D. B. (2011) ‘Green roofs as a means of pollution abatement’, *Environmental*

*Pollution*, 159, 2100–2110.

Sailor, D. J. (2008) ‘A green roof model for building energy simulation programs’,

*Energy and Buildings*, 40, 1466–1478.



Saiz, S., Kennedy, C., Bass, B. and Pressnail, K. (2006) ‘Comparative life cycle assess-

ment of standard and green roofs’, *Environmental Science & Technology*, 40, 4312–4316.

Savi, T., Andri, S. and Nardini, A. (2013) ‘Impact of different green roof layering on plant water status and drought survival’, *Ecological Engineering*, 57, 188–196.

Savi, T., Marin, M., Boldrin, D., Incerti, G., Andri, S. and Nardini, A. (2014) ‘Green roofs for a drier world: effects of hydrogel amendment on substrate and plant

water status’, *Science of the Total Environment*, 490, 467–476.

Shashua-Bar, L., Pearlmutter, D. and Erell, E. (2009) ‘The cooling efficiency of urban landscape strategies in a hot dry climate’, *Landscape and Urban Planning*, 92,

179–186.

Speak, A. F., Rothwell, J. J., Lindley, S. J. and Smith, C. L. (2012) ‘Urban particulate pollution reduction by four species of green roof vegetation in a UK city’,

*Atmospheric Environment*, 61, 283–293.

Speak, A., Rothwell, J., Lindley, S. and Smith, C. (2014) ‘Metal and nutrient dynam-

ics on an aged intensive green roof', *Environmental Pollution*, 184, 33–43.

Stovin, V. (2010) 'The potential of green roofs to manage urban stormwater', *Water and Environment Journal*, 24, 192–199.

Stovin, V., Vesuviano, G. and Kasmin, H. (2012) 'The hydrological performance of a

green roof test bed under UK climatic conditions', *Journal of Hydrology*, 414,

148–161.

Taha, H., Akbari, H., Rosenfeld, A. and Huang, J. (1988) 'Residential cooling loads

and the urban heat island – the effects of albedo', *Building and Environment*, 23, 271–283.

Taiz, L. and Zeiger, E. (2010) *Plant Physiology*. Sinauer Associates: Sunderland.

Van Woert, N. D., Rowe, D. B., Andresen, J. A., Rugh, C. L. and Xiao, L. (2005)

'Watering regime and green roof substrate design affect *Sedum* plant growth',

*HortScience*, 40, 659–664.

Vaz Monteiro, M. M. (2015) ' *Plants and temperature regulation: the impact of leaf*

*and plant structure and function on leaf temperature and surface energy balance*'.

PhD thesis, University of Reading, UK.

Vaz Monteiro, M.M., Blanusa, T., Verhoef, A., Hadley, P., Cameron, R.W.F. (2016a)

‘Relative importance of transpiration rate and leaf morphological traits for the

regulation of leaf temperature’, *Australian Journal of Botany*, 64, 32–44.

Vaz Monteiro, M., Hadley, P., Blanusa, T., Cameron, R.W.F. (2016b) ‘Implication of

plant selection for building insulation’, *Acta Horticulturae*, 1108, 339–344.

Volder, A. and Dvorak, B. (2014) ‘Event size, substrate water content and vegetation

affect storm water retention efficiency of an un-irrigated extensive green roof

system in Central Texas’, *Sustainable Cities and Society*, 10, 59–64.

Wong, N. H., Chen, Y., Ong, C. L. and Sia, A. (2003) ‘Investigation of thermal

benefits of rooftop garden in the tropical environment’, *Building and Environment*, 38, 261–270.

**18**

# Green Roof Retrofitting and Conservation of Endangered Flora

**Paul Osmond and John Blair**

UNSW, Sydney, Australia

## 8.0 Introduction

Multiple environmental, social and economic benefits of green roofs are

widely reported in the literature, which includes: landmark studies such

as Banting *et al*. (2005), Kennedy *et al*. (2008) and Snodgrass and McIntyre (2010); robust cost–benefit analyses from the Center for Neighborhood

Technology and American Rivers (2010), the US General Services

Administration (USGSA, 2011) and Kats and Glassbrook (2015); and in

Australia – a latecomer to green roof research and practice – the pioneer-

ing studies of Williams *et al*., (2010) and Hopkins and Goodwin (2011).

However, the question of biodiversity protection and conservation of

endangered flora has received much less attention than benefits such as

stormwater detention or building energy savings. This chapter provides a

brief theoretical context for biodiversity conservation more generally,

before examining the current state of play regarding the application of

roof greening in the protection of endangered flora. The chapter con-

cludes with the presentation of a research design for a rooftop conserva-

tion project which is intended to address some of the knowledge gaps identified. The plant species involved belong to the Eastern Suburbs Banksia Scrub (ESBS), an endangered plant community indigenous to Sydney's coastal region.

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



**8.1**

## Biodiversity Conservation – a Strategic Overview

Biodiversity conservation – whether conceived for the benefit of future generations of humans or for its own sake – stands alongside climate change mitigation and adaptation as one of the overarching environmental challenges of the 21st century. Paradoxically, the process of urbanisation both enhances and diminishes vegetation biodiversity. As the existing indigenous flora submits to the bulldozer and the chainsaw, a veritable cornucopia of exotic plants sourced from around the world is taking root in the

city's public and private gardens. Moreover, together with the spread of

those ever-present camp followers that accompany human settlement, a.k.a.

'weeds', the invasion of this new artificial biodiversity challenges remnant

native biodiversity on all three levels: community, species and genetic.

Although it is neither scientifically defensible nor practical to turn back the

tide of neo-biodiversity,1 it is justifiable to resist the trend towards bio-

homogeneity. From this perspective, the effort to retain maximal variety2

across plant communities, species and genetic information must include

strategies for conserving a place's original flora.

Margules and Pressey (2000) have argued for a more systematic approach

to conservation planning, which both ensures the representation of a region's

biodiversity and separates this biodiversity from processes that threaten its

persistence. In the city, this is difficult. Habitat becomes increasingly frag-

mented into smaller, albeit more numerous, remnant patches (McKinney,

2002) within an inhospitable matrix of developed land. Moreover, species

richness generally declines as fragment area decreases (Collinge, 1996).

Accordingly, the significance of all types of urban green space for biodiver-

sity conservation grows (Goddard *et al*., 2010), including rooftops, espe-

cially in inner city areas where open space at grade is limited. Moreover,

green roofs designed to facilitate habitat conservation on new developments

could help resolve the invariable conflicts between ecology and commerce

(Gedge and Kadas, 2005), and provide new opportunities for denatured

urbanites to re-engage with their environment. With the majority of the

world's population now being city dwellers, our main experiences of 'nature'

increasingly occur within the urban fabric (Kowarik, 2011).

Remnant indigenous species typically survive, indeed often thrive, in those

spaces which are overlooked, unavailable or inappropriate for urban devel-

opment, including cliffs, gullies, swamps, infrastructure easements and cem-

eteries. Such spaces are defined primarily by fragmentation, and, thanks to

the role of linear easements, connectivity. At this local scale, the ‘edge effect’3

becomes noteworthy. Fragmentation of continuous natural habitat results in

1 We return to the topic of neo-biodiversity or ‘novel ecosystems’ (Hobbs *et al*., 2013) later in this chapter.

2 Ecologically, to build resilience to external disturbance (such as climate change);

from an anthropocentric perspective, to build potential for provision of food, fibre,

medicines, etc.

3 Changes in species composition, population and community structure at the bound-

ary between two habitats.



(a)

(b)

(c)

**Figure 8.1** (a) Pre-development habitat; (b) fragmented landscape post-development, showing a rail reserve, major park and smaller green spaces; (c) new ‘stepping stone’ spaces (such as green roofs) link existing parks and reserves. The black lines represent connectivity.

a decrease in the ratio of area to perimeter of the newly created frag-

ments – in other words, longer boundaries. For example, the area-to-

perimeter ratio for the intact green space depicted in Figure 8.1(a) is 24:1;

the ratio for the dispersed green space in Figure 8.1(b) is just 2.2:1. Although

the area of green space in the built-up example is less than one-sixth that

of the undeveloped example, the total perimeter is almost twice the length.

More edge means more opportunities for fragmented natural habitats to be

influenced by surrounding built-up habitats, through exchanges of materi-

als, energy and organisms (Collinge, 1996) – for example, invasive garden

escapees and weeds.

As noted above, corridors enable connectivity between habitat fragments,

an issue of more relevance to fauna than flora, but nonetheless an opportu-

nity for the spread of organisms (and the exchange of genes) between intact

fragments. A detailed meta-analysis by Beier and Noss (1998) found that

despite some scepticism about their value, the evidence from well-designed

studies suggests that corridors are valuable conservation tools. The sketch in

Figure 8.1(c) shows schematically how a series of small retrofitted green

spaces such as backyards or green roofs could be planted with indigenous

species to act as links between more significant areas of indigenous biodiver-

sity. Although not strictly corridors, such ecological stepping stones can pro-

vide stop-off points for birds and invertebrates (Hopkins and Goodwin,

2011) and an opportunity for seeds to disperse, settle and germinate.

Following from the above, the starting point for the preservation and

management of remnant indigenous vegetation in urban areas – including

examples of rare and endangered species – may be characterised in terms of

‘honey pots and spider webs’. The former represent discrete reservoirs of

native biodiversity, while the latter represent existing or newly designed con-

nections between them. It is in this context that a city-wide green roof strat-

egy to support biodiversity conservation and enhancement may be fashioned.

Such a strategy, of course, goes beyond the biodiversity conservation

objectives articulated in this chapter to address a plethora of co-benefits.

This green roof strategy represents a landscape design response to the socio-

environmental problems common to built-up places – not just the loss and



simplification of ecosystems, but pollution, excessive motor traffic, the

overwhelming pervasiveness of artificial structures and also an opportunity

to build on the positive aspects of city living.

Before moving from landscape planning at city scale to landscape design

at neighbourhood and building scale, several other principles are worth

recording:

■

In habitat conservation, *individually* insignificant sites become important

*collectively* (i.e., as an integrated system).

■

An increased number of ecosystem connections and interactions height-

ens stability and resilience (Naveh and Lieberman, 1990), which under-

pins design objectives to improve current habitat linkages and establish

new ones.

■

Full *replication* of the complex plant communities which existed pre-

development is not ecologically possible in the city, hence *indication* is

the appropriate objective (Osmond, 1994).

■

In turn, this can inform a new landscape design aesthetic in which plant-

ing is based on context and function in addition to ecology to create ecologically multi-functional landscapes with their own local identity.

Another important consideration is the unavoidable *incrementalism* resulting from private (residential or business) premises becoming the main focus of rooftop greening for nature conservation (as distinct from government and other public buildings), which is crucial to any city-wide rollout. In these circumstances, sites, resources and the time to connect them become available less by design and more as a by-product of the interactions of a myriad of public and private actors. However, while the need to operate in an incremental framework is at odds with outcome-oriented master planning, it does allow for the flexibility and experimentation fundamental to the evolution of a new design/conservation concept.

Further, involvement of householders and businesses in green roof installation and maintenance represents a fine example of bottom-up

‘reconciliation ecology’ – reconciling human and non-human use of urban

space to support biological conservation (Francis and Lorimer, 2011).

Enlisting community support for local biodiversity conservation is

achievable, as evidenced by the numerous bush-care groups operating in

the Sydney region. In contrast, the effort involved in public awareness

building and citizen training and education to achieve the necessary level

of adaptive collaborative management (Henry and Frascaria-Lacoste,

2011) should not be underestimated.

## 8.2

## A Review of Green Roofs in Habitat Conservation

A focus on optimising the *physical* benefits of green roofs, such as stormwa-

ter detention, microclimate modification and heating/cooling energy reduc-

tion, has meant that a key *biological* variable – plant species – has often been treated as if it were a constant. The conventional response to the objective of



ensuring viable plant cover to optimise the above benefits is to install those

plants known to perform well on rooftops, such as *Sedum* species (e.g.,

Monterusso *et al*., 2005). Although most research relating to green roof bio-

diversity has focused on fauna (Williams *et al*., 2014), recent studies from

several countries have found that a low-diversity mix of cosmopolitan

succulents is not the only solution to plant performance.

Sutton *et al*. (2012), for example, found that many North American

prairie and grassland species, subject to harsh growing conditions in their

natural habitats, will flourish on extensive green roofs. Across the

Atlantic, Madre *et al*. (2014) confirmed the benefits of rooftop greening

in creating indigenous habitat, in this case through providing a medium

for colonisation by a variety of ‘volunteer’ flora. 86% of species across

115 roofs were native to the locality (northern France). They found that

plant diversity was strongly related to substrate depth, and the taxonomic

and functional composition of the colonising plant communities was also

shaped by green roof age, surface area, and height and maintenance

intensity at building scale (Madre *et al*., 2014). Ishimatsu and Ito (2013)

explored the notion of ‘brown/biodiverse’ roofs on brownfield (previ-

ously developed, now abandoned) sites in the UK. They argue that brown-

fields provide habitat conditions similar to more natural habitats and can

help maintain populations of some rare species. The key, they found, is to

preserve the top layer of natural substrate, including existing vegetation,

seed bank and soil organisms, for subsequent installation on the roofs of

new developments.

The broadly generalisable conclusion from the literature is that indige-

nous species, which thrive in shallow soils, tolerate drought and are adapted

to high winds, extreme temperatures and intense sunlight (particularly dry

grassland, coastal and alpine floras; Oberndorfer *et al*., 2007), are well

suited to green roof installation. As Williams *et al*. (2014) point out, how-

ever, rare and threatened plant species or communities that do not fall into

this category are probably best conserved and managed in situ at ground

level at this stage.

The concept of ‘novel ecosystems’ was mentioned at the beginning of this

chapter, referring to the changes in species composition resulting from the

interaction between existing native biota, introduced flora and fauna, and

the altered physical/environmental conditions of urbanisation. They are

defined by human agency, so that these ‘intermingled’ ecosystems are the

result of deliberate or inadvertent human action (Hobbs *et al*., 2006). While

urban habitats can harbour self-sustaining populations of rare and endan-

gered native species, they cannot replace the complete functionality of

nature (Kowarik, 2011). However, even intermingled urban ecosystems may

support threatened native plants. *Functional diversity* (Van Mechelen *et al*., 2015) offers one useful framework for designing this kind of ecosystem,

including opportunities to incorporate threatened local species. A functional

trait is any measurable property of an organism that reflects what it is doing

and how it interacts with other organisms and its physical environment. The

functional diversity of vegetation is defined by traits such as plant height,

longevity, leaf area, succulence and flowering time. Moreover, functional



diversity is strongly associated with the provision of ecosystem services.4

Where there is demonstrable correlation between species biodiversity and

functional (trait) diversity, the inclusion of rare indigenous plants with the

desired traits in a new green roof assemblage could address the dual objec-

tives of maximising ecosystem services and species conservation. Preservation

of threatened species, possibly as part of a biodiverse intermingled ecosys-

tem, thus becomes one way in which the principle of *indication* rather than

*replication* of pre-development biodiversity introduced above (Osmond,

1994) may be given practical expression on our urban rooftops through

skilful design.

The general principles of urban biodiversity conservation discussed above

affirm that the habitat potential of a green roof can only be evaluated in the

context of the broader urban landscape. Green roof characteristics like

height above ground, available area, human visitation (if any), microclimate

and relation to key natural areas in the urban landscape underpin their bio-

diversity benefits and must be considered in any policies advocating green

roofs as habitat (Williams *et al*., 2014). Blank *et al*. (2013) also point out that establishing a viable network of green roofs would help support biodiversity and serve as stepping stones to shorten links between existing habi-

tats. These two groups of researchers also suggest that there will be

difficulties in achieving this with green roofs given the confounding issues of

plant health and abundance, substrate depth and roof load-bearing capacity.

Finding rooftops in strategic locations to connect the generally fragmented

networks of threatened and endangered species, and then managing them,

could be demanding. Generating strong levels of collaborative management

could meet the challenge, however (Francis and Lorimer, 2011).

The biodiversity research conducted on green roofs can offer a degree of

guidance on endangered species, although most of the research has focused

on locally abundant species, not necessarily endangered or under threat.

One frequently occurring message from the recent literature is that local

species exhibit improved performance over the common *Sedum* roof

(Lundholm *et al*., 2010; McIvor and Lundholm, 2011). Nagase and Dunnett

(2012) found that *Sedum* roofs had greater levels of stormwater runoff than

bare roofs, and McIvor and Lundholm (2011) found surprising performance

differences in growth rates and vegetation abundance between the local spe-

cies used in their study – such as *Carex argyrathra* and *Carex nigra* – and the industry standard green roof succulents, *Sedum acre* and *Sedum spurium*.

Perhaps *Sedum* vegetation is popular because it is easier to install, easily

modularised and relatively cheap. Kraft (2013: 1) quotes McIvor, a conser-

vation biologist: ‘The problem is that *Sedum* plants aren’t really performing

on green roofs… They’re just there.’ Apart from not absorbing water as

efficiently as other species, at certain times of the year *Sedum* actually

absorbs heat instead of deflecting it (Kraft, 2013).

4 Those services which the natural environment provides to humanity – such as

food and fibre, carbon sequestration, and cultural and recreational opportunities.



Another frequent theme is the need to match substrate depth and nutrient

quality with the desired plant species (McIvor and Lundholm, 2011). Nagase

and Dunnett (2011) found that the response to higher levels of organic matter

was different for different species, and that species from a nitrogen-rich habi-

tat tended to be encouraged by a high nitrogen content. Similarly, Brenneisen’s

work (2006) on green roofs in Zurich, Switzerland has shown that the use of

natural soils can benefit biodiversity, with useful implications for sustaining

endangered species. Australia has a uniquely high proportion of nutrient-poor

soils to which (along with fire) much of the continent's native flora is adapted

(Orians and Milewski, 2007). Hence, the substrate nutrient status needs to be

carefully considered in green roof design using locally indigenous species, irre-

spective of whether natural or manufactured growing media are selected.

At the same time, little research has been done on the non-plant biota

associated with green roofs. McGuire *et al*. (2013) have pointed out that the

microbial biomass and bacterial-to-fungal ratios are higher in ground-level

parks than in green roof substrates in New York. The authors suggest that

microbial levels may influence plant functionality and propose that microbes

and fungi on green roofs may be an underestimated component of these

systems. The lesson from these studies is that careful planning around

targeted plant species is likely to produce better performance.

## 8.3

## Knowledge Gaps and Further Research

Blank *et al*. (2013) found that research on green roof biodiversity had increased significantly but still received only a small fraction of the total research effort.

Nevertheless, the breadth and depth of current green roof research belies the

relative youth of the subject, though there are still substantial knowledge gaps

relevant to habitat restoration and conservation. Although tentative evidence

suggests green roofs can provide habitat for both generalist and some rare

species, Williams *et al*. (2014) point out that there have not been enough eco-

logical studies globally with adequate replication and controls, or of sufficient

duration, to adequately test the proposition that green roofs have sufficient

potential to connect to ground-level habitats.

Drawing on a four-year study of plant assemblages on two green roofs in

Birmingham, UK, designed to emulate diverse brownfield habitats, Bates

*et al*. (2013) also highlight the need for more medium and long-term studies,

and specifically the role of rooftop micro-habitats including the effects of

different types of growing media. In their detailed investigation of the roof-

top performance of native American grassland species, Sutton *et al*. (2012)

list several significant knowledge gaps, verified by researchers such as

Lundholm *et al*. (2010), MacIvor and Lundholm (2011), Nagase and

Dunnett (2011, 2012) and McGuire *et al*. (2013), and applicable in princi-

ple to a wide range of plant communities and climate zones:

- relationships between substrate, root structure and plant growth;
- nutrient turnover and substrate fertility;
- water–plant relations and the role of irrigation;

■

roof temperatures and plant performance under extreme conditions;

■

soil microbiological diversity.

A case study research design that would address most of these gaps follows. It is

framed around the ESBS, Sydney's endangered coastal plant community, but the

principles and many of the details are applicable to any jurisdiction interested

in applying roof greening to biodiversity and endangered species conservation.

### 8.3.1

### A Research Programme for Conserving Endangered Species

### on Green Roofs

To quote Williams *et al*. (2014: 1643): 'Ecologists need to work with the industry to evaluate green roof biodiversity and help design green roofs based on

ecological principles to maximize biodiversity gains.' While this statement is

applicable to most green roof endeavours, intuitively the ESBS community may

not need high levels of management. It has displayed considerable resilience in

its natural growing conditions, with plant cover in long unburned fragments of

ESBS being species poor but the soil seed bank retaining diversity. The intense

sunlight, coastal sea breezes (which can be strong) and unusually nutrient-poor

Aeolian sands are further evidence of the resilience of the ESBS (Pellow *et al*., 2015). Artificial conditions on the rooftops of the low-rise buildings typical of

this part of Sydney are unlikely to be significantly more challenging.

Objective 3 of the ESBS Recovery Plan is to improve the conservation

management of the community (NSW Department of Environment and

Conservation, 2004: 10–12): ‘To restore, and where practical, connect and

enlarge remnants through appropriate management.’ Since the area of ESBS

is declining (Perkins *et al*., 2012), one possible way of arresting the loss is to follow the reconciliation ecology concept and establish new sites in the form

of green roofs, which represent considerable potential for urban conserva-

tion given the limited opportunities for establishing new parks and reserves

in urban areas (Francis and Lorimer, 2011).

### 8.3.2

### The Endangered Community of the Eastern

### Suburbs Banksia Scrub

The ESBS is a shrub-dominated and largely sclerophyllous heath community

on nutrient-poor Aeolian dune sand, confined to the coastal suburbs of

Sydney, NSW, Australia (NSW Scientific Committee, 2002). The ESBS con-

sists of a minimum of 63 separate plant species, is near extinct (Perkins *et al*., 2012), and is listed at the state and national levels as an endangered ecological

community. It covered approximately 5300 ha at the time of European

settlement in 1788, but is now a highly fragmented 145 ha on about 24 sites

(Figure 8.2). Less than 3% of its original area remains (NSW Department of

Environment and Conservation, 2004) and several small fragments are

under imminent threat of development and exhibit quite high levels of

degradation (Perkins *et al*., 2012: 224; Pellow *et al*., 2015).



148 Green Roof Retrofit

MANLY

WILLOUGHBY

**NORTH**

LANE COVE

**HEAD**

NORTH SYDNEY

MOSMAN

**PORT**

**JACKSON**

LEICHHARDT

**WOOLLAHRA**

**SOUTH SYDNEY**

**WAVERLEY**

MARRICKVILLE

**RANDWICK**

**PACIFIC**

**OCEAN**

ROCKDALE

**BOTANY**

LOCAL GOVERNMENT AREA

PREVIOUS DISTRIBUTION (approx 5,300 ha)

CURRENT DISTRIBUTION (149 ha)

**Figure 8.2** Location of ESBS sites.

*Source:* NSW Department of Environment and Climate Change (2009).

**Figure 8.3** The ‘scrub’ in rich profusion.

*Source*: NSW Department of Environment and Conservation (2004).

Common species in the ESBS community (Figure 8.3) include over-storey

4–5

m trees like the Heath-leaved Banksia ( *Banksia ericifolia*), Old

Man Banksia ( *B. serrata*), Coast Teatree ( *Leptospermum laevigatum*)

and Tree Broom-heath ( *Monotoca elliptica*); sub-shrubs and ground-cover

species like *Epacris* spp., Pink Wax Flower ( *Eriostemon australasius*),

Variable Sword Sedge ( *Lepidosperma laterale*) and Grass Tree ( *Xanthorrhoea*

*resinifera*). The ESBS is a predominantly fire-adapted community, highly

dynamic and characterised by periodic ecological disturbance, regenerating

by re-sprouting and germinating from the soil seed bank (Bradstock *et al*.,

1995; NSW Department of Environment and Climate Change, 2009).

The ESBS community was the first ecological community to be listed as

endangered under the NSW Threatened Species Conservation Act 1995. It

has also been listed as endangered under the Australian Government's

Environment Protection and Biodiversity Conservation Act 1999. Both stat-

utes required a recovery plan, which was approved in 2004, followed by

best-practice guidelines (NSW Department of Environment and Climate

Change, 2009) and management plans for a limited number of sites.

The degree and extent of regeneration from the persistent seed bank

following restoration at one of the medium-size sites were ‘sensational’

(Perkins and McDonald, 2012: 132). The total number of native species

increased only slightly over the six years (2001–2007), from 31 to 35 species,

but there was a dramatic increase in abundance and distribution across the

site (Perkins *et al*., 2012).

In all management units, the removal of weed or heavy shade was suffi-

cient to trigger germination of a range of species in most of the treated

quadrats, although germination still occurred in poorer-condition plots

without the addition of seeds. Practitioners also found that discarding the

thick leaf-litter layer and debris crust was important in that it revealed the

more natural Aeolian sandy soil and simultaneously removed weedy and

nutrient-rich top soils. This is an important finding given the intention to

raise species *indicative* of the ESBS on trial green roofs in coastal Sydney. It is also pertinent in a more general sense that plant resilience in the ESBS’s

case has been remarkable, a characteristic that bodes well for its transfer to

the environment of green roofs, which are normally viewed as extreme. It

certainly raises confidence that conservation objectives might readily be

achieved with some plant species, whether endangered or more abundant.

## 8.4

## A Model Research Design for Species Conservation

### 8.4.1

### Extensive or Intensive Roofs?

The selection of extensive versus intensive roofs will depend on the vegeta-

tion structure desired at maturity. However, the height and canopy cover

possible on intensive roofs is unlikely to occur in Sydney, where most green

roof retrofits will take place on buildings that do not generally have the

load-bearing capacity for thick substrates and luxuriant vegetation. A fur-

ther issue connected with green roofs, at least in Sydney, is noise and privacy.

Local councils often place access restrictions on development approv-

als – except for maintenance (Wise, 2011; Knierem, 2014). It may mean that

extensive roofs will be favoured, since they are not especially conducive for

passive relaxation and avoid the possible need for structural upgrades for

intensive roofs. Ironically, access restrictions may mean that conservation



objectives for establishing threatened or endangered species on roofs can be

more easily met. As noted above, the ESBS grows on nutrient-poor sands but

supports a density and variety of vegetation more normally associated with

the deeper and richer substrates of intensive roofs, which then become more

attractive as recreation space for building occupants.

### 8.4.2

### Research Objectives

The research should be long term – four to five years - to allow monitoring

of plant condition and especially to observe a full cycle of seed planting and

germination, growth into young seedlings, maturation, further seed genera-

tion by the maturing plants and natural germination. The research in this

case would have the overall goal of supporting Objective 3 of the ESBS

Recovery Plan (NSW Department of Environment and Conservation, 2004)

and helping to combat the apparent ongoing loss of species and restricted

gene pool in some fragments of the ESBS (Perkins *et al*., 2012). However, the

framework suggested here would be applicable broadly to green roof research

and biodiversity conservation.5 Moreover, such research not only implements

endangered plant species conservation but also offers more general ecosys-

tem benefits.

Specific objectives for the ESBS are as follows:

(i) Develop the green roofs as new sites to establish ‘indicator’ species of

the ESBS and track their relative performance on natural and artifi-

cial substrates of different depths (Figure 8.4).

(ii) Establish the ability of green roofs to act as a conservation medium

and seed bank for a range of species within the ESBS community.

(iii) Support the reintroduction of species now absent from remnant sites.

(iv) In particular, use the green roof sites to re-establish ESBS species that

are sensitive to being crowded out by more vigorous and resilient

native species (e.g., *Acacia* spp.), which are no longer controlled by

fire (Gill, 1981; Tozer and Bradstock, 2002).

(v) Support species that do not form soil seed banks (e.g., *Banksia* spp.)

and those whose seed banks are not persistent.

(vi) Test the ability of green roofs to mimic natural ground-level habitats

with a view to scaling up their role more generally in the conserva-

tion of threatened and endangered species.

(vii) Gauge the effectiveness of green roofs to act as stepping stones for

nectarivorous birds and insects (e.g., native bees) that may help with

pollination.

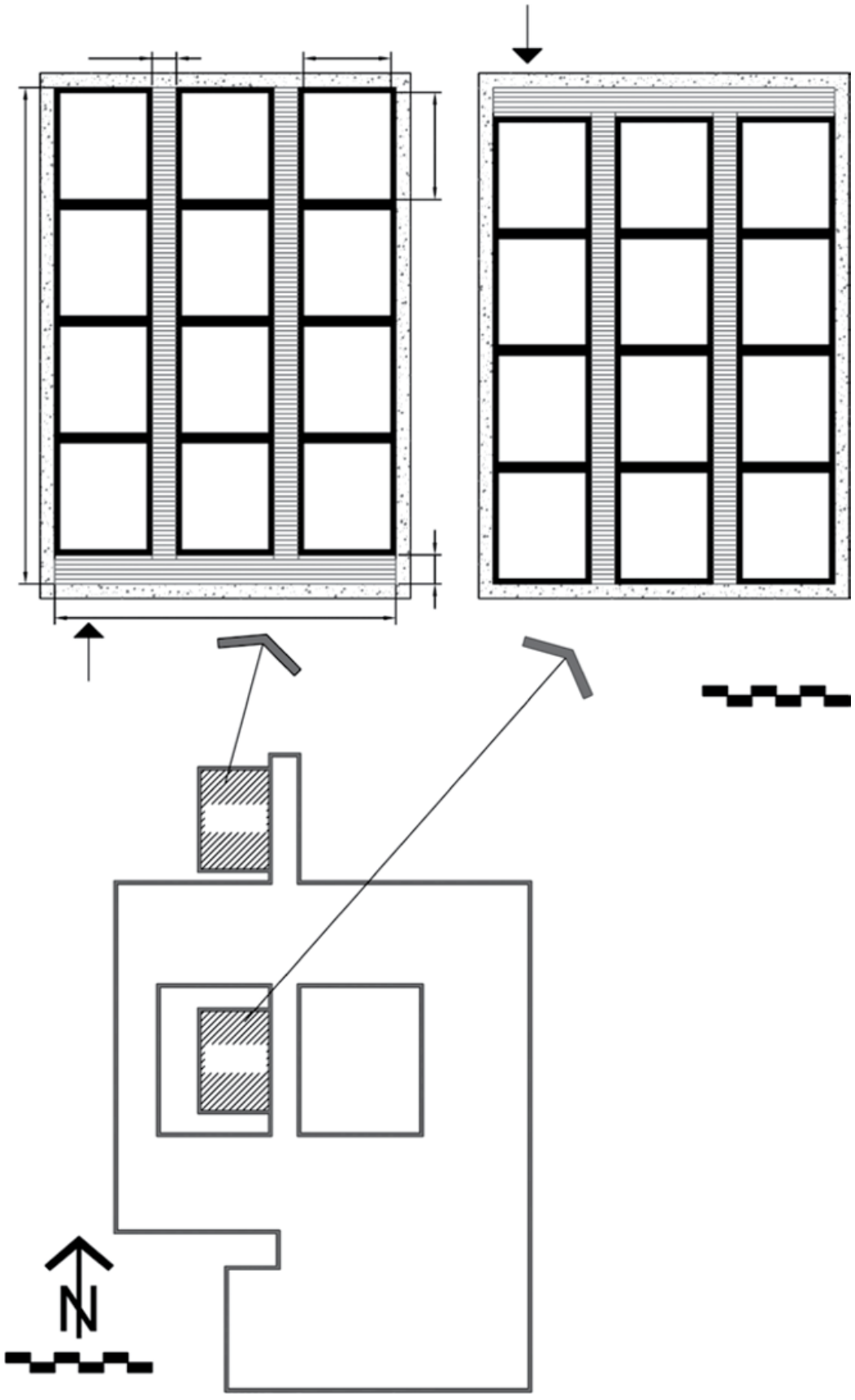
(viii) The project will necessitate cross-disciplinary contact among UNSW

researchers as well as collaboration with external partners such as

5 The authors will seek funding to implement this research design and propose to use

two derelict green roofs at the UNSW campus, each 73 m at first-floor level, to test

the suitability of roof greening as a strategy for ESBS conservation. The roofs are on student accommodation and are about 20 m apart.


N

Green Roof Retrofitting and Conservation of Endangered Flora 151

Ladder

0.5

GR1

1.8

GR2

A

B

C

1

1

1

C

B

A

2.2

i

ii

iii

2

3

2

ii

ii

ii

B

C

A

1

1

1

A

C

B

i

ii

iii

1

1

1

i

ii

iii

C

A

B

10.2

1

1

1

B

A

C

i

ii

iii

1

1

1

i

ii

iii

A

B

C

3

2

3

C

B

A

ii

ii

ii

1

1

1

i

ii

iii

0.6

7

Ladder

0

1

2

3 m

Garden GR1

at grade

Experimental design

Substrate type

A = Natural Aeolian sand

B = Artificial Aeolian sand

C = Commercial GR substrate

Vegetation type

1 = ESBS

GR2

Courtyard

2 = Sedum sp

3 = Unplanted

Courtyard

Substrate depth

International house

i = 50 mm

ii = 100 mm

iii = 150 mm

0

5

10 15 m

**Figure 8.4** Experimental design for the ESBS green roof project.



the City of Randwick and its community nursery; industry sources of materials for infrastructure and substrates; and organisations that have worked on site restoration of the ESBS or who are familiar with restoration principles.

### 8.4.3 Guiding Principles for ESBS Regeneration

(i) The relationship often existing between substrate depth and fertility and plant abundance (e.g., Brenneisen, 2006; Madre *et al*., 2014) may not exist in the case of the ESBS, since lush vegetation can exist on

infertile and relatively thin sands. Consequently, the guiding principle should be to match conditions on the green roof closely with those enjoyed by the natural community (e.g., Oberndorfer *et al*., 2007; Razzaghmanesh *et al*., 2014; Williams *et al*., 2014). This may seem self-evident, but it is likely to be critical to success.

(ii) Matching tactics should also test the ESBS Aeolian sand mantle for soil micro-organisms and fungal populations and ensure representative communities are included in the green roof substrate (McGuire *et al*., 2013).

(iii) The green roof installation should employ features found at grade, such as rocks and tree branches, to provide suitable microclimates as well as shade (from companion plants) and sunny areas to encourage plant diversity (Köhler, 2006). Features like tree branches many need to be fabricated from lightweight materials to minimise roof loads.

(iv) The planting design should maximise ecosystem services by increasing the functional diversity of species planted, within the constraints imposed by substrate depth.

(v) Irrigation will not be used, since Razzaghmanesh *et al*.'s (2014) find-

ings regarding improved plant survival rates with supplementary

watering do not apply to the higher precipitation levels experienced by

Sydney and the ESBS is drought adapted.

(vi) Successful implementation will require a detailed monitoring plan in

order to track progress in achieving objectives.

**8.4.4**

**Preparatory Steps**

(i) The sites currently do not have fixed access from ground level. Access

compliant with the New South Wales Workplace Health and Safety

Act 2011 will be constructed and green roof infrastructure installed

on both roofs (membrane, drainage layer, root barrier and substrate).

(ii) Roofs will be prepared for planting by removing existing weeds,

scoria and rubbish.

(iii) The roofs will each be subdivided into 12 approximately 4 m2 test

beds according to a modified Latin square design based on substrate

type.

(iv) Three substrate types will be intalled: samples of the natural Aeolian

sand mantle of the ESBS from a fragmentary site about to be developed; a manufactured sand mantle, which closely mimics the original ESBS substrate; and a standard commercial green roof growing mix, all inoculated with suitable micro-organisms.

(v) Three substrate depths will be used: 50 mm, 100 mm and 150 mm.

(vi) The experimental design will include two test beds of *Sedum* spp. as

controls, and two unplanted beds. The latter are included to test the substrates' capacity to facilitate germination of 'volunteer' seeds. This will include seeds from the soil seed bank for the natural Aeolian sand, and airborne seeds for the articifial Aeolian sand.

(vii) ESBS seedlings and seeds will be sourced from the community nursery

operated by Randwick City Council. Randwick is the Sydney local government area (LGA) containing the greatest proportion of remaining ESBS, and also the LGA in which the university is situated.

### 8.4.5 Monitoring

The following monitoring programme is proposed for the two green roofs:

a) Assess ESBS species survival, viability and growth through performance

parameters such as re-sprouting and self-germination propensity, leaf

area index, plant coverage and plant abundance compared with the

same plants on restored ESBS fragments described above and managed

by the NSW Office of Environment and Heritage.

b) Assess native faunal biodiversity (avian, reptilian, invertebrate) through

data collection and application of suitable diversity indices.

c) Collect and germinate seed to evaluate the viability of the green roof as

a seed orchard for selected ESBS species.

d) Evaluate the seeding and germination potential of ESBS species which

have had reproduction difficulties in cultivation.

e) Record the volunteer plants on the unplanted natural and manufac-

tured ESBS substrates.

**8.4.6**

**Expected Outcomes**

(i) Performance parameters for selected plants in the ESBS endangered

community on green roofs (e.g., viability, growth rates and vigour);

ESBS performance parameters tested against several types of substrate.

(ii) Green roof performance vis-à-vis faunal biodiversity (invertebrate and

avian).

(iii) Capacity of green roofs to provide ESBS seed orchard services.

(iv) Provision of seeds for distribution to the four local councils that still

have remnants in their area; NSW government agencies, especially the

Department of Environment, Climate Change and Water and the

Office of Environment and Heritage.



## 8.5 Conclusions

Green roof benefits such as stormwater detention and reduction of building

heating and cooling energy needs are well researched, relatively easy to

quantify and widely understood by built environment professionals. Much

less attention has been paid to the potential of rooftop greening as a strategy

for biodiversity protection and conservation of endangered vegetation in

our densifying cities. Nonetheless, work done to date on this topic suggests

that green roofs may have an important role. For example, the harsh condi-

tions associated with growing plants on a structure mimic the circumstances

frequently associated with the persistence of remnant indigenous flora,

including threatened species, at grade.

Urban ecosystem conservation and management strategies include the

development of networks of reserves and corridors – ‘honey pots and spider

webs’ – to maximise resilience and diversity. Strategies may also include estab-

lishment of functional ‘novel’ or intermingled plant communities in circum-

stances where spatial fragmentation and loss of biodiversity mean that it is

not possible to replicate a city’s pre-development natural communities. In this

situation, *indication* rather than *replication* of original ecosystems becomes a design objective. This is also the default scenario where extensive green

roofs – which automatically exclude the use of trees and larger shrubs – are

installed to supplement conventional ground-level conservation efforts.

While the relatively sparse literature on roof greening as a vegetation con-

servation strategy offers some general principles, specific case studies are

important both to test and to validate these principles, and to contribute to

the cumulative experience needed to inform future practice. Australia is

known for its unique flora and fauna, but less positively for its record of

extinctions over the past 200 years. On the contrary, individual native spe-

cies and fragmented communities such as Sydney's Eastern Suburbs Banksia

Scrub manage to survive even in highly built-up areas. The ESBS is intro-

duced here as the focus for a five-year programme with the objectives of

evaluating the role of green roofs in the management of this particular com-

munity and addressing the more general research gaps around roof greening

and indigenous plant conservation identified above. Such a research agenda

will hopefully contribute to establishing green roofs as a viable conservation

strategy with outcomes applicable at international as well as local scale.

**References**

Banting, D., Doshi, H., Li, J. and Missios, P. (2005) Report on the Environmental

Benefits and Costs of Green Roof Technology for the City of Toronto. Ryerson

University, Toronto.

Bates, A. J., Sadler, J. P. and Mackay, R. (2013) 'Vegetation development over four years on two green roofs in the UK', *Urban Forestry & Urban Greening*, 12, 98–108.

Beier, P. and Reed, N. (1998) 'Do habitat corridors provide connectivity?',

*Conservation Biology*, 12(6), 1241–1252.

Blank, L., Vasl, A., Levy, S., *et al*. (2013) 'Directions in green roof research: a biblio-metric study', *Building and Environment*, 66, 23–28.

Green Roof Retrofitting and Conservation of Endangered Flora 155

Bradstock, R. A., Keith, D. A. and Auld, T. D. (1995) 'Fire and conservation: impera-

tives and constraints on managing for diversity'. In Bradstock, R. A., Auld, T. D.,

Keith, D. A., *et al*. (eds), *Conserving Biodiversity: Threats and solutions*. NSW

National Parks and Wildife Service: Sydney; pp. 323–333.

Brenneisen, S. (2006) ‘Space for urban wildlife: designing green roofs as habitats in

Switzerland’, *Urban Habitats*, Vol. 4: Dec.

Center for Neighborhood Technology and American Rivers (2010). *The Value of*

*Green Infrastructure*. CNT and American Rivers: Washington D.C.

Collinge, S. K. (1996) ‘Ecological consequences of habitat fragmentation: implica-

tions for landscape architecture and planning’, *Landscape and Urban Planning*,

36, 59–77.

Francis, R. and Lorimer, J. (2011) ‘Urban reconciliation ecology: the potential

of living roofs and walls’, *Journal of Environmental Management*, 92(6),

1429–1437.

Gedge, D. and Kadas, G. (2005) ‘Green roofs and biodiversity’, *Biologist*, 52(3), 161–169.

Gill, A. M. (1981) ‘Adaptive responses of Australian vascular plant species to fires’.

In Gill, A. M., Groves, R. H. and Noble, I. R. (eds), *Fire and the Australian Biota*.

Australian Academy of Science: Canberra.

Goddard, M. A., Dougill, A. J. and Benton, T. G. (2010) ‘Scaling up from gardens:

biodiversity conservation in urban environments’, *Trends in Ecology & Evolution*, 25(2), 90–98.

Henry, A. and Frascaria-Lacoste, N. (2011) ‘The green roof dilemma – discussion of

Francis and Lorimer’, *Journal of Environmental Management*, 104, 91–92.

Hobbs, R. J., Arico, S., Aronson, J., *et al*. (2006) ‘Novel ecosystems: theoretical and management aspects of the new ecological world order’, *Global Ecology and*

*Biogeography*, 15, 1–7.

Hobbs, R. J., Higgs, E. and Hall, C. M. (eds) (2013) *Novel Ecosystems: Intervening in the new ecological world order*. John Wiley & Sons: Chichester.

Hopkins, G. and Goodwin, C. (2011) *Living Architecture: Green Roofs and Living*

*Walls*. CSIRO: Collingwood, Vict.

Ishimatsu, K. and Ito, K. (2013) ‘Brown/biodiverse roofs: a conservation action for

threatened brownfields to support urban biodiversity’, *Landscape and Ecological*

*Engineering*, 9, 299–304.

Kats, G. and Glassbrook, K. (2015) Washington D.C. Smart Roof Cost–Benefit

Report. District of Columbia Department of General Services, Washington,

D.C.

Kennedy, J., Haas, P. and Eyring, B. (2008) ‘Measuring the economic impacts of

greening: the Center for Neighborhood Technology green values calculator’. In

Birch, E. and Wachter, S. (eds), *Growing Greener Cities: Urban Sustainability in*

*the Twenty-First Century*. University of Pennsylvania Press: Philadelphia, PA.

Köhler, M. (2006) ‘Long-term vegetation research on two extensive green roofs in

Berlin’, *Urban Habitats*, Vol. 4: Dec.

Kowarik, I. (2011) ‘Novel urban ecosystems, biodiversity, and conservation’,

*Environmental Pollution*, 159, 1974–1983.

Kraft, A. (2013) ‘Why Manhattan’s green roofs don’t work – and how to fix them’,

*Scientific American*, 17 May.

Lundholm, J., MacIvor, J. S., MacDougall, Z. and Ranalli, M. (2010) ‘Plant species

and functional group combinations affect green roof ecosystem functions’, *PLoS*

*ONE*, 5(3), e9677.

Knierem, C. (2014) Personal interview with Mr Chris Knierem, professional builder

and green roof installation specialist, 23 September, Sydney, Australia.



MacIvor, J. S. and Lundholm, J. (2011) ‘Performance evaluation of native plants

suited to extensive green roof conditions in a maritime climate’, *Ecological*

*Engineering*, 37, 407–417.

Madre, F., Vergnes, A., Machon, N. and Clergeau, P. (2014) ‘Green roofs as habitats

for wild plant species in urban landscapes: first insights from a large-scale sam-

pling’, *Landscape and Urban Planning*, 122, 100–107.

Margules, C. R. and Pressey, R. L. (2000) ‘Systematic conservation planning’, *Nature*, 405, 243–253.

McGuire, K. L., Payne, S. G., Palmer, M. I., *et al*. (2013) ‘Digging the New York city skyline: soil fungal communities in green roofs and city parks’, *PLoS ONE*, 8(3), e58020.

McKinney, M. L. (2002) ‘Urbanization, biodiversity, and conservation’, *BioScience*, 52(10), 883–890.

Monterusso, M. A., Rowe, D. B. and Rugh, C. L. (2005) ‘Establishment and persis-

tence of Sedum spp. and native taxa for green roof applications’, *HortScience*, 40(2), 391–396.

Nagase, A. and Dunnett, N. (2011) ‘The relationship between percentage of organic

matter in substrate and plant growth in extensive green roofs’, *Landscape and*

*Urban Planning*, 103, 230–236.

Nagase, A. and Dunnett, N. (2012) ‘Amount of water runoff from different vegeta-

tion types on extensive green roofs: effects of plant species, diversity and plant

structure’, *Landscape and Urban Planning*, 104, 356–363.

Naveh, Z. and Lieberman, A. S. (1990) *Landscape Ecology, Theory and Application*.

Springer-Verlag: New York.

NSW Department of Environment and Climate Change (2009) *Best Practice*

*Guidelines: Eastern Suburbs Banksia Scrub*. NSW DECC: Sydney.

NSW Department of Environment and Conservation (2004) *Eastern Suburbs Banksia*

*Scrub Endangered Ecological Community Recovery Plan*. NSW DEC: Sydney.

NSW Scientific Committee (2002) *Eastern Suburbs Banksia Scrub in the Sydney*

*Basin Bio-region: Endangered Ecological Community Listing, Final Determination*.

NSW Scientific Committee: Sydney.

Oberndorfer, E., Lundholm, J., Bass, B., *et al*. (2007) ‘Green roofs as urban ecosystems: ecological structures, functions, and services’, *BioScience*, 57(10), 823–833.

Orians, G. H. and Milewski, A. V. (2007) ‘Ecology of Australia: the effects of nutri-

ent-poor soils and intense fires’, *Biological Reviews*, 82(3), 393–423.

Osmond, P. (1994) ‘Environmental sustainability and inner-urban landscape design’.

A Vision for a Greener City: National Greening Australia Conference, Fremantle,

4–6 October.

Pellow, B., Lambert, J. and Lambert, G. (2015) ‘Impacts of fire, thinning and

herbivory on species diversity in Eastern Suburbs Banksia Scrub’, *Ecology*

*Consulting*, 3, 25–26.

Perkins, I. and McDonald, T. (2012) ‘Speaking multiple languages: practice, manage-

ment and ecology. Interview with Ian Perkins’, *Ecological Management and*

*Restoration*, 13(2), 126–134.

Perkins, I., Diamond, J., SanRoque, G., *et al*. (2012) ‘Eastern Suburbs Banksia Scrub: rescuing an endangered ecological community’, *Ecological Management and*

*Restoration*, 13(3), 224–237.

Razzaghmanesh, M., Beecham, S. and Kazemi, F. (2014) ‘The growth and survival of

plants in urban green roofs in a dry climate’, *Science of the Total Environment*, 476/477, 288–297.

Snodgrass, E. and McIntyre, L. (2010) *The Green Roof Manual: A Professional Design Guide to Design, Installation and Maintenance*. Timber Press: Portland, OR.

Green Roof Retrofitting and Conservation of Endangered Flora 157

Sutton, R. K., Harrington, J. A., Skabelund, L., MacDonagh, P., Coffman, R. R. and

Koch, G. (2012) ‘Prairie-based green roofs: literature, templates, and analogs’,

*Journal of Green Building*, 7, 143–172.

Tozer, M. G. and Bradstock, R. A. (2002) ‘Fire-mediated effects of over storey on

plant species diversity and abundance in an eastern Australian heath’, *Plant*

*Ecology*, 164, 213–223.

USGSA (2011) *The Benefits and Challenges of Green Roofs on Public and*

*Commercial Buildings*. USA General Services Administration: Washington D.C.

Van Mechelen, C., Van Meerbeek, K., Dutoit, T. and Hermy, M. (2015) ‘Functional

diversity as a framework for novel ecosystem design: the example of extensive

green roofs', *Landscape and Urban Planning*, 136, 165–173.

Williams, N. S. G., Rayner, J. P. and Raynor, K. J. (2010) 'Green roofs for a wide

brown land: opportunities and barriers for rooftop greening in Australia', *Urban*

*Forestry & Urban Greening*, 9(3), 245–251.

Williams, N., Lundholm, J. and McIvor, S. (2014) 'Do green roofs help urban biodi-

versity conservation?', *Journal of Applied Ecology*, 51(6), 1643–1649.

Wise, T. (2011) Personal interview with Mr Timothy Wise, development planner

with the council of the City of Sydney, 22 August, Sydney, Australia.

**19**

## Urban Food Production on Retrofitted Rooftops

**Sara Wilkinson and Fraser Torpy**

UTS, Australia

### 9.0 Introduction

In this chapter the issues of food security, human health, population, access

to nutritious food sources and the carbon impact of current food production

methods are discussed. The potential for urban rooftop food production is

examined, as well as the typical features required of rooftops for successful

outcomes. Australia ranks as the 18th most urbanised country in the world

out of 195 countries, with 89.2% of its population living in towns and

cities. With predictions that 2.2 billion more people will be living in cities

by 2050, Sydney is a good city to investigate this aspect of green roofs.

Significant amounts of urban regeneration are underway as the city seeks to

reintroduce mixed uses, including residential land use in the CBD, and to

maintain liveability. Not only does urban food production present an

opportunity for inhabitants to maintain contact with the natural world in

high-density environments, but it also allows younger generations to learn

where food comes from and to get an appreciation for the natural world.

The chapter describes empirical research into rooftop food production

conducted on campus at the University of Technology Sydney; including

social, environmental and economic aspects, as well as setting out typical

specifications and considerations in respect of bed systems. The main focus

is on the technical, environmental and economic aspects of larger-scale

food rooftop production. Finally, the chapter concludes by discussing the

potential on a city-wide scale for urban food production as well as on an

individual building basis.

This chapter discusses the potential for using modular, intensive green

roof technology to create rooftop vegetable gardens on existing buildings

with a view to minimising food miles, shortening the supply chain and

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



reducing the carbon footprint of growing and transporting food. The

research considers the economic and environmental benefits of *retrofit-*

*ting* existing buildings with green roofs for owners and investors, and the

desirable social and psychological impacts on the inhabitants – including

the potential betterment of the community by utilising roof space for

urban agriculture.

**9.1**

## Green Roof Retrofit and Urban Food Production

‘Roofs can represent up to 32% of the horizontal surface of built-up areas’

(Frazer, 2005), and many have the potential to become urban farmland.

There are many successful established examples, such as Eagle Street

Rooftop Farm, which has over 500 m2 of intensive green roof sustaining an

organic vegetable farm located on a warehouse rooftop in Greenpoint,

Brooklyn, NY (Rooftop Farms, 2013). The use of existing urban horizontal

spaces as farmland increases the food security of a city. As global tempera-

tures rise and crops fail, and droughts become more frequent and severe, it

will become increasingly desirable to equip urban dwellers with the ability

to cultivate food, or to encourage urban farmers to produce food locally.

Difficulties in harvesting and transporting crops long distances from

regional production areas to urban centres as the global transport energy

transitions from oil may also play a role in the general decentralisation/

urbanisation of food production. Concomitant to these outcomes are the

social benefits and the financial and environmental imperatives. A green

roof offers a building and its surrounding environment many benefits.

These include stormwater management, improved water runoff quality

(Mentens, 2006; Hilten, 2008), improved air quality in the urban canyon

(Yang *et al*., 2008), prolonged durability of the roof skin (Köhler, 2002),

increased efficiency of energy use in buildings (Castleton, 2010) and a

reduction of the urban heat island effect (Rizwan *et al*., 2008). Other ben-

efits also include enhanced architectural interest and biodiversity (Castleton,

2010: 62) as well as reintroducing the natural world into the anthropogenic environment.

As millions face starvation globally and the proliferation of food waste becomes endemic, a report released by the Institute of Mechanical Engineers (Fox, 2013) estimated ‘that 30–50% (or 1.2–2 billion tonnes) of all food produced is lost before reaching a human stomach’. Some reasons are poor engineering and inefficient agricultural practices, inadequate transport and storage infrastructure. Urban rooftop farming has the potential to ameliorate some of these problems by shortening the food supply chain. With claims that food security will become an issue in future because of the expanding global population, the opportunity to reduce food wastage through inefficiencies in harvesting and/or storage should be explored. A further issue arises where, through commercial decisions made by food retailers, there is destruction of crops in the field due to overproduction because it is no longer profitable to harvest and sell the produce.

Rooftop agriculture has the potential to create healthier communities in

both alimentary and psychological ways. Urban rooftop agriculture could

provide access to fresh, healthy, nutritious produce due to the reduced time

spent in transit and storage. City dwellers and workers are increasingly

detached from nature, and this contributes to rising stress levels and dissat-

isfaction with contemporary society (Shephard, 1982). Kellert and Wilson

(1995) claimed that ‘humans have a profound need for regular contact with

the natural environment for continued wellbeing’. ‘Rooftop gardening

means taking up an inspiring, ecological and productive activity, and devel-

oping new links with the food chain, the seasons, the environment and the

community’ (Germain, 2008).

A supplementary social benefit of rooftop agriculture may be commu-

nity volunteer programmes whereby residents and workers engage in food

production. Eagle Street Rooftop Farm in Brooklyn, NY (Rooftop

Farms, 2013) operates a small community-supported agriculture (CSA)

programme and an onsite farm market which caters to local restaurants.

It utilises trained interns and urban farming apprentices and hosts volun-

teers during growing seasons. In partnership with the Growing Chefs

organisation, the farm hosts educational and volunteer programmes to

bring city dwellers closer to their food source (Growing Chefs, 2013).

Whilst there are many successful examples of urban agriculture in the

northern hemisphere, it is surprising that Sydney has so few examples of

rooftop urban food production, and to date, no empirical studies as to its

viability.

Climate and local weather conditions have a considerable impact on

what can be grown and the duration of the growing season. With regard

to prevailing weather conditions, Sydney is located in a temperate climatic

zone with rainfall spread throughout the year. Annual meteorological data

for 2012 showed 1213.6 mm of rainfall, a mean maximum temperature of

22.7°C and a mean minimum of 14.4°C (Australian Bureau of Meteorology,

2013). Sydney's annual sunshine averages almost seven hours a day (City

of Sydney, 2013), with Sydney's rainfall an average 11 wet days per month.

Overall, these are good conditions for growing food currently. But what is

predicted in the future? New South Wales Government Agencies and the

University of New South Wales have been developing climate change fore-

casts for the NSW State Plan regions and Sydney's weather is projected to

become hotter over all seasons (2–3°C), with summer rainfall projected to

increase by 20–50% and winter rainfall projected to decrease (NSW

Environment and Heritage, 2015). The pattern of the El Niño–Southern

Oscillation cycle is projected to continue, but with higher temperatures

than currently experienced. El Niño years are likely to continue to be drier

than average and become hotter. La Niña years are likely to continue to be

wetter than average and also to become warmer. In El Niño events, water

stress is projected to be more intense due to higher temperatures. During

La Niña years, storms with heavy downpours are projected to be more

frequent (Plan, 2008). Given these predictions of climate change impact

on Sydney's growing seasons, rooftop farmers will need to adapt their

taxonomic palette.



A further consideration is the characteristics of the building stock and the

numbers of potential consumers for the food produced. In June 2011, the

City of Sydney LGA housed 169,505 people (Australian Bureau of Statistics,

2015), with the CBD covering 25 km2 and a population density of 6780.2/

km2 (City of Sydney, 2013). Based on previous studies of the potential for

green roof retrofit (Osmond, 2012), it is possible that 17–20% of Sydney

rooftops could accommodate intensive green roofs. There are over 17.5 mil-

lion square metres of built form within the CBD. Whilst no data exists

regarding the potential for vegetated rooftop gardens, given that there are

17.5 km2 of roofs with a 20% intensive green roof potentiality factor,

approximately 3.5 km2 of roof space is available to support urban agricul-

ture in containerised garden beds (Osmond, 2012).

## 9.2

## Stakeholders and Urban Food Production

There are a number of stakeholders involved in urban food production. The

regulators include urban and regional planners, building code regulators,

food regulators and public health and safety regulators. Each regulator

covers a different aspect of urban food production from food standards to

minimum building safety standards where food may be grown. The urban

and regional planners take a longer-term and wider perspective in respect of

trying to develop policies and guidelines that will lead to liveable cities and

settlements for the community with regard to social, economic and environ-

mental sustainability. This remit gives them a broad interest in urban food

production within the urban environment, as well as significant power to

influence the variables, which can lead to greater levels of food production.

For the community, people have the ability to engage in, and to adopt, urban

food production in various ways. To date, this has typically been in private

gardens on a household basis or in community gardens on a wider scale.

Community gardens are typically at ground level and can be located on private

or council-owned land. Typically, land values increase in city centres, and here

there is less land available for garden activities; herein lies the opportunity for

rooftop gardening and to use space that typically has no active use. Generally,

the community is keen to engage in gardening and the positive social outcomes

associated with it, as discussed in greater detail in Chapter 10.

The owner stakeholder group are diverse and can comprise private indi-

viduals and commercial organisations. The land-use types which can sup-

port rooftop food production are very varied and include retail, residential

(multi-unit and individual household), commercial office and industrial

buildings. The key criteria are for a relatively shallow-sloping, well-drained,

accessible rooftop with good access to sun and a water supply. As noted

above, there is a large area of rooftops in city centres which could support

food production, however, to date in capitalist economies there are barriers

to uptake. The main one is that owners are reluctant to allow agricultural

production on their rooftop due to perceptions of increased maintenance

liabilities or potential overloading of the roof or drainage problems.

Wilkinson *et al*. (2016) posited that the adoption of rooftop licences in



Sydney would assuage the fears of owners by setting out start and termina-

tion dates for rooftop food production, along with a schedule of condition

at commencement and an agreement to make good any wants of repair at

the termination. Furthermore, there is an, as yet, untapped opportunity for

owners to gain income from rooftops and potentially to add to their corpo-

rate social responsibility (CSR) profile. The argument for CSR is that in

allowing rooftop food production, the owner indirectly adds to biodiversity,

improves air quality and reduces stormwater runoff and the urban heat

island effect. There are plans to pilot the rooftop licence in Sydney, Australia

in 2016. Another model with greater social sustainability, and again which

can feature in CSR, is where food produced on the rooftop is donated to

charities. Owner-occupiers have fewer barriers related to legal entities

around access to, and use of, roofs. Where food is produced commercially

for distribution or sale to the public, then legislation in respect of food

supply and food safety applies.

To date, very few commercial food producers are found in city centre

rooftops globally, and this may be due to perceived costs of production and

economies of scale. In times of restricted food supply, countries like Cuba

have turned to wide-scale urban food production, including rooftop food

production to feed the people. Rooftop food production is likely to appeal

to niche markets, to supply local cafes or food co-operatives, or small retail-

ers. Therefore, larger commercial producers are less likely to enter this mar-

ket, with their production focused around peri-urban and rural areas. It is

likely that over time, the barriers to urban food production will diminish as

food security issues become more known to the wider public. At this point

an enlightened community will see benefits in having a local food supply, so

that younger members of the society are able to learn directly where fresh

food comes from and how it grows.

## 9.3

## Contamination and Air-Quality Issues

As agriculture within the bounds of urban settlement increases, the ecosys-

tem services provided by intensively disturbed urban soils previously used

for residential, waste management and industrial purposes will play a more

central role in the future of human development (Luo *et al*., 2012). The

growing of urban crops for human consumption, with the simultaneous

reduction in air pollutants, as well as stormwater management, are the major

services sought. Timely, intensive study of these soils is thus a pressing

concern. Whilst the development of intensive agriculture in densely populated

urban areas presents many problems, the major concern for human health is

the contamination of crops due to the close proximity of past or current

polluting activities (Wiseman *et al*., 2013; Galal and Shehata, 2015a). Given

that pollutant concentrations will be unevenly distributed across urban areas

dependent on land use (e.g., Luo *et al*., 2012), an understanding of both

pollutant distribution and remediation techniques and their limitations,

along with the contaminant uptake mechanisms of the crops themselves, is

essential for the safe expansion of urban farming activities.



The major sources of urban soil pollutants are a vast range of industrial

processes and emissions from road traffic. Vehicular traffic contributes to

urban soil pollution primarily from exhaust emissions, but also through the

wear of components such as brakes and tyres (Zereini *et al*., 2012). In recent

years, it has been shown that heavy metal levels in soil and vegetation have

increased considerably as daily traffic increases (Onder and Dursun, 2006).

Farmaki and Thomaidis (2008) reported increased concentrations of the met-

als lead, copper, zinc and palladium in the urban environment, including the

topsoil, highways and streets. Areas with highly elevated metal concentrations

were generally located in industrial and residential areas, roadsides and

crowded commercial districts (Cicchella *et al*., 2008; Alyemenia and Almohisen, 2014). Further, vehicular traffic emissions are of concern as they consist of

gaseous pollutants (Laschober *et al*., 2004), which may remain in the air for

some time, but most are deposited in roadside soils and plant materials near

the road. These toxins can enter plant tissues directly via rain and dust and be

taken up from the soil through the root system (Jozic *et al*., 2009).

Luo *et al*. (2012) reviewed heavy metal concentrations from different

cities around the world, finding very wide variations between the concentra-

tions of all metals, ranging from safe to extremely high levels (e.g., 37 mg/kg

of lead in Moscow to 395 mg/kg in Chicago urban soils). This variability

was directly related to either the predominant industries or traffic patterns

in the cities, but also the age of the cities, population density, environmental

regulations and local climates.

### 9.3.1

### Types of Pollutant

Heavy metals are the primary pollutants of concern within the context of

the contamination of urban food crops. Heavy metal pollution is becoming

a growing global problem as the global population increases, and urbanisa-

tion and industrialisation expand. Organic pollutants make up a lower pro-

portion of total soil contamination than do metals (De Nicola *et al*., 2015),

and are bioaccumulated by plants and translocated amongst plant tissues

(Zhang *et al*., 2015). This class of pollutants is generally considered of lower concern in food crops, and will not be considered further.

Metals of major concern include cadmium, exposure to which can lead to

various cancers and renal dysfunction syndromes (Żukowska and Biziuk,

2008). Lead exposure can lead to a broad range of conditions, notably in

the nervous, skeletal, circulatory, enzymatic, endocrine and immune systems

(Li *et al*., 2015). In addition, exposure to high levels of chromium, arsenic, mer-cury, copper, zinc and nickel is also of significant health concern (Chen *et al*., 2005). Furthermore, the replacement of lead in automotive fuel with methylcy-clopentadienyl manganese tricarbonyl (MMT) has the potential to lead to high

levels of manganese in urban soils from exhaust pollution (Brault *et al*., 1994).

In urban environments, lead is the heavy metal toxicant of most concern

(see Lu *et al*., 2015). There is growing evidence that lead levels in many

urban soils are at or above levels that warrant vigilance, including both

industrialised areas and non-industrial urban areas, across both developing



and developed countries (Laidlaw and Taylor, 2011; Lu *et al*., 2015). The

greatest single source of soil-borne lead comes from its prior use in motor

vehicle fuels. Mielke *et al*. (2011) estimated that approximately 1.4 million

tonnes of lead in the US environment came from this source between 1950

and 1982, when its use ceased, resulting in a median concentration of

16.5 mg/kg soil throughout that country, with far higher levels in urban

areas. Other sources of lead include smelting and many other industrial

processes (e.g., Lu *et al*., 2015). Lead-containing house paint was once con-

sidered a major source, however its contribution has become less significant

compared with other sources after its use has been progressively reduced

since the 1980s (Laidlaw and Taylor, 2011).

Once any of the heavy metals are present in soil, they persist indefinitely

(Peña-Fernández *et al*., 2015), and long-term exposure to some metals, even

in low concentrations, can cause health problems, especially in foetal devel-

opment (Grandjean and Landrigan, 2006). Lead has been associated with

health effects including decreased academic achievement, attention deficit

hyperactivity disorder, learning and conduct difficulties in both children and

adults, at levels below many international health standards (5 μg/dL blood)

(Taylor *et al*., 2012). Anthropogenic derived lead behaves differently in the

biosphere to naturally occurring forms, as it is concentrated in carbonate,

iron and manganese hydroxide soil fractions, which are easily absorbed by

living organisms. Whilst human blood lead concentrations decreased mark-

edly once it ceased being used as a fuel additive (Thomas *et al*., 1999), its

presence in soil, especially that in which food plants are grown, is still a

health concern.

### 9.3.2

### Most Urban Soils are Contaminated

Most urban land worldwide is affected by some environmental pollution.

Mitchell *et al*. (2014) analysed the substrate from 54 urban gardens in New

York, USA and found that 70% produced at least one sample that exceeded

health regulation levels for at least one pollutant. Lead is the most common

contaminant found in levels that are high enough to cause health concerns

(Angotti, 2015), with children especially being susceptible (Centers for

Disease Control and Prevention, 2013). Mireles *et al*. (2012) tested urban

soils in the cities of Zacatecas and Guadalupe in Mexico that had experi-

enced both long-term mining and increasing traffic activity, to assess whether

residents might be at risk of exposure. The authors found high levels of cae-

sium, zinc, arsenic and antimony relative to US and Mexican regulatory

standards. Clarke *et al*. (2015) assessed urban garden soils in Los Angeles,

USA for heavy metals, finding increased soil concentrations with proximity

to roads for lead, arsenic and cadmium. Neighbourhood age was also associ-

ated with lead levels, which the authors concluded was due to the previous

use of lead-based paints. Karim *et al*. (2015) found metal contamination of

the urban soils of Karachi, Pakistan to be moderate to moderately severe for

lead and moderate for chromium and copper. Peña-Fernández *et al*. (2015)

found that cadmium, copper, lead and zinc contamination in the urban soils

of an urban area in Madrid, Spain could be attributed to traffic emissions,

while arsenic, nickel and beryllium originated from industrial pollution.

Chen *et al*. (2005) found high levels of copper and lead in urban parks in

Beijing, China, and associated these pollutants with anthropogenic sources.

Qing *et al*. (2015) found moderate to high soil concentrations of cadmium,

zinc, copper and lead in an industrial city in northern China. Highly indus-

trialised areas of Bangladesh have been found to be heavily polluted with a

range of metals; Islam *et al*. (2015) showed that soils contaminated with

tannery waste, metal-work industry pollution and electrical waste were

heavily contaminated with nickel, copper, arsenic, cadmium and lead.

Cadmium was of particular concern in this study, and was most likely

sourced from smelting operations (Islam *et al*., 2015). Thus it is apparent

that urban soil contamination is widespread, although concentrations vary

on both large scales (i.e., between cities) and at a finer level, between differ-

ent sites depending on exposure to current and past polluting activities. Thus,

urban garden designers need to be cognisant of previous activities in the area,

especially when food production is proposed, and to make provision for

adequate testing of produce, as well as soils, air quality and water supply.

### 9.3.3

### Do Contaminants Accumulate in Urban Crops?

Many studies have investigated heavy metal levels of crops grown in con-

taminated soils. The conclusions drawn from these studies are quite incon-

sistent, leading to difficulty in predicting whether crops grown in an area

with a specific contaminant profile will be of concern to health, or which

crop species accumulate contaminants at higher rates. Furthermore, it is

unknown whether the contaminant levels in urban-grown produce are

higher than those from commercial agriculture, where the substrates have a

long history of fertiliser and pesticide use (Angotti, 2015).

A study in Brescia, Italy examined whether proximity to long-term

ferroalloy industry sites could be associated with higher concentrations of

toxic metals in home-grown vegetables (Ferri *et al*., 2015). They found

aluminium, cadmium, iron, manganese, lead and zinc were all higher in

garden soils close to the plants, in contrast to remote reference sites.

Spinach plants were found to have high concentrations of lead, and to a

lesser extent cadmium. The other crop tested – turnips – did not have high

metal concentrations.

Hibben *et al*. (1984) compared lead and cadmium in food crops between

gardens in Brooklyn, New York, which suffers from increased environmen-

tal metal concentrations due primarily to air pollution, and the same plant

species grown in an unpolluted suburban area. The authors found low levels

of cadmium in both sites in all plants, and only higher lead concentrations

in radish and lettuce leaves in the Brooklyn sites, concluding that the levels

of these metals in urban crops are unlikely to be a health concern.

The bioaccumulation of metals by a range of crop plants in highly cad-

mium-contaminated soil in China was tested and several crops accumulated

cadmium at unsafe levels, including Chinese cabbage and lettuce (Hu *et al*.,

166 Green Roof Retrofit

2013). A greater number of crops did not accumulate cadmium. Hu *et al*.

(2013) concluded that crop species where the stems and leaves are eaten are

more likely to cause health problems – the authors recommend avoiding such

crops on contaminated soils. In contrast, McBride (2013) concluded that

root vegetables such as carrots may concentrate some metals at a greater rate

than leafy crops and recommended avoiding such crops in suspected soils.

Sipter *et al*. (2008) tested metal accumulation in vegetables grown in soil

heavily contaminated with mine tailings in Hungary. Despite very high soil

metal levels, only moderate concentrations of cadmium and lead, and no

arsenic, were detected in all crops, including fruit, leaf and root species.

Given that the population in the sampled area is generally non-mobile, and

people spend their entire lives consuming these crops, the authors calculated

lifetime exposure rates and concluded that the consumption of vegetables

did not pose a high health risk. Soil exposure, however, was noted as a

potential hazard, especially for children. In contrast to these findings, Finster

*et al*. (2004) tested vegetables grown in contaminated residential gardens in

Chicago, USA, finding metal concentrations in numerous crops that were far

higher than those detected by Sipter *et al*. (2008), which clearly represented

a significant health hazard. These high levels included detergent-washed

plant tissues, negating the presence of adherent contaminated soil. It should

be noted that Chicago is well known to possess highly contaminated soil in

parts of the urban area (Witzling *et al*., 2011; Luo *et al*., 2012). Säumel *et al*.

(2012) detected varying levels of metals in a range of vegetables grown in

urban Berlin, with proximity to traffic a major determinant of the contami-

nation level.

Wild and commercially grown mushrooms exposed to high traffic in

Berlin, Germany were tested for heavy metals (Schlecht and Säumel, 2015).

Wild mushrooms contained metals that exceeded EU standards in most

cases, despite being thoroughly cleaned before testing. Cultivated varieties,

in contrast, did not exceed the limits. It is thus possible that some fungi

accumulate metals from the soil at a different rate to plant material – vege-

tables sampled from the same areas contained far lower concentrations of

contaminants. Schlecht and Säumel (2015) prudently recommended further

research into the health consequences of the consumption of wild fungi

from heavy traffic areas.

The presence of fairly high levels of metals in soils does not always indicate

contaminated vegetables. McBride (2013) found that a range of crops grown

in soil with up to 400 mg/kg lead and 100 mg/kg arsenic produced vegetables

with concentrations of both contaminants below the limits of international

health standards. Similarly, Warming *et al*. (2015) tested the concentrations

of seven toxic metals in both leafy and root crops grown in urban areas of

Copenhagen, Denmark. The levels of all metals found were within an accept-

able range, and were not related to the concentrations in the soil, which

ranged from very low to very high across the three sites sampled.

McBride *et al*. (2014) conducted a study to assess the relationship between

soil and vegetable lead levels. Whilst a number of samples exceeded EU stand-

ards, the authors concluded that in general, urban-grown vegetables should

be safe for consumption. A critical observation made in McBride *et al*.'s



(2014) study was that many high metal levels detected in urban crops are a

result of soil particle adherence or incorporation into plant tissues, thus rein-

forcing the necessity of careful cleaning of vegetables grown in potentially

contaminated soil before consumption. The authors concluded that acciden-

tal soil ingestion posed the greatest exposure risk in urban food production,

rather than the consumption of contaminated produce.

### 9.3.4

### Mitigating Urban Crop Contamination

Owing to the inconsistency in the conclusions drawn from the literature,

there is no universally recommended means of mitigating the potential of

urban crop contamination. There are, however, a range of techniques for the

amelioration or avoidance of toxic produce, all of which should be effective

to varying degrees, and more so in combination.

Contaminated soil can be treated to reduce or remove the contaminants,

either by remediating the soil or replacing it altogether. Historically, soil

replacement has been the most common solution (Angotti, 2015). Whilst

simple, this method can be expensive, does not address the problems with

the existing soil, and relies on the assumption that the imported soil is of

greater quality than the existing substrate, generally with no testing being

performed (Angotti, 2015). If uncontaminated replacement soil is used,

however, this method will clearly lead to reduced levels of heavy metals in

crops (Mitchell *et al*., 2014).

Phytoextraction and phytoremediation involve using sacrificial plants to

concentrate and remove pollutants from a contaminated environment (Peng

*et al*., 2008). This process involves growing plants known to accumulate

pollutants, with harvesting and disposal of plant materials off-site. This

method is far less commonly used, as it is often thought to be time consum-

ing – in the range of years to decades – and the technology is unfamiliar to

most urban gardeners (Angotti, 2015).

The selection of phytoextraction species has received significant research

attention. Galal and Shehata (2015a,b) tested the capacity of several envi-

ronmental weed species as bioaccumulators of heavy metals in polluted

roadway soils. They found that the capacity of the plants to bioaccumulate

heavy metals was generally limited to below that of the concentration in

the soil, with some translocation of the metals from roots to shoot parts

of the plants demonstrated for most plant species and pollutants. For exam-

ple, the wetland plant *Phragmites australis* has been shown to be an effective

bioaccumulator of aluminium, iron and manganese (Wang and Jia, 2009).

Jambhulkar and Juwarkar (2009) tested the capacity of six plant species to

accumulate metal pollutants from a fly ash dump in Nagpur, India. The

authors detected bioaccumulation of iron, manganese, nickel, zinc, copper,

chromium and lead, with the species *Cassia siamea* accumulating all metals

at higher concentrations than the other tested plants, suggesting that hyper-

accumulator species exist. Such species may be useful for the remediation

of highly metal-contaminated soils prior to crop sowing, especially if the

simpler methods are ineffective in a specific area.



Soil treatments may also be used to effectively reduce contaminant levels

or capacity to enter plant tissues. The progressive amendment of contami-

nated soil with compost has been used with some success (Angotti, 2015;

Clarke *et al*., 2015), but as this method does not physically remove metals

from the substrate, the only means by which they can be removed are still

through consumption of crops or windblown dust – neither of which are

desirable outcomes. McBride *et al*. (2013) tested whether soil lead transfers

into leafy vegetable crops could be reduced by adding a range of soil amend-

ments including composts, peat, calcium phosphate, gypsum and iron oxide.

All additions were generally unsuccessful. Low pH, however, unquestiona-

bly increases the solubility, and thus the uptake rate of many metals

(McBride, 2013). Increasing the soil pH above 6.5 should thus lead to

reduced rates of metal transfer, and can generally be recommended for all

potentially contaminated soils, in combination with testing of crops if high

levels of contamination are suspected.

McBride *et al*. (2013) noted that one of the main reasons why these

amendments are unsuccessful is that the main mechanism by which lead

contaminates crops is through soil adhesion. Ferri *et al*. (2015) similarly

observed that washed spinach had lower metal concentrations than

unwashed produce, leading to the recommendation that urban-grown pro-

duce should be washed thoroughly before consumption. This practice is

strongly recommended for all crops grown in urban areas for the reduction

of contamination.

Perhaps the simplest way to minimise the potential for crop contamina-

tion is to select sites with a reduced likelihood of contamination. Clarke

*et al*.'s (2015) study indicated that locating plots further from roadways

was associated with decreasing metal concentrations. Rooftops poten-

tially offer a good location. Säumel *et al*. (2012) found that whilst con-

tamination levels in urban vegetables were higher in high-road-traffic

areas, the presence of buildings or vegetation barriers between crops and

roads substantially reduced crop metal contamination. Witzling *et al*.

(2011) noted that raised beds can result in lower soil metal levels. Findings

that the soils from urban parks and recreational areas have far lower lev-

els of contaminants than industrial or high-traffic areas in China (Luo

*et al*., 2012) is evidence that with some targeted *a priori* field testing, safe areas for urban food production should be available in even the most

populous of cities.

Overall, although a number of studies have raised the possibility that

under certain conditions, metal contamination of urban-grown produce may

be of concern for our health, it is more likely that the outcomes of eating

greater quantities of fresh fruit and vegetables will provide far greater health

benefits (Guitart *et al*., 2014) than the generally minor risks associated with contamination. Despite inconsistent literature regarding the mitigation of

crop contamination from polluted soils, it can safely be recommended that

the selection of areas less likely to harbour high contaminant levels, main-

taining high soil pH and organic matter, and careful cleaning of produce

before consumption should lead to minimal risks, without the expense of

phytoextracting or replacing existing soils.



### 9.3.5

### Urban Gardens and Air Quality

There is a growing body of literature supporting the hypothesis that plants can

play a major role in ameliorating poor ambient air quality. This is in line with

the larger body of literature from indoor urban environments, where plants

have been shown to reduce or remove virtually all types of air pollutants (e.g.,

Orwell *et al*., 2004, 2006; Torpy *et al*., 2014). Although limited studies to date have examined urban air-quality effects from urban food gardens, recent evidence (Irga *et al*., 2015) indicates that plants other than mowed grass have a

major influence on a number of air pollutants in urban areas. Irga *et al*.'s (2015) study found that the local density of all components of urban vegetation – other

than grass – had the greatest influence on the proximal air quality of any vari-

ables measured, which included rainfall and traffic density. It is reasonable to

expect that many urban food crops could provide the same subsidiary health

benefits to the urban environment. Tong *et al*.'s (2015) finding that urban food gardens can remove airborne particulate matter supports this hypothesis. The

finding that the leaves from tree species in polluted environments may accumu-

late higher levels of toxic metals than the same species in uncontaminated envi-

ronments (Hu *et al*., 2014) suggests another area of research that may yield

dividends, although the resulting contamination of crops with airborne con-

taminants such as heavy metals is of concern, as described previously. It is sug-

gested that following the recommendations given in Section 9.3.5 should

reduce the toxic effects of above-surface plant contamination to a safe level in

the same way that they reduce soil-sourced contaminants.

Green roofs have been theorised to improve outdoor air quality by col-

lecting particulate matter, filtering noxious gases and reducing building CO

2

emissions by reducing demands on air-conditioning systems through keep-

ing a building at thermal comfort levels (Refahi and Talkhabi, 2015).

Substantial research has shown that green roof systems in densely populated

areas can effectively remove tonnes of air pollutants annually (Yang *et al*.,

2008; Rowe, 2011). Indirectly, vegetation facilitates evapotranspiration and

thus cools surfaces and can shade a building’s roof to help lower indoor

temperatures and thus decrease the need to use air conditioning (Heisler,

1986). Yang *et al*. (2008) found through a modelling procedure that 19.8 ha

of green roofs with canopies of herbaceous plants, short grass and decidu-

ous trees in Chicago, USA effectively removed 85 kg ha1 yr1 of air pollutants

from 2006–2007. Currie and Bass's (2005) study estimated that 109 ha of

green roofs can account for the annual removal of 7.87 tonnes of air pollut-

ants. Tan and Sia (2005) measured the concentrations of sulphur oxides and

particulate matter on a 4000 m2 roof before and after the installation of a

roof garden. They recorded a 6% reduction in sulphur oxides and a 37%

particulate matter reduction. There is thus significant potential for roof gar-

dens to provide subsidiary benefits in air-quality improvement. The empiri-

cal degree to which they do this, and the specifics of how much of which

pollutants are removed and whether this removal interacts with food qual-

ity, are both areas in need of further study. The following section reports on

a research project at UTS to grow food on retrofitted campus rooftops,

where many of the issues identified above were investigated and analysed.



170 Green Roof Retrofit

**9.4**

## The Research Design and Methodology

This research uses empirical evidence derived from growing plants and

vegetables on three rooftops at UTS, New South Wales, Australia during

2013 and 2014. UTS is located in Ultimo on the fringe of the CBD and was

founded in 1988, although it can trace its origins to the 1870s. In 2013 the

university had just under 38,000 students, taught in buildings having a mix

of architectural styles which reflect the different periods in which the

buildings and grounds were constructed and renovated. The university

offers self-catered student accommodation in five buildings. Gumal

Ngurang housed one of the rooftop sites, and is the second-largest com-

plex located on the busy Broadway street. It is a high-density inner-city

location and offered great potential to learn about issues related to urban

food production.

Three different types of rooftop garden beds are described in three illus-

trative case studies. The research is qualitative, sharing the three basic

assumptions identified by Patton (1980) of being naturalistic, holistic and

inductive. Naturalism involves seeing the phenomenon in its naturally

occurring state, in this case by visiting the three sites to observe what has

taken place. The holistic aspect involves looking at the whole problem to

develop a more complete understanding of the influencing factors and vari-

ables with regard to three different approaches to rooftop food production

in Sydney. Figure 9.1 shows the location of the university and rooftop in the

centre of Sydney. The inductive approach is derived from the literature

review, whereby a picture of the problems and issues emerges as the

researcher becomes more familiar with the topic area. A literature review

identifies which areas need to be addressed.

An advantage of case study research is that it is a flexible method, which

can be adapted during the research (Robson, 2003). With this research,

three different beds are evaluated on three different roofs and so it is not

possible to make an exact comparison of outputs. However, that is not to

Main UTS

campus

including

science and

DAB buildings

Gumal housing, Broadway

**Figure 9.1** Location of UTS campus and project rooftops.



say that the conclusions drawn from the study are not valid. A limitation of

the technique is that the researcher does not sample widely enough and that

studies may represent the peripheries and not the average (Robson, 2003).

However, Yin (1989) observes that the case study is concerned with analyti-

cal and not statistical generalisation. Care was taken to ensure the conclu-

sions drawn are noted as being analytically general rather than statistically

representative. The criticism of the case study as a ‘soft option’ was rejected

as the method requires preparation, knowledge of procedures (in this case

food production on Sydney rooftops) and analytical skills (Robson, 2003).

It is soft only in the sense that no hard and fast rules exist for the researcher

to follow. The means of data collection was through observation and direct

experience, which was deemed most suitable because it allowed the

researcher to collect identical data from each site (Moser and Kalton, 1979).

Records were kept on biodiversity, watering, weather, bed costs, planting,

dates, fertilisers used and crop yields.

### 9.4.1

### Case Studies

The first task was to find suitable roofs on the university campus. After a

number of visits to rooftops it was found that there were issues such as

accessibility or uses which precluded other activity, such as telecommunica-

tions equipment. A third roof was discounted as it was heavily overshad-

owed and had poor orientation. Property managers were a significant factor,

and finally the team met one who was also a gardener. This staff member

was helpful and knowledgeable, and took the team to several potential roofs

before a joint decision was arrived at. The Science Faculty had test beds on

their roof and permission was given to position another bed there. Finally,

the researchers' home faculty has a roof space directly outside the staff

kitchen and the DAB Faculty Manager gave permission to site the V Garden

beds there.

**9.4.2**

**Gumal Student Housing**

This roof, located at ninth-floor level on Broadway, Sydney faces southeast.

The construction is reinforced concrete with an impervious tiled covering.

The roof is designed for access and has a concrete perimeter wall approxi-

mately 1200 mm high, 600 mm wide and 800 mm deep, which is planted out

along a recessed top surface. There is lift access to level 9. It is exposed and

open to the wind and sun. The garden bed chosen for this site was a recycled

plastic raised bed supported on a timber-frame trestle. The UV-resistant recy-

cled plastic was extremely light, easily assembled and its dimensions were

3300 mm long × 1200 mm wide × 300 mm deep. See Figures 9.2 and 9.3.

A 3600 × 1200 mm2 trestle was constructed from 90 × 45 mm2 treated pine

frames, braced with galvanised strapping tied together using a 90 × 45 mm2

treated pine rail top and bottom. The frames were prefabricated off-site to

minimise the noise impact during construction, and for easier transportation.



172 Green Roof Retrofit

**Figure 9.2** Gumal bed under construction.

Two sheets of ply 1800 × 1200 mm2 formed the top of the trestle and sup-

ported the plastic framework for the bed.

A layer of food-grade rubber waterproofing membrane, ethylene propyl-

ene diene monomer (M-class EPDM rubber), was placed over the timber

trestle as weather protection. The plastic pod was positioned on the mem-

brane and a bead of food-grade silicone sealed the base of the garden bed

and held it in place. At one end a floor drain was installed and sealed with

silicone, and using a spirit level and some small plastic wedges, the end of

the trestle furthest from the floor drain was raised slightly to facilitate drain-

age. A layer of 20 mm drainage cell sheeting was placed across the floor of

the bed with a layer of geotextile fabric laid over the drainage cells to

keep the soil and plant roots from blocking the drain. A layer of fine gravel

20 mm deep was laid onto the geotextile fabric, followed by another layer of





**Figure 9.3** Gumal bed planted out.

*Source*: Wilkinson**.**

geotextile fabric. The bed was divided into two sections for different grow-

ing media; one was filled with an organic composted cow manure and gar-

den soil mixture and the other a lightweight engineered substrate with a

mixture of coir bark, perlite P400, Canadian peat, 0–8 mm composted pine

bark, trace elements, calcium nitrate, coarse granular dolomite, gypsum,

superphosphate, zeolite 1–3 mm and magrilime. Both beds were top dressed

with a compressed pelletised organic seaweed fertiliser (Seamungus) and

mulched with lucerne hay. Both were fertilised topically fortnightly with an

organic fish emulsion and Seasol (a seaweed tonic) was applied topically

once a month.

The beds were planted out with eggplant, zucchini, basil, carrots, beet-

root, lettuce, chilli, capsicum, silverbeet, celery, rocket, mizuna and mari-

golds. These beds were planted out in November 2013 and the cost for the

two beds was $1350.62 plus labour.

**9.4.3**

**Science Roof**

This roof is located at seventh-floor level on the corner of Harris Street and

Thomas Street in Sydney and faces northwest. The construction comprises

reinforced concrete with an impervious covering. The roof is protected with

walled structures approximately 3 m high to three sides and a glazed screen

to the Thomas Street elevation. The garden bed chosen for this site was a

plastic wicking bed.



174 Green Roof Retrofit

The bed was a pond purchased at a cost of $280 with a 320 litre capacity

and dimensions of 1500 mm × 750 mm × 300 mm high. The reservoir in

the bed was created by laying 100 mm agricultural drainage pipe across

the base of the pond. A short section of tube was positioned vertically

from the bottom of the pond up to the top (in a place where the overflow

was visible). This was the filler tube, for which a section of agricultural

pipe was used. A hole, to accommodate a 30 mm threaded tank outlet,

was drilled into the pond shell at the height presented by the top of the

agricultural pipe, 100 mm from the base. The outlet had a washer to

eliminate leaks. The overflow outlet was located as close as possible to

the rooftop drain to minimise the trip hazard created by a hose. Geotextile

fabric was placed on the agricultural pipe to prevent the soil and roots

from entering the reservoir and to allow the capillary or wicking action

to irrigate the garden bed. Figures 9.4 and 9.5 show the bed immediately

following planting in December 2013 and then four weeks later in

January 2014.

**Figure 9.4** Wicking bed on Science roof (December 2013).

*Source*: Wilkinson.





**Figure 9.5** Wicking bed on Science roof (January 2014).

*Source*: Wilkinson.

The bed was filled with soil and compost to a depth of approximately

200 mm. It was top dressed with a compressed pelletised organic seaweed

fertiliser (Seamungus). The bed was filled with water through the vertical

filler tube until it overflowed from the outlet. It was topped up over the

two days while the soil conditioned and after this initial phase it was

topped up with 30–40 litres of water every five to six days. The bed was

planted with a mix of eggplant, zucchini, basil, carrots, beetroot, lettuce,

chilli, capsicum, silverbeet, celery, rocket, mizuna and marigolds. After

planting, the bed was mulched with lucerne hay and fertilised topically

fortnightly with an organic fish emulsion and Seasol (a seaweed tonic) was

applied topically once a month. The bed was planted out in December

2013, which is summer in Sydney, Australia. The total cost of the bed was

$412 plus labour.

**9.4.4**

**Vertical Gardens**

This roof is located at fifth-floor level on Harris Street in Sydney. The roof

faces northwest. The roof construction comprises reinforced concrete with

an impervious tiled covering. The roof is designed for access and has a con-

crete parapet approximately 1200 mm high and 200 mm deep to one side.

Two sides are flanked by buildings that rise to a height of 7 floors and 20

floors. The remaining edge has a metal-framed glazed fence and overlooks

an internal courtyard at fourth-floor level. The roof is enclosed on all sides

by tall buildings. In summer months, when the sun is high, there are around

six hours of direct sunlight on the roof, however in winter months there is



176 Green Roof Retrofit

**Figure 9.6** V Gardens on level 5 roof.

*Source*: Wilkinson.

minimal direct sun. Furthermore, the buildings do lead to very high wind

levels at times. There is lift access to level 5, however there are steps out onto

the roof terrace area, which made transportation less easy. The beds were

supplied by V Gardens, Sydney. The beds have a timber frame and a large

base bed with a series of metal-framed horizontal trays to a height of

1600 mm. The horizontal trays are approximately 150 mm deep. One bed

has a self-watering system on a 12 volt timer, which utilises a submersible 12

volt pump and drippers. It is powered by a battery, which is recharged by

photovoltaic cells and the sun. The reservoir at the base of the garden houses

the submersible pump and acts as a wicking bed for the lowest garden. The

second bed is identical in design apart from the irrigation system and wick-

ing bed. See Figures 9.6 and 9.7.

These beds were planted with a variety of herbs including basil, mint and

oregano and vegetables such as lettuce, eggplant, silverbeet and capsicums.

Larger root vegetables such as carrots and beetroots were grown in the base

bed. The beds were planted out in November 2013.

**9.4.5**

**Results and Interpretation**

Social

There was considerable interaction and interest from staff within the fac-

ulties where the beds were sited around the university. This interest was

focused on what had been planted, and whether anyone could join in to

water the plants and harvest the food. Without prompting, staff in the





**Figure 9.7** V Garden with wicking bed.

*Source*: Wilkinson.

Design, Architecture and Building faculty put up a wall calendar with a

pen in the staff kitchen to record whether the plants had been watered.

When watered, the staff member or person simply ticked the date and others knew when the plants had been watered. It is a simple system, and few plants died despite a record-breaking hot, dry Sydney summer. People asked and talked about the plants regularly and would often describe the meals they cooked with the plants and the flavour of the herbs and vegetables they used. Other staff – such as security guards – also expressed interest in the rooftop gardens, imparting tips and guidance where they thought it was needed. One staff member, upon learning that the beds were an experiment to see what could be grown on Sydney rooftops, noted that: ‘this is why the Cubans survived and the North Koreans starved to death’. They have given advice also about the timing of the watering and care of the plants. Students approached the researchers when attending the gardens at Gumal and chatted freely about the plants.

A journalism student from Germany decided to write about the gardens for her assignment. Industrial design students used the gardens and

rooftop agriculture in their major design projects. Overall, the social

interactions were high and positive.

178 Green Roof Retrofit

Economic

The costs of the beds varied, as did the amount of growing space between

the three roofs. The costs were reasonably affordable, although it would

take many years to grow sufficient food to pay back the initial costs.

Environmental Considerations

The three locations experienced different weather conditions to some extent.

For example, the Gumal rooftop is exposed to sun and high winds, which

desiccated the plants on a number of hot summer days. The beds needed

more watering due to accelerated evapotranspiration. The Science roof was

sheltered from wind on three sides, and the plants received more shade dur-

ing the hottest months, resulting in less leaf burn and water stress. High

winds were experienced in the DAB roof area and although the V Garden’s

construction, with the weight centred at the base, meant that neither struc-

ture was affected by the winds, some of the larger vegetables were badly

battered on these occasions. The DAB roof is surrounded by high buildings

on all four sides and consequently during autumn and winter periods less

direct sun was experienced on the roof, which affected growing rates.

However, in the summer, plants on this building had more respite from

intense heat and direct sunlight.

In terms of thermal performance, the installation of rooftop gardens inev-

itably results in some reductions in air-conditioning-system cooling loads.

Owing to the inherent thermal properties of shading, the temperature under

the raised bed was significantly lower and this provided a reduction in the

temperature of the roof covering. With the wicking bed and its direct surface

contact, higher levels of thermal performance would be expected. No data

was recorded on temperatures in the rooms directly below the beds, as the

air-conditioning (A/C) systems in the building would ameliorate any tem-

perature changes caused by the roof garden, but this is worth exploring in

the future, especially with regard to any effects on the energy use of the A/C

systems. Given the absorptive properties of the growing media, there was a

noticeable diminution in the amount of water entering the rainwater drain-

age systems of each of the roofs as a result of the installation of the garden

beds. The Gumal beds had plastic tanks sited below the drainage outlet, and

this allowed the researchers to ascertain the approximate amounts of rain-

water runoff from the beds compared with the rainfall recorded in a rain

gauge. The Science roof beds drained onto the roof and into an open drain-

age channel. No silting of the drains occurred on any of the roofs as the

geotextile fabric ensured only water passed through the textile.

With regard to attracting biodiversity, as soon as all three roofs were

planted, insects appeared. Native and European bees were spotted on all

sites. On the Gumal roof, a group of sulphur-crested cockatoos (*Cacatua*

*galerita*) visited the site on the first day and uprooted the majority of the

plants. Protective screens of wire mesh were fixed temporarily to deter the

birds. Both yellow and orange lady beetles encamped within just a few



weeks, and within all the beds worms were seen on a regular basis. No

actual tests have been conducted on air quality around the beds, but it

should be the case that the air will have higher levels of oxygen and lower

carbon dioxide as the plants photosynthesise.

Physical and Location

Access to the three roofs varied. Gumal was always intended for public

access and had good conditions from the basement car park to the rooftop.

There are good water and power sources on this roof. The recycled plastic

garden beds were delivered in a long lightweight tube, which fitted into the

lift. The prefabricated trestle frames and the pine sheet were heavy and cum-

bersome but could fit in the lift, as did substrates and membranes. The

3600 mm rails had to be carried up the fire stairs. Once assembled, these

beds were very heavy and not easily relocated.

With the Science roof, access was via a goods lift from the car park to level 7.

However, due to the sensitivity and security concerns of the science labs, special

access had to be negotiated for the researchers and no public access was possi-

ble. With the DAB rooftop there is lift access to the floor but the space planning

and configuration of offices meant there was a circuitous route to get the V

Garden to the rooftop. Fortunately, the units were not too heavy for two people

to carry. The DAB roof does not have a water or power supply, and therefore

water had to be transported from the adjoining staff kitchen to the gardens.

Although a solar-powered pump on the larger bed with wicking provided irri-

gation to that bed, it required topping up with water on a regular basis. Table 9.1

summarises the three bed types and their respective performance.

**Table 9.1** Three bed types and performance

Bed 1 – Science

Bed 2 – Gumal

roof wicking bed

raised bed

Bed 3 – V Garden

Transportability

Very easy

Difficult. Some

Units easily transported with

and assembly

carpentry

two people and a trolley but

skills required

location presented a challenge

Ease of working

Low to ground

Easy

Very easy

Costs/sq. m of

Medium

Very high

High

growing area

Ease of watering

Easy

Manual, every

Easy

other day in

summer

Plant growth

Very good

Varied

Good

Water usage

Low

Medium to

Medium

high

Exposure to wind

Low

High

High

Exposure to excessive

Medium

High

Medium

summer sun/heat

Biodiversity attracted

Very good

Very good

Good

to bed

180 Green Roof Retrofit

### 9.4.6 Findings

This section of the chapter reports on three rooftops set up in 2013 in

Sydney for the production of food. The social, economic, environmental and

physical aspects of the installation are described. Despite varying conditions

on all three rooftops, production over the summer period in 2014 was good.

There were different challenges with all three roofs, due to the physical envi-

ronment and environmental conditions. The social impacts were over-

whelmingly positive in all respects. Economically there was variation in the

costs of the beds and the amount of skill and labour required for installation

and setup, however there are options to suit most budgets. In this project,

plants were tested for the presence of heavy metals; initially, moderate levels

of lead were found in the soil (see Section 9.3.2), which were bio-remediated

in subsequent crops.

## 9.5

## The Carbon Footprint of Food Grown on Demonstration Beds

Currently, fresh food consumed in cities is trucked great distances. It has

been estimated that the cost of transport of a $1 supermarket lettuce head is

around 40 cents (Midmore, 2011). Using the Australian Greenhouse Office

(2006) *Factors and Methods Workbook*, it is possible to calculate that a

diesel-powered truck (manufactured post-2004) with an average carrying

capacity of 24 tonnes has an average fuel consumption of 2.10 km/litre and

average CO emissions of 42.8 kg/tonne of freight. The University of

2

Queensland conducted a ‘lifecycle assessment study’ of lettuce using a tech-

nique approved in 1998 by Standards Australia (Kershaw and Gafel, 2008).

It concluded that to transport a 1 kg lettuce would create 0.0005 kg CO

2

emissions/kg lettuce/km.

Initially it was intended that the carbon footprint of growing vegetables

in our demonstration rooftop gardens might easily be calculable by keeping

a log of trips made to and from the gardens, however, once the gardens had

been constructed, except for several replantings, almost all journeys over the

389 days to date were made by pushbike or walking. There were obviously

elevator rides, and a log was kept, but as a conceptual model of urban roof-

top farming, where it is assumed that the food will be consumed in situ, this

seems somewhat irrelevant because if the gardens were being maintained by

residents of the building, then those elevator rides would be incorporated

into a daily routine anyway regardless of whether there was a rooftop

garden or not.

However, this almost zero-carbon output can be compared with the car-

bon footprint calculations of commercially grown foodstuff which is trucked

from a market garden/farm to a depot, from a depot to a retailer and then

once purchased, transported to a residence, quite often by car, train or bus.

The Australian Greenhouse Office (2006) calculates petrol as producing

2.7 kg of GHG emissions per litre combusted, and it calculates diesel as

producing 2.9 kg of GHG emissions per litre combusted. If an average inner-

city car consumes 8 litres/100 km (or 12.5 km/litre) and a typical short



round trip from home to purchase vegetables of 6 km is assumed, then

approximately 1.296–1.392 kg of GHG emissions is produced per trip.

Based on a weekly shopping trip, total transport GHG emissions are

67.392–72.384 kg p.a. It is also worth noting the estimate that the vegetable

industry contributes close to 60% of the GHG emissions within horticulture

(Deuter, 2008), and this figure includes cultivation as well as transport.

## 9.6

## Potential Reductions in Carbon Footprint

The carbon footprint of food, or ‘food miles’, measures the transport dis-

tance travelled by food products between production and consumption.

Food can travel by ship, plane, rail or road transport, each having a different

degree of environmental impact. Trucks vary from light commercial to

heavy articulated vehicles, and fuel type can be diesel or unleaded petrol.

Most food in Australia is transported by road (Gaballa and Abraham,

2007). Another variable to take into account is whether the trucks are full

or partly full, as this affects fuel consumption and GHG emissions. When

the sustainability of food is considered, food miles are an important part of

the complete lifecycle assessment. A further consideration is that food trans-

ported over long distances and stored for long periods can have severely

reduced nutritional value when it arrives at the point of consumption

(Gaballa and Abraham, 2007). In some countries, supermarkets (e.g., Tesco

in the UK) label food miles on some products for consumers (Pretty *et al*.,

2005). Lengthy storage times are causing concern, and more local produc-

tion may be favoured in future, however some areas do not suit local pro-

duction due to soil and climate conditions. Any analysis of the embodied

energy of food must acknowledge that food miles are one part of the food

production system and are related to fossil-fuel input, and GHG emissions

occur at many, if not all, stages (Gaballa and Abraham, 2007). Another

variable is packaging. There is little empirical research on food miles in

Australia, and this research makes some preliminary estimates with regard

to the carbon footprint of the current supply of City of Sydney LGA food

compared with the rooftop production model.

The formula for calculating emissions estimates was sourced following

the guidelines in the Australian Greenhouse Office (2006) *Factors and*

*Methods Workbook* as follows:

Emissions TCO e Distance km FuelConsumptionRates FCR l/kkm

2

EmissionsFactor EF per fuel type TCO

e / kl / 1000

2

Emission estimates using this formula are calculated for an average

food-transporting truck transporting 1 tonne of truck mass and 1 tonne

of food mass. Weighted averages are used to calculate an average truck,

average truck mass, average fuel consumption rate of an average fuel

and average emissions factor. Emissions estimates are based on data

from the Australian Bureau of Science and the Australian Greenhouse



**Table 9.2** Food miles and carbon emissions in Sydney, Australia

Emissions: 1 tonne of food item

Emissions: 1 kg of

Transport

transported by road (transport

food item transported

Food item

(km)

km × 0.0002205 T CO -e)

by road (g CO -e)

2

2

Tomatoes

1618

356.8

357

Lettuce

54

11.9

12

Carrots

311

68.6

69

Onions

782

172.4

172

*Source*: Adapted from Gaballa and Abraham (2007).

Office and some data was not available for all years, consequently some

inaccuracy may exist. Table 9.2 illustrates the food miles and carbon

emissions for four vegetables, two of which were grown in the UTS roof-

top garden beds.

It is apparent that for the four vegetables above, lettuce has the smallest

carbon footprint, partly due to it representing the smallest distance trav-

elled. Typically these vegetables require little processing and packaging,

and are sold in their original form and therefore have lower carbon foot-

print compared with other foods such as bread or meat products. With the

four vegetables in Table 9.2, however, it would appear that growing toma-

toes and onions in the CBD would have the greatest impact on reducing

carbon food miles as they have the highest footprint. This estimate is to be

treated with caution, as the calculation was based on information pro-

vided by third parties and there was some incomplete information. Source

data also varies from year to year. However, the estimates do give consum-

ers some idea of the comparative levels of carbon food miles between

vegetables. For example, the adoption of intensive production techniques

may produce higher yields. Further research is required to fully assess the

impacts and vulnerabilities of the Australian, NSW and Sydney food sys-

tem. Food labelling is recommended so that consumer awareness is raised

with regard to carbon food miles. Such awareness may lead to a greater

desire to adopt increased urban food production, especially on retrofitted

rooftops. Furthermore, the potential health impacts of eating fresher,

locally grown food cannot be understated. Such knowledge would lead to

deeper understanding of the environmental and social impacts of our

food systems.

Wilkinson *et al*. (2013) estimated that, if the 15% of City of Sydney LGA

rooftops identified by Osmond (2012) as suited for green roofs were used to

grow lettuces, then 405,000 kg could be grown in total, leading to a reduc-

tion of 4860 kg of CO -e. Were tomatoes grown, the emissions reduction

would be greater. Based on a typical yield for the Sydney area of 300 tonnes

of organic tomatoes per hectare (Scoop it, 2012), and with a total estimated

area of 1.6875 km2 (or 168.75 ha) available for food production, the total

production of tomatoes would be 50,625 tonnes. Therefore, a reduction of

18,073 kg of CO -e could be achieved if all suited rooftop space was given

2

over to tomato production.



## 9.7 Conclusions

This chapter has described issues of food security, human health, population,

access to nutritious food sources and the carbon impact of current food

production methods, mostly in reference to Sydney, Australia, although the

issues are pertinent to other cities and countries. Furthermore, the research

reported here relates to university property, which has different drivers and

ownership patterns to high-density residential and commercial property. It is

possible, however, to adapt the model to residential and commercial prop-

erty, and this is being proposed in ongoing research into urban food produc-

tion. The potential for urban rooftop food production was examined, and

the typical features required in rooftops for successful outcomes were dis-

cussed. Clearly there are social health and wellbeing benefits for those

engaged in food production, and local production will increase awareness of

food security issues and carbon food miles. The chapter described research

conducted at UTS in rooftop food production including social, environmen-

tal and economic aspects, as well as setting out the specifications and consid-

erations in respect of bed systems. The issue of contamination of urban sites

and soils was described in detail; this is a significant issue that must be

addressed to ensure safe, healthy food is grown on rooftops. Each site and

city will have slightly different locational issues to contend with, however it

is possible to grow contaminant-free food with care and planning.

The technical environmental and economic aspects of larger-scale food

rooftop production were described, along with some initial modelling on

production potential. McClintock and Cooper (2009) concluded that

5–10% of Oakland's fruit and vegetable requirements for a population of

423,000 could be met from 486 ha of food production on 495 aggregated

public land sites. Toronto estimated that 10% of cities' food needs could be

grown within the city boundary (MacRae *et al*., 2010), on rooftops and in

public spaces. The potential for Sydney is modelled here, albeit at a very

rudimentary level, however it does show the scope for urban rooftop food

production and, as the city grows by approximately 2000 people per week,

it is an option we will need to consider increasingly. The stakeholders were

described, along with their drivers and concerns in respect of rooftop food

production. These concerns are not insurmountable; it is largely a case of

being risk adverse in the face of adopting a practice that is new and unknown.

Given guidelines and experience, these concerns will be addressed and the

overall positive aspects of urban food production socially and environmen-

tally will prevail. In Sydney, further research is needed into other methods of

urban food production such as vertical urban farming and more intensive

modes of production.

## References

Alyemenia, M. N. and Almohisen, I. A. A. (2014) ‘Traffic and industrial activities

around Riyadh cause the accumulation of heavy metals in legumes: a case study’,

*Saudi Journal of Biological Sciences*, 21, 167–172.



Angotti, T. (2015) ‘Urban agriculture: long-term strategy or impossible dream?

Lessons from Prospect Farm in Brooklyn, New York', *Public Health*, 129,

336–341.

Australian Bureau of Meteorology (2013) www.bom.gov.au.

Australian Bureau of Statistics (2015) www.censusdata.abs.gov.au/census_services/

getproduct/census/2011/quickstat/LGA17200?opendocument&navpos=220.

Australian Greenhouse Office (2006) *Factors and Methods Workbook*. Available at:

s3.amazonaws.com/zanran_storage/www.minkvote.no/ContentPages/

2483521100.pdf.

Brault, N., Loranger, S., Courchesne, F., Kennedy, G. and Zayed, J. (1994)

'Bioaccumulation of manganese by plants: influence of MMT as a gasoline addi-

tive', *Science of the Total Environment*, 153, 77–84.

Castleton, H. (2010) 'Green roofs; building energy savings and the potential for

retrofit', *Energy and Buildings*, 42, 1582–1591.

Centers for Disease Control and Prevention (2013) 'Childhood lead poisoning data,

statistics, and surveillance, ' available at: www.cdc.gov/nceh/lead/data/index.htm.

Chen, T.-B., Zheng, Y.-M., Lei, M., *et al*. (2005) 'Assessment of heavy metal pollution in surface soils of urban parks in Beijing, China', *Chemosphere*, 60, 542–551.

Cicchella, D., De Vivo, B., Lima, A., Albanese, S., McGill, R. A. R. and Parrish, R. R.

(2008) 'Heavy metal pollution and Pb isotopes in urban soils of Napoli, Italy',

*Geochemistry: Exploration, Environment, Analysis*, 8(1), 103–112.

City of Sydney (2013) 'aboutsydney', available at: www.cityofsydney.nsw.gov.au/

aboutsydney/CityResearch/AtAGlance.asp.

Clarke, L. W., Jenerette, G. D. and Bain, D. J. (2015) 'Urban legacies and soil management affect the concentration and speciation of trace metals in Los Angeles com-

munity garden soils', *Environmental Pollution*, 197, 1–12.

Currie, B. and Bass, B. (2008) 'Estimates of air pollution mitigation with green plants and green roofs using the UFORE model', *Urban Ecosystems*, 11, 409–422.

De Nicola, F., Baldantoni, D., Sessa, L., Monaci, F., Bargagli, B. and Alfani, A.

(2015) 'Distribution of heavy metals and polycyclic aromatic hydrocarbons in

holm oak plant–soil system evaluated along urbanization gradients',

*Chemosphere*, 134, 91–97.

Deuter, P. (2008) 'Defining the impacts of climate change on horticulture in Australia', *Garnaut Climate Change Review*.

Cambridge University Press: Cambridge.

Farmaki, E. G. and Thomaidis, N. S. (2008) ‘Current status of the metal pollution of

the environment of Greece—a review’, *Global NEST Journal*, 10, 366–375.

Ferri, R., Hashim, D., Smith, D. R., *et al*. (2015) ‘Metal contamination of home garden soils and cultivated vegetables in the province of Brescia, Italy: implications for human exposure’, *Science of the Total Environment*, 518/519,

507–517.

Finster, M. E., Gray, A. K. and Binns, H. (2004) ‘Lead levels of edibles grown in con-

taminated residential soils: a field survey’, *Science of the Total Environment*, 320, 245–257.

Fox, T. E. (2013) *Global Food, Waste Not Want Not*. Institute of Mechanical

Engineers: London.

Frazer, L. (2005) ‘Paving paradise’, *Environmental Health Perspectives*, 113,

457–462.

Gaballa, S. and Abraham, A. B. (2007) *Food Miles in Australia: A Preliminary Study of Melbourne, Victoria*. CERES Community Park, Brunswick, Victoria. Available

at: www.theage.com.au/ed_docs/food_miles.pdf.

Galal, T. M. and Shehata, H. S. (2015a) ‘Bioaccumulation and translocation of heavy

metals by *Plantago major* L. grown in contaminated soils under the effect of traffic pollution', *Ecological Indicators*, 48, 244–251.

Urban Food Production on Retrofitted Rooftops 185

Galal, T. M. and Shehata, H. S. (2015b) 'Impact of nutrients and heavy metals

capture by weeds on the growth and production of rice ( *Oryza sativa* L.) irrigated with different water sources', *Ecological Indicators*, 54, 108–115.

Germain, A. E. (2008) *Guide to Setting Up Your Own Edible Rooftop Garden*.

Alternatives and the Rooftop Garden Project. Available at: archives.rooftopgar

dens.ca/files/howto_EN_FINAL_lowres.pdf.

Grandjean, P. and Landrigan, P. J. (2006) 'Developmental neurotoxicity of industrial

chemicals', *The Lancet*, 368, 2167–2178.

Growing Chefs (2013) www.growingchefs.ca/.

Guitart, D. A., Pickering, C. M. and Byrne, J. A. (2014) 'Color me healthy: food

diversity in school community gardens in two rapidly urbanising Australian cities',

*Health & Place*, 26, 110–117.

Heisler, M. (1986) 'Effects of individual trees on the solar radiation climate of small buildings', *Urban Ecology*, 9, 337–359.

Hibben, C. R., Hagar, S. S. and Mazza, C. P. (1984) ‘Comparison of cadmium and

lead content of vegetable crops grown in urban and suburban gardens’,

*Environmental Pollution (Series B)*, 7, 71–80.

Hilten, R. (2008) ‘Modeling stormwater runoff from green roofs with HYDRUS-1D’,

*Journal of Hydrology*, 358(3/4), 288–293.

Hu, J., Wu, F., Wu, S., Sun, X., Lin, X. and Wong, M. H. (2013) ‘Phytoavailability and phytovariety codetermine the bioaccumulation risk of heavy metal from soils,

focusing on Cd-contaminated vegetable farms around the Pearl River Delta,

China’, *Ecotoxicology and Environmental Safety*, 91, 18–24.

Hu, Y., Wang, D., Wei, L., Zhang, X. and Song, B. (2014) ‘Bioaccumulation of heavy

metals in plant leaves from Yan’an city of the Loess Plateau, China’, *Ecotoxicology and Environmental Safety*, 110, 82–88.

Irga, P. J., Burchett, M. D. and Torpy, F. R. (2015) ‘Does urban forestry have a quan-

titative effect on ambient air quality in an urban environment?’, *Atmospheric*

*Environment*, 120, 173–181.

Islam, M. S., Ahmed, M. K., Habibullah-Al-Mamun, M. and Masunaga, S. (2015)

‘Potential ecological risk of hazardous elements in different land-use urban soils of

Bangladesh’, *Science of the Total Environment*, 512/513, 94–102.

Jambhulkar, H. P. and Juwarkar, A. A. (2009) ‘Assessment of bioaccumulation of

heavy metals by different plant species grown on fly ash dump’, *Ecotoxicology*

*and Environmental Safety*, 72, 1122–1128.

Jozic, M., Peer, T. and Turk, R. (2009) ‘The impact of the tunnel exhausts in terms of heavy metals to the surrounding ecosystem’, *Environmental Monitoring and*

*Assessment*, 150, 261–271.

Karim, Z., Qureshi, B. A. and Mumtaz, M. (2015) ‘Geochemical baseline determina-

tion and pollution assessment of heavy metals in urban soils of Karachi, Pakistan’,

*Ecological Indicators*, 48, 358–364.

Kellert, S. R. and Wilson, E. O. (1995) *The Biophilia Hypothesis*. Island Press: Washington D.C.

Kelly, M. J. (2008) *Britain’s Building Stock. A Carbon Challenge*. Available at: www.

lcmp.eng.cam.ac.uk/wp-content/uploads/081012_kelly.pdf.

Kershaw, W. and Gaffel, J. (2008) *The Australian Dairy Manufacturing Industry*

*Sustainability Report 2007/2008*. Available at: dmsc.com.au/wpcontent/

uploads/2011/03/admsr0708.pdf.

Köhler, M. (2008) 'Green facades – a view back and some visions', *Urban Ecosystems*, 11(4), 423–436.

Laidlaw, M. A. S. and Taylor, M. P. (2011) 'Potential for childhood lead poisoning in

the inner cities of Australia due to exposure to lead in soil dust', *Environmental Pollution*, 159, 1–9.



Laschober, C., Limbeck, A., Rendl, J. and Puxbaum, H. (2004) 'Particulate emissions

from on-road vehicles in the Kaisermühlen-tunnel (Vienna, Austria)', *Atmospheric*

*Environment*, 38, 2187–2195.

Li, Z. Y., Ma, Z. W., Kuijp, T. J., Yuan, Z. W. and Huang, L. (2014) 'A review of soil heavy metal pollution from mines in China: pollution and health risk assessment',

*Science of the Total Environment*, 468/469, 843–853.

Li, J., Jia, C., Lua, Y., Tang, S. and Shimb, H. (2015) 'Multivariate analysis of heavy metal leaching from urban soils following simulated acid rain', *Microchemical*

*Journal*, 122, 89–95.

Lu, Y., Song, S., Wang, R., *et al*. (2015) 'Impacts of soil and water pollution on food safety and health risks in China', *Environment International*, 77, 5–15.

Luo, X.-S., Yu, S., Zhu, Y.-G. and Li, X.-D. (2012) ‘Trace metal contamination in

urban soils of China’, *Science of the Total Environment*, 421/422, 17–30.

MacRae, R., Gallant, E., Patel, S., Michalak, M., Bunch, M. and Schaffner, S. (2010)

‘Could Toronto provide 10% of its fresh vegetable requirements from within its own

boundaries? Matching consumption requirements with growing spaces *’, Journal of*

*Agriculture, Food Systems, and Community Development*, 1(2), 105–127.

McBride, M. B. (2013) ‘Arsenic and lead uptake by vegetable crops grown on historically contaminated orchard soils’, *Applied Environmental Soil Science*, 2013, 1–8.

McBride, M. B., Simon, T., Tam, G. and Wharton, S. (2013) ‘Lead and arsenic uptake

by leafy vegetables grown on contaminated soils: effects of mineral and organic

amendments’, *Water, Air & Soil Pollution*, 224, 1378.

McBride, M. B., Shayler, H. A., Spliethoff, H. M., *et al*. (2014) ‘Concentrations of lead, cadmium and barium in urban garden-grown vegetables: the impact of soil

variables’, *Environmental Pollution*, 194, 254–261.

McClintock, N. and Cooper, J. (2009) Cultivating the Commons: An assessment of

the potential for urban agriculture on Oakland's public lands. Department of

Geography, University of California, Berkeley. Available at: www.oaklandfood.

org/media/AA/AD/oaklandfood-org/downloads/27621/Cultivating_the_

Commons_COMPLETE.pdf.

Mentens, J. (2006) 'Green roofs as a tool for solving the rainwater runoff problem in

the urbanized 21st century?', *Landscape and Planning*, 217–266.

Midmore, D. E. (2011) 'Roof-top gardens an option for green roof-tops and self-

sufficient fresh food production', *Rural Industries Research and Development*

*Corporation*, 067(11).

Mielke, H. W., Laidlaw, M. A. S. and Gonzales, C. R. (2012) 'Estimation of leaded

(Pb) gasoline's continuing material and health impacts on 90 US urbanized areas',

*Environment International*, 37, 248–257.

Mireles, F., Davila, J. I., Pinedo, J. L., Reyes, E., Speakman, R. J. and Glascock, M. D.

(2012) 'Assessing urban soil pollution in the cities of Zacatecas and Guadalupe,

Mexico by instrumental neutron activation analysis', *Microchemical Journal*, 103, 158–164.

Mitchell, R. G., Spliethoff, H. M., Ribaudo, L. N., *et al*. (2014) 'Lead (Pb) and other metals in New York city community garden soils: factors influencing contaminant

distributions', *Environmental Pollution*, 187, 162–169.

Moser, C. and Kalton, G. (1979) *Survey Methods in Social Investigation*. Dartmouth Publishing: Aldershot.

New South Wales Environment and Heritage (2015) 'About climate change in NSW',

available at: www.climatechange.environment.nsw.gov.au/About-climate-change-

in-NSW/Understand-climate-change.

Onder, S. and Dursun, S. (2006) 'Air borne heavy metal pollution of *Cedrus libani* (A.

Rich) in the city centre of Konya (Turkey)', *Atmospheric Environment*, 40, 1122–1133.

Urban Food Production on Retrofitted Rooftops 187

Orwell, R. L., Wood, R. A., Tarran, J., Torpy, F. R. and Burchett, M. (2004) 'Removal

of benzene by the indoor plant/substrate microcosm and implications for air qual-

ity', *Water, Air & Soil Pollution*, 157, 193–207.

Orwell, R. L., Wood, R. A., Burchett, M., Tarran, J. and Torpy, F. R. (2006) 'The

potted-plant microcosm substantially reduces indoor air VOC pollution. (ii)

Laboratory study', *Water, Air & Soil Pollution*, 177, 59–80.

Osmond, P. (2012) *Green Roofs and Walls Perception Study – Final Report and*

*Recommendations*. University of New South Wales, Sydney.

Patton, M. Q. (1980) *Qualitative Research and Evaluation Methods*. Sage

Publications: Thousand Oaks, CA.

Peña-Fernández, A., Lobo-Bedmar, M. C. and González-Muñoz, M. J. (2015) 'Annual

and seasonal variability of metals and metalloids in urban and industrial soils in

Alcaláde Henares (Spain)', *Environmental Research*, 136, 40–46.

Peng, K., Luo, C., Lou, L., Li, X. and Shen, Z. (2008) 'Bioaccumulation of heavy

metals by the aquatic plants *Potamogeton pectinatus* L. and *Potamogeton mala-ianus* Miq. and their potential use for contamination indicators and in wastewater treatment', *Science of the Total Environment*, 392, 22–29.

Plan, N. G. (2008) *Summary of Climate Change Impact Statement*. NSW Government, Department of Environment and Climate Change, Sydney.

Pretty, J. N., Ball, A. S., Lang, T. and Morison, J. I. (2005) 'Farm costs and food miles: an assessment of the full cost of the UK weekly food basket', *Food Policy*, 30(1), 1–19.

Qing, X., Zong, Y. and Lu, S. (2015) ‘Assessment of heavy metal pollution and

human health risk in urban soils of steel industrial city (Anshan), Liaoning,

Northeast China’, *Ecotoxicology and Environmental Safety*, 120, 377–385.

Refahi, H. and Talkhabi, H. (2015) ‘Investigating the effective factors on the reduc-

tion of energy consumption in residential buildings with green roofs’, *Renewable*

*Energy*, 80, 595–603.

Rizwan, A. M., Dennis, L. Y. and Chunho, L. I. U. (2008) ‘A review on the generation,

determination and mitigation of urban heat island’, *Journal of Environmental*

*Sciences*, 20(1), 120–128.

Robson, C. (2003) *Real World Research*. Blackwell: London.

Rooftop Farms (2013) www.rooftopfarms.org.

Rowe, D. B. (2011) ‘Green roofs as a means of pollution abatement’, *Environmental*

*Pollution*, 159, 2100–2110.

Säumel, I., Kotsyuk, I., Holscher, M., Lenkereit, C., Weber, F. and Kowarik, I. (2012)

‘How healthy is urban horticulture in high traffic areas? Trace metal concentra-

tions in vegetable crops from plantings within inner city neighbourhoods in Berlin,

Germany', *Environmental Pollution*, 165, 124–132.

Schlecht, M. T. and Säumel, I. (2015) 'Wild growing mushrooms for the Edible City?

Cadmium and lead content in edible mushrooms harvested within the urban

agglomeration of Berlin, Germany', *Environmental Pollution*, 204, 298–305.

Scoop it (2012) '300 tonnes tomatoes per hectare', available at: www.scoop.it/t/

organic-farming/p/995411992/2012/01/17/300-tons-tomatoes-per-hectare.

Shephard, P. (1982) *Nature and Madness*. University of Georgia Press: Athens, GA.

Sipter, E., Rozsa, E., Gruiz, K., Tatrai, E. and Morvai, V. (2008) 'Site-specific risk assessment in contaminated vegetable gardens', *Chemosphere*, 71, 1301–1307.

Tan, P. and Sia, A. (2005) 'A pilot green roof research project in Singapore',

Proceedings of Third Annual Greening Rooftops for Sustainable Communities

Conference, Washington D.C., 2–6 May.

Taylor, M. P., Winder, C. and Lanphear, B. P. (2012) 'Eliminating childhood lead

toxicity in Australia: a call to lower the intervention level', *Medical Journal of Australia*, 197, 493.



Thomas, V. M., Socolow, R. H., Fanelli, J. J. and Spiro, T. G. (1999) 'Effects of reducing lead in gasoline: an analysis of the international experience', *Environmental*

*Science & Technology*, 33, 3942–3948.

Tong, Z., Whitlow, T. H., Landers, A. and Flanner, B. (2015) 'A case study of air quality above an urban roof top vegetable farm', *Environmental Pollution*, in press.

Torpy, F. R., Irga, P. J. and Burchett, M. D. (2014) 'Profiling indoor plants for the

amelioration of high CO concentrations', *Urban Forestry and Urban Greening*,

2

13, 227–233.

Wang, H. and Jia, Y. (2009) 'Bioaccumulation of heavy metals by *Phragmites austra-*

*lis* cultivated in synthesized substrates', *Journal of Environmental Sciences*, 21, 1409–1414.

Warming, M., Hansen, M. G., Holm, P. E., Magid, J., Hansen, T. H. and Trapp, S.

(2015) 'Does intake of trace elements through urban gardening in Copenhagen

pose a risk to human health?', *Environmental Pollution*, 202, 17–23.

Wilkinson, S. J., Ghosh, S. and Page, L. (2013) ‘Options for green roof retrofit and

urban food production in the Sydney CBD’, Proceedings of the RICS COBRA

Conference, New Delhi, India.

Wilkinson, S., van der Kallen, P., Teale, A. and Antoniades, H. (2016) ‘Retrofitting

cities for tomorrow’s world’. In Eames, M., Dixon, T., Hunt, M. and Lannon, S.

(eds), *Transforming the Commercial Property Market in Australian Cities:*

*Contemporary practices and the future potential of green roof retrofits*. John

Wiley & Sons: Chichester.

Wiseman, C. L. S., Zereini, F. and Püttmann, W. (2013) ‘Traffic-related trace element

fate and uptake by plants cultivated in roadside soils in Toronto, Canada’, *Science of the Total Environment*, 442, 86–95.

Witzling, L., Wander, M. and Phillips, E. (2011) ‘Testing and educating on urban soil

lead: a case of Chicago community gardens’, *Journal of Agriculture, Food Systems,*

*and Community Development*, in press.

Yang, J., Yu, Q. and Gong, P. (2008) ‘Quantifying air pollution removal by green

roofs in Chicago', *Atmospheric Environment*, 42, 7266–7273.

Zereini, F., Alsenz, H., Wiseman, C. L. S., *et al*. (2012) 'Platinum group elements (Pt, Pd, Rh) in airborne particulate matter in rural vs. urban areas of Germany:

concentrations and spatial patterns of distribution', *Science of the Total Environment*, 416, 261–268.

Zhang, Y., Luo, X.-J., Mo, L., Wu, J.-P., Mai, B.-X. and Peng, Y.-H. (2015)

'Bioaccumulation and translocation of polyhalogenated compounds in rice ( *Oryza*

*sativa* L.) planted in paddy soil collected from an electronic waste recycling site, South China', *Chemosphere*, 137, 25–32.

Żukowska, J. and Biziuk, M. (2008) 'Methodological evaluation of method for

dietary heavy metal intake', *Journal of Food Science*, 73, 21–29.

**10**

## Social Aspects of Institutional Rooftop Gardens

**Sumita Ghosh, Ilaria Vanni and Angela Giovanangeli**

UTS, Australia

**10.0**

## Introduction and Objectives

Across the world, rooftop gardens are a common feature of the contemporary

city. In fact, rooftop gardens have a long history that dates back to antiquity,

with the earliest documented roof gardens identified as the hanging gardens of

Semiramis (present-day Syria), considered to be one of the seven wonders of

the ancient world (Oberndorfer *et al*., 2007: 824). In more recent times, how-

ever, literature on rooftop gardens links the origins of these spaces to environ-

mental concerns that took place in Germany when, at the turn of the 20th

century, gardens were installed on roofs to counteract the damage of solar

destruction on roof structures (Oberndorfer *et al*., 2007: 825), followed in the 1970s by environmental policies and technologies on stormwater management, energy conservation and urban habitat provision (Oberndorfer *et al*.,

2007: 827). Similarly, work on urban planning refers to the way modern cities

over the last 50 years have been designed around the use of the car and the

decline of the community (Zande, 2006: 206), arguing that some city planners

have shifted values in the way that they consider urban structures to reflect

sustainable design, including rooftop gardens (Zande, 2006: 210). Today, roof-

top gardens cover one in every ten buildings in Europe and are mandated in

Germany, Switzerland and France, as well as in Japan (Litichevskaya, 2011).

While the origins of modern rooftop gardens demonstrate a concern

for the natural and built environment, the reasons for, and benefits of,

rooftop gardens are known to include other factors. Rooftop gardens have

been incorporated onto building structures to serve either public or private

interests, as well as ornamental and/or functional purposes.

Media articles have documented the way rooftop gardens visually enhance

spaces, such as the rooftops of hotels or dams (Beauty and Environmental

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



Benefits, 2009; Fujita Kanko Incorporated, 2012), particularly where green

space is limited and the roof garden is seen as a way of being connected with

the outdoors and with landscaping (Hoffman, 1983; Wilkerson, 2010).

Furthermore, rooftop gardens are seen as a way of maximising the opportu-

nities associated with the value of properties and projects (Wilkerson, 2010).

Media and scholarly articles on rooftop gardens identify the therapeutic

effects of rooftop gardens in places such as hospitals, where the garden is

considered an advantage to the wellbeing of patients (Wilkerson, 2010;

Davis, 2011; Solnik, 2011).

The aim of this chapter is to explore the social life of rooftop gardens.

It does this through a case study analysis of two rooftop gardens in higher-

density areas of inner-city Sydney, Australia, as well as a comparative analy-

sis of eight institutional rooftop case studies from around the world. Out of

the two rooftop gardens in Sydney, the first case study, is on the rooftop

garden set up on the roof of Gumal, a UTS student housing building in

Ultimo that has a Roof Gardening Club for UTS staff and students. UTS is

an important educational institution, located in Sydney CBD, where social

aspects of a rooftop garden were analysed considering the aspirations of staff

and students as a workplace community. The second case study is the 107

Projects rooftop garden on the roof of a retrofitted warehouse (area: 1700 m2)

in Redfern (107 Projects, 2015). 107 Projects is a multidisciplinary creative

space opened in 2012, including, in addition to the rooftop terrace and adja-

cent space, a gallery, performance space, bar and cafe, studio and workshop

areas. Milkwood Permaculture, one of the resident organisations at 107

Projects, is a social enterprise focusing on permaculture education (Milkwood,

2015). Permaculture is understood as ‘a creative design process based on

ethics and design principles’ (Permaculturepriniciples, 2015), rooted in the

reproduction and use of patterns and relationships occurring in nature.

Finally, varying objectives and social needs of rooftop gardens are explored in eight institutional rooftop case studies in different educational institutions in different countries of the world. The main objectives of this chapter are:

- To comprehend the social aspects of community development and aspirations, motivations, expectations and satisfactions of participants through rooftop food production in educational institutions.
- To explore how the evolving ecology of human and non-human elements created through permaculture principles on the 107 Projects rooftop garden designed by Milkwood Permaculture generate forms of sociality.

## 10.1 Social Aspects, Productivity and Sustainability Potential of Rooftop Gardens

Increasing literature on rooftop gardens refers to the importance of these spaces in the context of urban consumption. The term ‘urban consumption’

could be viewed very differently from various disciplinary and research

perspectives (Miles and Paddison, 1998; Newton, 2011). It could extend



beyond traditional understanding of purchasing goods to include consumers'

participation and reproduction of physical spaces in urban contexts as well

as the creation of culture-specific and meaningful ways of life (Miles and

Paddison, 1998). Newton (2011: 13) identified that determinants of urban

resource consumption on the supply side are indirect and are influenced

by urban form, technology, design innovation and materials used and

reused, while the demand-side determinants are direct and include social

milieu, household (practice and structure) and individual (structural and

behavioural) attributes. Urban gardens on rooftops are part of a range of

different typologies of regenerative green infrastructure provisions and food

production systems in urban areas, such as plots on public land assigned to

individuals or families, community gardens in abandoned and/or vacant

areas, and individual or common gardens in either yards, balconies or the

rooftops of buildings (Gorgolewski *et al*., 2011; Orsini *et al*., 2014).

The contributions of urban horticulture to city food supplies have been

estimated in a number of cities across the world. For instance, in Toronto

(Canada), Peck (2003) found that from a total of 650,000 m2 of ‘greened’

rooftops growing vegetable crops, an annual total yield of 4.7 million kg of

produce could be harvested. Subsequently, Kaethler (2006) states that in

Vancouver (Canada) it is easy to find rooftop gardens producing food above

supermarkets, restaurants and social housing.

A range of studies have addressed the role played by urban vegetable

gardens in improving human wellbeing through the provision of both eco-

system services and food supplies to city dwellers (Matsuo, 1995; Brown

and Jameton, 2000; McClintock, 2010; Orsini *et al*., 2014). For instance,

rooftop gardens may reduce a city's ecological footprint (EF) through the

reduction of pollution and noise, the absorption of carbon dioxide ($CO_2$)

emissions and control of the UHI effect by shading (Malcevschi *et al*., 1996;

Wackernagel and Rees, 1996; Shin and Lee, 2005). Rooftop gardens can

contribute to the biodiversity in the urban environment and achieve more

sustainable conditions for new habitat creation (Bennett, 2003; Khandaker,

2004; Miller, 2005; Maas *et al*., 2006; Sanyé-Mengual *et al*., 2013).

Furthermore, in countries such as South Africa or the USA, limited urban

space and poverty have been the reasons behind rooftop projects where the

growing of vegetables provides inexpensive food to locals (Johannesburg

Rooftop Garden, 2012; Lt. Governor Simon Awards, 2012). Meanwhile, a

number of research papers argue that the rate of urbanisation is increasing

over time and that food production sites should increasingly be located near

main consumption centres (Matsuo, 1995; Brown and Jameton, 2000;

McClintock, 2010; Orsini *et al*., 2014).

Rooftop gardens for urban consumption are sites for collaboration

between artists and community in the growing of food (Franklin, 2011). In

some instances, the creative structural elements of the garden are designed

and built by local artists using recycled and reclaimed materials, while the

sharing of knowledge on how to grow food is seen to have an educational

and community impact as a result of spaces that bring people together

and teach them about production systems (Franklin, 2011; Gorgolewski

*et al*., 2011).



Rooftop gardens producing food, on institutional and office buildings

in higher-density developments, have notably been the particular focus of

research on urban agriculture within built environments. Integrating roof-

top gardens in urban developments could provide significant social, envi-

ronmental and economic values for the users and urban residents. Unused

roof spaces in such structures are utilised effectively to recreate meaningful

and easily accessible places for users, while regenerating ecologies of lost

green open spaces successfully within denser urban environments. Rooftop

gardens in institutional and office buildings are seen to create places where

people engage in different ways in various activities, enhancing place-mak-

ing (Gehl, 1987). People from different socio-economic backgrounds work

together in a social networking space growing food to improve community

engagement (Foss *et al*., 2011). Even viewing a roof with green grass for

40 seconds could enrich mental concentration, as found in a University of

Melbourne, Australia study (Lee *et al*., 2015). Urban design theories high-

light that the ‘imageability’ of a city is primarily cognitive and based

on people's perception, reasoning and rational thinking (Lynch, 1960).

Responsive design of physical environments could affect people's choices for

seven different qualities of built environments: permeability (access or no

access to places); variety (different types of use available); legibility (clarity

around understanding of opportunities that a built environment offers);

robustness (the degree to which places can be used by people for different

purposes); richness (people's choice of sensory experience); visual appropri-

ateness (people's perceptions on the detailed appearance of place and the

choices available); and personalisation (to what extent people can put their

own identity on a place) (Bentley *et al*., 1985). Unused spaces are utilised for various purposes in rooftop gardens. They enable urban regeneration and

renewal processes, promote people's engagement with different types of

social activities and community building, interactions with nature, develop-

ment of sustainability awareness, creation of local identities and new ways

of re-imagining human environments. Montgomery's (1998) review of a

number of urban design approaches to successful place-making identified

three basic qualities: '… successful urban places must combine quality in

three essential elements: physical space, the sensory experience and activity'

(Montgomery, 1998: 96). Rooftop gardens provide access to physical spaces,

enable tangible, perceptive and psychological experience of working with

soil, plants, sun and fresh air in natural environmental settings, and motivate

carrying out physical activities through gardening practices. Thus, rooftop

gardens become an important constituent of successful place-making and

urban regeneration in cities and towns.

In the USA, some practical examples of rooftop urban agriculture that are

driving social networking and creating new spaces for community building

and interactions are: Eagle Street Rooftop Farm (2015) and Brooklyn

Grange Rooftop Farm (2015) in New York; Uncommon Ground (2015),

Chicago; and Boston's Higher Ground Farm (Boyer, 2013). For instance,

Eagle Street Rooftop Farm is located on the third-floor warehouse roof

of Broadway Stages in Brooklyn and covers 6000 ft2 or 557 m2 (Eagle Street

Rooftop Farm, 2015). It produces organic vegetables and supplies vegetables



to an on-site market and local restaurants, conducts farm educational

programmes, supports a small CSA programme and has Italian honey

beehives as part of the farm (Gordon, 2010; Eagle Street Rooftop Farm,

2015). Brooklyn Grange Rooftop Farm includes two rooftop organic vege-

table farms with a land area of 2.5 acres or 1 hectare and produces over

22,680 kg of food annually (Brooklyn Grange Rooftop Farm, 2015). New

York City's largest apiary, with more than 30 naturally managed honey

beehives, is located on this farm (Brooklyn Grange Rooftop Farm, 2015).

Uncommon Ground, Chicago is comparatively small, with an area of

60 m2. It produces 317 kg of vegetables, such as peppers (capsicums), lettuce,

tomatoes, beans, mustard greens and herbs, in the raised rooftop beds

and supplies a considerable share of vegetables to the Uncommon Ground

Restaurant in addition to educational programmes (Perasso, 2012).

In the UK, the Business Improvement District for Bloomsbury, Holborn

and St Giles in London has rooftop gardens on office buildings producing

vegetables with the aim of reducing food miles, enhancing carbon and ther-

mal performance benefits, encouraging user engagement and increasing

business productivity (Mavrogordato, 2013). Lend Lease, a transnational

construction company, has a rooftop garden for staff at its Regents Park

office in London, with a biodiversity roof attached which has a ‘bug hotel’

to encourage local biodiversity (Wilkinson, 2015a). Furthermore, wild flow-

ers are also grown on two green roofs of the law firm Mischon de Reya and

the Trade Union Congress to help increase the local bee population

(Mavrogordato, 2013). These rooftop gardens are crucially important for

the surrounding communities, staff members, clients and visitors to these

buildings and environments.

In the Australian context, a rooftop garden at 131 Queen Street,

Melbourne, Victoria acts as a social gathering space for building occupants;

rented for functions, it is an important initiative under the Inner Melbourne

Action Plan (IMAP) (City of Melbourne, 2015; University of Melbourne,

2015). Meanwhile, St Canice Kitchen Garden, Kings Cross, Sydney, a roof-

top food garden on the roof of the Refugee Centre, founded by Woods Bagot

and designed by PEPO Botanic Design, is creating ‘flexible space for com-

munal gatherings and social events’ (Woods Bagot, 2015). More informa-

tion on this garden is included later in the chapter. Australian media articles

have been placing significant emphasis on the emerging social importance

of rooftop gardens (Sydney Morning Herald, 2008; Carlyon, 2014; Zhou

and Stolz, 2014).

## 10.2 Methodology

Recent academic writing on social issues connected with aspects of rooftop

and urban gardening tends to see rooftops as possible sites of urban agricul-

ture and for the purpose of greening the city or in relation to urban food

systems. A ‘rooftop garden’ is different from a ‘green roof’ in terms of differ-

ent technical requirements and performance potential. Similarly, a ‘rooftop

garden in an institutional setting’ is different from a ‘community garden on



a rooftop’ in terms of ownership patterns, mode of operation and user types.

A ‘rooftop garden’ is a very specific typology of an urban food production

space that has been focused on in this chapter.

Three methodological approaches adopted for case study-based research

are: comparative analysis of eight university rooftop garden case studies;

semi-structured interviews with UTS Roof Gardening Club and 107 Projects;

a sensory ethnography approach. A comparative analysis of eight university

rooftop gardens that are growing food was conducted to understand their

objectives, aspirations, motivations, achievements and social contributions.

This chapter applies interviews and sensory ethnography research methods

to understand the social aspects of rooftop gardens in inner-city Sydney

through two selected case studies: UTS rooftop garden, managed by staff

and student members of the UTS Roof Gardening Club and 107 Projects

rooftop garden, designed and managed by Milkwood Permaculture. Both

rooftop case studies share similar characteristics: they are located in the

inner city of Sydney in high-density suburbs, Ultimo and Redfern, which are

in the process of urban regeneration and renewal. Both rooftops have lim-

ited access: while one is on the roof of Gumal, a UTS student residence,

supported and funded by the City of Sydney's Environmental

Grant Programme, the other is part of a multidisciplinary creative space,

107 Projects, developed as part of the City of Sydney's Accommodation

Grant Programme, a community programme that leases city buildings to

community groups at no or reduced rent. Both spaces have been designed

within the building guidelines imposed by, respectively, a university and a

city council, and with the workplace and resident community in mind: on

the one hand, resident and non-resident students and staff members; on the

other hand, a mixture of artists, permaculture students, permaculture urban

gardeners and visitors during special events. This chapter adds to the body

of literature by providing an analysis of two rooftop gardens that captures

the experience, imagination and expectations of gardeners and visitors.

These two different methodological approaches for the analysis of two

Sydney case studies allow for a textured analysis of the way people both

imagine and experience rooftop gardens, which, we contend, can help

researchers to unpack different understandings of the concept of ‘social’

when talking about rooftop gardens. Articulating the way gardens are

imagined and experienced, in turn, boosts our understanding of the way

rooftop gardens can have an impact on social and cultural practices.

While comparative analysis focuses on unfold contrasts, similarities or pat-

terns across the case studies, the semi-structured interviews explore the untold

stories of the aspirations, motivations and hopes of the gardeners. A sensory

ethnographic approach, participant observation and visual methods allow an

understanding of people’s socio-cultural practices in rooftop gardens. These

research methods are distinctly different from each other in terms of their

mode of enquiry, analytical methods and interpretations of results, but

these methods together generate a very good understanding. Details of the

three methods are outlined further in the following three sections. In addition

to these, a discussion of St Canice Kitchen Garden, located on the roof of the

Refugee Centre at Kings Cross, Sydney, is included in Section 10.3.4.



### 10.2.1 Comparative Analysis of Eight University Rooftop Garden Case Studies

Very limited research has been conducted specifically to understand the

social issues and contributions of institutional rooftop gardens using

qualitative methods such as surveys and interviews. Owing to the non-

availability of relevant data in this field, a comparative analysis of similar

and important rooftop garden case studies in educational institutions has

been chosen. This provides a snapshot of the significance and potential of

emerging rooftop gardens in universities and their connections to social

aspects of university communities. This desktop analysis of eight rooftop gar-

dens located in different educational institutions has been conducted using

Internet resources and publications to comprehend conditions, objectives,

roles and contributions of rooftop gardens. These case studies are evaluated

for four criteria (produce; goals and motivations; achievements and out-

comes) to provide evidence on their achievements in multiple domains and to

allow the synthesis of information to provide strategic future directions.

### 10.2.2 Semi-Structured Interviews with UTS Roof Gardening Club

The City of Sydney's Environmental Grant Programme 2013–2014

provided funding support to set up a UTS Roof Gardening Club in 2014 on

the ninth-floor roof of the UTS student housing building named Gumal in

the inner-city Sydney precinct of Broadway. This roof was selected, after

several other potential rooftop sites were visited, on the basis of accessibility

and health and safety considerations. This roof had been designed for user

access, with a lift to roof level. Accessibility to this rooftop garden was

limited to UTS staff and student members of the garden using security access

cards. Interviews were conducted with the UTS Roof Gardening Club

participants. The key qualitative research objectives were:

1. To understand the motivations, perceptions and influences that guide

social participation.

2. To know the expectations of participants to create a successful urban

place.

3. To understand the hopes and types of activity that would satisfy the

participants the most.

4. To delineate useful ways for long-term management and funding of the

garden.

The research to date, however, has been very limited in exploring and

identifying the motivations and aspirations of participants in the setting-up

stage of a rooftop garden in an institutional setting. While the UTS Roof

Gardening Club was comprised of a small number of members at an early

stage, the insight into how the members' aspirations, motivations and

satisfactions are intertwined with the social aspects through rooftop food



production in its initial stage is highly important. These members are likely

to have significant interests, pioneering motivations, awareness and sound

abilities to initiate a social change and to reflect upon the social aspects of

urban food production – especially in a workplace context. Sample sizes are

governed by the nature of the qualitative research project (Silverman, 2013).

A total of eight semi-structured interviews representing a 67% response rate

were conducted based on a carefully designed questionnaire with a total of

17 questions. Although eight interviews is a small number, it is adequate and

valuable as each participant was a highly suitable and competent respond-

ent for the interviews and the sample met reliability and validity criteria for

qualitative research (Silverman, 2013). The duration of the interviews with

the UTS Roof Gardening Club members ranged from 30 to 40 minutes. An

ethics approval from the UTS Human Resource Ethics Committee (HREC)

was sought for conducting the interviews. These interviews were conducted

after obtaining consent from the respondents. A number of factors – previous

experience, motivations, expectations and satisfactions, influences, time

commitment, management and financial contributions – associated with

growing food were analysed.

### 10.2.3 107 Projects Rooftop Garden: A Sensory Ethnography

Sensory ethnography is best defined as a set of practices based on qualitative

methodologies such as participatory observation, ethnographic interviews

and visual methodologies like video and photography (Pink, 2007, 2009).

The starting point of sensory ethnography is that the way we understand the

world and our meaning-making practices are always emplaced and result

from a form of embodiment that exceeds the body–mind duopoly to bring

in the senses. Howes (2005: 7), one of the first anthropologists to attend

to the senses, explains this as the emerging paradigm of emplacement, a

‘sensuous interrelationship of body–mind–environment’, where environ-

ment is understood as ‘a bundle of sensory and social values’. To understand

this entanglement of social and sensory values, this section follows specifi-

cally Pink’s (2009: 64) work on sensory ethnography as a ‘process of learn-

ing through the ethnographer’s own multisensory, emplaced experience’.

The emphasis on emplacement is key to the study of others’ experiences

in specific environments, such as rooftop gardens. In turn, the study of

emplaced experiences opens up the possibility to understand the impact

of the lived and sensory experience on social and cultural practices. The

researcher takes part in the same experience as others, and supports the

understanding of this experience through continuous narrative unstructured

interviews. This kind of methodology enables the researcher to comprehend

if and how the material and sensory characteristics of an environment, activity

or event have an effect on others' perceptions, behaviours and opinions.

On a practical level, attending to sensorial experiences involves the

researcher paying attention to her/his own embodied experiences and to

other people's practices, including in her/his methods the consideration of,

for instance, smells, taste, touch and movement in addition to the more



traditional focus on the visual in participant observation (Pink, 2009, 2012).

For this research on rooftop gardening this meant participating in the gardening

activities, for instance planting, sitting in the garden, watering plants, har-

vesting, talking about the smells, feel, taste of produce, learning particular

skills, socialising with fellow gardeners, strolling around, sharing food and

stories, and documenting the site and interactions with photography.

It also involved short, informal interviews carried out as part of the

general ‘being in the garden’, as standard ethnographic practice, where, as

pointed out by Pink, there is no clear distinction between observation and

interviews (Pink, 2009: 83). These two methods are intertwined and these

conversations are akin to unstructured interviews. In the context of sensory

ethnography, interviews are understood as emplaced and embodied instances

in which meaning is made and knowledge shared beyond the sharing of

verbal information (Pink, 2009: 83).

It is common for gardeners to talk of their gardens in terms of sensorial

experiences of colours, touch, smell, sounds and of their body in relation to

the garden (Tilley, 2006). ‘For most of the time appreciating the garden is

thus a synesthetic experience involving all the five human senses – sight,

smell, touch, sound and taste, which usually intermingle and feed into each

other' (Tilley, 2006: 312).

In addition to this, as any gardener will confirm when asked about any

aspect of tending to their garden, gardening is a practice that cannot be

understood only by talking. A variety of sensory ways of sharing knowledge

and apprehending garden practices – such as how one needs to touch,

taste, smell and look at the changes to determine the health and needs of a

garden – were observed during the fieldwork. In short, good gardening is

a full-body experience, and gardening knowledge can only be transferred

through the sharing of those experiences, rather than simply through verbal

communication.

It follows that to understand others' social experiences in a garden, a

sensory dimension and understanding need to be taken into consideration.

To do so, one of the following subsections will provide an analysis of the

rooftop designed by Milkwood Permaculture, one of the resident organisa-

tions at 107 Projects. The chapter will continue with a narrative illustrating

the rooftop garden as an environment constituted through a bundle of social

and sensory values (Howes, 2005).

## 10.3

## Main Findings

### 10.3.1 Comparative Analysis of Eight Rooftop Gardens in Universities

Some notable examples of rooftop gardens in educational institutions exist,

such as those at Concordia University (Concordia Food Coalition (CFC),

2015) and Trent University (Blyth and Menagh, 2006), both in Canada, or

the University of Maryland's rooftop garden on South Campus Dining Hall,

Ellicott Community Diner in the USA (University of Maryland, 2010). The

rooftop gardens are responsible for biodiversity protection; improvement

in health, mental wellbeing and livelihoods; sharing of knowledge and a

‘culture of sustainability’ in students and staff, as demonstrated in a number

of universities. Table 10.1 compares the eight rooftop gardens growing food

in different universities.

In Table 10.1, the areas of the rooftop gardens vary from small to larger

and a variety of vegetables are produced on the roof and vertical walls,

developed with appropriate technologies and in raised planter boxes. The

harvesting capacities of these roof gardens vary too. Kaestart University,

Thailand has applied a 900 cm2 green roof mat, a vertical green block with

attached containers for planting and a bio-façade for climbing plants

(Alimurung, 2012; Sunakorn, 2012). New Jersey Institute of Technology,

USA has raised planters for growing food and aims to supply fruits and

vegetables to up to 9000 university students (Heyboer, 2010). The most

important goals identified are: improving access and daily supply of fresh

fruits and vegetables; building resilience and food security in case of an

emergency; improving and recreating urban ecologies and connections to

nature; promoting learning for organic gardening; developing an integrative

sustainability approach using a closed-loop food system; creating well-

knit institutional communities (Blyth and Menagh, 2006; Heyboer, 2010;

Alimurung, 2012; Ducharm, 2015; Rye's HomeGrown, 2015; The

Sustainable Campus, 2015). Many of these goals have been achieved already.

North Carolina State University, USA and Trent University, Canada have

created successful closed-loop food systems by supplying the food produced

on the rooftops to campus cafes (Blyth and Menagh, 2006; Kinen-Ferguson,

2015). These rooftop gardening initiatives are supported significantly by the

universities and from other funding sources. Outcomes relate significantly

to social aspects of staff, students and immediate communities developing a

deeper understanding of built environments and food, social responsibility

and participation, enhancement of food localism, connectivity, responsive-

ness and self-sufficiency of supply of food (Table 10.1).

### 10.3.2 Qualitative Analysis of UTS Roof Gardening Club

#### Semi-Structured Interviews

Demographic data collected showed that 75% of respondents came from an

Australian background and were female; 62.5% of respondents came from

the 41–60 years age group, while 37.5% were aged 26–40 years.

Half of the respondents had *previous experience in growing food* in home

environments, representing intra-generational connections through parents

to grandparents and inter-generational links through friends, colleagues and

families. Experience of growing culinary herbs, indigenous plants, flowers

and different types of vegetables and fruits were common, and gardener

types ranged from fairly extensive gardener to non-gardener.

Two key *motivations – professional* and *personal* – for joining the UTS

Roof Gardening Club were linked to the ‘institutional’ quality of a rooftop

garden. The *professional* motivation visualised the roof garden as ‘ *a catalyst*’

and ‘ *a neutral space*’ for community building and people engagement,

y

)

tivit

*ued*

ood

y

omoting

ood

rowing

onnec

, f

y with a

ation and

( *Contin*

or pr

ts

o local f

tions in g

, social c

egener

ted micr

ban r

tisfac

e of dining f

eness

casing special culinar

ienc

ticula

comes

w

ood self-sufficienc

em

ut

ell-ar

st

O

Sho

exper

responsiv

and f

w

sy

Enhancing social aspec

localism, ur

immense sa

food

y

em

ing

e in

tion.

tion in

st

ts

or

ater

ve the

.

te

aiting

e f

’s

e.

oduc

tur

ins with

ticipa

tur

’ in mak

e plac

emen

den

ood sy

dening and

tiv

o-pla

.

e w

.

.

ooms

t.

tly

o obser

o ma

t par

y.

.

ood pr

itchen.

oduc

den-t

ess beg

ersit

ood

oc

.

t k

ganic gar

‘localness

ban f

nifican

ood t

tes a special culinar

e pr

onmen

ths or mor

or diners

o 70%.

ea

row and ma

e f

ee f

ting

omposting and w

e of

ativ

vir

ten gar

e sig

or the f

ienc

ease studen

den.

tanc

ations and achiev

ing cr

ee mon

apeutic benefits

tes a closed-loop f

ting living class r

ganic c

vings up t

y and happiness t

egener

otiv

To shor

distanc

Thr

time f

cook

exper

The dining pr

seed plan

To incr

the gar

To understand the gar

ther

Crea

within the univ

A self-sufficien

Or

sa

Jo

seedlings g

Crea

Promoting or

pesticide-fr

Impor

a r

a dense en

Localism in ur

M

•

•

•

•

•

•

•

•

•

•

•

•

•

.

ts

aise

o

t

ersities

ganic

.

y

esh

, fruits and

y.

ough

o up t

e or

tion on the

onduc

y’s dining hall

te and r

ood

ersit

.

o c

o the

ts

omot

ollec

eness in studen

ch.

dens in univ

bs t

ersit

dening and

ar

ta c

den t

oals

To supply fr

vegetables

her

univ

To pr

gar

sustainabilit

To educa

aw

and staff thr

growing f

To supply fruits and

vegetables t

9000 univ

studen

Da

gar

resear

G

•

•

•

•

•

top gar

oof

,

t r

,

,

reens

rots

aised

e

,

, beets

, car

nips

es

of r

sis of eigh

toes and

chini, squash,

bs

, leafy g

2

ters

m

Produc

Zuc

peppers

cucumbers

toma

her

Kale

greens

lettuc

and tur

20

plan

e analy

,

ativ

olina

k, NJ

ar

ar

, New

Compar

y,

th C

, 2010)

ter

e of

den

, New

tennial

ersit

guson, 2015)

en

en

, Nor

er

t C

nstitut

top gar

, Cval

te Univ

inen-F

**Table 10.1**

Roof

O

Campus

Sta

Rayleigh, NC, USA

(K

Studen

Jersey I

Technology

USA (Heyboer

ole in

oved

t r

t and

tan

ommunities

tion in

tion; impr

y and ethical

elopmen

ticipa

rowing

y an impor

y dev

o g

e and wider c

ts pla

t-led sustainable business

cess;

esponsibilit

comes

oving par

kplac

tion and educa

oach t

ut

or

ea

O

Studen

communit

impr

w

Studen

cr

food ac

social r

appr

.

,

t

ood

y of

.

ts

es

y.

ood

tiv

rowing

top

chools

ts and

oof

top

tivit

ed f

emen

y members

’ initia

vailabilit

.

oof

t-run campus

ts

om S

.

oduc

o studen

y.

connec

ied a

und

ting

om r

eness of local f

e.

ost on campus

ter

ar

y F

.

ceptions of g

e fr

ar

ood t

t and facult

e.

w

oduc

.

y studen

ations in the r

o a studen

ood c

ough visual

oduc

t and an independen

ting v

ed funding fr

ommunit

’ Club

ativ

.

ed in plan

an

e and in

ed f

ations and achiev

ted b

eiv

oved per

eased a

ecia

volv

mers

den.

vours

otiv

ppr

Crea

Rec

Sustainabilit

Supplying f

wider c

100 studen

in

Established a campus-based

Far

Impr

food thr

demonstr

gar

Fresh pr

supplied t

restaur

co-oper

Incr

cultur

A

seasonal pr

Food ethics

Fresh and locally pr

fla

Reduc

M

•

•

•

•

•

•

•

•

•

•

•

•

or

ts

altham

y about

rowing

oach.

ning

ood

ough

and W

y.

e of g

.

ove f

te studen

ts

ove

ommunit

tanc

ood

t as a lear

e.

ood thr

om-up appr

cess and health f

oals

To impr

ac

studen

communit

To educa

and c

impor

local f

To ac

spac

To impr

understanding of

local f

bott

G

•

•

•

•

,

kg

bs

1588

top

e

e

ted

roof

egetables

oduc

2

s v

m

ow

ganically

Produc

Estima

of pr

139

Gr

fruits and her

or

y,

es

,

)

io

*’d*

y,

ersit

tar

,

cienc

( *Cont*

ersit

t Univ

den

tal S

enagh,

A, USA

ren

m, 2015)

, T

ough, On

e Building

top gar

on, M

onmen

bor

andeis Univ

uchar

vir

er

**Table 10.1**

Roof

Scienc

Br

Bost

(D

En

Building

Pet

Canada

(Blyth and M

2006)

e

)

ativ

*ued*

all

o

ing of

ies in

ver

o-oper

y building

’ deeper

or

( *Contin*

ts

pose t

or social

olog

ts; c

king

ood; o

or

ban ec

w

onmen

ommunit

t and monit

vir

o c

e of studen

ood bank f

t

o f

tanc

den; unique pur

men

comes

oving ur

oach t

er

utO

Impr

denser en

appr

and social net

Impor

understanding of f

managemen

the gar

supply t

bett

.ts

’ and

ests

’

o

ts

t

t

ter

y.

ts

ted

ood

oval and

ology

ed in

ation and

.

emen

tal impac

tuden

e.

ours and

ood tha

onnec

y.

volv

t.

to S

.

rowing in

y’s appr

e supplied t

oduc

ts run with other

ell-c

ts in

on

ough t

.

.

onmen

ood bank

ojec

vir

itious f

ersit

.

t, administr

oduc

Tor

kshops

oof

ood-g

, staff and facult

ommunit

esh pr

‘responsible ec

or

e f

ts

y c

om multiple

SU) f

tions

y of

roups

tiv

.

ed univ

tion.

casing thr

t g

ations and achiev

ting

eloping a w

ersit

em.

ted in 2010 with studen

ts

ersit

w

owing nutr

eiv

tnership pr

ev

st

or

ganisa

oduc

aining w

otiv

Crea

an edible r

Reducing en

Gr

ripens on the plan

Collec

of studen

D

univ

Establishing a closed-loop f

sy

Star

eff

Rec

funding fr

or

Staff and studen

managemen

pr

90% of the pr

Univ

Union (UT

Supply of fr

Sho

tr

Par

studen

M

•

•

•

•

•

•

•

•

•

•

•

•

•

,

ted

t

mers

ood on

e a

tion.

onnec

y far

ood

esh f

y.

oduc

e

.

te a c

e pr

ersit

.

t popula

row fr

ea

ket

em in wider st

oals

To g

campus

To cr

communit

To shar

the univ

mar

To enhanc

understanding of

sustainable f

sy

studen

G

•

•

•

•

,

e

in,

bs

loom

oduc

o w

,

toes

es

, her

,

kg

e

ts

, squashes

oma

2

ries

e in t

350

plan

, t

m

toes

own in

tainers:

chini, heir

oduc

Produc

Egg

peppers

basil

and lettuc

1011

Gr

con

squash, pumpk

zuc

toma

raspber

and other pr

Total

pr

years

ing

e,

y,

,

to,

anada

ineer

tr

on

, C

en

ye’s

or

io

y

oalition,

den

ersit

i Eng

den,

of T

tar

ar

er C

anada

own, 2015)

ar

y

y G

io Health

top gar

ge V

to, C

aith Building

to, On

omput

ersit

on

on

tar

eor

albr

Roof

G

& C

Ryerson Univ

Tor

(Sloan, 2015; R

HomeGr

The Sk

G

Univ

Tor

(On

Communities C

2015)

e;

e in

e

ricultur

tur

cess using

esilienc

e solutionstiv

taining links

y r

ec

ban ag

ood ac

ommunit

oving f

e and eff

tion on ur

comes

ting and main

een people and naw

vativ

ut

ea

O

Educa

cr

bet

Building c

food; impr

inno

.

ough

t

e

ts

t’

e

tical

rowing

’.

Thai

tion, the

ills thr

tur

vativ

oof ma

er

ts such as

emen

rojec

ough

t g

.

om

e and

o 50 CHUK

ology

y thr

ming;

ounda

ming and

ec

tur

y.

, inno

reen r

ttached

ting and a bio

c.

o

ation P

o:

aining

ec

dening sk

ersit

ood

ts and their families

ban far

micr

y funds fr

ultiv

e of far

y.

ood miles and

.

rchit

module), a v

or plan

2

chini, et

tion of up t

ommunit

e edible plan

;

et

romotion F

t Univ

cm

or climbing plan

top ur

ove gar

essional tr

tanc

tion.

ing human and na

tions

ted b

y of A

tions of a g

, zuc

ations and achiev

top C

ticipa

, studen

ted in 2014 t

omot

of

eloping ‘

tur

ac

row local f

tainers f

oof

build c

roof

pr

locally

impr

pr

ter

× 30

otiv

Par

staff

‘R

star

Impor

educa

Food saf

Reducing f

dev

Nur

in

Suppor

Health P

Facult

Kasetsar

To g

applica

(30

green block with a

con

façade f

beans

M

•

•

–

–

–

•

•

•

•

•

•

tal

ban

benefits

ood

y.

e

top ur

ood

o achieving

onmen

ical

e f

ood in case

genc

rativ

vir

oof

.

teg

olog

.

oach t

, en

ec

omot

ity.

n in

ough r

ming

oals

A

appr

social

and

thr

far

To pr

secur

To sustain daily f

supply

To supply f

of an emer

G

•

•

•

•

,

m

bs

, basil

ban far

e

ess

t,

cr

ur2

plan

owing fruits and

m

ater

Produc

Gr

vegetables

Chinese spinach,

w

egg

beans and her

196

)

y of

,

*’d*

),

he

y of

y,

eaching

acult

( *Cont*

, F

den

ersit

CHUK

ersit

, China

oof

e Building

hailand

, 2012;

rated T

(AITB), T

, 2015)

tur

t Univ

, T

n, 2012)

top gar

loor r

ec

Integn

rchit

limurung

**Table 10.1**

Roof

A

Building

Chinese Univ

Hong Kong (

Hong Kong

(The Sustainable

Campus

7th-F

A

Kaestar

Bangkok

(A

Sunakor

creating new professional linkages in an informal way and cultivating sus-

tainability responsiveness within the university community. Motivations to

share gardening knowledge and practices, gain essential access to nature in

a workplace, grow own food and observe how the rooftop garden unravels

pathways to a successful social change were significantly important too.

‘ *There is a relation between growing together and connecting …*’

(Interview M)

‘ *… you can share knowledge*, *in a lovely equal environment …*’

(Interview H)

‘… *So it is a very good way to establish a community*’ (Interview M)

With easy access and providing some time away from the desk, a work-

place rooftop garden could provide immense health benefits and a brilliant

way of establishing a well-knit university community, which was unlikely

otherwise.

‘… *it is wonderful to get up from a desk and spend an hour pottering*

*in the garden and then go back to your keyboard. I find that a very*

*rewarding way of working*' (Interview H)

'… *new contacts through the garden club both students and staff …*

*make those professional linkages … spending on structured quality*

*time with people … I find that the garden is a place where you can …*

*it's a neutral space*' (Interview H)

The *personal* motivation included making friends, sharing and learning

gardening techniques, involvement in active exercise through gardening,

experiencing nature, sunlight and fresh air, and feeling immense happiness

and pride associated with growing fresh and nutritious food.

'… *wanted to have living things around me*' (Interview L)

'… *like the experience of being able to eat the things I have grown*,

*having that pride in that this is something I have made* (Interview L)

'… *how to plant*, *how to see what seeds work with other seeds so it is*

*just gaining knowledge from people who have a little bit of experience*

*in that*' (Interview K)

Incorporating permaculture principles in gardening, worm farming, miti-

gating environmental impacts through growing own food, and on-site

composting and supporting a sustainable lifestyle were important motiva-

tions for participation. Dreams and aspirations to regenerate memories,

cultural identities and practices of distant homelands locally resonated

prominently through the voices of respondents.

‘… *I come from a culture that produces fruits and vegetables*’

(Interview M)

These responses parallel some of the research on Vietnamese, Greek and

Italian migrants’ domestic gardens in Australia, identifying that the





**Figure 10.1** Vegetable production at the UTS rooftop garden, Sydney.

*Source*: Photo by Sumita Ghosh.

production of traditional fruits, vegetables, herbs and flowers is linked to

their specific cultural identities, memories and traditional practices, and is

dynamic and continuously evolving (Graham and Connell, 2006).

Furthermore, the rooftop garden provided access to a highly valued produc-

tive space at work to implement aspirations in reality for the participants, as

shown in Figure 10.1.

Getting to know someone in the UTS Roof Gardening Club or from

other gardening initiatives *influenced* the decisions to join the garden. The

predominant *expectations and satisfactions* of the participants were to

grow a variety of vegetables, fruits, indigenous edible plants (e.g., warrigal

greens), exotic vegetables and medicinal herbs in the garden. Preferred

choices were: green leafy vegetables (like lettuce), tomatoes, eggplants,

sweet potatoes, zucchini, cucumber, green beans, corn, squash, pumpkin

and all-year-round vegetables (e.g., cabbage and brassicas), strawberries,

lemons and some tropical fruits such as papaya. Herbs such as thyme, rose-

mary, basil, oregano, sage, parsley, coriander, marjoram or deal and fennel,

and some medicinal plants such as chamomile and turmeric, were favoured.

In addition, participants' expectations were also to engage in university

community development, sharing knowledge and seeing the garden as

‘ *a space for learning*’.

‘… *it is a space for learning not only for the garden club but for all*

*users of the garden*’ (Interview J)



Time commitments vary at different times of the year, during vacation time, at

the end of and early in the year, as it is an educational institution. Most of the

respondents were ready to commit a couple of hours per week, although this

varied from a couple of hours per week to a couple of hours per fortnight.

There was restricted access, by security card only, due to the location of the

rooftop garden on the student housing building, which limited easy access

and engagement in gardening activities. Location and access play important

roles in fostering participation and a connected university community.

Some respondents (5 out of 8) supported the need for small financial

contributions, while the rest thought that obtaining university funding

would be more useful, an aspect which has been noted in some rooftop

case studies such as the University of Toronto and Kaestart University

(Table 10.1). With regard to managerial expectations of the garden,

respondents stated that regular planning meetings, record keeping, alloca-

tion of specific responsibilities to members considering individual exper-

tise, and the importance of a leadership role would be essential for the

long-term continuity of the garden. Clarity around decisions and the con-

sensus of all members would be vital.

'… *all the decisions should be made by consultations and consensus as*

*much as possible*' (Interview M)

### 10.3.3 107 Projects Rooftop Garden, Sydney

The 107 Projects rooftop garden in Redfern is a productive and educational

space designed and managed by Milkwood Permaculture. Permaculture is

defined as an agricultural process based on ethics and design principles. It

guides us to mimic the patterns and relationships we find in nature, and can

be applied to all aspects of human habitation, from agriculture to ecological

building, from appropriate technology to education and even economics

(Holmgren, 2015; Permaculturepriniciples, 2015). As it is based on a set of

three ethics and twelve design principles, permaculture is a malleable system

and its elements can be re-contextualised and adapted to different environ-

ments (Crosby *et al*., 2014). In 2014 Milkwood started a crowdfunding cam-

paign to turn the empty rooftop terrace into an urban permaculture garden

for learning workshops, events and talks, and a place in which to create a

green space and food system in the city open to community seeds and cut-

tings swaps. Volunteers backed the project, donating their skills, labour and

products. The rooftop garden opened in early 2015 and has since been used

as the location for permaculture courses, talks and public events.

The Social Life of the Rooftop

The analysis of these events emphasises the assemblage of different users,

residents and organisations and highlights how the garden was produced

and is managed according to permaculture ethics and design principles.



206 Green Roof Retrofit

**Figure 10.2** Milkwood, 107 Projects rooftop garden, Sydney.

*Source*: Photo by Ilaria Vanni.

As an example, one of these events is briefly sketched here. At the beginning

of autumn in 2015, the rooftop garden was part of 107 Projects Open Day

(see Figure 10.2). While the majority of visitors were young, white cultural

producers linked to the site through art world connections, some older local

residents attended the event. The round tanks of the movable food forest

had been moved along the edges of the rooftop, so that visitors entered the

garden and walked following the wavy borders of planters, and could

choose to sit at the tables or along the seats included in the design of the

garden beds. Some decided to take up the free botanical illustration class

offered, some came for a look, or a chat and a drink in the open air.

During the research fieldwork, visitors to the garden stopped to talk,

to exchange opinions on herbs and on the garden, to ask questions about

specific design elements or plants, and to suggest ways to fix various plant

disease problems. Some visitors walked slowly, savouring the multi-sensory

dimension of the garden and patting plants, smelling them, nibbling on

leaves and engaging in conversation with fellow visitors. Others sat on the

edges of planters, contemplating the garden and talking about different

experiences with permaculture, different roles in relation to the garden, and

planned future involvement with the rooftop and other community gardens,

while still others illustrated what they saw. There were short informal meet-

ings. A local resident stopped to talk about the basil plants and to sniff the

scent. While all these interactions were temporary, the frequency and repe-

tition of a variety of events organised on the rooftop garden has enabled



Milkwood to create a group of returning visitors and, as a follow-up to

these encounters, a strong digital community that supports the exchange

of information and data and functions like a repository of collective per-

maculture intelligence. The ‘social and sensory bundle’ (Howes, 2005)

engendered by the rooftop garden is part of the discussion below.

Analysis: Permaculture on the Rooftop

107 Projects rooftop garden is seen as an evolving ecology of objects, design,

plants, animals, bacteria, people, elements, ideas, policies and principles.

It is proposed that this ecology generates particular forms of sociality reflect-

ing permaculture principles in two ways: one is through the design of space

that guides certain types of interactions, and the other is through learning

permaculture practices. While Milkwood offers courses and workshops in

different locations, the rooftop has quickly become a site where people with

similar interests and values converge and a community based on a definite

set of practices is created.

During the fieldwork for this research it became apparent that the curvy

shape of the planters, the vertical gardens along the walls, the movable food

forest and the inclusion of seats made with recycled wood (producing no

waste being a principle) on the edge of garden beds determined the pace and

flow of visitors to the garden, inviting them to walk slowly and to linger in

places to touch, smell, taste and talk. It is possible to discern several design

principles behind these choices:

■

‘observe and interact’ in order to learn from the environment;

■

‘obtain a yield’ and produce abundance;

■

‘integrate rather than segregate’ in the way plants are located.

Also, in the inclusion of structural elements such as rain tanks to catch and

store water in the flow of space, as well as ways of integrating gardeners

and visitors in the space. Further, in ‘use edges and value the marginal’, as in

nature, the edge of two spaces or systems is rich in diversity (another princi-

ple is ‘use and value diversity’) and opportunities. The vertical gardens along

the perimeter and the seats on the edge of garden beds, for instance, are

examples of using an edge, but also of maximising space to produce an

abundant yield. At the same time they invite gardeners and visitors to stop,

observe and interact with the environment.

Similarly, the ethical values of ‘earth care’, ‘people care’ and ‘fair share’ or

exchanging skills geared towards environmental protection, sharing pro-

duce, labour and knowledge to give back to and create a community are

employed successfully in weekend workshops, including planting, garden-

ing, making seed-raising mixes and seed bombs, and making tomato pasta

at the end of summer. It is important to stress that these values are not simply

communicated verbally, but they are embodied and put into action. During

free workshops the public is welcomed to garden on the rooftop, and acquire

new skills and competences in exchange for their labour. It is a type of



208 Green Roof Retrofit

informal learning, and permaculture knowledge is transmitted by inter-

actions, gestures, being together and sharing a sensory dimension and

embodied experiences. Unlike in community gardens, the interactions in the

107 Projects rooftop garden are mediated through learning specific skills,

and are consequently structured in activities.

These two aspects of the rooftop sociality, learning by permaculture ethics

and design principles and through structured activities, means also the

absence of the conflictual aspects emerging in many community gardens

and described in manuals dedicated to community garden management and

conflict resolution (Cultivating Community, 2002; Nettle, 2009, 2014;

Newcastle Community Garden Project, 2010; Glenelg North Community

Garden, 2013).

### 10.3.4 St Canice Kitchen Garden, Kings Cross, Sydney

St Canice Kitchen Garden, Kings Cross, Sydney is an excellent initiative to

provide health, wellbeing, social connectedness and support communities

and patients (as shown in Figure 10.3). The ‘GROW’ horticulture therapy

programme in this garden is supported by funding from the City of Sydney

and is organised in meaningful partnerships with Inside Out Organic Soup

Kitchen, St Vincent Hospital and Hurricane Duke (Kaziro, 2015). Under

this programme, outpatients from St Vincent Hospital, Mental Health Service

**Figure 10.3** ‘GROW’ programme at St Canice Kitchen Garden, Kings Cross, Sydney.

*Source*: Photo by Sumita Ghosh.



are refereed and can access this garden for therapeutic benefits through

gardening and attending workshops. The produce grown in this garden is

supplied for food preparation and for sale to the Inside Out Organic Soup

Kitchen located at the ground floor of the Refugee Centre, thus forming a

closed-loop localised food system. Hurricane Duke provides training and

workshops to build organic gardening skills and confidence in patients as

well as in refugees and participants from the surrounding communities

(Kaziro, 2015). The garden has fruit trees such as lemons, medicinal herbs,

different types of indigenous and non-indigenous vegetables, and edible and

non-edible flowers to attract bees and insects and provide a visually sooth-

ing atmosphere and socially interactive space. Some of the plants are: climb-

ing beans ( *Phaseolus vulgaris*), broad beans ( *Vicia faba*), warrigal greens ( *Tetragonia tetragonioides*), leeks ( *Allium porrum*), celery, eggplant, peas, silver beet, spring onions, curry plant ( *Helichrysum italicum angustifolium*),

borage ( *Borago officinalis*), nasturtium ( *Tropaeolum*), lavender, calendula, lemon verbena ( *Aloysia citrodora*) and others (Kaziro, 2015).

From a social perspective, this garden acts as a shared community

meeting place for getting together and making friends. It is unique in its

objectives to provide horticulture therapy and build socially inclusive and

resilient communities through effective collaborative efforts and partner-

ships. The participation of a number of volunteers in the garden programme

and urban food production showcases their commitment to social responsi-

bility and forms new connections to grow the community. Participants can

also take produce home from the garden. The partnership of three organisa-

tions in the ‘GROW’ programme plays a key role in delivering a restorative

and remedial outcome to those who are in need, and also extends the oppor-

tunities to the wider community. The ‘GROW’ programme uses a *strength-*

*based approach* and a *community recovery model*, where people recover

naturally within a human–nature interactive setting and feel connected,

revitalised, relaxed and inspired (Kaziro, 2015). The essences of flowers,

plants and activities in the garden provoke participants’ associations with

happy memories, initiate new learning and create a safe, calming and tran-

quil environment in the garden with useful healing processes that make

positive changes over the lifetimes of the participants (Kaziro, 2015).

## 10.4

## Recommendations, Discussions and Conclusions

The rooftop gardens producing food in universities (Table 10.1) show that

they contribute hugely to sustainability, social networking and inclusion,

community engagement, education, training and relevant skill development

for students, staff and community. This research highlights that the people

engagement that takes place through food production on the campus is cre-

ating successful social connections, leading to better prospects. Outcomes

suggest that there is enhancement in workplace community building, rise

of food localism, activation of urban regeneration through innovative place-

making for positive engagement, immense joy associated with growing food,

promotion of self-sufficiency of food and concern for ethical growing



(Table 10.1). In these case studies, the key components of alternative food

systems are: short food supply chains (SFSCs); social embeddedness; quality

of the produce and defensive localism (where people value traditional,

healthy and fresh local foods such as organically produced vegetables in

nearby locations) (Daniels *et al*., 2008). This comparative analysis demon-

strates, therefore, that a significant change is already happening in work-

places too.

In the UTS Roof Gardening Club, participants' previous experiences pro-

vided multi-generational connections to growing food. Motivations detailed

by participants were shaped by their aspirations, goals and commitment to

sustainability. Expectations and satisfaction from growing food, as well as

influences that guide these collective engagements in rooftop gardens, are

deeply rooted in culture, lived experiences and professional and personal

commitments. The key expectation of the UTS Roof Gardening Club mem-

bers was that the rooftop garden would become a suitable model of social

change in the Sydney CBD.

'… *become a model*, *I guess of social change and experiments*'

(Interview K)

Individual time constraints, management of the garden and financial sup-

port were key concerns with regard to the long-term continuity of the col-

lective and collaborative effort of the gardening club. Notably, some of the

outcomes of the qualitative study from the UTS Roof Gardening Club,

although in an early stage, are similar and could effectively be linked to the

eight rooftops (Table 10.1). A limitation of this research is that the out-

comes of these early-stage interviews provide a snapshot of members' view-

points at a particular point of time. Over the garden's lifecycle, the

perspectives of existing and future members may change or remain unal-

tered based on the productive potential and quality of engagement offered

by the garden. To address this, similar interviews at different stages of this

garden could be undertaken to understand these variations, and could form

a longitudinal study.

The key findings from the study of the 107 Projects rooftop garden

are that the social aspects observed are based around shared interests, such

as learning (at any level) about permaculture and related practices, and a

shared ethos based on permaculture principles. These principles can easily

be applied in everyday practices in other contexts, contributing to a change

in the direction towards resilience. In addition, the rooftop garden is

extended virtually through a strong online presence, which documents the

progress of the garden, offers short ‘how to’ sections, participates in current

debates and creates a digital community.

The ‘GROW’ horticulture therapy programme at St Canice Kitchen

Garden presents an excellent example of working together in partnership

with appropriate local organisations and communities to make a differ-

ence. This process uniquely integrates and implements ways to contribute

to improved social wellbeing and health benefits, creating a sustainable

food system, promoting local economic growth, building better communities



and connecting to multidisciplinary fields of knowledge on this rooftop

garden.

There are also a number of barriers to establishing rooftop gardens in an institutional setting. Generally, there are property or facility managers in institutions responsible for the management of buildings and their rooftops (Wilkinson, 2015b). First, it is difficult and time consuming to provide assurance and gain trust from various gatekeepers, requiring different routes of approach in the process of getting approval to set up a rooftop garden. Second, managers with previous experience in urban food production on rooftops may understand the benefits more easily than managers with very limited or no experience. Third, the installation of a rooftop garden needs to satisfy a set of criteria such as: a certain time line within which a garden would operate; that the garden is safe and accessible to participants, satisfies insurance and legal requirements and has the full support of managers. Fourth, understanding which user groups would be accessing the garden, for example, students, staff, occupants and

residents; what type of access they would require (weekly, daily, monthly

or other); and their choice of times for gardening activities. The level of

access could be restricted depending on various factors. In Gumal rooftop

garden, located on the student housing in UTS, access to the garden cre-

ated some frustration for participants coming from outside the housing

(Wilkinson, 2015b).

Different exploratory methodological approaches have been applied in

this chapter to understand and observe the social phenomena connecting

multiple aspects happening across different institutional rooftop garden

settings. Recommendations based on the analysis suggest that setting up

more rooftop gardens at suitable locations (mainly higher-density areas of

cities) and organising events, open days and cooking classes to encourage

social networking, participation and knowledge sharing could facilitate

multiple community benefits across different domains. Developing and

applying innovative sustainable practices and permaculture principles in

the design and planning of rooftop gardens, as well as developing guide-

lines for rooftop plant selection suggestions, could assist keen but less

experienced gardeners immensely. It is important to highlight the social

and cultural importance of rooftop gardens. For the long-term continuity

of the gardens, appropriate management processes need to be formulated.

A framework for creating a localised closed-loop food system – including

production, distribution and disposal – and working in partnerships would

be critical for uptake. Non-governmental organisations (NGOs), govern-

ment as well as private organisations, local governments and developers

could provide help for this initiative. Future research should focus on

conducting transdisciplinary research on rooftop gardens and developing

useful integrated approaches with regard to the meaningful uptake of

urban agriculture in denser urban settlements. This research has informed

a discussion on how building community resilience, social connectedness,

and health and environmental benefits could be effectively initiated, devel-

oped and integrated using collaborative approaches through institutional

rooftop gardens.

212 Green Roof Retrofit

**Acknowledgement**

The researchers would like to acknowledge the City of Sydney for funding

provided to the Urban Food Production on Sydney CBD Rooftops through

the Environmental Grants Program for the UTS Rooftop.

**References**

107 Projects (2015) 107projects.org/upstairs-107/.

Alimurung, A. (2012) ‘Kasetsart university in Thailand builds an innovative rooftop

garden on campus’mpuvailable at: inhabitat.com/kasetsart-university-in-thailand-

builds-an-innovative-rooftop-garden-on-campus/.

Beauty and Environmental Benefits Meet on a Rooftop (2009) *Waste Disposal and*

*Water Management in Australia*, Vol. 36, No. 4, p. 21. Available at: search.

informit.com.au.ezproxy.lib.uts.edu.au/documentSummary;dn=79596 99335462

81;res=IELENG> ISSN: 0311-3558.

Bennett, A. F. (2003) *Linkages in the Landscape: The Role of Corridors and*

*Connectivity in Wildlife Conservation*. IUCN: Gland, Switzerland.

Bentley, I., Alcock, A., Murrain, P., McGlynn, S. and Smith, G. (1985) *Responsive*

*Environments: A Manual for Designers*. Architectural Press: London.

Blyth, A. and Menagh, L. (2006) 'From the rooftop to the restaurant, a university

café fed by rooftop garden', *The Canadian Organic Grower*, Fall, 50–53.

Boyer, M. (2013) 'Boston's higher ground farm will be the second-biggest rooftop

farm in the world', available at: inhabitat.com/bostons-higher-ground-farm-will-

be-the-second-biggest-rooftop-farm-in-the-world/.

Brooklyn Grange Rooftop Farm (2015) brooklyngrangefarm.com/.

Brown, K. H. and Jameton, A. L. (2000) ‘Public health implications of urban

agriculture’, *Journal of Public Health Policy*, 21, 20–39.

Carlyon, P. (2014) ‘Green thumbs emphasise the benefits of roof-top gardens’,

available at: www.abc.net.au/news/2014-03-20/green-thumbs-emphasise-the-

benefits-of-roof-top-gardens/5334744.

City of Melbourne (2015) ‘Green roofs’, available at: www.melbourne.vic.gov.au/

Sustainability/CouncilActions/Pages/Greenroofs.aspx.

Concordia Food Coalition (CFC) (2015) ‘Le Campus Potager’, available at: www.

concordiafoodcoalition.com/cfc-projects/concordia-rooftop-projects/.

Crosby, A. L., Lorber-Kasunic, J. and Vanni Accarigi, I. (2014) ‘Value the edge:

permaculture as counterculture in Australia’, *M/C Journal*, 17(6), available at:

journal.media-culture.org.au/index.php/mcjournal/article/viewArticle/915.

Cultivating Community (2002) Milne, G. (ed.), *The Good Practice Guide for*

*Community Gardens*. Available at: communitygarden.org.au/wp-content/uploads/

2010/06/Good_Practice_Guide_CG.pdf.

Daniels, P., Bradshaw, M., Shaw, D. and Sidaway, J. (2008) *An Introduction to*

*Human Geography*, 3rd edn. Pearson Education: Oxford.

Davis, B. E. (2011) 'Rooftop hospital gardens for physical therapy: A post-occupancy

evaluation', *HERD*, 4(3), 14–43.

Ducharm, J. (2015) 'A group of Brandeis students started a rooftop farm on

campus', available at: www.bostonmagazine.com/health/blog/2015/06/04/

brandeis-university-rooftop-farm/.

Eagle Street Rooftop Farm (2015) rooftopfarms.org/.

Social Aspects of Institutional Rooftop Gardens 213

Foss, J., Quesnel, A. and Danielsson, N. (2011) *Sustainable Rooftop Agriculture.*

*A Strategic Guide to City Implementation*. Available at: bieb.ruaf.org/ruaf_bieb/

upload/3694.pdf.

Franklin, E. (2011) 'A rooftop gardening project in Toronto with the About Face

collective' (an interview with an urban farmer, Natalie Boustead), *Women &*

*Environments International Magazine*, Fall 88/89, 40–41.

Fujita Kanko Incorporated (2012) 'Hotel Chinzanso Tokyo's one-of-a-kind rooftop

garden unveils at hotel's rebranding opening in January 2013', *Business Wire*, 12

November.

Gehl, J. (1987) *Life Between Buildings: Using Public Space*. Island Press: London.

Glenelg North Community Garden (2013) 'Conflict process for the community

garden', available at: gncg.wordpress.com/2013/10/26/conflict-process-for-the-

community-garden/.

Gordon, H. C. (2010) 'Rooftop farming: a visit to Brooklyn's Eagle Street Rooftop

Farm', **a**vailable **at**: inhabitat.com/urban-farming-a-visit-to-brooklyns-eagle-street-

rooftop-farm/.

Gorgolewski, M., Komisar, J. and Nasr, J. (2011) *Carrot City. Creating Places for*

*Urban Agriculture*. Monacelli Press: New York.

Graham, S. and Connell, J. (2006) ‘Nurturing relationships: the gardens of Greek

and Vietnamese migrants in Marrickville, Sydney’, *Australian Geographer*, 37(3), 375–393.

Heyboer, K. (2010) ‘Rooftop garden at NJIT student center encourages students to

eat organic’, available at: www.nj.com/news/index.ssf/2010/09/rooftop_garden_

at_njit_student.html.

Holmgren, D. (2015) ‘About permaculture’, available at: holmgren.com.au/about-

permaculture/.

Hoffman, M. (1983) ‘Rooftop gardens offer urban communities places of beauty,

quiet’, *The Christian Science Monitor*, 17 March.

Howes, D. (2005) *Empire of the Senses. The Sensual Culture Reader*. Berg Publishers: London.

Johannesburg Rooftop Garden (2012) ‘Johannesburg rooftop garden aims to fight

poverty’, *States News Service*, 8 November, available at: go.galegroup.com/ps/i.

do?id=GALE%7CA307868886&v=2.1&u=uts&it=r&p=&sw=w&asid=8e5842

0603d5812040893cfa85e7f827.

Kaethler, T. M. (2006) ‘Growing space: the potential for urban agriculture in the city of Vancouver’, School of Community and Regional Planning, University of British

Columbia, available at: bitsandbytes.ca/sites/default/files/Growing_Space_Rpt.pdf.

Kaziro, P. (2015) ‘GROW’ horticulture therapy programme at St Canice Kitchen

Garden, Kings Cross, Sydney (personal Communication).

Khandaker, M. S. I. (2004) ‘Rooftop gardening as a strategy of urban agriculture

for food security: the case of Dhaka City, Bangladesh’, *Acta Horticulturae*, 643, 241–247.

Kinen-Ferguson, C. (2015) ‘University dining goes green with rooftop garden’,

*Technician*, 8 July, available at: www.technicianonline.com/news/article_

bd6dab08-07de-11e4-9575-001a4bcf6878.html.

Lee, K. E., Williams, K. J. H., Sargent, L. D., Williams, N. S. G. and Johnson, K. A.

(2015) ‘40-second green roof views sustain attention: the role of micro-breaks in

attention restoration’, *Journal of Environmental Psychology*, 42, 182–189.

Litichevskaya, J. (2011) ‘Reviving the world wonder: why rooftop gardens should

cover urban landscapes', *Rutgers Computer & Technology Law Journal*, 37(1/2), 58–92.

214 Green Roof Retrofit

LT. Governor Simon Awards (2012) 'LT. Governor Simon awards grant to uptown farm-

ers market dedicated wireless link card machine, tours rooftop gardens', *States News Service*, 23 August, available at: go.galegroup.com/ps/i.do?id=GALE%7CA30065387

5&v=2.1&u=uts&it=r&p=&sw=w&asid=c0a5c39c5ac0e3ae650391bbe5bb5bdf.

Lynch, K. (1960) *The Image of the City*. MIT Press: Cambridge, MA.

Maas, J., Verheij, R. A., Groenewegen, P. P., De Vries, S. and Spreeuwenberg, P.

(2006) 'Green space, urbanity, and health: how strong is the relation?', *Journal of Epidemiology & Community Health*, 60, 587–592.

Malcevschi, S., Bisogni, L. and Gariboldi, A. (1996) *Reti ecologiche ed interventi di miglioramento ambientale*. Il Verde Editoriale: Milan.

Matsuo, E. (1995) 'Horticulture helps us to live as human beings: providing balance

and harmony in our behavior and thought and life worth living', *Acta Horticulturae*, 391, 19–30.

Mavrogordato, T. (2013) 'Offices are turning their roofs into edible gardens and

bee sanctuaries', available at: www.theguardian.com/sustainable-business/offices-

roofs-edible-garden-sustainable-cities.

McClintock, N. (2010) ‘Why farm the city? Theorizing urban agriculture through

a lens of metabolic rift’, *Cambridge Journal of Regions, Economy and Society*, 3, 191–207.

Miles, S. and Paddison, R. (1998) ‘Urban consumption: a historiographical note’,

*Urban Studies*, 35(5/6), 815–823.

Milkwood (2015) ‘Milkwood permaculture, 18 July, available at: www.milkwood.

net/about/.

Miller, J. R. (2005) ‘Biodiversity conservation and the extinction of experience’,

*Trends in Ecology and Evolution*, 20, 430–434.

Montgomery, J. (1998) ‘Making a city: urbanity, vitality and urban design’, *Journal of Urban Design*, 3(1), 93–116.

Nettle, C. (2009) *Growing Community Starting and Nurturing Community Gardens*,

Health SA, Government of South Australia and Neighbourhood Houses and Centres

Association Inc., Adelaide.

Nettle, C. (2014) *Community Gardening as Social Action*. Ashgate Publishing:

Farnham, Surrey.

Newcastle Community Garden Project (2010) Cameron, J. and Pomfrett, J. (eds),

*A Community Garden Manifesto*, Centre for Urban and Regional Studies,

University of Newcastle, Newcastle, UK.

Newton, P. (2011) 'Consumption and environmental sustainability.' In Newton, P.

(ed.), *Urban Consumption*. CSIRO Publishing: Australia.

Oberndorfer, E., Lundholm, J., Bass, B., *et al*. (2007) 'Green roofs as urban ecosystems: ecological structures, functions, and services', *BioScience*, 57(10), 823–833.

Ontario Healthy Communities Coalition (2015) www.ohcc-ccso.ca/.

Orsini, F., Gasperi, D., Marchetti, L., *et al*. (2014) 'Exploring the production capacity of rooftop gardens (RTGs) in urban agriculture: the potential impact on food and

nutrition security, biodiversity and other ecosystem services in the City of Bologna', *Food Security*, 6(6), 781–792.

Peck, S. (2003) 'Towards an integrated green roof infrastructure evaluation for

Toronto', *The Green Roof Infrastructure Monitor*, 5, 4–7.

Perasso, E. (2012) 'A green kitchen starting from the top', Available at: www.finedining

lovers.com/stories/green-restaurants-uncommon-ground/.

Permacultureprinciples (2015) permacultureprinciples.com.

Pink, S. (2007) 'Walking with video', *Visual Studies*, 22(3), 240–252.

Pink, S. (2009) *Doing Sensory Ethnography*. Sage: London.

Pink, S. (2012) *Situating Everyday Life: Practices and Places*. Sage: London.



Rye's Home Grown (2015) 'Rooftop garden', available at: ryeshomegrown.word

press.com/rooftop-garden/.

Sanyé-Mengual, E., Cerón-Palma, I., Oliver-Solà, J., Montero, J. I. and Rieradevall,

J. (2013) 'Environmental analysis of the logistics of agricultural products from

roof top greenhouses in Mediterranean urban areas', *Journal of Science, Food and*

*Agriculture*, 93, 100–109.

Shin, D. H. and Lee, K. S. (2005) 'Use of remote sensing and geographical information

system to estimate green space temperature change as a result of urban expansion',

*Landscape and Ecological Engineering*, 1, 169–176.

Silverman, D. (2013) *Doing Practical Research: A Practical Handbook*, 4th edn.

Sage: London.

Sloan, W. (2015) 'Farmers' market to welcome some home grown food', 13 May,

available at:
www.ryerson.ca/ryersontoday/data/news/2015/05/20150513-farmers-

market-to-welcome-some-homegrown-food.html.

Solnik, C. (2011) 'Mather Hospital in Port Jefferson opens rooftop garden', *Long*

*Island Business News*, 19 September.

Sunakorn, P. (2012) 'AKU roof top garden', available at:
www.cbit.arch.ku.ac.th/

home/index.php?option=com_content&view=%20article%20&id=27.

Sydney Morning Herald (2008) 'Future farms over our heads', available at:

www.smh.com.au/news/environment/future-farms-over-our
heads/2008/10/11/

1223145699162.html.

The Sustainable Campus (2015) 'CUHK's splendid rooftop farm', e-newsletter No.

7, The Chinese University of Hong Kong, available at:
www.iso.cuhk.edu.hk/

english/publications/sustainable-campus/article.aspx?articleid=61081.

Tilley, C. (2006) 'The sensory dimension of gardening', *Senses and Society*, 1(3), 311–330.

Uncommon Ground (2015) www.uncommonground.com/home.

University of Maryland (2010) 'Rooftop garden – the diner', available at: www.

sustainability.umd.edu/content/campus/dining.php#South.

University of Melbourne (2015) ‘Growing up rooftop garden’, available at: www.

growinggreenguide.org/victorian-case-studies/growing-up-rooftop-garden/.

Wackernagel, M. and Rees, W. (1996) *Our Ecological Footprint: Reducing human*

*impact on the Earth*. New Society Publisher: Philadelphia.

Wilkerson, A. (2010) ‘Rooftop garden in OKC provides fertile ground for community

growth’, *Journal Record*, 5 August.

Wilkinson, S. (2015a) ‘Lend lease rooftop garden, London’, personal communication.

Wilkinson, S. (2015b) ‘Barriers to establishing an institutional rooftop garden’,

personal communication.

Woods Bagot (2015) ‘Refugee garden brings community together in Sydney’,

available at: www.woodsbagot.com/news/refugee-garden-brings-community-

together-in-sydney.

Zande, R. V. (2006) ‘The advantages of a rooftop garden and other things’,

*International Journal of Art & Design Education*, 25(2), 205–221.

Zhou, C. and Stolz, A. (2014) ‘Rooftop gardens on the rise as inner-city Melbourne

grows green’, available at: canberratimes.domain.com.au/real-estate-news/rooftop-

gardens-on-the-rise-as-innercity-melbourne-grows-green-20140827-108xa5.html.

**1**

**11**

# Cool Roof Retrofits as an Alternative to Green Roofs

**Dominique Hes, Chris Jensen and Lu Aye**

The University of Melbourne, Australia

## 11.0 Introduction

In this chapter another means of retrofitting a roof is discussed. This is

the ‘cool roof’ option. The chapter outlines a research methodology and

approach adopted to evaluate the cool roof option in Australia over four

fieldwork experiments:

1. cool roof retrofit;

2. cool roof modelling for industrial, commercial and residential buildings;

3. preliminary look at green roof versus cool roof retrofit;

4. cool roof and photovoltaics.

The advantages and disadvantages of cool roof specifications are discussed,

summarising when the cool roof is most effective at keeping heat out of

buildings. The chapter concludes by setting out the circumstances whereby

the cool roof option is favoured over a retrofit green roof alternative.

**11.1**

**What is a Cool Roof?**

As we have seen in other chapters in this book, there is a significant benefit

to retrofitting buildings and focusing effort on how to do this effectively and

efficiently. This chapter looks at the opportunities of the outer skin of the

roof, specifically using a cool roof treatment. Focusing on cool roof paints

(CRP), the chapter outlines the benefits and limitations, as well as briefly

referring to alternatives such as green roofs.

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



A cool roof is typically a treatment that is applied to the roof as paint, but

can be an integral part of the outer layers of the roof. It is cool because it

reflects the sun's heat and emits absorbed radiation back into the atmosphere

at a higher rate than standard materials (Urban and Roth, 2010). These types

of roof literally stay cooler, thus reducing the amount of heat held and trans-

ferred to the building below, keeping the building at a cooler and more

constant temperature. In a retrofit the paint can be applied to existing roofing

if its condition is reasonable, while the cool roof material is a larger, more

costly replacement option when roofing needs replacement. The research that

underpins this chapter is based on four experiments: (1) painting two 15-year-

old metal roofs white with different CRP products; (2) an initial look at

the comparison for the two white roof retrofits with a green roof retrofit;

(3) building two scale brick homes to current insulation standards with black

concrete tiles, one painted white; and (4) putting solar panels on the two scale

brick homes and measuring the impact of roof colour on PV output.

**11.2**

**Background – How does a Cool Roof Work?**

‘White’ or ‘cool’ roof paints have a significantly higher reflectivity and

thermal emittance compared with normal roof materials and coatings.

Cool roof performance may be achieved with additives to the base material,

or by applying a CRP to an existing roof.

It is important to note that with modern technology, CRPs need not be

white. There are many CRP products which use darker-coloured pigments

that have increased the reflectivity in the near-infrared (non-visible) portion

of the solar spectrum. With these technologies there are roofs that come in

a wide variety of colours and still maintain a high solar reflectance, due to

increased reflectivity in the infrared range of the spectrum, without affecting

the visible range which dictates colour. However, a darker roof will never be

as reflective as a light-coloured roof.

A second benefit of a cool roof is that it reduces the absorption and reten-

tion of heat and therefore the contribution to the urban heat island effect, as

seen by the reduction in roof temperature for all of the experiments.

## 11.3

## Cool Roof Studies and Measurements

Summarised below are several studies, mostly in the northern hemisphere,

using both field measurements and computer simulations that document the

energy savings from increasing the solar reflectance properties of buildings,

combined with an increased thermal emittance. It is now widely accepted

that the higher reflectivity a roof colour has, the lower the solar energy that

is absorbed into the building and the lower the surface temperature of the

roof will be (Kiehl and Trenberth, 2010).

In a 2001 study by Konopacki and Akbari, the Lawrence Berkeley

National Laboratory (LBNL) measured and calculated the reduction in

peak energy demand associated with a cool roof’s surface reflectivity.

218 Green Roof Retrofit

They found that, compared with the original black rubber roofing membrane

on the Texas retail building studied, a retrofitted vinyl membrane delivered

an average decrease of 24°C in surface temperature, an 11% decrease in

aggregate air-conditioning energy consumption and a corresponding 14%

drop in peak hour demand. The average daily summer-time temperature of

the black roof surface was 75°C, but once retrofitted with a white reflective

surface, it measured 52°C. Without considering any tax benefits or other

utility charges, the annual energy expenditure on providing comfort was

reduced by $7200, or $0.07/sq. ft (0.65 cents/m2).

Akbari and Konopacki (2005) have calculated the cooling energy savings

due to the application of heat island mitigation strategies (application of

cool materials and increase in vegetation cover) for 240 regions in the

United States. It was found that for residential buildings, the cooling energy

savings vary between 12% and 25%, for office buildings between 5% and

18%, and for commercial (retail store) buildings between 7% and 17%. In

Australia, Miller *et al*. (2015) looked at the benefits of CRP in subtropical

and tropical areas; they found measured reductions in temperature (roof

surface, roof cavity and non-air-conditioned internal spaces), power (kW)

and energy usage (kWh) within their studied buildings.

Other relevant field studies in California and Florida have demonstrated

direct cooling energy savings in excess of 20% upon raising the solar reflec-

tance of a roof to 0.6 from a prior value of 0.1–0.2 (i.e., 60% reflectance

from 10–20% reflectance). Energy savings are particularly pronounced in

older houses that have little or no roof insulation, especially if the roof space

contains air distribution ducts for ducted heating and cooling. Akbari *et al*.

(2009) observed cooling energy savings of 46% and peak power savings of

20%, achieved by increasing the roof reflectance of two identical portable

classrooms in Sacramento, California. Konopacki *et al*. (1998) documented

measured energy savings of 12–18% in two commercial buildings in

California. In a large retail store in Austin, Texas, Konopacki and Akbari

(2001) documented measured energy savings of 12%. The roof of the build-

ing was insulated metal, with a black membrane coating pre-retrofit, with a

white thermoplastic PVC membrane post-retrofit.

This research showed that there are benefits across most climatic regions,

but specifically in those that have a larger cooling rather than heating load.

The research suggests that the larger the cooling load, the greater the benefit

from the CRP. That is, it is not the building type but its cooling load result-

ing from energy transfer through the roof; if the CRP reduced the energy

ingress, then the energy used to maintain comfort was reduced. The studies

reported on in this chapter extend this work by looking at a climatic region

that has a high heating load.

## 11.4

## The Experiments

The studies reported on in this chapter include field research on residential-

type buildings. Within the modelling component, the data from the fieldwork

was used to calibrate a model which was then used to look at the benefit for



other building typologies; this ensures greater accuracy between modelled

results and reality, as outlined by Akbari *et al*. (1997).

Residential level was focused on due to the practicality of setting up test

buildings. Roof performance in a residential building is a balance between

summer-time heat reduction performance and winter heat absorption, and

this is dependent on the climate within which the building is located. The

temperate Melbourne climate (similar to the San Francisco Bay area, Cape

Town, Southern France and Northern Spain) is considered to be a heating

climate for the majority of the year. As the experiments were set up in a heat-

ing climate, it was expected that a cool roof product would increase the

heating requirements; thus, given our insulation requirements and the use of

the CRP, we wanted to see if the positive impact of summer benefits was

greater than the negative impact in winter. The key to the potential impact

of the insulation (due to saturation and heat balance between the roof cavity

and inside the house) is that in winter the insulation is designed to keep the

temperature up to 25°C within the house, while in summer the roof cavity

will get to over 50°C, resulting in heat moving into the house. This is

reinforced by research such as that of Gentle *et al*. (2011), who noted that

the roof surface typically does not present a dominant influence on average

winter heating needs in most temperate zones, enhancing the benefits of

cool roofs.

### 11.4.1 Results

The University of Melbourne research team has been looking at CRPs since

2010, with four different experiments underpinning this chapter. The loca-

tion of the research was eastern metropolitan Melbourne, with coordinates

37°48′49″S, 144°57′47″E.

The site is made up of nine buildings (Figure 11.1), six full scale (A–F) and

three one-third scale (G–J). Mixed experiments occurred on the site:

- buildings A and C were used for wall-shading studies;
- building B was the control for buildings A–F;
- buildings D and F had different brands of CRP;
- building E was a green roof;

■

building G was a one-third-scale building with another type of CRP used

to test the impact of weathering, dirt accumulation and cleaning;

■

buildings H and J were one-third-scale brick veneer buildings built to

current building standards with dark charcoal concrete roof tiles.

Buildings A–G

The test buildings are of a lightweight construction, typical of Australian

housing, and insulation levels are indicative of the 1991 minimum building

standards (approximately R1.0 walls and R0.82 ceilings), which would

have been in place at the time of construction. The uninsulated timber floors




220 Green Roof Retrofit

**Figure 11.1** Buildings and location.

*Source*: NearMap.

and the absence of weather strips to doors resulted in an assumed infiltra-

tion rate of approximately two air changes per hour (ACH). The doors and

windows were always closed, with the exception of those times access was

required for installation and maintenance of equipment. Blinds were

installed to north-facing windows in order to mitigate misleading sensor

output affected by glare and direct solar gain.

Data collected is depicted graphically in Figure 11.2, and included heat

transfer into the roof. Room heat flux sensors at roof and ceiling level meas-

ured the transfer of heat into the building through the roof. Vertical and

horizontal pyranometers mounted on a steel support above the roof meas-

ured the reflected radiation from the roof. Within the building, temperature

and humidity were measured to determine the ambient comfort conditions.

All sensors were connected to the Internet via the data logger.

The data from the onsite measurements discussed in Experiment 1 was

collected between December 2010 and July 2011, specifically in summer

(1–14 January) and winter (23 April–8 May, 2–16 June). Results are dis-

cussed in relation to internal temperature, reflectance and roof tempera-

ture. The summer indoor temperature profiles suggest that the CRP

product test buildings maintain a lower internal temperature by 2 or 3°C

compared with the control building at the warmest part of the day. This

visible difference is most obvious during the warmest parts of the day,

however a similar effect can be seen overnight also. The main source of

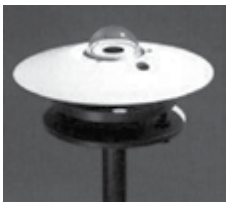
difference seen in the indoor temperatures of these test buildings is solar

radiation (Figure 11.3).

When looking at the data from the roof surface temperatures, the impact

of the CPR is the most marked. It is clear that the painted roofs have a much

lower external temperature. The summer roof temperature profile shows



Cool Roof Retrofits as an Alternative to Green Roofs 221

H

V

32°C

21°C

Pyranometer

Building E

**Figure 11.2** Experimental setup.

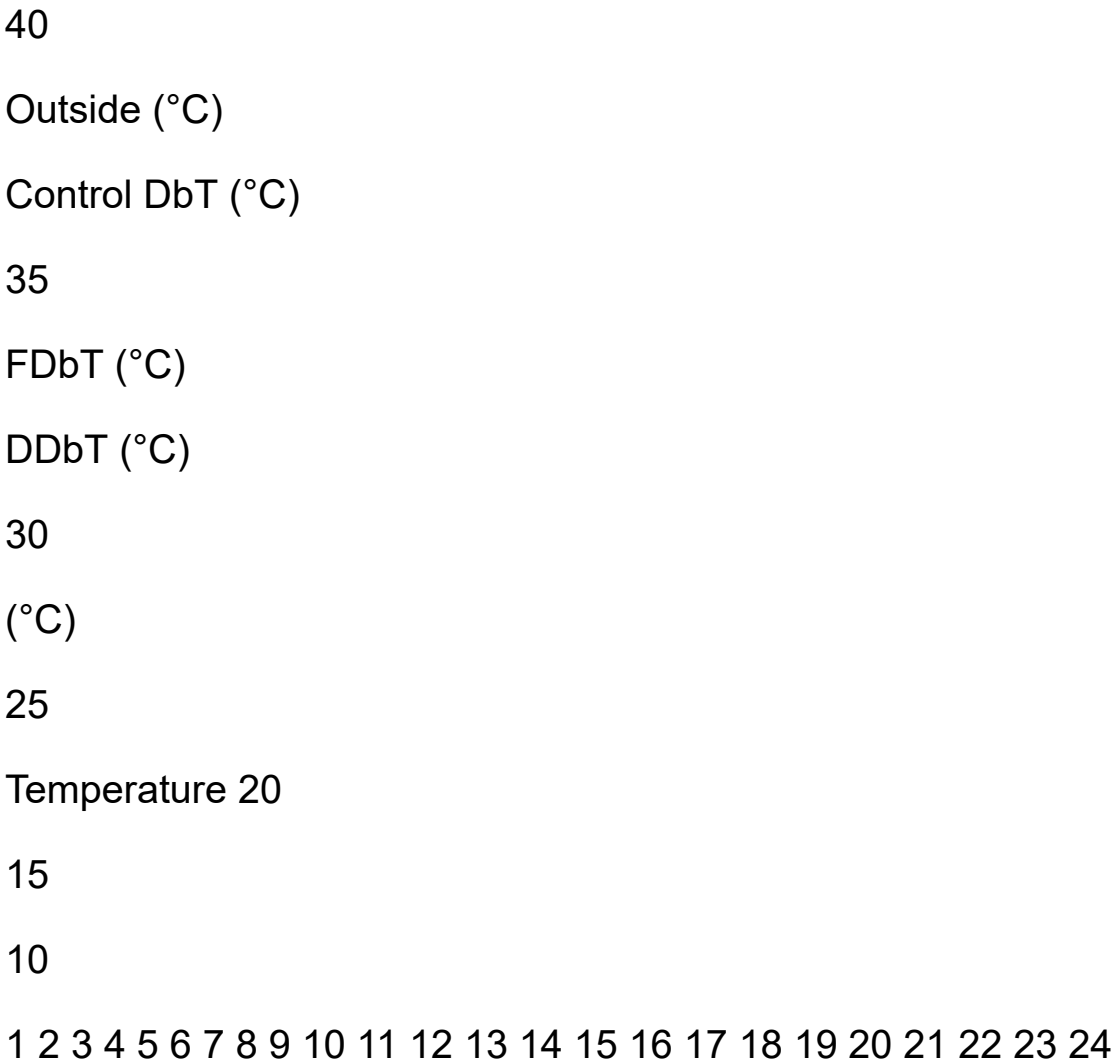



**Figure 11.3** Summer indoor temperature across 24 hours (note first letter for each line is the building – i.e. FDbT= building F Dry bulb temperature).

a clear difference of up to approximately 30°C (Figures 11.4 and 11.5).

As can be seen, on 6 January 2011 the control roof (zincalume) reaches

68°C whilst the coolest roof is at 35°C.

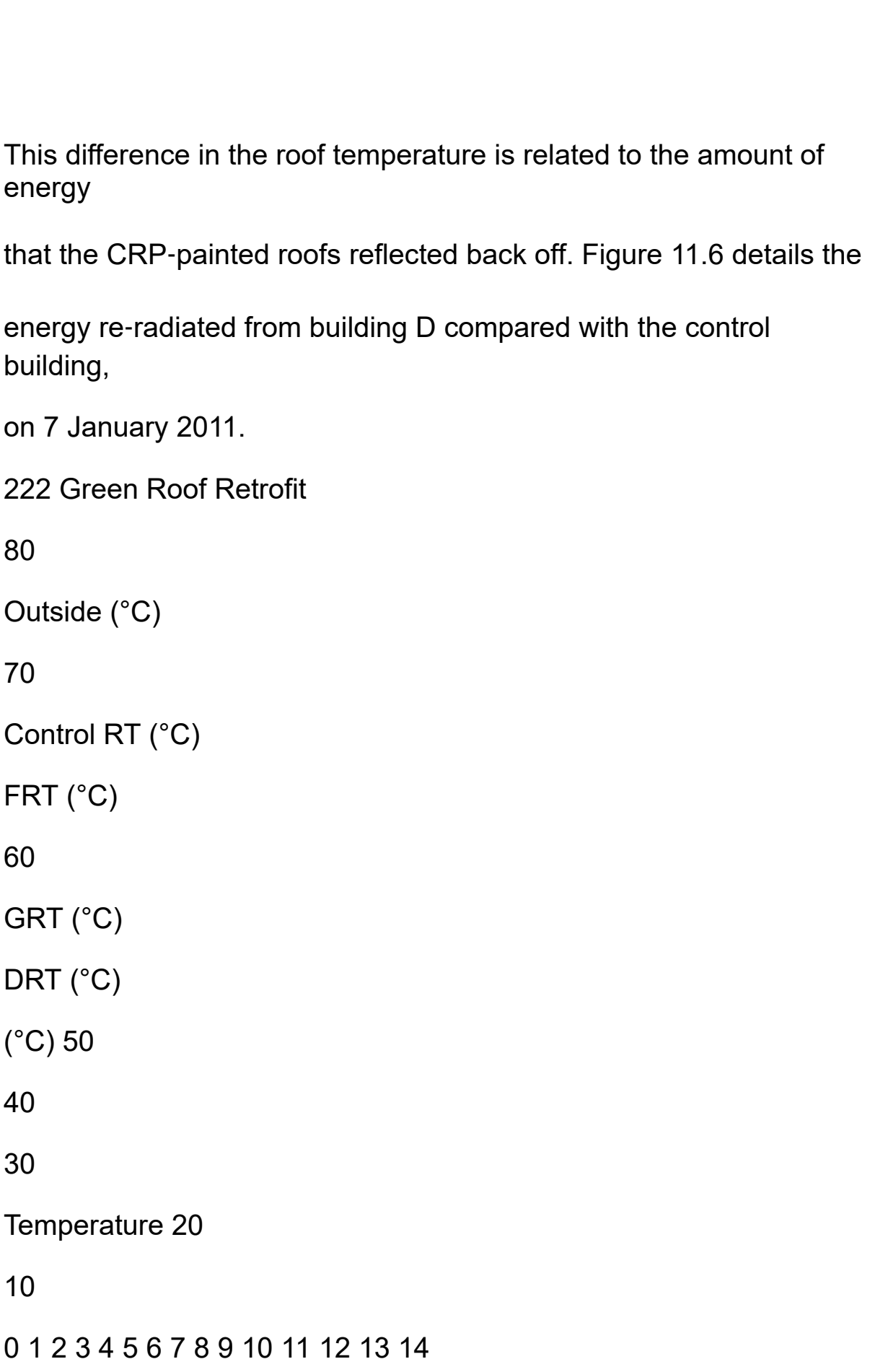
This difference in the roof temperature is related to the amount of energy

that the CRP-painted roofs reflected back off. Figure 11.6 details the

energy re-radiated from building D compared with the control building,

on 7 January 2011.

222 Green Roof Retrofit



January

**Figure 11.4** Summer roof temperature across 14 days (note first letter for each line is the building – i.e.

FRT= building F Roof Temperature).

60

Outside (°C)

BRT (°C)

50

FRT (°C)

DRT (°C)

40

(°C)

30

Temperature 20

10

0

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Jan - 07

**Figure 11.5** Summer roof temperature across 24 hours.

We used the field results to calibrate the simulated model, which was

developed in the Transient Systems Simulation Programme (TRNSYS). This

simulation showed that for all white roof paints there is a benefit annually

of between 0.88 and 1.53 MJ/m2. Scaling this up for an average 200 m2

home, this would be equal to between 176 and 306 MJ/year. This represents



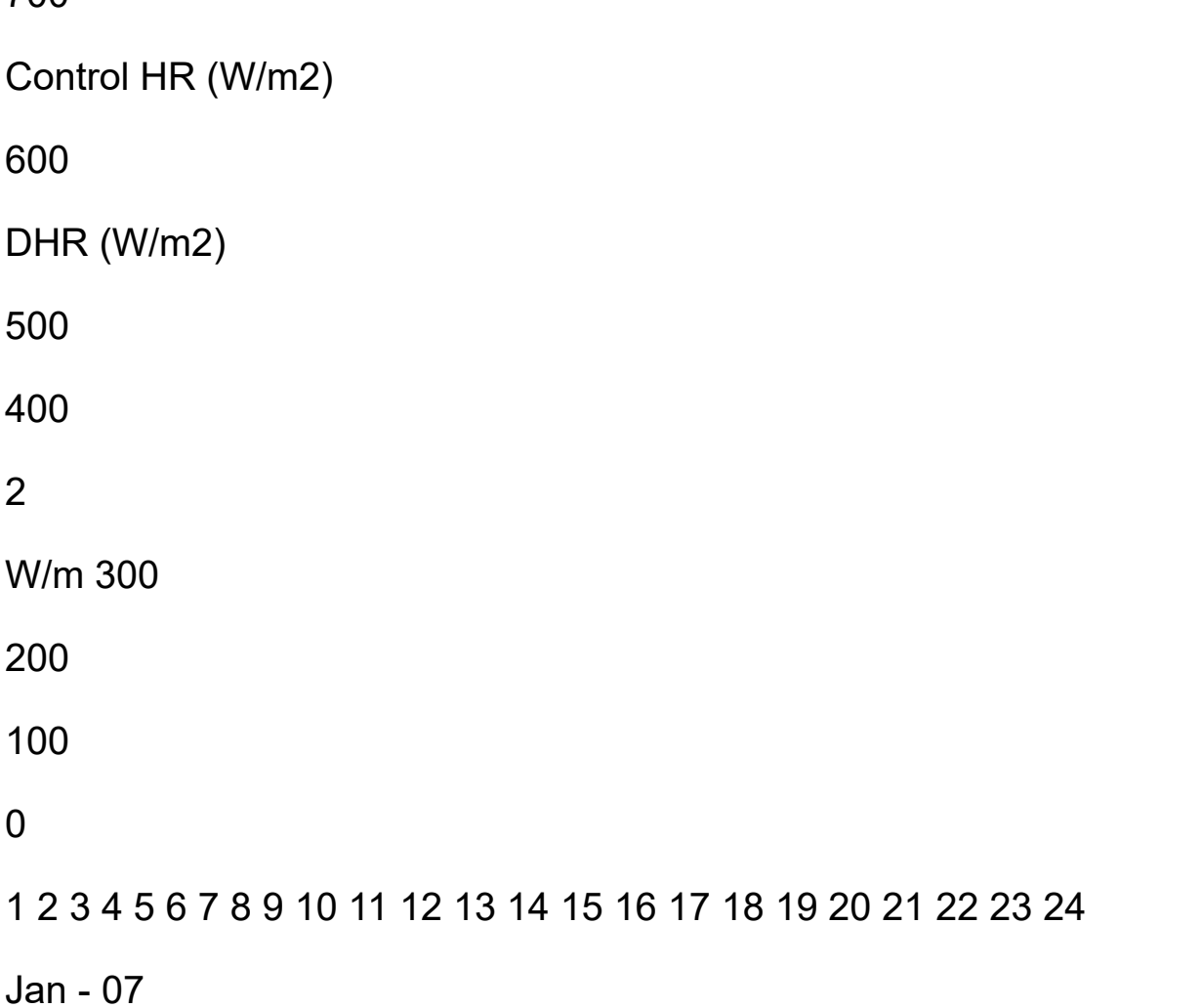


**Figure 11.6** Summer roof reflection across 24 hours.

only a small improvement for this type of building (total energy use in this

example being 7300 MJ, this represents a 4.2% benefit). With this model the

researchers were then able to test some aspects that help to determine when

the use of CPR would be most beneficial. The aspects tested were: roof

pitch, roof shading, insulation levels and roof-to-wall ratio. For cooling

energy the model showed that the steeper the roof slope, the greater the

benefit of the CRP (Figure 11.7). Therefore, from this simulation it makes

sense to paint sloped roofs if artificial cooling is used. This is also a useful

outcome for the central theme of this book: if retrofitting a roof with a steep

slope, a green roof is less appropriate.

The simulation of the shading of a roof and the benefit of CRP showed

that if a roof is shaded, there is little benefit of the CRP. Owing to the impor-

tance of the roof insulation on the impact of the CRP, the model tested

whether the location of the insulation (under the roof or over the ceiling)

made an impact. Across the year, the difference between using a CRP and

not using a CRP can result in an increased roof space temperature of up to

18.5°C (assuming R2.5 insulation fitted to the ceiling). Figure 11.8 shows

the temperature of the attic or ceiling space across a year; the highest tem-

perature in the roof space without CRP was 53°C, while at the same time

the painted roof was at 36°C.

If the insulation is moved from on top of the ceiling to under the roof

(i.e., from between the roof space and the habitable room to between the

roof and the roof space), it dramatically reduces the roof space temperature



58

56

Without paint

)2

With paint

m 54

52

50

energy (MJ/ 48

46

Cooling 44

42

0

4.8

20

50

Roof pitch (%)

**Figure 11.7** Simulated impact of roof pitch and CRP on cooling energy.

Attic temperature variation (insulation on ceiling)

60

Metal roof

Cool roof paint (CRP)

50

40

e °C

30

20

Temperatur

10

0 0

1000

2000

3000

4000

5000

6000

7000

8000

Time (hr)

**Figure 11.8** Simulated ceiling space temperatures.

to the point where the effect of the CRP is much less significant. In other

words, houses with an unvented roof space and insulation only on the ceiling

will get a significant benefit from the CRP, as roof space temperatures will

otherwise reach over 50°C, which will act to slowly heat the habitable space

below. Houses with vented roof spaces, or insulation under the roof material

(insulated sarking, aircell or similar) will receive less benefit from the use

of CRP, as the heat is not getting into the roof space. The simulation was

next asked to provide data on the contribution CRP can have to reducing

energy consumption as buildings become taller. Not surprisingly, the fewer

the floors and the greater the surface area of the roof space to the external

vertical walls, the greater the benefit of the CRP. As such, the CRP is most

effective when used on low-rise buildings, which led the researchers to

look at industrial-type buildings. It is with these buildings that the greatest

benefit was shown.



70

External air Temp

Building B - control

60

Building E - green

50

40

30

Temperature (°C)

20

10

0

5

6

7

8

9

10

11

12

13

14

15

16

17

18

January 2012

**Figure 11.9** Roof surface temperature for green roof and control metal roof.

Because industrial buildings generally do not use energy for heating or

cooling, the analysis was instead made on internal comfort conditions.

Although this approach results in a direct comparison of performance with

and without CRP, it is more difficult to assign a cost saving to the use of the

products. The results show that both the CRP and base case roofs result in

buildings which are uncomfortable at times, but that the CRP building

maintained a significantly lower internal temperature during these times. To

illustrate this, as can be seen from Figure 11.9, on a day when the base-case

building's internal temperature approached 40°C, the CRP building main-

tained a temperature of approximately 33°C. This represents a difference

of 7°C, or approximately 17% cooler conditions.

To understand the potential energy use consequences for industrial

buildings, the model examined two scenarios:

■

a high load profile (100 W/m2) representing a process-style building such

as manufacturing;

■

a low load profile (10 W/m2) representing a storage-style building such as

a warehouse.

It was found that if the buildings were heated and cooled, the simulation

showed that the cooling energy for both scenarios was significantly reduced

(59% reduction for high load, 70% for low load), and that the heating

energy was also increased (18.6% for high load, 22% for low load). What

is potentially more interesting is that the model showed that without heating



or cooling, the CRP would result in a 9% reduction in hours outside the

comfort zone (between 18 and 27°C). That is, the facility would be able to

continue to operate for a longer period.

Comparison of CRP results with the green roof

The full-scale buildings B, D and F were compared with building E (green

roof) to compare the performance of the green roof and that of the cool

roofs. The extensive (shallow) green roof was retrofitted on the building and

constructed of the following layers above the roof structure: protection

layer, drainage layer, filter fabric, substrate and plants. The roof was planted

with drought-tolerant succulents and not watered. It was expected that the

green roof would reduce the heat transmission through the roof because of

shading, evapotranspiration, absorption and the insulating properties or soil

and water (Gagliano *et al*., 2015). The control building (B) was found to

have daytime temperatures higher than those of the green roof. The field

tests clearly demonstrated low roof temperatures for the green roof com-

pared with a metal roof (Figure 11.9). It should be noted that the maximum

temperature reduction coincided with the peak cooling load period. The

bulk of the daytime heat gain is the effect of solar radiation absorption,

which is usually the most important factor (Suehrcke *et al*., 2008).

Comparing the white and green roofs, the surface temperature clearly shows

that the green roof stays much cooler and there is a slight lag, which is

expected with the additional thermal mass. The detail in Figure 11.10 is

based on one day chosen from 3 months of data collected over 2 years and

chosen to reflect a very typical Melbourne day of 35°C.

It was found that when comparing the green, white and control roofs, the

internal temperature conditions between the CRP and green roofs varied by

around 3°C on a 35°C day (Figure 11.11). Both types of roof retrofit reduced

the internal temperature, the white by up to 4°C and the green by up to 7°C.

(Remember that the insulation on these retrofits had an R-value below 1; it

shows the benefits of the retrofit, which would decrease once the insulation

is brought up to standard at an R-value of 2.5.) The graph in Figure 11.11

also shows that the green roofs keep the internal temperature warmer at

night, which has negative consequences for night-time comfort and cooling

in summer and benefits in winter – as one would expect with the added

thermal mass.

Finally, when the researchers looked at the re-radiation of energy from the

roofs, it was clear that the green roof did not reflect as much energy as the

CRP roofs, or even the old metal roof; instead, it was absorbed by the plants

(Figure 11.12).

This would suggest that green roofs are better at reducing the impact of

the roof surface on the urban heat island, although cool roofs also have an

impact by not holding onto the heat and reflecting it away from the build-

ing. Green roofs, as discussed in other chapters, also have many additional

benefits – such as providing potential places for ecosystem services, habitat,

biophilia, stormwater retention, absorption of emissions, etc.

Cool Roof Retrofits as an Alternative to Green Roofs 227

50

CRP1-D(°C)

45

Green-E(°C)

CRP2-F(°C)

40

35

30

Temperature °C 25

20

15

10 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

Time - 24 hours

**Figure 11.10** Roof surface temperature for green roofs and white roofs (7 February 2012) 39

38

CRP1-D (°C)

37

Green-E (°C)

36

35

CRP2-F (°C)

34

Outside Temperature (°C)

33

32

31

30

29

28

27

26

Temperature °C 25

24

23

22

21

20

19

18

17hh 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22

Time - 24 hour (1 January 2012)

**Figure 11.11** Internal temperature (1 January 2012).



Control (B)

700

CRP2 (F)

CRP3 (G)

Green ( E)

600

500

2

W/m 400

ection 300

efl

ntal r 200

rizo

Ho

100

0

–100

Time - 20/Feb/2012 – 13/Mar/2012

**Figure 11.12** Roof horizontal reflection.

### 11.4.2 Other Residential Building Typologies

Having looked at the lightweight timber buildings, the researchers set up

two one-third-scale brick veneer buildings designed to current building-code

standards. The buildings were built to one-third the scale of a standard

building. Building H had a proprietary cool roof product applied to the

concrete tile roof and building J had an untreated charcoal-coloured con-

crete tile roof. Both had the same orientation (magnetic north), the same

design, the same materials, and were constructed to a BCA 6 star equivalent

standard (115 MJ/m2). Given the scale and proportions of the buildings,

it was not appropriate to ‘rate’ the buildings at a 6 star performance level,

and, as such, the buildings were classified as ‘equivalent’ to the 6 star

standard, in accordance with an accredited rater’s experience of typical

building standards.

Buildings H and J had a 2000 × 2000 mm2 external base building meas-

urement, with a maximum height of 2250 mm above ground, a single pitch

roof of 24.7° (±0.3°). The roof is a skillion-style roof with the plaster

following the roof profile, rather than a suspended flat ceiling (to facilitate

easy access to the internal space). The external roof dimensions are

2400 × 2400 mm2 (including eaves), which is 5.76 m2. There were two open-

ings, one window 600 × 600 mm2 facing north and one door 600 × 1850 mm2

facing south. The buildings were monitored from October 2011 until

November 2013.



31

HBbT (°C)

JBbT (°C)

29

27

25

ature °C 23

mperTe 21

19

17

15

Time - from 4/Jan/2011 – 17/Jan/2011

**Figure 11.13** Internal summer temperature of buildings J and H (note first letter for each line is the building – i.e. HBbT= building H Black bulb temperature).

The data collected from log-tag mobile temperature recorders before the

application of the CPR showed that the two buildings were performing

within 0.2% of each other. That is, the internal temperature, humidity

and radiance were almost equal. The data after CRP application shows

the clear difference between the two buildings, most notably the reduced

internal temperatures of building H (CRP). Once the paint was applied

the internal temperature showed that the application of the CPR resulted in

a 2°C drop in summer temperature during the day and slightly higher at

night (Figure 11.13). Interestingly, it was also found that the CRP building's

internal temperature had a small increase in temperature in the winter

(Figure 11.14).

The field measurements also showed that the CRP had an impact on both

the roof surface temperature (by almost 20°C) and increased reflectivity

(over 90%).

This study confirmed and provided additional data for a growing field of

research that proves the benefit of CRP for increasing surface reflectivity,

reducing roof surface temperature (Figure 11.15) as well as indoor tem-

perature, subject to the properties of the building. This has been achieved

in a tightly controlled study based on code-compliant buildings typical of

Melbourne, Australia. Also, particular cool roof products can provide an

insulating benefit during the night time and in winter, although the results in

230 Green Roof Retrofit

21

HBbT (°C)

JBbT (°C)

19

17

15

ature °C 13

mperTe

11

9

7

5

Time - from 21/May/2012 – 17/June/2012

**Figure 11.14** Internal winter temperature of buildings J and H.

80

HRT (°C)

JRT (°C)

70

60

50

ature °C 40

mperTe 30

20

10

0

Night

Day

Night

Day

**Figure 11.15** Surface temperature of buildings J and H (24 February 2012).





this study were minor and require further research to identify the reasons

for the benefit. The important point, though, is that there was no negative

impact of the cool roof product tested in this experiment at night or in

winter. This could be attributed to the insulating properties of the nano-

ceramic spheres in the paint, but this would also need to be verified by

further testing.

### 11.4.3 Impact of CRP on PV Energy Generation

The final element of this chapter looks briefly at the preliminary outcomes

of an ongoing study on the impact of the cool roof on PV panel performance

due to temperature variations. It is well understood that a typical crystalline

PV module is subject to power output variations in accordance with cell

temperature, by increasing the conductivity of the crystalline semi-conductor,

which acts to reduce the individual cell voltage. A high cell temperature

reduces electrical productivity by up to 25% and a value of −0.45%/°C can

be applied for crystalline silicon PV cells (Makrides *et al*., 2009; Peck and

van der Linde, 2010).

Given this effect, and the predominant rooftop location of most solar cell

installations, it seems that the increased roof temperature of a dark roof will

act to lower the efficiency of a solar panel. It must be noted that the panel

does provide a shading effect for the roof, and therefore a roof covered in

panels will not necessarily reach the same high temperature as a bare roof.

Two identical PV installations, Suntech 12 V/85 W monocrystalline panels

(Figure 11.16), were installed (one per building) and linked to a series of

**Figure 11.16** Buildings J and H, and test PV panels.



light bulbs in order to generate load. The PV light-bulb wiring was a closed

loop with monitoring of the current and voltage only, which provided

the results.

Preliminary results found that on a typical day there is a 6.7% increase

in electrical output when installed over a cool roof, compared with an

identical installation on a black roof, based on the scale and properties

of the buildings used in the study.

## 11.5 Conclusions

### 11.5.1 Negative Impacts of Cool Roofs

The major negative impact of a cool roof is that of glare. This is an issue

that needs to be considered at the initial stage of any projects, because the

relatively light colours of CRPs can have a negative impact on people looking at the roof, or wall. Darker or low-glare colours should be considered if there is glare. Further, the performance of the white roof degrades over time and it is important that a maintenance regime is in place to clear the roof periodically (every one to two years depending on the amount of pollution, dust and other substance accumulation). Having said this, the technology is moving quickly, with new surface treatments being able to perform well even when soiled because of their consistency and layers (Gentle and Smith, 2015) – for example, sisalation still reflects energy away from the envelope of a building even though it is within the walls and roof surfaces.

### 11.5.2 Green Roofs Versus Cool Roofs

As other chapters in this book have outlined, there are many benefits to green roofs, particularly the multiple ecological benefits of provision of biodiversity, treatment of stormwater, visual amenity, uptake of emissions

and so forth (see Chapters 4 to 10). The major decision point is the addi-

tional cost of a green roof versus a white roof. Sproul *et al*. (2014), during

a lifecycle costing study of green roofs, black roofs and white roofs,

reported that thin extensive green roofs can cost $108–248/m2 ($10–23/ft2)

while heavier, deeper intensive green roofs can cost $355–2368/m2 ($33–

220/ft2). Based on 22 case studies, Sproul and colleagues used a mean of

$172/m2 ($14/ft2) in their analysis. A CRP, in contrast, they report at

$22/m2. Other considerations for green roofs are the maintenance aspects,

load-bearing requirements and availability of water for those roofs that

need irrigation.

Yet, as mentioned above, there are often intangible benefits to green roofs

including wellbeing and productivity benefits for those looking at and/or

having access to a green roof. These biophilic benefits are well documented

in the work of Stephen Kellert and others, including Chapters 9 and 10

of this book.

Cool Roof Retrofits as an Alternative to Green Roofs 233

### 11.5.3 Cool Roofs and Retrofits

The four experiments are limited in their extent and scope, but they repeat-

edly show a benefit to using the cool roof treatments in the temperate

Melbourne climate. Benefits have been shown to be greater further north

in Australia (Miller *et al*., 2014, 2015). In summary, the circumstances

whereby the cool roof option is most beneficial are:

- industrial buildings that have no heating or cooling;
- buildings that mainly have a cooling load;
- buildings with a large roof-to-total-surface-area ratio;
- buildings with roofs that are not overshadowed for more than 20%

of the time;

-

buildings with roofs that have a pitch above 23° (mainly due to increased

surface area);

■

buildings with a PV solar array on them.

As outlined above, the circumstances whereby the cool roof option is

favoured over a retrofit green roof alternative are where there are significant

aspects of cost, maintenance (including availability of water), structural

load and roof pitch.

### 11.5.4 Barriers and Stakeholders

This research was done in collaboration with the industry – both building

owners and cool roof paint providers. The key barrier identified was that of

accurate reputable information on benefits (actual benefits, in the field). Both

for CRPs and green roofs, data is still being collected for different climate

zones. Specifically, the CRP providers often found that the modelling may

not correctly identify the existence and extent of potential benefits.

### Acknowledgements

This study was part of the ‘Energy Saving Benefits of Urban Trees’ and

‘White Roofs’ collaborative research effort between the Melbourne

School of Land & Environment, the Melbourne School of Engineering

and the Faculty of Architecture, Building and Planning. This research was

funded by Nursery and Garden Industry Australia (NGIA) and special

thanks go to Anthony Kachenko for his support and encouragement.

The white roofs were funded by the City of Melbourne and the Department

of Sustainability and Environment. Thanks go to: Dr Stephen Livesley

and Dr Nick Williams for field and equipment support and discussions;

Lurian Klein and Kakau Foliaki for their data analysis. Final thanks

go to Ross Payne, Jamie Pearson, Tshewang Lhendup and Anthony

Dawkins for assisting with research infrastructure installation and basic

data collection.



**References**

Akbari, H. and Konopacki, S. (2005) ‘Calculating energy saving potentials of

heat-island reduction strategies’, *Energy Policy*, 33, 721–756.

Akbari, H., Kurn, D. M., Bretz, S. E. and Hanfford, J. W. (1997) ‘Peak power and

cooling energy savings of shade trees’, *Energy and Buildings*, 25, 139–148.

Akbari, H., Menon, S. and Rosenfeld, A. (2009) ‘Global cooling: increasing world-

wide albedos to offset CO2’, *Climate Change*, 94, 275–286.

Gagliano, A., Detommaso, M., Nocera, F. and Evola, G. (2015) ‘A multi-criteria

methodology for comparing the energy and environmental behavior of cool, green

and traditional roofs’, *Building and Environment*, 90, 71–81.

Gentle, A. R. and Smith, G. B. (2015) ‘A subambient open roof surface under the

mid-summer sun’, *Advanced Science*, 26 May [online].

Gentle, A. R., Aguilar, J. L. C. and Smith, G. B. (2011) ‘Optimized cool roofs:

integrating albedo and thermal emittance with R-value’, *Solar Energy Materials*

*and Solar Cells*, 95, 3207–3215.

Kiehl, J. T. and Trenberth, K. E. (2010) *Sustainability: Urban Heat Island*. Technical Bulletin No. 78, p. 197.

Konopacki, S. J. and Akbari, H. (2001) *Measured Energy Savings and Demand*

*Reduction from a Reflective Roof Membrane on a Large Retail Store in Austin*.

Lawrence Berkeley National Laboratory Report LBNL-47149, Berkeley, CA.

Konopacki, S. J., Akbari, H., Gartland, L. and Rainer, L. (1998) *Demonstration of*

*Energy Savings of Cool Roofs*. Lawrence Berkeley National Laboratory Report

LBNL-40673, Berkeley, CA.

Makrides, G., Zinsser, B., Georghiou, G. E., Schubert, M. and Werner, J. H. (2009)

'Temperature behaviour of different photovoltaic systems installed in Cyprus and

Germany', *Solar Energy Materials and Solar Cells*, 93, 1095–1099.

Miller, W. F., Bell, J. M. and Crompton, G. (2014) 'The impact of cool roof

applications on energy performance: results from Australian sub-tropical and

tropical field studies'. Proceedings of World Sustainable Buildings Conference

(SB14), CIB – International Council for Research and Innovation in Building

and Construction, Barcelona.

Miller, W. F., Crompton, G. and Bell, J. (2015) 'Analysis of cool roof coatings

for residential demand side management in tropical Australia', *Energies*, 8, 5303–

5318.

Peck, S. W. and van der Linde, D. (2010) 'System integration', *Eco-structure*,

September.

Sproul, J., Wan, M. P., Mandel, B. H. and Rosenfeld, A. H. (2014) 'Economic

comparison of white, green, and black flat roofs in the United States', *Energy*

*and Buildings*, 71, 20–27.

Suehrcke, H., Peterson, E. and Selby, N. (2008) 'Effect of roof solar reflectance on

the building heat gain in a hot climate', *Energy and Buildings*, 40, 2224–2235.

Urban, B. and Roth, K. (2010) *Guidelines for Selecting Cool Roofs*. US Department of Energy, Energy Efficiency and Renewable Energy, Building Technologies Program.

**12**

# Looking to the Future

**Sara Wilkinson1 and Tim Dixon2**

1 UTS, Australia

2 University of Reading, UK

## 12.0 Introduction

This book has discussed a wide range of reasons why individual stakeholders

might have to retrofit a green roof. These benefits include thermal performance,

stormwater attenuation, species conversation, promotion of biodiversity, urban

food production and provision of spaces for social engagement and interaction.

Often, the primary reason for green roof retrofit is the only one considered,

and the other co-benefits are not recognised. In this chapter we articulate the

primary reason along with co- or secondary benefits that stakeholders might,

more readily, understand the full range of benefits, including improved urban

resilience, that exist in green roofs. However, it starts with a review of the latest

initiatives in best practice at the city scale, before moving on to examine the

complex, and often thorny, issue of whether mandatory or voluntary approaches

are the best way to deliver greater uptake of green roof retrofit.

## 12.1

## City-level Actions: Basel and Paris

Basel, Switzerland has the highest number of green roofs per capita in the

world, with some 20% of its flat roof area comprising green roofs. These

have been brought about by a number of financial incentives and building

regulations (Kazmierczak and Carter, 2010). In Basel and other cities in

Switzerland, green roofs became more popular and commonplace in the

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



1970s as a test bed for green construction, and this led to the development

of pilots in the 1980s. Then, in 1996 and 1997, Basel implemented a law,

which encouraged and supported energy-saving measures in the city, where

5% of all customers' energy bills are put into an Energy Saving Fund, which

can then be used for a variety of measures, including green roofs. As a result,

in Basel, there is a clear link between energy consumption reduction and

biodiversity protection.

Indeed, this incentive programme was also linked to the burgeoning interest in research into green roofs in the city, and was further strengthened by an incentive programme in 2005/2006 which also incorporated design specifications into the green roof guidelines. Moreover, in 2002, after the first incentive programme, an amendment to Basel's Building and Construction

Law was passed, stipulating that all new and renovated flat roofs must be

greened and that they must meet particular guidelines, for example, the

growing medium must be native, natural, regional soils and vegetation

should be a mix of native Basel species. This legislation was possible because

of Basel's canton-based and semi-independent powers. The vision of the city

has also been important in shaping this agenda. Basel is known for its

'2000-W society' and its vision for sustainable energy use (i.e., a reduction

in primary energy consumption in Switzerland by a factor of three from the

current 6000 W per person to 2000 W). In 2001 a pilot region was launched in

Basel, where the vision was realised as a co-operative project (public/private

partnership) between Novatlantis, the Department of Building for the

Canton of Basel-Stadt, the University of Applied Sciences for both Cantons

of Basel, and the University of Basel. Since the launch of the Basel pilot

region in 2001, urban development and mobility issues have underpinned

the ongoing applied research, and the inherent expertise in sustainable

development has been used to help enhance urban design in Basel, all of

which also underpinned and linked with the growth of green roofs in the

city (TCPA, 2012).

Other European and global cities have also followed Basel's example. For

example, Copenhagen, Denmark passed a similar ordinance in 2010, seeking

to add some 53,000 sq. ft of new green roofs per year (NASA, 2012). In

Toronto, from 1 February 2010 to 1 March 2015, 260 green roofs have been

created, consisting of 196,000 m2 of green roof area, with a total of 444 green

roofs existing in the City of Toronto (City of Toronto, 2015). Toronto is the

first city in North America to have a bylaw to require and govern the construction of green roofs on new development, and the bylaw was adopted by Toronto City Council in May 2009, under the authority of Section 108 of the

City of Toronto Act. The bylaw applies to new building permit applications

for residential, commercial and institutional development made after 31

January 2010 and will apply to new industrial development as of 30 April

2012. In Toronto, all large new commercial institutional and residential

buildings are required to have at least 20–60% of their roof space dedicated

to green roofs, depending on size (Berardi *et al*., 2014; City of Toronto, 2015).

More recently, in 2015, France announced plans to require all new

commercial buildings in the country (not just cities) to have either solar

panels or green roofs. This should be seen in the context of Paris' adaptation

strategy for its Climate Change Plan, which has emphasised greening since

2007, and which is also underpinned by its Biodiversity Plan (2011) as well

as the Paris Rain Plan. There have been recent high-profile examples in the

city of experiments in green roofs on existing buildings, which is estimated

to have a green flat roof potential of 460 ha1 (Baltus, 2015). For example, in

April 2013, the largest green roof in Paris – covering 7000 m2, equivalent to

a football stadium (and the largest in Paris), and of which 700 m2 is dedicated to shared gardens – was officially opened on top of the newly renovated 1970s Beaugrenelle shopping centre in the 15th arrondissement (Garric, 2013). The aim of this green roof garden is to provide a haven for

biodiversity and limit temperature extremes inside, and outside, the building. Gecina, the owner of the shopping centre, put the retrofit cost at €450 m ($585 m). Several thousand plants and flowers, all species native to the Paris

region, have been planted in order to help preserve biodiversity and provide

local residents with an attractive landscape, and this habitat serves as a

sanctuary for a number of species of birds (blackbirds, tits, greenfinches,

robins, etc.) and also reduces the discharge of rainwater (Bouygues

Construction, 2015). In this respect the targets set by the city are important.

The main targets are to achieve 100 ha of green roofs and façades, a third of

which is dedicated to the production of fruit and vegetables, to increase the

number of trees by 20,000, to construct ‘zero-waste, zero-carbon’ districts,

to significantly boost recycling and composting, to improve energy recovery

and to strengthen the ‘green’ and ‘blue’ infrastructures endorsed by the

Grenelle de l’environnement process with guidelines for land, waterway and

wetlands management, and to ensure ecological continuity within the city

(Mairie de Paris, 2015).

As towns and cities continue to grow, replanting vegetation has become a

form of urban utopia and green roofs are spreading fast. 1. In 2012, 1 million square metres of plant-covered roofing was built in France, as much as in the USA, and 10 times more than in Germany, the pioneer in this field

( *The Guardian*, 2013). In Australia, a nationwide group named 202020

Vision has a target ‘to create 20% more green space in our urban areas by

2020’, some of which will be green roofs (202020 Vision, 2015). Sydney is

one of 39 government agencies endorsing the vision. Furthermore, the

Australian cities of Sydney and Melbourne both have targets for becoming

zero-net-emissions cities by 2030 and 2020, respectively (City of Melbourne,

2015). Green roofs can play a part in achieving these targets.

## 12.2

## City-level Actions: Requirements or Inducements?

Cities vary in the way they approach the green roof policy. As Mees *et al*.

(2013) point out, Chicago has promoted green roofs since 2001 through a

combination of performance-based regulations for stormwater management,

1 44 ha planted (mainly on municipal buildings), 80 ha ready for planting and the

remaining 380 ha requiring major adjustments.

energy efficiency and landscaping, and through a mandatory requirement

for all new buildings that receive funding to be subject to review. In addition, there are limited financial incentives including a density bonus, where developers are permitted to build more units per area if their building has a

green roof, and the Green Permit Program, which involves fast-tracking permissions and a fee reduction for developers installing a green roof. In contrast, London's policy is more restrained (Mees *et al*., 2013), encouraging the development of green roofs where this is feasible. London, however, has

made some progress in helping promote green roofs, with 700 green roofs

in central London alone, covering an area of over 175,000 m2 (17.5 ha). The

City of London (2003, 2011) has published helpful guidance and case study

information.2

Often within cities property companies also promote their innovation in

green roofs. British Land, for example. In the City of London alone, green

roof space has increased from around 10,000 m2 of green roofs on London's

Square Mile in 2004 to almost 70,000 m2 in 2014 (Cary, 2015). Green roofs

are now also standard on British Land's central London developments, with

some 12 new green roofs being created in central London on British Land

new builds since the introduction of the Sustainability Brief in 2004.

Moreover, at Exchange Square in Broadgate, 2000 m2 of pocket habitats

were retrofitted on the building (commercial offices) in 2011.

Other cities such as Portland, OR (GLA, 2008) have also adopted varying

approaches to green roof policy. In Portland, city-owned buildings are required

to have a green roof covering at least 70% of the roof area. The remaining

roof surfaces must be covered with energy-efficient roofing materials. Other

incentives offered by the city include ‘floor area bonuses’ – a preferential

property tax – and a 35% reduction in stormwater management charges. The

city’s Ecoroof initiative is intended to raise awareness of the benefits of green

roofs. In Tokyo there is a law which requires the installation of green roofs in

private buildings with built areas larger than 1000 m2 and in public areas

larger than 250 m2, while integrated green roofs must not encompass less than

20% of the whole rooftop area (Berardi *et al*., 2014).

Mees *et al*. (2013) provide a valuable and helpful comparison of green

roof policies in five major cities, setting their analysis within the context of

a typology of governance arrangements (Table 12.1). Their work shows that

there is a dominance of 'hierarchical' arrangements (where local authorities

determine strategy and policy mix to draw in private-sector action), underpinned by a strong public sector, in the early stages of green roof policies in all five cities, but that in Basel and Stuttgart this public policy dominance has

prevailed throughout the whole policy process. That is not to say that interactive governance (shared responsibilities between public and private actors) or, indeed, market governance (with private-sector interests dominating) are

2 See www.london.gov.uk/priorities/environment/greening-london/urbangreening/

greeningroofsandwalls/greenroofmap and www.cityoflondon.gov.uk/services/

environmentandplanning/planning/design/sustainable-design/Pages/green

roofs.aspx.

**Table 12.1** Implementation levels of green roof technology

| Characteristic | Basel | Chicago | London | Rotterdam | Stuttgart |
|---|---|---|---|---|---|
| Policy introduced | 1996 | 2003 | 2004 | 2008 | 1986 |
| Sq. metres installed by 2010 | 1,000,000 | 700,000 | 715,000 | 40,000 | 1,000,000 |

Inhabitants

170,000

3,000,000

7,800,000

600,000

600,000

Sq. metres per capita

5.8824

0.2333

0.0917

0.0667

1.6667

% of eligible roof space covered

25%

<1%

<1%

<1%

22%

Average price/m2 (euros) for a

25–35

40–80

50–90

50–90

10–40

common green roof

*Source*: Adapted from Mees *et al*. (2013).

not important: there is evidence to suggest from the research that private

responsibility also matters, especially at implementation and maintenance

stages, but if London, Rotterdam and Chicago are to progress in terms of

green roof implementation, a clearer and more decisive role for the public

sector could help drive change.

In Basel and Stuttgart, for example, these cities have, in comparison, with

London, Rotterdam and Chicago, deeper green roof implementation. This is

partly because these two cities have employed the broadest mix of instruments, using coercive regulations to make green roofs mandatory on new buildings and also rewarding green roof installations with financial incentives, such as stormwater fee reduction and also (historically) with subsidies.

In both cities this has been underpinned by strong parallel environmental

agendas: biodiversity in Basel and air quality in Stuttgart, whereas Chicago

and Rotterdam use voluntary instruments with financial incentives complemented by education and communication campaigns. As noted above, London is more restrained in both respects.

The research by Mees *et al*. (2013) suggests that local authorities need to

take a clear lead throughout the green roof policy lifecycle. However, in

Basel and Stuttgart three other factors have played an important role in

contributing to green roof implementation. Firstly, both cities have a strong

green political climate and culture, which has helped drive change. Secondly,

these cities have had policies in place for green roofs over a relatively long

time period. Thirdly, this might explain the lower installation costs in these

cities. Sydney, Australia has a green roof and green walls policy launched in

April 2014. The city is committed to increasing the number of high-quality

green roofs and walls in Sydney, and to date 58 green roofs are listed on the

City of Sydney website. Initially, policy documents and guides for stakeholders were supported by a full-time project officer, but this role was subsumed into planning at the end of 2014 (City of Sydney, 2015).

On a practical level, work by Lawlor *et al*. (2006) for CMHC (Canada)

has suggested that there need to be six phases in the development of a green

roof policy programme at city (or community/jurisdiction) level.

*Phase 1: Introductory and awareness*. During this phase, the overall environmental benefits of green roofs are examined. The city may hold a green roof workshop, send delegates to a green roof conference or visit another

city/community with existing green roofs or a green roof policy. For example,

240 Green Roof Retrofit

Green Roofs for Healthy Cities has been key in helping North American

municipalities organise green roof workshops to bring local stakeholders

together.

*Phase 2: Community engagement*. In this phase, a local champion or a

green roof committee may seek to raise the profile of green roofs, including,

for example, meetings with community leaders, mayors, architects, landscaping professionals, building owners and environmental groups

to gain support for green roofs. Funding sources, such as government programmes,

utilities or green roof manufacturers, will be explored and deals struck. The

champion or committee will outline the opportunities, threats, strengths and

weaknesses of green roof development in the city.

*Phase 3: Action plan development and implementation*. The city (or community) may establish a green roof advisory or working committee made up of key community leaders. A green roof demonstration project may be

launched, perhaps with scientific monitoring equipment, depending on the

need for local research data. Green roof tours and ongoing planning

meetings often include site visits to buildings with different types and designs

of green roofs, leading to the formation of a green roof database/inventory.

A review of existing policy options and tools may be explored in this phase,

and various programmes and policy opportunities identified.

*Phase 4: Technical research*. The local green roof advisory committee, the

local champion(s) or both, along with a possible consortium of public/private partnerships, set up a research site. In some cases, the technical research consists of demonstration projects or green roof installations on prominent

sites. Research typically involves assessing the ability of green roofs to

manage stormwater, mitigate the urban heat island or provide other necessary environmental benefits. Often, experimental findings are shared at international green roof conferences.

*Phase 5: Programme and policy development*. The green roof advisory

committee may expand to include more professionals, such as landscape

designers, horticulturalists, designers and municipal urban planners. This

phase translates local and regional research into policy options and tools.

This involves establishing ways of offering incentives to contractors, developers and building owners to retrofit or plan new buildings with green roofs. This can include financial incentives, tax credits or density bonuses.

*Phase 6: Continuous improvement*. During this phase, a city now has a

mature view of green roofs and a familiarity with green roof technology.

Therefore, the effectiveness of policies and programmes is determined and

policy options are explored. There is also a need to gather information and

assess programme success, through constructive feedback from users, professionals and the building community. This phase typically

involves exploring other policy options or further research to fine-tune existing programmes.

## 12.3

## Tools and Information Sources

Appendix 3 provides a table of some of the key tools and information

sources globally in respect of green roofs. A summary of the tool or information

source is provided with links to websites.

Looking to the Future 241

## 12.4

## Green Roofs: The Big Picture of GI and Future Developments

Green roofs need to be seen as one important element within a GI strategy

in cities. ARUP (2015), for example, suggests that a GI-led design approach

to cities needs to create a network of healthy and attractive new and retrofitted

city environments, sustainable routes and places. The longer-term ambition

for cities is therefore to see GI and green roofs as part of that – as creating a

city ecosystem, which will benefit citizens in social, environmental and

economic terms but also protect and mitigate the effects of climate change.

Thinking about the bigger picture will therefore require perhaps city and

local authority collaborations, new funding models and a more integrated

and scaled-up approach to GI across cities.

It will also be important to ensure that guiding principles are followed

when planning for climate-resilient GI. TCPA (2013), for example, suggests

ten principles.

■

Principle 1: GI needs to be strategically planned to provide a comprehensive

and integrated network across scales.

■

Principle 2: GI requires wide partnership buy-in from across disciplines,

organisations and boundaries.

■

Principle 3: GI needs to be planned using sound ecological evidence and

baseline information on GI assets.

■

Principle 4: GI needs to demonstrate multi-functionality (i.e., its ability

to perform several functions and provide several benefits on the same

spatial area), which may require the integration and interaction of different

functions within a single site.

■

Principle 5: GI creation and maintenance needs to be properly resourced,

and includes costs relating to purchase, design, implementation, monitoring and management of GI.

■

Principle 6: GI needs to be central to the development's design and must

reflect and enhance the area's locally distinctive character.

■

Principle 7: GI should contribute to biodiversity gains by safeguarding,

enhancing, restoring and creating wildlife habitats and by integrating

biodiversity into the built environment.

■

Principle 8: GI should achieve physical and functional connectivity

between sites at strategic and local levels, locally through proximity, or

strategically through landscape-based connections.

■

Principle 9: GI needs to include accessible spaces and facilitate physically

active travel.

■

Principle 10: GI needs to be integrated with other policy initiatives.

As Lennon *et al*. (2015) suggest, a GI approach to planning and design

moves beyond traditional site-based approaches of protect and preserve

towards a more holistic and integrated approach which recognises the

complexities of social–ecological interactions. For Lennon *et al*. (2015), GI

thinking is characterised by four key elements:

■

treating GI assets as fundamental infrastructure;

■

promoting spatial connectivity between GI elements;

■

using a multifunctional approach to planning, which recognises the

complexity of social–ecological relations;

■

a focus on interdisciplinary collaboration, which breaks down silo thinking.

Increasingly, therefore, cities are adopting forward-thinking visions to underpin

their transition to a more sustainable future. Vancouver, for example, under the

leadership of Gregor Robertson since 2008 has developed a vision to make it

the world's greenest city by 2020. This ambition is structured around a 2020

action plan, with a number of targets aimed at improving green spaces and

access to wildlife and nature, as well as encouraging green roofs, which link

with the concepts of increased urban food production and improving urban

drainage systems. Similarly, in its strategy to become a carbon-neutral city by

2025, Copenhagen became, in 2010, the first Scandinavian city to adopt a policy that requires green roofs for all new buildings with roof

slopes of less than 30°. The impetus for this was in 2009, when Denmark hosted the UN Climate

Change Conference COP15, which helped define the framework for tackling

global climate change. During that period, the focus on green roofs intensified

and led to setting a goal for urban design with green roofs in the Climate Plan

of the City of Copenhagen. Since then, green roofs have become integrated into

different city guidelines, such as the guidelines for sustainability in construction

and civil work, which mandates green roofs for all the Municipality's buildings.

Green roofs are also a part of the city's Strategy for Biodiversity, and so since

2010 green roofs are mandated in most new local plans. A recent calculation

based on approved new local plans mandating green roofs gives a total of

200,000 m2 of green roofs to be installed in Copenhagen, which today has more

than 40 green roofs. Moreover, buildings with green roofs in Copenhagen must

be able to fulfil at least two of the following requirements (CesIfo/DICE, 2012):

■

absorb 50–80% of the precipitation falling on the roof;

■

provide a cooling and insulating effect on the building and reduce reflection;

■

make the city greener;

■

reduce the urban heat island effect;

■

counteract increased temperatures in the city.

Green roofs also need to contribute to an aesthetic and visual improvement

in urban design that improves quality of life and also helps increase the life

of the roofing membrane by reducing UV impact.

Looking further into the future, it seems likely that green roofs will continue to play an important role in GI provision in urban areas. A recent report by ARUP (2015) took a forward-looking view of how buildings in

2050 might look. The report focused on structures whose components are

dynamic, intelligent and reactive, and imagined a futuristic city skyscraper

building in the year 2050 that includes flexible modular pods, urban agriculture, climate-conscious façades and intelligent building systems. In the building there is a strong focus on vertical farming, so that green spaces are

designed as integral parts of the building, to encourage interaction with

plants, birds and insects whilst utilising vertical farming techniques such as

hydroponics to facilitate food production. Indeed, ARUP has piloted one

particular innovation in Hamburg, which is an apartment building designed



around a biomass façade, which generates heat and electricity from algae on

exterior walls. The two south-facing façades are covered in a shell of bioreactors, clear containers that create a controlled environment for an algae farm.

Exposed to sunlight, the algae photosynthesise, absorbing CO as they grow.

2

Nutrients and CO are circulated through the bioreactors to encourage

2

growth, and the algae are regularly collected and fermented in a nearby biomass plant, then burned to produce electricity (Forum for the Future, 2013).

## 12.5

## Recognising the Multiple Benefits of Green Roof Retrofit

It is the case that stakeholders may decide to retrofit a green roof for one or

more of the following reasons:

1. thermal performance – to improve insulation and reduce energy

c onsumption;

2. urban heat island;

3. stormwater – attenuation of pluvial flooding;

4. biodiversity enhancement;

5. conservation of endangered flora and fauna;

6. urban food production;

7. provision of social space.

The majority of stakeholders will be concerned primarily with the building

level rather than the city level. In Table 12.2 the primary and secondary

benefits are identified for each type of green roof.

In Table 12.3 each green roof type is identified along with the co-benefits

accruing. In decision-making, stakeholders should be aware that these

secondary or co-benefits exist.

Throughout this book there has been an underlying theme that green roofs,

as part of GI, can help build and develop urban resilience. Although there is

no overall agreement on the meaning of the concept of urban resilience, most

**Table 12.2** Green roof primary and secondary benefits

Primary benefit

Secondary benefits

(environmental,

(environmental,

Green roof type

economic or social)

economic or social)

Thermal – to improve insulation

Environmental

Economic

and reduce energy consumption

Stormwater – attenuation of

Environmental

Economic

pluvial flooding

Biodiversity enhancement

Environmental

Conservation of endangered

Environmental

flora and fauna

Urban food production

Environmental/

Social

economic

Provision of social space

Social

Environmental/

economic

244 Green Roof Retrofit

**Table 12.3** Green-roof-type primary and co-benefits

Green roof type

Primary reason

Co-benefits

Thermal

Improve insulation and

■

Stormwater attenuation

reduce energy

■

Urban heat island

consumption

■

Biodiversity

■

Air quality

Stormwater

Attenuate pluvial

■

Thermal improvement

flooding

■

Urban heat island

■

Biodiversity

■

Air quality

Biodiversity enhancement

Increase local

■

Air quality

biodiversity

■

Urban heat island

■

Thermal improvement

■

Stormwater attenuation

Conservation of

Provide environment

■

Air quality

endangered flora and fauna

for endangered species

■

Urban heat island

■

Thermal improvement

■

Stormwater attenuation

Urban food production

Local food production

■

Reduce carbon food miles

■

Air quality

■

Urban heat island

■

Thermal improvement

■

Increase biodiversity

■

Stormwater attenuation

Provision of social space

Amenity space

■

Thermal improvement

■

Air quality

■

Urban heat island

■

Thermal improvement

■

Stormwater attenuation

■

Food production

definitions highlight the capacity of individuals, communities, institutions,

businesses and systems within a city to thrive and survive, adapt and grow

whatever what kinds of chronic stresses and acute shocks they experience

(Rockefeller, 2015; Buurman and Bobovic, 2015, Meerow *et al*, 2016). The

complexity of cities makes them a particularly important focus for resilience

because they are constantly changing and adapting, and green roofs provide

important citywide benefits for helping develop both adaptive and mitigation

capacity. In other words, the multiple benefits of green roofs also connect to

the wider notion that greening our cities can make them less likely to overheat or flood, and that when cities do suffer more severe climatic impacts they are resilient enough to bounce back from those shocks.

## 12.6

## Overall Conclusions

Green roofs have numerous benefits, and many existing buildings in city

centres are suited to retrofit, and yet relatively few green roof retrofits

are undertaken. This is most likely to be a result of the majority of existing



professionals having little or no knowledge of the benefits, the technology

and the performance of green roofs. There are changes in university education programme content, in the amount of best-practice guides and information available on the Internet (often hosted on local or city authority websites) that will provide the knowledge and awareness of green roofs for

built environment students and existing practitioners over time. This dissemination of information needs expanding into continuing professional development events for existing practitioner to upskill and educate them. A

fear of the unknown is a factor in deterring existing practitioners from recommending green roof retrofit to clients. As direct experience of the technology increases, the uptake of green roofs will grow exponentially. This book is part of the attempt to increase knowledge and awareness, particularly in the wider context of improving and developing urban resilience.

Each chapter has provided a detailed overview of the primary benefits of

green roof retrofit, as well as some illustrative case studies to show how the

technology can be applied in practice in different countries. Clearly, given

the different climate zones and geographical regions, it may be the case that

saving energy through greater insulation may drive green roof retrofit in one

place, whereas species conservation and biodiversity may drive adoption

elsewhere. This chapter has shown the co-benefits that also co-exist with

each primary driver, as well as some of the issues of retrofitting in various

locations and climate zones globally.

A city-scale vision is also shown to be a method of increasing uptake and

raising awareness to deliver community-wide benefits of reducing urban heat

islands and improving air quality. With increasing urbanisation, such visions

are going to be needed more than ever to deliver liveable cities. Furthermore,

with increasing urbanisation, the potential for inhabitants of cities to become

increasingly detached from the natural environment grows. This detachment,

lack of understanding and knowledge of the natural environment could lead

to less willingness to act to save endangered environments in the broader

population. The adoption of green roofs could help to plug that gap in knowledge and understanding for city inhabitants and the community, and on this basis is seen to be a key reason to advocate more green roof retrofitting.

On an individual building basis, occupants and users can benefit where

roof access is provided and/or in reduced energy consumption and lower

operating costs. Owners will benefit economically in markets where green

buildings command a premium in capital value. Thus, the benefits of green

roof retrofit are derived at all levels from the city scale to the building scale

and the individual scale.

**References**

202020 Vision (2015) ‘Our cities need more plants and trees’, available at:

202020vision.com.au/the-vision/.

ARUP (2015) *Cities Alive: Rethinking Green Infrastructure*.

Baltus, R. (2015) ‘City centre rooftops: go green, classify or densify?’, available at:

rogerbaltuscolumn.tumblr.com/post/120762732544/to-the-point-roger-baltuss-

column-city-centre.



Berardi, U., GhaffarianHoseini, A. H. and GhaffarianHoseini, A. (2014) ‘State-of-the-art analysis of the environmental benefits of green roofs’, *Applied Energy*, 115, 411–428.

Bouygues Construction (2015) ‘Beaugrenelle Shopping Centre’, available at:

bouygues-construction.com.au/project/beaugrenelle-shopping-centre-france/.

Buurman, J., and Babovic, V. (2015) ‘Designing Adaptive Systems for Enhancement

of Urban Water Resilience’, *Lee Kuan Yew School of Public Policy Research Paper*

*No. 15–28*. Available at SSRN: http://ssrn.com/abstract=2653481

Cary, S. (2015) ‘Green roofs go mainstream: British Land’, available at: views.

britishland.com/2015/02/green-roofs-go-mainstream/.

CESIfo/DICE (2015) ‘Green infrastructure: national approaches and experiences’,

available at: www.cesifo-group.de/ifoHome/facts/DICE/Energy-and-Natural-

Environment/Natural-Environment/Instruments-by-Environmental-Domains/

gree-infr-nati-appr-expe/fileBinary/gree-infr-nati-appr-expe.pdf.

City of Melbourne, (2015) ‘Green roofs’, available at: www.melbourne.vic.gov.au/

Sustainability/CouncilActions/Pages/Greenroofs.aspx.

City of Sydney (2015) ‘Green walls and roofs’, available at: www.cityofsydney.nsw.

gov.au/vision/towards-2030/sustainability/greening-the-city/green-roofs-and-walls.

City of Toronto (2015) ‘Green roofs’, available at: www1.toronto.ca/wps/portal/con

tentonly?
vgnextoid=3a7a036318061410VgnVCM10000071d60f89RCRD.

Forum for the Future (2013) ‘A building powered by algae’, available at: www.

forumforthefuture.org/greenfutures/articles/building-powered-algae.

Garric, A. (2013) ‘Paris shopping centre opens green roof as French cities make room

for nature’, *The Guardian*, 4 May, available at: www.theguardian.com/environ

ment/2013/may/04/paris-green-roofs-building-climate-environment.

GLA (2008) *Living Roofs and Walls Technical Report: Supporting London Plan Policy*.

Kazmierczak, A. and Carter, J. (2010) ‘Adaptation to climate change using green and

blue infrastructure: a database of case studies’, available at: www.grabs-eu.org/

membersArea/files/Database_Final_no_hyperlinks.pdf.

Lawlor, G., Currie, B., Doshi, H. and Wieditz, I. (2006) *Green Roofs: A Resource*

*Manual for Municipal Policy Makers*. CMHC, Canada.

Lennon, M., Scott, M., Collier, M. and Foley, K. (2015) ‘Developing green infrastructure thinking: devising and applying an interactive group-based methodology for practitioners’, *Journal of Environmental Planning and Management*, in press.

Mairie de Paris (2014) *The Paris Greening Programme*, Available at: www.energy-

cities.eu/db/Paris_Programme-vegetalisation_2014_en.pdf.

Meerow, S., Newell, J., Stults, M. (2016) 'Defining urban resilience: a review',

*Landscape and Urban Planning*, 147, 38–49.

Mees, H., Driessen, P., Runhaar, H. and Stamatelos, J. (2013) 'Who governs climate

change adaptation? Getting green roofs for stormwater retention off the ground',

*Journal of Environmental Planning and Management*, 56(6), 802–825.

NASA (2012) *NASA and Green Roof Research*.

Rockefeller Foundation (2015) 100 Resilient Cities. https://www.rockefellerfoundation.

org/ourwork/initiatives/100resilientcities/

TCPA (2012) *Planning for a Healthy Environment: Good Practice Guidance for*

*Green Infrastructure and Biodiversity*. TCPA, London.

*The Guardian* (2013) 'Paris shopping centre opens green roof as French cities make room for nature', 4 May, available at: www.theguardian.com/environment/2013/

may/04/paris-green-roofs-building climate-environment.

**A1**

## Appendices

## Appendix 1: A Checklist for Appraising the Suitability of an Existing

## Roof for Green Roof Retrofit

This checklist is designed for building surveyors to use in an **initial appraisal**

of an existing building for green roof retrofit.

Please review the following aspects and take into account in your decision

making.

1. Position of the building

■

What is the position of the building within the settlement? Is it over-

shadowed by other adjoining buildings which may affect access to

sunlight and the growth of plants?

○

Not overshadowed (good)

○

Partly overshadowed (maybe OK)

○

Overshadowed (may not be OK)

■

What is the quality of the building? For example, those with a high quality may experience an increase in capital value and yield as a result of having sustainability features such as a green roof.

○

High quality (in Australia, PCA Grades Premium and A) – more likely to enhance value

○

Medium quality – may enhance value

○

Low quality – unlikely to enhance value

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



2. Location of the building

■

What is the prevailing climatic condition? For example, is the building in a hot arid climate zone or a maritime zone? Each has different char-

acteristics which favour different types of green roof solution. For

example, those locations which experience heavy rainfall may favour a stormwater solution aimed to reduce as much runoff as possible.

○

The prevailing climate is ……

○

The building and roof location is exposed to

☐

High winds

☐

Medium winds

☐

Low winds

○

The building and roof location is exposed to

☐

High rainfall

☐

Medium rainfall

☐

Low rainfall

□

Wide seasonal variation in rainfall

■

Does the location favour (tick all which apply and rank in order of preference):

○

Stormwater design

○

Improving water quality entering sewer system

○

Thermal design

○

Reducing urban heat island

○

Reducing noise pollution

○

Biodiversity design

○

Aesthetic and social space design

3. Orientation of the roof

■

North facing is good in the southern hemisphere, whereas south facing is better in the northern hemisphere

○

What is the orientation of the roof?

□

Good

□

OK

□

Poor

4. Height above ground

■

How high is the building? In some locations high buildings are subject to high winds and/or fierce heat, which can make growing plants challenging.

○

How high is the roof? …… floors

5. Roof pitch

What is the roof pitch?

■

Up to 21° is suited to green roof retrofit

■

Exceeding 22° is too steep and not suited

■

Minimum roof pitch less than 3°

6. Existing roof construction

What is the existing structural form of the roof?

■

Timber (size and spacing of beams) ……

■

Concrete slab (depth in mm) ……



■

Structural steel (size and spacing of beams) ……

■

Other (describe) ……

7. Load limitations of the building

■

What is the dead load-bearing capacity of the existing roof?

■

What is the live load-bearing capacity of the existing roof?

8. Preferred planting options

■

What is the budget?

○

High

○

Medium

○

Low

■

How much maintenance is available for the green roof plants?

○

High

○

Medium

○

Low

■

Is there a water supply on the roof?

○

Yes

○

No

■

Is there a power supply to the roof?

○

Yes

○

No

■

Are there any potential environmental hazards?

○

Yes

○

No

9. Presence of plant and other equipment on the roof

■

The presence of plant such as air conditioning or HVAC may affect

plant growth by creating micro-climates on the rooftop through the discharge of fumes and warm air.

○

Is there any HVAC equipment on the roof?

☐

Yes (please indicate approximate area covered in sq. metres)

☐

No

○

Are there window-cleaning tracks on the roof?

☐

Yes

☐

No

☐

Partly

○

Is there a safety guardrail around the roof?

☐

Yes

☐

No

☐

Partly

○

Are there any PV panels mounted on the roof?

☐

Yes (please indicate approximate are covered in sq. metres)

☐

No

○

Is there any other equipment on the roof which may affect the area that could be retrofitted?

☐

Yes (please indicate type of equipment and approximate area covered in sq. metres)

☐

No

250 Appendices

10. Access for construction and installation of the roof

Materials and equipment will have to be taken up to the roof during construction and installation. The presence of scaffolding for other external works may provide a good means of moving materials to the roof.

■

What is the access like for construction and installation?

○

Very good (i.e., lift directly to roof level)

○

OK (wide stairs to roof, say one floor below roof)

○

Poor (narrow/winding stair access only)

11. Levels of maintenance

■

What is the access like for maintenance to the plants? To the roof?

○

Very good (i.e., lift directly to roof level)

○

OK (wide stairs to roof, say one floor below roof)

○

Poor (narrow/winding stair access only)

12. Costs

■

How much is the owner prepared to pay for a green roof?

○

High

○

Medium

○

Low

■

Can the costs be partially offset by the improvement in thermal

performance and energy savings?

**Other Notes**

In this section, please note down any other factors that may affect the instal-

lation of a retrofit green roof.

**Final Evaluation**

Based on the review of the factors above, what is the potential for green roof

retrofit?

## Appendix 2: Checklist for Designers of Biodiverse Green Roofs

This checklist is designed for anyone interested in creating or retrofitting a

green roof for the purpose of enhancing or increasing biodiversity.

1. *Focus animal group* Which animal group(s) is the roof designed for?

Invertebrates

■

Pollinators (bees, flies, butterflies)

■

Soil invertebrates (millipedes, collembolans, centipedes, earthworms,

nematodes, mites)



■

Ground-dwelling arthropods (beetles, ants, centipedes, millipedes)

■

Spiders

■

Snails and slugs

■

All invertebrates

■

Other (specify)

Vertebrates

■

Small terrestrial mammals (mice, voles, rabbits)

■

Bats

■

Birds

■

Reptiles

■

Other (specify)

2. *Habitat requirements* Which of the following resources need to be pro-

vided on the rooftop to support the focal animal group? For non-flying

animals, all resources must be within walking distance. Note that some

invertebrates are able to survive on very little water and can often pros-

per from ephemeral water sources such as dew.

■

Food (ex. flowers for pollinators, flying insects for bats, etc.)

■

Water

■

Nest sites (specify type, ex. nest boxes for bats)

■

Other (specify)

Will all habitat requirements be provided on the green roof?

Y

N

If not, are these resources available within flying range?

Y

N

3. *Measuring success* What is the goal of your green roof?

■

To increase the number of species within a target group

■

To increase the abundance of a particular species

■

To increase the breeding success of a focal species

■

Other

What kinds of site will be used as comparison (control) sites?

■

Adjacent ground-level sites

■

Conventional roofs

■

Other kinds of green roof

How will you sample the taxa to measure changes in biodiversity associ-

ated with your green roof intervention?

■

Pitfall trapping (appropriate for ground-dwelling arthropods)

■

Intercept traps (appropriate for flying insects)

■

Hand netting (appropriate for many pollinators)

■

Pan trapping (appropriate for flying insects and pollinators)

■

Visual count surveys (appropriate for birds and some pollinators)

■

Acoustic monitoring (appropriate for bats)

When and how often will you sample the green roof and comparison sites?

I will sample … times, starting … after roof constructions



Do you require specialist help in identifying members of your focus group?

Y* (if yes, contact specialists immediately; museums and universities are good contacts)

N

* *Note:* 'yes' will be the case in most invertebrate surveys, unless the designer has training in invertebrate taxonomy.

4. *Habitat complexity* How will you increase the habitat complexity (par-

ticularly for invertebrate biodiversity)?

■

Use of diverse substrates (rocks of different sizes, wood piles, wood

chips, etc.)

■

Planting complex, multi-level vegetation

■

Planting a variety of flowers with different flowering periods

■

Planting native species

■

Planting both nectar and pollen-providing plants

■

Use of topographic features such as slopes

)

*ued*

tal/

o_v2.php

( *Contin*

nf

torl

xtoid=

.pdx.edu/GR_

gne

alcula

to.ca/wps/poron

e

or

tonly?v

CRD

C_v2/C

ebsit

w1.t

ten

W

greenbuilding

CAL

ww con 77420621f3161410 VgnVCM10000071d 60f89R

,

e

t air

o

t model

y (multiple

d is t

**ome Examples**

oof

anspor

om the

tandar

**s – S**

y setting out

es and the

een R

**of**

ed)

tiv

ation fr

tion S

s b

oof

to Gr

tions

y and soil tr

on

ysics:

rowing media with moistur

anspir

onstruc

y’s objec

Tor

**reen Ro**

reen r

tion if desir

oof ph

xchange among the ambien

oof C

xchange within the canop

t e

riga

e and tr

ts

**for G**

tion canop

t in the g

fac

tion of g

eas:

w scupper loca

**IS**

reen r

een R

flo

egeta

tion e

emen

anspor

t meet the cit

ver

e

wing g

to Gr

adia

wing ar

e tr

tion (and ir

onstruc

e included in the

on

equir

ts tha

y

ates a v

ollo

es

ollo

et

ave r

y

Tor

manc

**apping/G**

ode r

por

fac

tw

y on sensible hea

ecipita

om the soil sur

n and c

emen

t and/or o

for

or

y

ts the f

e

, shading)

ovisions ar

or the f

t

tion

y and saf

tion

om pr

equir

y

oofing

en

y

esen

y pr

oof assembly

tions

ation fr

tion canop

tion f

et

et

tion per

t of canop

y loads

pr

mal and moistur

pose of the

tor

t selec

tion

tenanc

**ces and M**

epr

ec

apor

n the desig

io Building C

apet heigh

cupanc

t r

e saf

ater

ainage

ater r

reflec

leaf and soil sur

inputs fr

vegeta

ver

tar

anda

**our**

Summar

This model inc

tha

– long and shor

– eff

– ther

– ev

The pur

go

minimum r

On

M

Construc

– green r – gravit – slope stabilit – par – wind uplif – fir – oc – w – dr – w – vegeta – plan – irriga – main **tion S**

y

**orma**

tr

**nf, l**

Coun

USA

Canada

tion

y

**Tools**

gy

to

ma

ator

or

on

nf

Tor

**endix 3:**

oof Ener

tor I

ch Labor

oof

tion

ds –

**ppA**

een R

een Building

**Tools**

Gr

Calcula

Gr

Resear

een RGr Construc Standar

it

o.uk/.c ts& Toolk

ools/

om/

w

.c

en

ojec

tion

g/t

tur

.or

alua

rey

eV

astruc

tur

technology

oof

x.php?page=pr

astruc

e

reeninfr

reeningtheg

reenr

.g

nfr

.g

.g

w

w

w

ebsit

w

eenl

w

w

W

w

html/inde

Gr

=true

w

w

ts

k

ts

or

e

ools

or

t,

or

ce

al

tion

, t

n f

,

ems

tur

ouncils

ce bank f

rovides

ools and

e without

st

y

esig

onsultan

onmen

ondon

amew

ovemen

Valua

vic

em

, the

vir

gencies in

om

e

eadership in

. P

e t

e specialised

e, the CEO of

st

man

t, D

t A

ional C

e policies

oof sy

tion fr

esour

er

ns fr

tur

or L

ommunities and

vativ

y sy

or En

tal impr

ee open-sour

eg

, c

vativ

e, and much mor

echnology

Technology

ed ser

mor

t f

ter f

e, some of the

reen r

onmen

king with c

alua

etur

astruc

tur

tur

oof

ther

al England

en

tal and r

e, inno

vir

or

elopmen

ejudic

ur

or man

tmen

onmen

nfr

’s C

tion of R

oadest sense

y cities

tur

ineers who ar

. F

roup including Na

tur

ev

astruc

een R

idlands and the L

t of a v

vir

ype and fr

astruc

er

epar

een l

ot

Tech

ype of living t

. Gr

tur

ing g

ay, Na

ssocia

ional D

ot

e as a por

astruc

ers unpr

est M

e in its br

y t

eer

W

easons wh

n

eg

W

elopmen

vic

reen infr

e and en

tions

er

tur

reen infr

ts and eng

t off

ers in the USA and G

t st

ed has been w

e, the Gr

Virginia

tional A

, case studies of inno

ec

eloped multiple g

oof solutions f

tur

ther

om the D

ee R

tur

y

tage

onomic and wider r

reen infr

est S

n of an

e loca

ojec

e and the Built En

t fr

astruc

ound g

an

or

ange of r

e g

chit

t or manufac

tur

vest in g

ode tha

reen r

astruc

omplet

, ar

ec

dv

, the thr

tial ec

vailable as a pr

tained b

o in

anc

ts

emot

, the Nor

, A

y on the dev

en

t is c

oduc

reen infr

or doing so

est

rchit

Valley Unlimit

y and the Na

o adv

eloped ar

y pr

w

ffairs

genc

t ethics c

reen infr

ojec

ies f

round r

ic

echnical g

oofing manufac

th

or A

om the US F

tion and desig

Tees

al A

t A

onsultan

ateg

t in g

t fr

Technology has dev

ed t

ve decided t

y

ember 2008, a pr

ly in g

o a str

ec

y Nor

rammes t

on LLP) with suppor

th of England

t the pr

oof

anc

ce

e built and main

tion about g

tion about the full r

og

ch being dev

es t

e D

it is being made a

tion with an

elopmen

ma

ma

essional c

enec

ions ha

ticular

ev

vestmen

w tha

ebsit

or

or

een R

oviders and r

Summar

Sinc

Econom

Commission f

London and

(G

Food and Rur

the Nor

D

for assessing the pot

in

No

Toolk

resour

W

Global Sustainabilit

with suppor

inf

inf

reg

financing str

and pr

resear

Prof

in the specifica

par

adher

affilia

Gr

and adv

pr

ytr

Coun

UK

USA

USA

e tur it

ey

)

astruc

oolk

nfr

**tion**

oof

*ued*

tion T

een I

eening the Gr

**orma**

een R

Gr

Valua

Gr

**Inf**

Gr

Technology

( *Contin*

)

*ued*

x.php

( *Contin*

om/inde

om/

g/

.c

s.c

ld

s.or

or

oof

tm

roof

.h

e

ra-w

reenr

.ig

.g

ces

.living

w

w

w

ebsit

w

w

w

W

w

w

resour

w

or

or

k

.

k f

e f

or

ing

or

opics

,

w

tions

ofit

,

w

tur

ts who

etr

iendly

eness of

oof t

tional

ganisa

ation of

o r

o do with

ar

astruc

oof

xper

w

oof

oof net

s and living

eder

oss the globe

ed in ensur

e of our cities

reen r

, media, NGO/

tally fr

reen r

oof e

tal

oof

aise a

volv

reen r

reen r

xemplar case

o r

) is a global net

essional or

onmen

opean F

o e

A

m and infr

reen r

nmen

of

reen r

tion on g

vir

ur

or all things t

e the futur

tus as a multina

ortf

tional g

ver

ts and the need t

ma

es and g

es g

ce f

g aims t

ompanies and suppliers

e ar

or

k with political decision-

e na

o join the g

, go

al en

s.or

ic in our cities acr

tur

tion (IGR

or

ts c

o its sta

ofit and pr

omot

esour

roof

elopmen

ers the pla

y w

tional

t pr

ts and individuals in

astruc

ssocia

ch institut

tion of inf

ldwide

wing t

oof idea t

A off

’ lobb

or

rom their benefits t

, living

oof A

. O

omes persons and g

ts

oof

A members ar

esear

o educa

ted and gener

tion tha

s. F

elc

reen r

tal), non-pr

ela

onsultan

reen infr

oof r

oof

s in new dev

es and highligh

, c

een R

. IGR

tion, IGR

reen r

o plan

ors

ical g

nmen

oof-r

rammes w

ganisa

tions

oof

y t

xisting building fabr

ners

echnology

o g

reen r

ovides an in-depth r

omot

ver

og

t or

es and g

vest

A also w

, g

olog

ssocia

g pr

reen r

g pr

vic

tional Gr

oof t

ganisa

t ‘pr

reen r

. IGR

s and living r

y

na

tions

s.or

om polic

or g

s.or

ofit or

t the ec

oof A

oof

, fr

tion on the e

em ser

nter

omotion and dissemina

reen r

roof

roof

st

ate (non-go

s in the UK and is the UK member of the E

essional desig

ganisa

iv

omoting g

tivities and pr

n independen

een R

of

osy

Summar

The I

the pr

and g

non-pr

independen

makers and in

or

companies

suppor

Provides a listing of links t

pr

pr

ac

A

roof

Gr

Living

green r

studies

the need f

vegeta

Living

pr

ec

y

tional

tr

na

Coun

Inter

USA

UK

een

tion

oms.c

s

tional Gr

ssocia

oof

oof

na

een R

Inter

Roof A

Gr

Living R

s-

ities/

oof

ior

reening-r

oof-map

tonly?

v.uk/pr

reening-london/

ten

t/g

reen-r

to.ca/

on

on

= 3a7a03

tal/c

CRD

e

reening/g

or

.london.go

alls/g

w

onmen

w1.t

xtoid

ebsit

w

vir

ban-g

w

W

w

en

ur

and-w

w

wps/por

vgne

VgnVCM10000071

d60f89R

ound

o

ondon

t

ea it

al Ltr

een a map w

, institutional

ou need t

en

ha, or ar

tion on the

cial

ma

t y

to

o see a shor

s in c

te of the ar

ch bet

or

on

t is 17.5

. You can find out

oof

oof t

ommer

Tor

. Tha

tions

2

, get inf

reen r

m

reen r

oof

oof in

o new c

code and swit

t applica

reen r

d and find out wha

reen r

ype and an estima

ound 700 g

ver 175,000

y post

e a g

oof t

w applies t

elopmen

tandar

e ar

ch b

yla

equir

o build a g

e ar

ea of o

You can click on a g

reen r

ts r

tion S

raph

oof B

tial dev

t ther

ches!

og

e going t

ing an ar

een R

onstruc

esiden

elopmen

y

s thaw over

ou ar

ial phot

y r

oof C

, c

iption of the g

. You can also sear

y’s Gr

ootball pit

w if y

een R

Summar

This sho

alone

25 f

descr

covers

and aer

The cit

and man

which dev

Gr

kno

ytr

Coun

UK

Canada

oof

oof

een R

een R

)

*ued*

to Gr

ap

on

ap

**GIS/mapping**

London Gr

M

Tor

M

( *Contin*

**Index**

Page numbers in *italics* refer to figures; page numbers in **bold** refer to tables/boxes. This index is ordered letter-by-letter (ignoring hyphens and spaces)

107 Projects 190, 194, 196–197, 205–208,

Basel, Switzerland 235–236, 239

*206*, 210

Beare Park, Sydney, Australia 27, 30, *30*, *31*

access to green roofs

*Bergenia cordifolia* 123, *124*

amenity spaces 24–25, 89

BES *see* Bureau of Environmental Services

biodiversity 107

bioaccumulation 165–167

maintenance strategies 25–26, 89, 98

biodiversity 106–117

social sustainability 211

building resilience 4, 5

stormwater runoff 93, 95, 98

city-level actions 237

Accommodation Grant Programme 194

concepts and definitions 10, 108–109

action plans 240

conclusions and future directions

*Agrostis stolonifera* 134

112–115

air conditioning

consequences of urbanisation 106–107

building resilience 7

designing biodiverse green roofs

cool roof paint 218

113–115

planting 120, 125

ecological traps 110

thermal performance 66

food resources 109, 111

urban food production 178
gardens 107
urban heat island 40
habitat fragmentation and simplification
amenity spaces
106–107, 108, 141–142, *142*
access to green roof 24–25, 89
insect hotels 114
107 Cheapside, London, United
invertebrate conservation and green
Kingdom 34–35
roofs 107, 110–112, 113–115
distributed benefits to stakeholders
nesting sites 110
101–102, *102*
planting 120, 123, 133–134
social sustainability 11, 189–215
sampling and species identification
urban food production 160
109, 113

asphalt 19–20

social sustainability 191, 193

Australian Greenhouse Office 180–182

species suitability of green roofs 107, 112

awareness campaigns 239–240

stepping stone connectivity 111–112, 142

strategic overview of biodiversity

*Banksia* spp. 148

conservation 141–143

barrel roofs 20

Toronto, Canada 114, **115**

*Green Roof Retrofit: Building Urban Resilience*, First Edition.

Edited by Sara Wilkinson and Tim Dixon.

© 2016 John Wiley & Sons, Ltd. Published 2016 by John Wiley & Sons, Ltd.



biodiversity ( *cont'd* )

climate change

types of biological diversity **108**

building resilience 1, 3

urban adaptors 106–107

city-level actions 236–237

vertebrate conservation and green

green infrastructure 241–242

roofs 107, 109–110, 112, 115

planting 130–131

*see also* indigenous/endangered flora

thermal performance 64

bioreactors 243

urban food production 160

Birmingham, United Kingdom 146

urban heat island 37, 39–40

bituminous roofing felt 19

CLUHI *see* canopy layer urban heat island

BIV *see* building-integrated vegetation

Commonwealth Scientific and Industrial

boundary layer urban heat island

Research Organisation (CSIRO) 50

(BLUHI) 38–39, *39*, 42

community engagement 240

Brescia, Italy 165

community gardens
British Land 238
social sustainability of institutional
Brooklyn Grange Rooftop Farm 192–193
rooftop gardens 191, 193, 206, 208
Brooklyn, United States 159, 160, 165,
urban food production 161
192–193
community-supported agriculture (CSA)
brownfield sites 144, 146
160, 161
building height 92–93, *93*, 95, *95*
comparative analysis 194, 195, 197–198,
building-integrated vegetation (BIV) 7–8
**199–202**, 209–210
Bureau of Environmental Services (BES)
computational fluid dynamics (CFD)
100, 101
models 47
Business Improvement District 193

conservation

biodiversity 107, 109–115

Canal Saude Building, Rio de Janeiro, Brazil

green roofs in habitat conservation

*see* Oswaldo Cruz Foundation

143–146

canopy layer urban heat island

indigenous/endangered flora 10–11,

(CLUHI) 38–39, *39*, 42, 50–55

140–157

carbon footprint 159, 180–182, **182**, 191

invertebrates 107, 110–112, 113–114

*Carex* spp. 145

strategic overview of biodiversity

car parking 96–97

conservation 141–143

*Cassia siamea* 167

vertebrates 107, 109–110, 112, 115

central business district (CBD)

*see also* heritage

building resilience 1, 8
contaminated land
social sustainability 190
accumulation of contaminants in crops
stormwater runoff 86–88, *87*, 92–94,
165–167
101–103
global levels of land contamination
urban food production 158, 161
164–165
urban heat island 46, 50–55
mitigating urban crop contamination
CFD *see* computational fluid dynamics
167–168
Chatswood, Sydney, Australia 42, *43*, 50–58
types of pollutant 163–164
107 Cheapside, London, United
urban food production 162–168, 183
Kingdom 34–35, *34*
cool roof paint (CRP) 216–234

Chicago, United States 239
barriers and stakeholders 233
city-level actions
ceiling space temperature simulation
Basel, Switzerland 235–236, 239
223, *224*
developmental phases 239–240
comparison with green roofs 225–226,
implementation levels 238–239, **239**, 243
*225*, *227*, *228*, 233
Paris, France 236–237
concepts and definitions 11–12, 216–217
requirements versus inducements 237–240
conclusions and future directions
City of Sydney’s Environmental Grant
232–233
Programme 195
energy exchange processes 120
Index 259
experimental setup 220, *221*

growing market for green roofs 7–8
industrial building typologies 219–228
stormwater runoff 99–102, *100*, **102**
negative impacts of cool roofs 232
urban food production 178
photovoltaics 216, 231–232
urban heat island 40
reflectivity and thermal emittance 217
*see also* installation/maintenance costs
research findings 219–228
Eco-Roof Incentive Programme (ERIP) 34
research methodology 218–219
Ecoroof Programme 101–102, **102**, 103
residential building typologies 228–231
ecosystem diversity **108**
retrofits 233
education 193, 194, 197, 203–208
roof horizontal reflection 226, *228*
El Niño–Southern Oscillation (ENSO) 160
roof pitch simulation 223, *224*

endangered flora *see* indigenous/endangered
shading effects 223, *224*
flora
studies and measurements 217–218
energy consumption
summer indoor temperatures 220, *221*,
cool roof paint 218
226, *227*, *229*
planting 120–121, 125
summer roof reflection *221*, *223*
thermal performance 65–66
summer roof temperatures 220–221, *222*,
urban heat island 40, 42
*225*, *227*, *230*
energy exchange processes 120–122, *121*
thermal performance 81
engineering considerations *see* technical/
winter indoor temperature 229–231, *230*
engineering considerations
Copenhagen, Denmark 242

ENSO *see* El Niño–Southern Oscillation
corporate social responsibility (CSR) 162
Environment Protection and Biodiversity
*Cotoneaster franchetii* 133
Conservation Act (1999) 149
*Crassulaceae* spp. 122
*Eriostemon australasius* 148
crowdfunding 205
ERIP *see* Eco-Roof Incentive Programme
CRP *see* cool roof paint
ESBS *see* Eastern Suburbs Banksia Scrub
CSA *see* community-supported agriculture
ETp *see* evapotranspiration
CSIRO *see* Commonwealth Scientific and
evapotranspiration (ETp)
Industrial Research Organisation
planting 10, 121–123, 128, 131, 135
CSR *see* corporate social responsibility
thermal performance 66, 79, 81
Cuba 162

extensive green roof systems

curved roofs 20

concepts and definitions 5

indigenous/endangered flora 149–150

data loggers 67

stormwater runoff **97**

drainage

technical/engineering considerations

stormwater runoff 86–87, 90, 99

16–17, *16*, 20–23, **22**, 26–27,

technical/engineering considerations 24

**28–29**, 33

drought conditions

thermal performance 64

indigenous/endangered flora 144

urban heat island 46–47

planting 125–126, 135

urban food production 160

*Festuca rubra* 134

FioCruz *see* Oswaldo Cruz Foundation

Eagle Street Rooftop Farm 159, 160, 165,

floodwater *see* stormwater runoff

192–193

food security 11, 159, 183

Eastern Suburbs Banksia Scrub (ESBS)

functional diversity 144–145

community 140, 147–154, *148*

*Echeveria glauca* 67

gardens

ecological traps 110

biodiversity 107

economic factors

social sustainability of institutional

building resilience 5–7

rooftop gardens 190–215

distributed benefits to stakeholders

urban food production 161

99–103, *100*, **102**

genetic diversity **108**

260 Index

geographic information system (GIS)
concepts and definitions 10–11, 140
49, 51
conclusions and future directions 154
geotextile fabric
Eastern Suburbs Banksia Scrub
technical/engineering considerations 20
community 140, 147–154, *148*
thermal performance 67
expected outcomes 153
urban food production 172–174, 178
experimental design for ESBS green roof
GHG *see* greenhouse gas
project *151*
GI *see* green infrastructure
extensive versus intensive green roof
GIS *see* geographic information system
systems 149–150
greenhouse gas (GHG) emissions
functional diversity 144–145

building resilience 1
green roofs in habitat conservation
thermal performance 62
143–146
urban food production 180–181
guiding principles for ESBS
green infrastructure (GI)
regeneration 152
building resilience 2–4, 5–7
habitat fragmentation and
examples of GI assets **3**
simplification 141–142, *142*
future developments 241–243
honey pots and spider webs strategy
green roofs 4–5
142–143
multiple benefits of green roof
incrementalism 143
retrofit 243, **243**, **244**
indication versus replication strategy 143,

potential benefits in retail centres **6**

145, 154

valuing GI and wider economic

knowledge gaps and further research

benefits 5–7

146–149

greywater 135

landscape planning and design 143

GROW horticulture therapy programme

model research design for species

208–209, *208*, 210–211

conservation 149–153

Gumal Housing, Sydney, Australia

monitoring 153

170–180, *170*, 190, 194

non-plant biota 146

preparatory steps 152–153

habitat fragmentation and simplification

reconciliation ecology 143

106–107, 108, 141–142, *142*

research objectives 150–152
Hanging Gardens of Babylon 4, *5*
stepping stone connectivity 142
HDPE *see* recycled polyethylene
strategic overview of biodiversity
heating, ventilation and air conditioning
conservation 141–143
(HVAC) systems 7
substrate nutrient status 146
heavy metal pollution 163–166
thermal performance 145
*Hedera hibernica* 123, *125*
Inner Melbourne Action Plan (IMAP) 193
heritage
insect hotels 114
stormwater runoff 89, 92, **96**
installation/maintenance costs
technical/engineering considerations 24
Canal Saude Building, Rio de Janeiro,
*Heuchera* spp. 126, *128*, 131, 132

Brazil 30
horticulture therapy 208–209, 210–211
concepts and definitions 10
Howard, Luke 38
indigenous/endangered flora 145
Human Resource Ethics Committee
modular green roof systems 20–21
(HREC) 196
planting 10, 118, 134–135
HVAC *see* heating, ventilation and air
1214 Queen St West, Toronto, Canada 33
conditioning
stormwater runoff 99
hyperspectral imaging 50–51
technical/engineering considerations
19, 21
IMAP *see* Inner Melbourne Action Plan
thermal performance 63, 66, 67,
incrementalism 193
81–82

indigenous/endangered flora 140–157
urban food production 178
Index 261
insulation
social sustainability 192–193
planting 129–130
stormwater runoff 85, *87*, 92–94, 97–99,
technical/engineering considerations 17, 23
102–103
thermal performance 78–79, 81
thermal performance 63
urban heat island 43
urban heat island 39, 46
intensive green roof systems
Milkwood Permaculture 190, 194, 197,
concepts and definitions 5
205–208, *206*, 210
indigenous/endangered flora 149–150
MLR *see* multiple linear regression
stormwater runoff **97**

modular green roof systems
technical/engineering considerations 16,
technical/engineering considerations
22, **22**, 26–27, **28–29**, 34
20–21, *21*
thermal performance 63–64
thermal performance 68–82
urban food production 158–161
urban food production 158–159
urban heat island 46–47
*Monotoca elliptica* 148
Inter-American Development Bank 7
multiple linear regression (MLR) 49
invertebrate conservation 107, 110–112,
113–115
National Ecosystems Assessment 3
National Planning Policy Framework
*Kalanchoe quicksilver* 67
(NPPF) 2
National Wildlife Federation 107

landscape planning and design 143, 189–190
NDVI *see* normalised difference vegetation
*Lavandula angustifolia* 133
index
Lawrence Berkeley National Laboratory
Newcastle, United Kingdom 85, 87, *87*,
(LBNL) 217–218
95–99, 102–103
LCZ *see* local climate zone
New York, United States 159, 160, 165,
leaf area indices (LAI) 10, 123, 126, 128,
192–193
131, 153
normalised difference vegetation index
*Lepidosperma laterale* 149
(NDVI) 50–51
*Leptospermum laevigatum* 148
NPPF *see* National Planning Policy
Lidar 48–51, 57
Framework

load-bearing capacity
numerical modelling 47
intensive/extensive green roof systems 21
planting 136
Oswaldo Cruz Foundation (FioCruz),
stormwater runoff 88–89, 94, 96–98
Rio de Janeiro, Brazil 30–33, *32*,
technical/engineering considerations 14,
68–74, 78–82
21–23
thermal performance 63, 64
Paris, France 236–237
local climate zone (LCZ) model 46, 49–58
permaculture 11, 190, 194, 197,
London, United Kingdom
205–208, 210
biodiversity 109
photosynthesis 121
city-level actions 239
photovoltaics (PV) 217, 231–232

technical/engineering considerations
*Phragmites australis* 167
34–35, *34*
phytoremediation 167
*Pinus mugo* 133
maintenance strategies
pitched roof structures
access to green space 25–26
cool roof paint 223, *224*
maintenance frequency 26
pitch and shear forces 17–18, *17*, *18*
stormwater runoff 89, 95
pitched roof coverings 16–18
Manchester, United Kingdom 134
profiled metal sheeting 16–18, *16*
Melbourne, Australia
stormwater runoff 96, **97**
building resilience 8, 9, 12
technical/engineering considerations
cool roof paint 219–231

15–18

262 Index

*Plantago lanceolata* 134

reconciliation ecology 143

planting 118–139

recycled polyethylene (HDPE) 16

biodiversity 111–112, 113–115, 120,

remote sensing 37, 41, 45, 47–50, 57–58

123, 133–134

Rio de Janeiro, Brazil 30–33, *32*, 68–74,

building cooling 120–128

78–82

concepts and definitions 10, 118–119

Rotterdam, The Netherlands 239

conclusions and future directions 135–136

drought conditions 125–126, 135

St Canice Kitchen Garden 193–194,

ecosystem services delivery 120, 134

208–211, *208*

energy exchange processes 120–122, *121*

*Salvia* spp.

evapotranspiration 10, 121–123, 128, 131

stormwater runoff 131, 132

greywater 135

thermal performance 122, 126, **130**

new plant choices and adaptation of

*Sedum* spp.

current systems 134–135

biodiversity 133

pollution 133, 134

indigenous/endangered flora 144, 145

reflection of light energy 121–122

pollution 133

stormwater runoff 89, 130–133

stormwater runoff 131–133

substrate and climatic conditions

thermal performance 118, *119*, 122–126,

118–119

*124*, 128–129

substrate moisture content **132**

SEM *see* spatial error model

summer-time surface cooling

semi-structured interviews 194, 195–196,

123–128, **129**

198, 203–205

technical/engineering considerations 26

*Sempervivum* spp. 126, *127*, 129

thermal performance 67, 120–130

sensory ethnography 196–197, 205–208

urban food production 176–177

shading effects

water retention 132–133, **133**

building orientation 92–93, *94*

winter-time insulation 129–130, **130**

cool roof paint 223, *224*

*see also individual species*

planting 122, 126

pluvial flooding *see* stormwater runoff

stormwater runoff 92–93, *94*, 95,

pollution

98–99
bioaccumulation 165–167
thermal performance 74, *74*, 79
building resilience 3
shear brackets/barriers 16
contaminated land 162–168, 183
SMC *see* substrate moisture content
planting 131, 133
social sustainability 189–215
thermal performance 63
107 Projects 190, 194, 196–197,
urban food production 162–169
205–208, *206*, 210
urban gardens and air quality 169
biodiversity 191, 193
urban heat island 37, 40
comparative analysis of eight rooftop
polymer-based roofing materials 19
gardens 194, 195, 197–198, **199–202**,
Portland, Oregon, United States 85, 87–88,

209–210
*88*, 99–102, 103, 238
concepts and definitions 11, 189–190
poverty 191
conclusions and future directions
profiled metal sheeting
209–211
flat roof structures 19
education 193, 194, 197, 203–208
modular green roof systems 21, *21*
Gumal Housing, Sydney, Australia
pitched roof structures 16–18, *16*
190, 194
*Prunus laurocerasus*, thermal
horticulture therapy 208–209, 210–211
performance 122
methodology 193–197
qualitative analysis 198, 203–205
qualitative analysis 198, 203–205
research findings 197–209

1214 Queen St West, Toronto, Canada
St Canice Kitchen Garden 193–194,
33–34, *33*
208–211, *208*
Index 263
semi-structured interviews 194, 195–196,
specifications for stormwater roofs and
198, 203–205
retrofit issues 88–90
sensory ethnography 196–197, 205–208
substrate moisture content **132**
social, productivity and sustainability
technical/engineering considerations
potential of rooftop gardens 190–193
88–89, 92–98
thermal performance 62–63
water retention 131–132, **133**
Ultimo Roof Gardening Club 190,
Stuttgart, Germany 239
194–196, 198, 203–205, *204*, 210

substrate moisture content (SMC) **132**
urban food production 160, 161
substrate nutrient status 146
Society for the Protection of Ancient
SuDS *see* sustainable drainage schemes
Buildings (SPAB) 24
surface urban heat island (SUHI) 38–39, 42,
solar cells *see* photovoltaics
50–55
SPAB *see* Society for the Protection of
Surry Hill Library, Sydney, Australia 27,
Ancient Buildings
*29*, 30
spatial error model (SEM) 49–50
sustainable drainage schemes (SuDS) 90
species diversity **108**
Sydney, Australia
*Stachys byzantina*
biodiversity 107
stormwater runoff 132–133

city-level actions 239
thermal performance 123–126,
indigenous/endangered flora 140,
*125*, 129
147–154
stormwater runoff 85–105
social sustainability 190, 193–211
access to green roof 93, 95, 98
technical/engineering considerations 27,
assessment of retrofit at a building
*29*, 30, *30*, *31*
scale 85, 99–102
thermal performance 68–69, 74–82
building height 92–93, *93*, 95, *95*
urban food production 158, 160, 162,
building resilience 4
170–183
building suitability **94**, **96**, **97**, **98**
urban heat island 42, *43*, 50–58
car parking 96–97

city-level actions 237–238
technical/engineering considerations
concepts and definitions 9, 85
14–36
conclusions and future directions
access to green roof 24–26, 89
102–103
available space 21
distributed benefits to stakeholders
barrel roofs and curved roofs 20
99–103, *100*, **102**
case studies 27–35
Ecoroof Programme 101–102, **102**, 103
city-level actions 240
estimating runoff reduction 89–90,
concepts and definitions 8, 14–15
97–99, **98**
drainage 24
indigenous/endangered flora 145
flat roof coverings 19–20

local authority investment in green roof
flat roof structures 18–19
benefits 90–91, *91*
heritage 24
Melbourne, Australia 85, 87, *87*, 92–94,
load-bearing capacity 21–23
97–99, 102–103
maintenance strategies 25–26
modelling for city-scale stormwater
modular green roof systems 20–21, *21*
attenuation 85, 90–99
pitch and shear forces 17–18, *17*, *18*
Newcastle, United Kingdom 85, 87, *87*,
pitched roof coverings 16–18
95–99, 102–103
pitched roof structures 15–16, 96, **97**
planting 130–133
planting 136
Portland, Oregon, United States 85,
planting and climate considerations 26

87–88, *88*, 99–102, 103

profiled metal sheeting 16–18, *16*

problem of pluvial flooding 86–88

roof structure and covering

shading effects and building

typologies 15–21

orientation 92–93, *94*, 95, 98–99

stormwater runoff 88–89, 92–98



technical/engineering considerations ( *cont'd* )

urban canyons 40–42, *41*, 63–64

suitability of green roof type 26–27, **28**

Urban Ecology Action Plan 107

urban food production 161

urban food production 158–188

urban heat island 45–46

accumulation of contaminants in

waterproof membranes and insulation

crops 165–167

20, 23

air quality 169

thermal imaging 50–51

building resilience 7

thermal performance 62–84

carbon footprint 159, 180–182, **182**

case studies 68–80

case studies 171

concepts and definitions 9, 62–63

city-level actions 237

conclusions and future directions 80–82

climate and local weather conditions 160

cool roof paint 11–12, 81

concepts and definitions 11, 158–159

energy consumption 65–66

conclusions and future directions 183

evaluation of case studies 78–80, **78**

contaminated land 162–169, 183

evapotranspiration 66, 79, 81

Eagle Street Rooftop Farm 159,

experimental setup 68–69, *68*, *69*

160, 165
green roof retrofit 63–66
environmental considerations 178–179
indigenous/endangered flora 145
food security 11, 159
installation/maintenance costs 66, 67
global levels of land contamination
insulation and thermal mass 78–79, 81
164–165
intensive versus extensive green roof
green roof retrofit 159–161
systems 64
Gumal Housing, Sydney, Australia
internal temperature *70–71*, *75*
170–180, *170*
load-bearing capacity 63, 64
mitigating urban crop
maximum, minimum and average
contamination 167–168
temperatures **72**, *73*, *77*, **78**

naturalistic, holistic and inductive

non-green/green roof comparison 69–80

approaches 170

planting 120–130

performance comparison **179**

planting and drainage characteristics 67

physical and location factors 179

research methodology 67

phytoextraction and

Rio de Janeiro, Brazil case study 68–74,

phytoremediation 167

78–82

raised bed construction and

shading effects 74, *74*, 79

planting 171–173, *172*, *173*

Sydney, Australia case study 68–69,

research design and methodology

74–82

170–180

temperature difference *72*, *73*, *76*

results and interpretation 176–180
urban heat island 49–50, 63–64
social sustainability 160, 161
*U*-values 78–80
social sustainability of institutional
water soil content 79–81
rooftop gardens 190–215
Toronto, Canada
stakeholders 161–162, 183
biodiversity 114, **115**
technical/engineering considerations 161
city-level actions 236
types of pollutant 163–164
social sustainability 191
vertical gardens 175–176, *176*, *177*
technical/engineering considerations
wicking bed on science roof 173–175,
33–34, *33*
*174*, *175*
Transient Systems Simulation Programme

urban heat island (UHI) 37–61
(TRNSYS) 222–223
boundaries for mitigation by green roof
retrofit 45–47
UHI *see* urban heat island
boundary layer, canopy layer and surface
Ultimo Roof Gardening Club 190, 194–196,
heat islands 38–39, *39*, 42, 50–55
198, 203–205, *204*, 210
building resilience 4
urban adaptors 106–107
causative factors 38
Index 265
Chatswood, Sydney, Australia 42, *43*,
overview of methods 47–48
50–58
pollution 37, 40
climate change 37, 39–40
roof availability and suitability 45–46,
concepts and definitions 9, 37–39

48–49
conclusions and future directions 57–59
thermal performance of green roof
cool roof paint 226
retrofit 49–50, 63–64
energy balance model 44–45, *44*
*U*-values 43, 78–80
green roof cooling mechanisms 43–45, **44**
impacts on environment, society and
Vancouver, Canada 191
economy 39–40
vertebrate conservation 107, 109–110,
intensive versus extensive green roof
112, 115
systems 46–47
vertical gardens 175–176, *176*, *177*
local climate zone subgroups and
Village Mall, Rio de Janeiro, Brazil
characteristics 51–54, **52–53**
30–33, *32*

microclimatic effects of rooftop

greening 40–42, *43*

waterproof membranes 20, 23

mitigation scenarios for green roof

water soil content 79–81

retrofit 55–57, **56**

World Health Organisation (WHO) 7

model development 47–50

model implementation 50–57

*Xanthorrhoea resinifera* 149

night and daytime surface

temperature 54–55, **55**

zero acreage farming (Z farming) 7

WILEY END USER LICENSE AGREEMENT

Go to www.wiley.com/go/eula to access Wiley's ebook EULA.

# Document Outline


- Title Page
- Copyright Page
- Contents
- Notes on Editors
- Notes on Contributors
- Foreword
- Acknowledgements
- Chapter 1 Building Resilience in Urban Settlements Through Green Roof Retrofit
  - 1.0 Introduction
  - 1.1 Background and Context: Green Infrastructure
    - 1.1.1 Green Roofs
  - 1.2 Extensive and Intensive Systems
  - 1.3 Valuing Green Infrastructure and Wider Economic Benefits
  - 1.4 Measures of Greenness in Cities and the Growing Market for Green Roofs
  - 1.5 A Growing Global Market for Green Roofs
  - 1.6 Overview of the Structure of the Book
  - 1.7 Conclusion
  - References
- Chapter 2 Technical and Engineering Issues in Green Roof Retrofit
  - 2.0 Introduction
  - 2.1 Technical and Engineering Considerations
  - 2.2 Roof Structure and Covering Typologies
    - 2.2.1 Pitched Roof Structures
    - 2.2.2 Pitched Roof Coverings
    - 2.2.3 Flat Roof Structures
    - 2.2.4 Flat Roof Coverings
    - 2.2.5 Other Roof Designs
    - 2.2.6 Green Roof Modular Systems
  - 2.3 Available Space

    - 2.4 Structural Capacity
    - 2.5 Waterproof Membranes and Insulation
    - 2.6 Drainage
    - 2.7 Heritage
    - 2.8 Green Roof Access
        - 2.8.1 Access for Maintenance
        - 2.8.2 Temporary or Permanent Access Strategies
        - 2.8.3 Maintenance frequency
    - 2.9 Other Issues
    - 2.10 How to Determine Which Green Roof Type is Best Suited to Different Structures
    - 2.11 Illustrative Case Studies
        - 2.11.1 Australia – Surry Hills Library and Beare Park, Sydney
        - 2.11.2 Brazil
        - 2.11.3 1214 Queen St West, Toronto, Ontario, Canada
        - 2.11.4 107 Cheapside, London, UK
    - 2.12 Conclusions
    - References
- Chapter 3 Green Roof Retrofit and the Urban Heat Island
    - 3.0 Introduction
    - 3.1 Defining the Urban Heat Island
        - 3.1.1 UHI Impacts on Environment, Society and Economy
    - 3.2 Microclimatic Effects of Rooftop Greening
    - 3.3 Green Roof Cooling Mechanisms
    - 3.4 Green Roof Retrofit for Uhi Mitigation – Defining the Boundaries
        - 3.4.1 Roof Availability and Suitability
        - 3.4.2 Design Considerations – Intensive Versus Extensive
    - 3.5 Green Roof Retrofit for Uhi Mitigation – Developing the Model
        - 3.5.1 Overview of Methods
        - 3.5.2 Modelling Roof Availability and Suitability
        - 3.5.3 Modelling Thermal Performance

    - 3.6 Model Implementation – Evaluating Sydney's Surface and Canopy-Layer Heat Islands
    - 3.7 Green Roof Retrofit for Uhi Mitigation – Model Implementation
    - 3.8 Conclusions – Where to from Here?
        - 3.8.1 Limitations of the Research and Opportunities for Further Work
    - References
- Chapter 4 Thermal Performance of Green Roof Retrofit
    - 4.0 Introduction
    - 4.1 Green Roof Retrofit and Thermal Performance
    - 4.2 Research Methodology
    - 4.3 Case study: Rio de Janeiro and Sydney
        - 4.3.1 Rio de Janeiro Case Study
        - 4.3.2 Sydney Case Study
        - 4.3.3 Evaluation of Rio de Janeiro and Sydney Cases
    - 4.4 Conclusions
    - References
- Chapter 5 Stormwater Attenuation and Green Roof Retrofit
    - 5.0 Introduction
    - 5.1 The Problem of Pluvial Flooding
    - 5.2 Specifications for Stormwater Roofs and Issues for Retrofit
        - 5.2.1 Technical and Physical Issues in Retrofit
        - 5.2.2 Estimating Runoff Reduction
    - 5.3 Modelling for City-Scale Stormwater Attenuation
        - 5.3.1 Melbourne, Australia
        - 5.3.2 Newcastle-upon-Tyne, UK CBD Database
        - 5.3.3 Melbourne and Newcastle Runoff Estimation
    - 5.4 Assessment of Retrofit at a Building Scale
        - 5.4.1 Portland Ecoroof Programme
    - 5.5 Conclusions – Where to Next?
    - References
- Chapter 6 Biodiversity and Green Roof Retrofit
    - 6.0 Introduction
    - 6.1 What is Biodiversity?
    - 6.2 Green Roofs for Vertebrate Conservation

    - 6.3 Green Roofs for Invertebrate Conservation
    - 6.4 Conclusions
        - 6.4.1 Designing Biodiverse Green Roofs
    - References
- Chapter 7 Planting Choices for Retrofitted Green Roofs
    - 7.0 Introduction
    - 7.1 Ecosystem Services Delivery By Green Roofs: The Importance of Plant Choice
    - 7.2 Plant Species Choice and Building Cooling/Insulation
        - 7.2.1 Plants and Cooling – Basic Principles
        - 7.2.2 Plant Species Choice and Summer-Time Surface Cooling
        - 7.2.3 Plant Species Choice and Winter-Time Insulation
    - 7.3 Plant Species Choice and Stormwater Management
    - 7.4 Greater Plant Variety can Enhance Urban Biodiversity
    - 7.5 Plant Choices and Particle Pollution Mitigation
    - 7.6 New Plant Choices and Adaptation of Current Green Roof Systems
    - 7.7 Conclusions and Future Work
    - References
- Chapter 8 Green Roof Retrofitting and Conservation of Endangered Flora
    - 8.0 Introduction
    - 8.1 Biodiversity Conservation – a Strategic Overview
    - 8.2 A Review of Green Roofs in Habitat Conservation
    - 8.3 Knowledge Gaps and Further Research
        - 8.3.1 A Research Programme for Conserving Endangered Species on Green Roofs
        - 8.3.2 The Endangered Community of the Eastern Suburbs Banksia Scrub
    - 8.4 A Model Research Design for Species Conservation
        - 8.4.1 Extensive or Intensive Roofs?
        - 8.4.2 Research Objectives
        - 8.4.3 Guiding Principles for Esbs Regeneration
        - 8.4.4 Preparatory Steps
        - 8.4.5 Monitoring
        - 8.4.6 Expected Outcomes

    - 8.5 Conclusions
    - References
- Chapter 9 Urban Food Production on Retrofitted Rooftops
    - 9.0 Introduction
    - 9.1 Green Roof Retrofit and Urban Food Production
    - 9.2 Stakeholders and Urban Food Production
    - 9.3 Contamination and Air-Quality Issues
        - 9.3.1 Types of Pollutant
        - 9.3.2 Most Urban Soils are Contaminated
        - 9.3.3 Do Contaminants Accumulate in Urban Crops?
        - 9.3.4 Mitigating Urban Crop Contamination
        - 9.3.5 Urban Gardens and Air Quality
    - 9.4 The Research Design and Methodology
        - 9.4.1 Case Studies
        - 9.4.2 Gumal Student Housing
        - 9.4.3 Science Roof
        - 9.4.4 Vertical Gardens
        - 9.4.5 Results and Interpretation
        - 9.4.6 Findings
    - 9.5 The Carbon Footprint of Food Grown on Demonstration Beds
    - 9.6 Potential Reductions in Carbon Footprint
    - 9.7 Conclusions
    - References
- Chapter 10 Social Aspects of Institutional Rooftop Gardens
    - 10.0 Introduction and Objectives
    - 10.1 Social Aspects, Productivity and Sustainability Potential of Rooftop Gardens
    - 10.2 Methodology
        - 10.2.1 Comparative Analysis of Eight University Rooftop Garden Case Studies
        - 10.2.2 Semi-Structured Interviews with UTS Roof Gardening Club
        - 10.2.3 107 Projects Rooftop Garden: A Sensory Ethnography
    - 10.3 Main Findings

        - 10.3.1 Comparative Analysis of Eight Rooftop Gardens in Universities
        - 10.3.2 Qualitative Analysis of Uts Roof Gardening Club Semi-Structured Interviews
        - 10.3.3 107 Projects Rooftop Garden, Sydney
        - 10.3.4 St Canice Kitchen Garden, Kings Cross, Sydney
    - 10.4 Recommendations, Discussions and Conclusions
    - Acknowledgement
    - References
- Chapter 11 Cool Roof Retrofits as an Alternative to Green Roofs
    - 11.0 Introduction
    - 11.1 What is a Cool Roof?
    - 11.2 Background – How does a Cool Roof Work?
    - 11.3 Cool Roof Studies and Measurements
    - 11.4 The Experiments
        - 11.4.1 Results
        - 11.4.2 Other Residential Building Typologies
        - 11.4.3 Impact of CRP on PV Energy Generation
    - 11.5 Conclusions
        - 11.5.1 Negative Impacts of Cool Roofs
        - 11.5.2 Green Roofs Versus Cool Roofs
        - 11.5.3 Cool Roofs and Retrofits
        - 11.5.4 Barriers and Stakeholders
    - Acknowledgements
    - References
- Chapter 12 Looking to the Future
    - 12.0 Introduction
    - 12.1 City-level Actions: Basel and Paris
    - 12.2 City-level Actions: Requirements or Inducements?
    - 12.3 Tools and Information Sources
    - 12.4 Green Roofs: The Big Picture of GI and Future Developments
    - 12.5 Recognising the Multiple Benefits of Green Roof Retrofit
    - 12.6 Overall Conclusions
    - References
- Appendices

- Appendix 1: A Checklist for Appraising the Suitability of an ExistingRoof for Green Roof Retrofit
- Appendix 2: Checklist for Designers of Biodiverse Green Roofs
- Appendix 3: Tools, Information Sources and Mapping/Gis for Green Roofs – Some Examples
- Index
- EULA