



Expanded Second Edition

Building Performance Simulation for Design and Operation

Edited by
Jan L.M. Hensen and
Roberto Lamberts



ROUTLEDGE

Building Performance Simulation for Design and Operation

When used appropriately, building performance simulation has the potential to reduce the environmental impact of the built environment, to improve indoor quality and productivity, as well as to facilitate future innovation and technological progress in construction. Since publication of the first edition of *Building Performance Simulation for Design and Operation*, the discussion has shifted from a focus on software features to a new agenda, which centres on the effectiveness of building performance simulation in building life cycle processes.

This new edition provides a unique and comprehensive overview of building performance simulation for the complete building life cycle from conception to demolition, and from a single building to district level. It contains new chapters on building information modelling, occupant behaviour modelling, urban physics modelling, urban building energy modelling and renewable energy systems modelling. This new edition keeps the same chapter structure throughout including learning objectives, chapter summaries and assignments. Moreover, the book:

- Provides unique insights into the techniques of building performance modelling and simulation and their application to performance-based design and operation of buildings and the systems which service them.
- Provides readers with the essential concepts of computational support of performance-based design and operation.
- Provides examples of how to use building simulation techniques for practical design, management and operation, their limitations and future direction.

It is primarily intended for building and systems designers and operators, and postgraduate architectural, environmental or mechanical engineering students.

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**Edited by Jan L.M. Hensen and
Roberto Lamberts**

 **Routledge**
Taylor & Francis Group
LONDON AND NEW YORK



Second edition published 2019
by Routledge
2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

and by Routledge
52 Vanderbilt Avenue, New York, NY 10017

Routledge is an imprint of the Taylor & Francis Group, an informa business

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First edition published by Spon Press 2011

British Library Cataloguing-in-Publication Data

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

Library of Congress Cataloging-in-Publication Data

Names: Hensen, Jan, editor. | Lamberts, Roberto, editor.

Title: Building performance simulation for design and operation / [edited by]

Jan L.M. Hensen and Roberto Lamberts.

Description: Second edition. | Abingdon, Oxon ; New York, NY : Routledge, 2019. |

Includes bibliographical references and index.

Identifiers: LCCN 2018051032 | ISBN 9781138392199 (hbk : alk. paper) | ISBN

9780429402296 (ebk : alk. paper)

Subjects: LCSH: Buildings—Performance—Computer simulation.

Classification: LCC TH453 .B875 2019 | DDC 690/.22—dc23

LC record available at <https://lcn.loc.gov/2018051032>

ISBN: 978-1-138-39219-9 (hbk)

ISBN: 978-0-429-40229-6 (ebk)

Typeset in Times New Roman
by Apex CoVantage, LLC

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Foreword to the second edition

No research field stands still, and this is particularly true of building performance prediction in light of the myriad developments underpinning the clean energy transition agenda being pursued in many parts of the world. Such developments are extending both the scale and the scope of the energy utilization challenge at local, regional and national levels. Never has there been a greater need to consider the implications of design intentions in a holistic manner in order to maintain balance between conflicting aspects – for example, between energy saving and well-being, between renewables integration and utility costs, or between heightened complexity and operational resilience.

In this second edition, distinguished researchers contribute to these challenges by updating the reader on developments relating to the traditional targets of building performance simulation: ventilation systems, thermal comfort, daylight utilization, moisture flow, HVAC systems operation and automated control. It also introduces new materials that address domains that have hitherto been missing: the modelling of occupant behaviour, a dominant cause of the performance gap observed in practice; building-integrated renewable energy systems, seen as one way of attaining net-zero-energy designs; electrical grid interaction, forming the basis of future smart grids; micro-generation, providing a means to reduce the overall load on the electricity supply network; and urban scale considerations, facilitating community energy schemes and providing the link to the wider issue of resource utilization.

Additional new material then completes the state-of-the-art review by considering emerging concepts relating to building information management and modern approaches to software engineering. Such developments will surely help to integrate the design community by enabling model exchange and faster response to new functionality requests from users.

The book remains essential reading to those practitioners and researchers who seek to understand and apply building simulation in a professional manner.

Joe Clarke
August 2018

Foreword to the first edition

The fossil fuels are entering their tertiary stage and steps are being taken in many countries to kick-start the transition to an alternative energy infrastructure. A pressing question is how this transition can best be managed, negative impacts mitigated, and the various technology options blended over time: fossil fuel de-carbonisation and sequestration in the short term, the deployment of energy efficiency measures, the switch to new and renewable source of energy, and the removal of barriers confronting new nuclear plant. A key aspect of any future energy infrastructure will be real-time demand management to facilitate the matching of demand with supply – especially where the latter comprises significant inputs from stochastic, distributed renewable energy sources. Because a large portion of a country's energy demand is associated with the built environment, it is here that productive action can be taken to reduce energy consumption whilst ensuring that expectations relating to human comfort/health and environmental protection are met.

The built environment is inherently complex and as a consequence conflicts abound, preferred solutions are often polarised and consensus is difficult to attain. This situation gives rise to three fundamental engineering challenges: how to consider energy systems in a holistic manner in order to address the inherent complexity; how to include environmental and social considerations in the assessment of cost-performance in order to ensure sustainable solutions; and how to embrace inter-disciplinary working in order to derive benefit from the innovative approaches to be found at the interface between the disciplines. In short, energy systems require an integrated approach to design: will the widespread deployment of micro-CHP within the urban environment be acceptable if the global carbon emission reduction to result is attained at the expense of reduced local air quality and increased maintenance cost?

Integrated building performance simulation has emerged as an apt means of addressing the above challenges while allowing collaborating practitioners to identify the action combinations that will be most effective in providing acceptable overall performance as a function of the unique climate, design and operational parameters defining specific buildings and communities, planned or existing. IBPS does this by modelling the heat, air, moisture, light, electricity, pollutant and control signal flows within building/plant systems and, thereby, nurturing performance improvement by design. The benefits of the power and universal applicability of the approach comes at a price, however: application requires an understanding of design hypothesis abstraction, computer model building, multiple domain simulation, performance trade-offs, and the translation of outcomes to design evolution.

This book presents the complementary views of distinguished researchers in the field, arranged in a progressive format that covers the myriad issues underpinning the application of modelling and simulation when used to support decision-making relating to building performance and operation. In addition to the wide scope of topics covered, the book provides useful examples of the practical application of building simulation to formulate design and operational solutions that are acceptable in terms of performance criteria relating to indoor air

quality, thermal/visual/acoustic comfort, operational/embodied energy, carbon emissions, and capital/running cost. A unique feature of the book is the balance between theory and practice on the one hand, and between the issues at the individual building and community level on the other. The book is essential reading to those practitioners and researchers who seek to understand and apply building simulation in a professional manner.

Joe Clarke
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December 2009

Preface to the second edition

The first edition of this book was published in 2011. It was very well received, judging from the number of copies sold and the positive feedback of many readers from various fields. Since then, several years have passed and many new developments have taken place in the field of building performance simulation. All of the first edition chapter authors felt that – given recent developments in their particular areas – after eight years, their chapter could do with revisions and updates, and in several cases also expansions. Therefore, the collective authors agreed that it was high time for a new edition of the book.¹

We have also received numerous requests to publish an expanded second edition with more information on building information modelling, occupant behaviour modelling, urban physics modelling, urban building energy modelling and renewable energy systems modelling. In response, this second edition has five additional chapters.

For improved readability, in this second edition, the order of the chapters has changed. They are now organized according to the themes: fundamentals, design, operational optimization, systems and urban aspects.

As before, we would like to express our sincere gratitude to all co-authors, reviewers and others for the time and effort they have devoted to this book project.

Jan L.M. Hensen
Roberto Lamberts
September 2018

Note

- 1 In this context we also agreed that it would be a good idea for each chapter author to give a webinar presenting a summary of his/her chapter and to provide updates on recent developments. Feel free to watch these webinars, which were broadcasted in 2016/2017; they are still accessible from www.ibpsa.org/?page_id=695.

Preface to the first edition

The rise of technology over the past decades has been something of a mixed blessing. On the one hand it has increased our freedom to move and communicate and has provided us with more comfort. On the other hand, it is widely understood that the energy use currently required to drive our modern way of living has led to critical environmental problems. These problems have been highlighted to such a degree through the explosion of research and news coverage over recent years, that it is now common knowledge that our lifestyle is unsustainable. In modern terminology, to slow down and hopefully reverse the manmade damage, we need to develop a sustainable and net-zero-energy built environment. This will involve not only the design of net energy producing new ‘green’ buildings, but also the optimization of energy use of existing buildings.

In line with the rise of technology, buildings and the systems within them have become exponentially more complex in recent times. The modern built environment is populated by a variety of building types with highly demanding performance and user requirements. The difficulties involved in optimizing energy use in buildings have been recognized for quite some time. The complexity of the task arises from the number of variables from a wide range of fields that must be considered. Many professionals and researchers, including ourselves, concluded that solving such a complex problem requires two things: interdisciplinary research involving a wide variety of disciplines, and well-developed technological tools to make the problem manageable.

In 1986 a group of like-minded individuals established the International Building Performance Simulation Association, IBPSA (www.ibpsa.org), a non-profit society of building performance simulation researchers, developers and practitioners dedicated to improving the built environment. IBPSA provides a forum for researchers, developers and practitioners to review building model developments, facilitate evaluation, encourage the use of software programs, address standardization, and accelerate integration and technology transfer.

IBPSA covers broad areas of building environmental and building services engineering. Typical topics include building physics (including heat, air and moisture flow, electric and day lighting, acoustics, smoke transport); heating, ventilation and air-conditioning systems; energy supply systems (including renewable energy systems, thermal storage systems, district heating and cooling, combined heating and power systems); human factors (including health, productivity, thermal comfort, visual comfort, acoustical comfort, indoor air quality); building services; and advancements and developments in modelling and simulation, such as coupling with CAD, product modelling, software interoperability, user interface issues, validation and calibration techniques. All these topics may be addressed at different levels of resolution (from microscopic to the urban scale), and for different stages in the building life cycle (from early sketch design, via detailed design to construction, commissioning, operation, control and maintenance) of new and existing buildings worldwide.

In essence, IBPSA has two key objectives: to use computer simulation to (a) provide better support for the design of buildings; and (b) provide better support for building operation and management in the use phase of buildings. These two objectives have informed our own research over the last decades. This book aims to give the reader a thorough understanding of the recent progress made in building simulation and the key challenges that still need to be overcome.

The main motivation for developing this book was that at the time of writing no comprehensive textbook on the subject was available, even though building performance simulation has become an essential technology for architectural and engineering design and consultancy practices which aim to provide innovative solutions for their clients.

This book sets out to fill this gap by providing unique insight into the techniques of building performance modelling and simulation and their application to performance-based design and operation of buildings and the systems which service them. It provides readers with the essential concepts of computational support of performance-based design and operation – all in one book. It provides examples of how to use building simulation techniques for practical design, management and operation, and highlights their limitations and suggests future research directions.

This book provides a comprehensive overview of building performance simulation for the complete building life-cycle from conception to demolition. It addresses theory, development, quality assurance and use in practice of building performance simulation. The book is therefore both theoretical and practical, and as such will be of interest to those concerned with modelling issues (universities, research organizations and government agencies) and real world applications (architects, engineers, control bodies, building operators). The book is primarily intended for (future) building and systems designers and operators of a postgraduate level. However, due to the interdisciplinary nature of research into the built environment, the book should also prove useful for a variety of connected fields.

The interdisciplinary nature of the research becomes clear when it is understood that building performance simulation draws its underlying theories from many disciplines including physics; mathematics; material science; biophysics; human behavioral, environmental and computational sciences. The book would lend itself to adaption for multidisciplinary courses, for example, AEC related university courses which address building performance prediction and operational issues. Other courses might include it on their recommended reading list, especially at the postgraduate level.

The book begins by introducing and describing the key features of building performance simulation and sets the scene for the rest of the book. The concepts of performance indicators and targets are discussed, followed by a discussion of the current and future role of building simulation in performance-based building design and operation. This will lay the foundations for in-depth discussions of performance prediction for key aspects such as energy demand, indoor environmental quality (including thermal, visual, indoor air quality and moisture phenomena), HVAC and renewable system performance, urban level modelling, building operational optimization and automation. The book ends with a discussion of future directions for building performance simulation research and applications in practice. The book aims to show that when used appropriately, building performance simulation is a very powerful technique capable of helping us achieve a sustainable built environment, and at the same time improving indoor quality and productivity, as well as stimulating future innovation and technological progress in the architecture, engineering and construction (AEC) industry.

We believe this book to be long overdue. We have been contemplating the idea of writing it for many years. However, due to the interdisciplinary nature of the subject, writing such a book required the cooperation of many individuals. Toward the end of 2006 the idea became more concrete, and in early 2007 the co-authors and the publisher enthusiastically joined the

adventure. Despite our busy schedules, in 2008 a symposium was organized in Brazil to bring co-authors together and allow them to present the content of their chapters. We would like to thank Eletrobrás and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for their financial support of this event. The event proved to be an important catalyst that allowed the book to progress to its finished state, even if it took a fair bit longer to finish the book than originally anticipated. In the end, we are really very pleased with the results, and hope you will enjoy reading the book too.

This book is the result of cooperation and dedication of many individuals, in particular of course all co-authors. We would like to take the opportunity to also acknowledge the support of our universities: Eindhoven University of Technology, the Netherlands, and Universidade Federal de Santa Catarina, Brazil. Last but not least, we wish to express our gratitude to Duncan Harkness, Roel Loonen, Ana Paula Melo, Martin Ordenes Mizgier, Jikke Reinten and Marija Trcka for their editorial and practical support.

Jan L.M. Hensen
Roberto Lamberts
March 2010



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