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Edited by
Andreas Athienitis and William O'Brien

Modeling, Design, and Optimization of Net-Zero Energy Buildings

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SOLAR HEATING & COOLING PROGRAMME
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EBC
Energy in Buildings and Communities Programme

Edited by
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William O'Brien

Modeling, Design, and Optimization of Net-Zero Energy Buildings

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Cover: The cover photo shows the John Molson School of Business Building at Concordia University, Montreal. The building incorporates a building-integrated photovoltaic/thermal system along the top mechanical services floor. (Photo: Samson Yip)

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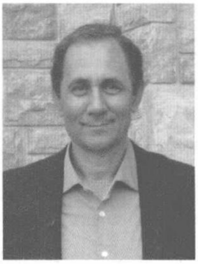

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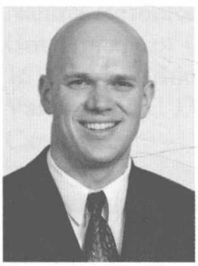

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Preface

Andreas Athienitis and William O'Brien

Just over five years ago, approximately 60 international experts of the International Energy Agency – Solar Heating and Cooling Task 40/Energy in Buildings and Communities (EBC) Annex 52: Towards Net-zero Energy Solar Buildings ("T40A52") met in Montreal at Concordia University for the first official experts meeting. Many of the experts were in for a surprise as they discovered the diversity of international perspectives on net-zero energy buildings (Net ZEBs) – including definitions, official building standards, business and legal aspects, and design strategies. Over the following five years, the experts traveled to an additional nine meeting destinations and became immersed in the local building design cultures, providing us with a valuable international perspective on Net ZEBs and giving us the pleasure of meeting in several Net ZEBs (several of which were meeting venues and are discussed in depth in this book).

The objective of this book is to present a wide perspective on Net ZEB modeling, design, and related issues, while also providing substantial depth for designers and graduate students. The book was written by a total of 22 authors from seven countries of diverse climates with experts from both industry and academia/research. The book begins with fundamentals of modeling, strategies and technologies required to reach net-zero energy including many methods to quantify performance. As emphasized by T40A52, comfort is a fundamental aspect of Net ZEB and not an afterthought; therefore, a full chapter was devoted to thermal, visual, and acoustic comfort and indoor air quality. The following two chapters are devoted to design, modeling, simulation, and optimization of Net ZEBs with several examples. It was realized early in T40/A52 that research on Net ZEBs must encapsulate interactions with electrical grids since net-zero energy definitions are primarily focused on energy balances; thus, a whole chapter is devoted to this issue. In the second to last chapter, four detailed Net ZEB case studies are described in detail and linked to earlier fundamental chapters, including energy performance, comfort, design intent versus real operation, and lessons learned. Finally, redesign of archetypes based on the case studies are presented.

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Foreword

Josef Ayoub

This book was produced in the context of the collaboration between approximately 75 national experts from 19 nations in Europe, North America, Oceania, and Southeast Asia of the International Energy Agency (IEA), in the framework of the programs on Solar Heating and Cooling (SHC Task 40) and Energy in Buildings and Communities (EBC Annex 52), under the title "Towards Net-Zero Energy Solar Buildings." T40A52 sought to study current net-zero, near-net-zero and very low energy buildings and to develop a common understanding of a harmonized international definitions framework, tools, innovative solutions, and industry guidelines to support the conversion of the Net ZEB concept from an idea into practical reality in the marketplace.

This Task/Annex pursued optimal integrated design solutions that provided a good indoor environment for both heating and cooling situations. The process recognized the importance of optimizing a design to meet the functional requirement, reducing loads, and designing energy systems that pave the way for seamless incorporation of renewable energy innovations, as they become cost effective. To achieve these results, the National Experts met twice annually at a hosting member country to coordinate the R&D activities and advance the work plan comprised of the following four major activities:

1. Subtask A dealt with establishing an internationally agreed understanding on Net ZEBs based on a common methodology. This was done by reviewing and analyzing existing Net ZEB definitions and data with respect to the demand and the supply side; studying grid interaction (power/heating/cooling) and time-dependent energy mismatch analysis; developing a harmonized international definition framework for the Net ZEB concepts considering large-scale implications, exergy, and credits for grid interaction (power/heating/cooling); and, developing a monitoring, verification and compliance guide for checking the annual balance in practice (energy, emissions, and costs) harmonized with the definition;
2. Subtask B aimed to identify and refine design approaches and tools to support industry adoption. This was done by conducting work along four major R&D streams: (i) in documenting and analyzing processes and tools currently being used to design Net ZEBs and under development by participating countries; (ii) assessing gaps, needs, and problems to inform simulation engine and detailed design tool developers of priorities for Net ZEBs; (iii) qualitative and quantitative benchmarking of selected tools; and (iv) selecting four case study buildings to conduct a detailed analysis of simulated/designed vs. actual performance, and proposing the redesign/optimization of these buildings;
3. Subtask C focused on developing and testing innovative, whole building net-zero solution sets for cold, moderate, and hot climates with exemplary architecture and technologies that would be the basis for demonstration projects and international collaboration. This was achieved by documenting and analyzing current Net ZEBs designs and technologies, benchmarking with near Net ZEBs and other very low energy buildings (new and existing), for cold, moderate, and hot climates considering sustainability, economy, and future prospects using a projects database, literature

review, and practitioner input (workshops); developing and assessing case studies and demonstration projects in close cooperation with practitioners; investigating advanced integrated design concepts and technologies in support of the case studies, demonstration projects, and solution sets; and developing Net ZEB solution sets and guidelines with respect to building types and climate, and to document design options in terms of market application;

4. Subtask D was crosscutting work that focused on dissemination to support knowledge transfer and market adoption of Net ZEBs on a national and international level. This was accomplished by establishing a Net ZEB webpage within the IEA SHC/EBC Programmes' framework and a database that can be expanded and updated with the latest projects and experiences; transferring the outputs (reports, sourcebooks, guidelines, other) to national policy groups, industry associations, utilities, academia, and funding programs; participating in national and international workshop, seminars, and industry exhibitions highlighting the results and activities of the Task/Annex contributing high-quality technical articles and features in journals to stimulate market adoption; and, establishing an education network of highly qualified people that will continue the work in the field for their future endeavors.

I am pleased to present the research results of Subtask B compiled in this volume of work entitled "*Modeling, Design, and Optimization of Net-Zero Energy Buildings*," as a major accomplishment in this field of research. Building energy design is currently going through a period of major changes driven largely by three key factors and related technological developments: (i) the increasingly widespread adoption in most OECD member countries and by influential engineering societies, such as ASHRAE, of net-zero energy as a long-term goal for new buildings; (ii) the need to reduce the peak electricity demand for buildings through optimal operation; and (iii) the need to efficiently integrate advanced energy technologies into buildings, such as photovoltaic/thermal systems, windows with semitransparent photovoltaic glazing, controlled shading/daylighting devices, and integrated thermal storage. It encapsulates the many and varied concepts of designing and optimizing net-zero energy buildings by government research organizations, international and regional research centers, academia, and industry. I am confident this book will find many interested readers.

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Natural Resources Canada Ressources naturelles Canada Canada

The Natural Sciences and Engineering Research Council of Canada (NSERC) through the NSERC Smart Net-zero Energy Buildings strategic Research Network (SNEBRN) funded related research on Net ZEBs by Andreas Athienitis, Scientific Director of SNEBRN and Professor of Building Engineering at Concordia University, and his students, several of whom contributed to this book and are listed as contributors. Concordia University hosted the first and last meetings of this 5-year Task.

NSERC SMART NET-ZERO ENERGY BUILDINGS STRATEGIC RESEARCH NETWORK

RÉSEAU DE RECHERCHE STRATÉGIQUE DU CRSNG SUR LES BÂTIMENTS INTELLIGENTS À CONSOMMATION ÉNERGÉTIQUE NETTE ZÉRO

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