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Edited by F. Garde, J. Ayoub, L. Aelenei,
D. Aelenei, and A. Scognamiglio

Solution Sets for Net Zero Energy Buildings

Feedback from 30 Net ZEBs worldwide

SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

EBC
Energy in Buildings and Communities Programme

Edited by
François Garde
Josef Ayoub
Daniel Aelenei
Laura Aelenei
Alessandra Scognamiglio

Solution Sets for Net Zero Energy Buildings

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Cover:
ENERPOS: a French Net Zero Energy Building (Net ZEB) and one of the first Net ZEBs designed in the tropics thanks to an efficient passive design using cross natural ventilation and building integrated PV roofs that produce electricity. ENERPOS is located on Reunion Island (France).
(Photo: Jerome Balleydier)

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Dr. Laura Aelenei is a senior researcher at the Energy Efficiency Unit of National Energy and Geology Laboratory and Invited Professor of Energy Efficiency studies at the Master of Energy and Environment Engineering at the Faculty of Sciences of the University of Lisbon (FCUL). She is a Civil Engineer, holding a Master Degree on Buildings Rehabilitation and a PhD in Civil Engineering (heat and mass transfer, fluid dynamics through building ventilated envelope systems). She is involved in several national and international research projects as participant or coordinator and participated

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Dr. Alessandra Scognamiglio is a researcher in the Photovoltaic Systems and Smart Grids Unit at the ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development). She holds a PhD in Technologies for Architecture and Environment from the Second University of Naples Luigi Vanvitelli, 2010, a Master in Architecture from the University of Naples Federico II, 1998, and is a licensed architect (Naples, 1998). Her main fields of activity are: Building Integrated Photovoltaics (BIPV), Photovoltaics and sensitive landscapes, Net Zero Energy Buildings and Smart Cities. Since 2003, she has been a teacher at the Italian National Institute of Architecture for a post graduate master course in "Designer of sustainable architectures." She is participating in European projects aimed at the development of special photovoltaic components for buildings. She is also involved in several IEA research collaborations, particularly: 2008–2012 IEA SHC Task 41 *"Solar Energy and Architecture"*; 2008–2013 IEA SHC Task 40-EBC Annex 52 *"Towards Net Zero Energy Solar Buildings,"* 2013–2017 IEA SHC

Task 51 *"Solar Energy in Urban Planning,"* and since 2015 in the IEA PVPS Task 15, "*Enabling framework for BIPV acceleration*". Since 2008 she has been topic organizer of the European Photovoltaic Solar Energy Conference (EUPVSEC) focusing on Photovoltaics and Architecture. She is an active member of the COST RELY action TUI 401 "Renewables and Landscape quality."

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IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is "*to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050*".

The members of the IEA SHC collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 57 projects have been initiated, 49 of which have been completed. Research topics include:

- Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44, 54)
- Solar Cooling (Tasks 25, 38, 48, 53)
- Solar Heat or Industrial or Agricultural Processes (Tasks 29, 33, 49)
- Solar District Heating (Tasks 7, 45, 55)
- Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52, 56)
- Solar Thermal & PV (Tasks 16, 35)
- Daylighting/Lighting (Tasks 21, 31, 50)
- Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43, 57)
- Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- Storage of Solar Heat (Tasks 7, 32, 42).

In addition to the project work, there are special activities:

- SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- Solar Heat Worldwide – annual statistics publication
- Memorandum of Understanding – working agreement with solar thermal trade organizations
- Workshops and seminars.

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Foreword

This work was produced in the context of a joint collaboration between approximately 75 national experts from 19 nations in Europe, North America, Oceania, and Southeast Asia of the International Energy Agency (IEA), under the framework of the IEA Solar Heating and Cooling (SHC) and Energy in Buildings and Communities (EBC) Technology Collaboration Programs. The joint SHC Task 40/EBC Annex 52 (T40A52) "Towards Net-Zero Energy Solar Buildings" 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 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 web page 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 in their future endeavors.

I am pleased to present the research results of Subtask C compiled in this volume of work entitled "*Solution Sets from Net Zero Energy Buildings: Feedback from 30 Net ZEBs worldwide"* 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. This body of work encapsulates the many and varied lessons learned of designing, building and operating 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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1 Introduction

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1.1 Why another book on net zero energy buildings?

This book is the principal output of a major international research project under the auspices of the International Energy Agency (IEA) Solar Heating and Cooling (SHC) and Energy in Buildings and Communities (EBC) Technology Collaborating Programs joint *SHC Task 40/EBC Annex 52: Towards Net Zero Energy Solar Buildings* [1]. The focus of the project was to examine the performance in use of net-zero energy buildings (Net ZEBs) across the globe in order to understand the strengths and weaknesses of the design solution sets adopted. The fundamental contribution of the part of the project described in these pages was this examination of many different built and functioning buildings and the general lessons about Net ZEBs that can be drawn.

At heart therefore, this book is an examination of 30 case studies. These projects all aimed to equalize their small annual energy needs, cost-effectively, through building integrated heating/cooling systems, power generation and interactions with utilities. These buildings had to meet strict criteria for inclusion in this analysis, beyond merely being labeled by their designers or promoters as "green" or "energy positive" or "net-zero energy." The most important among these criteria was the insistence that a minimum of one full year of metered performance data was available for analysis. In addition, the research team sought to identify buildings whose architecture and combinations of technologies formed "solution sets" which could potentially be useful exemplars for other design teams seeking to build a net-zero energy building.

The world of modern architecture has flirted for the past fifty years with idea of bioclimatic design and autonomous architecture. Too often these have been one-off exercises serving only a research agenda, and not integrated into the mainstream of architecture or society. As such, they have been incredibly useful learning vehicles, but have found little acceptance outside of a small world of academics and research scientists. The underlying concept of a Net ZEB is that it should be widely accepted and it should connect to community and national energy grids.

The buildings in this study, while excellent exemplars, cannot be copied or adopted without careful analysis of each new design situation. The analysis in this book is directed to assisting the readers' understanding of the circumstances of each exemplar and of their design and performance constraints in order that designers of future Net ZEBs will not require the same level of fundamental analysis undertaken in these buildings. The buildings documented here are pioneers in their society or circumstances.

Solution Sets for Net Zero Energy Buildings: Feedback from 30 Net ZEBs worldwide. First Edition.
Edited by François Garde, Josef Ayoub, Daniel Aelenei, Laura Aelenei, and Alessandra Scognamiglio.

They incorporate measures and technologies that are at the leading edge of technical innovation for their time and are all to that extent repeatable. The goal of this book is to reduce the impression of risk for the new investor. Documenting not just the technology, but also the success of that technology in real buildings is intended to assist those investing in new buildings to understand how best to apply the technology themselves.

The book eschews presentation of the data in a catalog of case studies. The approach has been to examine as carefully as possible the lessons that can be drawn from these individual cases. The complete case study data collected for the analysis is however available online in a standardized database format to enable the reader to extract their own information [2]. No particular building type has been focused on: the list includes both single family residential and commercial/institutional buildings. It is conventional in a book of this type to ascribe other broader world-view rationales for the writing. It is clear for example that this book is arriving at a time when in much of Europe and in the USA governments are setting or have set ambitious goals for new buildings to be designed to be net zero energy by 2030: in the USA within the Energy Independence and Security Act of 2007 (EISA 2007) and, at the European level within the "recast" Directive on Energy Performance of Buildings (EPBD).

The EISA 2007 supports a goal of net-zero energy for all new commercial buildings by 2025 and notes a longer term goal of net-zero for all U.S. commercial buildings by 2050 [3], whereas the EPBD proposes "nearly zero" energy buildings from 2020 for all new buildings [4]. It is our belief that this book will provide one of the tools to enable designers to achieve and even exceed these political goals.

It is not our intention to repeat the rationales or catalog government approaches of these or other government initiatives. Rather, it is anticipated that the reader picked up this book in the full understanding of this international, and their own local context, and wants to learn from those who have built what works and what does not work among the many candidate design techniques and technologies to be found in the many text books describing Building Physics, Bioclimatic Architecture, or low energy Environmental Systems Design.

1.2 What is a net zero energy building?

1.2.1 IEA SHC Task 40/EBC Annex52: Towards net zero energy solar buildings

Over 82 national experts from 19 different countries have been directly involved in this IEA research collaboration for over a 5-year period (October 2008 – September 2013). Their goal was to support the conversion of the Net ZEB concept from an idea into practical reality in the marketplace. This source book and the associated datasets provide realistic case studies of how Net ZEBs can be achieved. Demonstrating and documenting real projects has the ultimate goal of lowering industry resistance to adoption of these concepts.

The research team examined the many variations on the theme of Net Zero Energy that could be found in the literature as well as in the different participating countries. The goal was to discover a common language, and common performance metrics for what at first seems a simple concept: *a Net ZEB is an energy grid-connected building which on an annual basis contributes as much energy to the grid(s) to which it is connected as it*