ANALYTICS FOR BUILDING-SCALE SUSTAINABLE ECOSYSTEMS

US-CHINA RESEARCH PERSPECTIVES

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New York • Connecticut

ANALYTICS FOR BUILDING-SCALE SUSTAINABLE ECOSYSTEMS

EDITOR: YONG X. TAO

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ISBN: 978-1-56700-279-9 Print
ISBN: 978-1-56700-288-1 e-Book

PRINTED IN THE UNITED STATES OF AMERICA 1 2 3 4 5 6 7 8 9 0

Library of Congress Cataloging-in-Publication Data

Names: U.S.-China Workshop on Analytics for Building-Scale Sustainable Ecosystems (2012 : Beijing, China) | Tao, Yong X., editor. | Jiang, Yi, (Professor of architecture) editor.

Title: Analytics for building-scale sustainable ecosystems : US-China research perspectives / editor, Yong X. Tao, University of North Texas, USA ; co-editor, Yi Jiang, Tsinghua University, China.

Description: New York : Begell, [2016] | Comprises research and review chapters primarily resulting from the recent U.S.-China Workshop on Analytics for Building-Scale Sustainable Ecosystems, sponsored by the U.S. National Science Foundation (NSF), and held in Tsinghua University, Beijing, China, June12-13, 2012 | Includes bibliographical references and index.

Identifiers: LCCN 2016002613| ISBN 9781567002799 (hardcover : alk. paper) | ISBN 9781567002881 (e-Book)

Subjects: LCSH: Buildings--Energy Conservation--United States--Congresses. | Buildings--Energy Conservation--China--Congresses. | Sustainable buildings--Congresses. | Architecture and energy conservation--Congresses.

Classification: LCC TJ163.5.B84 U24 2012 | DDC 720/.47--dc23 LC record available at http://lccn.loc.gov/2016002613

Direct inquires to Begell House, Inc., 50 North Street, Danbury, CT 06810

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Preface

Yong Tao[1] **and Yi Jiang**[2]

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This edited volume comprises research and review chapters primarily resulting from the recent U.S.-China Workshop on Analytics for Building-Scale Sustainable Ecosystems, sponsored by the U.S. National Science Foundation (NSF), and held in Tsinghua University, Beijing, China, June 12–13, 2012. A group of researchers from both the United States and China academic institutions present in this volume their views of bottlenecks in engineering, software, and social sciences, forming a nexus of critical issues impeding wider application of net zero energy building technology in the context of defining building-scale sustainable ecosystems. The focus of these investigations is the fundamentals of sciences that lead to a robust, significant improvement toward modeling and predicting building performance indices such as energy usage with user integration and sustainability. Achievements and challenges in research and development initiatives and best practices from the United States and China provide a foundation for such development of analytics and possibility of benchmarking and comparability. The edited volume divides the topics in the following main parts.

PART ONE: OVERALL PROSPECTS

The book starts with Chapter 1 to address the challenges in U.S.-China research collaboration. With the initial successful launch of U.S.-China Clean Energy Research Center (CERC) initiative, the United States and China were able to exchange experts who would share their understanding of efficient building technologies. The chapter covers discussions about the opportunities for researchers from two countries to understand the significant differences in building energy utilization and the needs to explore the reasons behind the differences. By focusing on the difference and investigating the comparative reasons, it allows the research communities to invest their time and efforts effectively to arrive at the solutions that could minimize the uncertainties in predicting building energy consumptions, including such factors as building occupant behaviors.

Chapter 2 presents a detailed review of international research on zero-energy building design and technologies from outside of China. It points out the rapid progress primarily in the developed countries where the zero-energy building concept is being aggressively pursued.

Chapter 3 discusses a special aspect of the societal impact of sustainable buildings and its ecosystems for aging populations. It presents a few key factors through examples that the human demands for life experience directly impact the definition of what is sustainable. Because of the unique life experiences of this segment of the population, one cannot think of sustainability, or building ecosystems, in terms of only lowering an elder's footprint.

PART TWO: DATA COLLECTION, COMPARISON, AND ANALYSIS

This part contains three chapters. Chapter 4 discusses the role of life cycle assessment in sustainable building ecosystems and building energy comparison between China and the United States. It has be widely recognized that life cycle assessment arises as a promising method that supports the investigation of the relationship between built environments and ecosystems, even though limitations of this method are well known and documented. This is because life cycle assessment can reveal material and energy flows throughout the material realm and human societies, as well as model the environmental consequences of such flows throughout the life cycle stages of materials, products, or buildings. The chapter discusses in detail the energy and environmental challenges in both countries and evolving views of the relationship between built environments and ecosystems.

Chapter 5 covers one of the challenges facing comprehensive modeling for building energy assessment and evaluation of its sustainability, i.e., the interoperable modeling techniques. It discusses the research progress and methodologies to streamline the integration of parametric modeling, building information modeling (BIM), and building energy modeling. As sustainable building design becomes more of the norm than a luxury, the streamlined modeling process will provide prototypes and specifications for the development of design and simulation software tools.

Chapter 6 presents the research progress toward system integration for interoperable data models of building-scale ecosystems. It offers some emerging concepts on addressing the issues of mismatching between the building delivery process, which is commonly executed as a discrete and sequential set of activities, and sustainable building design analysis and evaluation tools, which employ modern advances in communication and dissemination technologies. The ability to assess the impact of building design on energy and environmental sustainability requires relatively easy exchanger of data information among tools used, for example, in dynamic life-cycle information modeling (DLIM) infrastructure and many certification and standard development processes.

PART THREE: HUMAN BEHAVIORS

Chapter 7 addresses several concepts toward understanding human behaviors in general that could potentially impact the design and adoption of building-scale sustainable ecosystems. It outlines some of the relevant cognitive biases and plausible incentives that might prove to be beneficial in helping architects and engineers to nudge building occupants toward behavior that maximizes the potential of buildings for their long-term

efficiency, usability, and sustainability. In addition, a few cases studied in China are presented to illustrate some of the current phenomenological methodologies in analyzing the human behavior factors that could account for differences in building energy consumption between the United States and China.

Chapter 8 focuses on developing occupancy influence parameters in commercial buildings. It illustrates how energy modeling and simulation of human behavior in buildings can be done using the current state-of-the-art tools and methods. The results help improve building energy simulation tools and building design and occupancy-focused interventions, and encourage the adoption of occupancy-focused interventions in energy policies and governmental initiatives.

Chapter 9 outlines the methodology that could be used to investigate a broader impact of human behaviors from building-scale to community-scale applications. The author proposes the theoretical foundations for the application of computational tools and methods to support sustainable design, and outlines four research directions that are believed to require substantial advances to further the goals for understanding the design and behavior of sustainable building-scale ecosystems.

PART FOUR: GREEN BUILDINGS AND INNOVATIVE BUILDING DESIGN AND TECHNOLOGY

Five chapters in this part present topics ranging from emerging practices of green building design and construction to example technologies used or proposed for the sustainable building ecosystems. Chapter 10 covers a comprehensive review of the sustainable construction concept that emerged since early 1990 in the United States and around the world. It outlines the emergence of building assessment systems such as BREEAM, LEED, Green Star, and DGNB, and the latest sustainable construction movement such as the net zero strategy or concept. It also covers the emergence of carbon accounting and environmental product declarations (EPDs) as significant and important shifts in the direction of the evolution of sustainable construction.

Chapter 11 covers the progresses in the European Union and the United States toward the net zero energy buildings targets. Through three different successfully implemented and benchmarked case studies of NET-ZEB and Plus-Energy building occupancy types, the analysis provides insights on how buildings should be better designed, built, and measured with resource footprinting on a common metric scale. The chapter points out that the importance of legislative and curricular efforts that must be based on actual, yearly, measured building energy performance balance, carbon intensity, and an integrated building life cycle analysis, rather than on modeled assumptions from somewhat exceptional national “demo buildings.”

Chapter 12 outlines a study on green air-conditioners using a refrigerant of low global warming potential (GWP). It focuses on the motivation of reducing the impact of refrigerants on the environment and therefore the development of prototype systems that can utilize alternative refrigerants, which include *hydrocarbon refrigerants, two-phase* carbon dioxide, ammonia, and naturally existing gases.

Chapter 13 includes the investigation of building supervisory control systems and the system model that is established to capture the dynamics of the building system. It demonstrates that the research on optimization algorithms of the control systems could contribute to the better utilization of energy in sustainable buildings.

Chapter 14 summarizes several recent works in Chinese building technology research including optimization of air-source heat pumps, seasonal cooling energy storage systems, hybrid ground source heat pumps, integrated building design based on minimizing thermal discomfort, innovative building automation systems, and indirect evaporative cooling technology. Some of the technologies could be deployed outside of China.

The additional materials presented in the workshop are included in the Appendix part of the book. It contains seven presentations from researchers at the Building Energy Center from Tsinghua University, China. It covers some of the current ongoing research topics in Tsinghua, including building energy monitoring systems and analysis, energy consumption patterns in the United States, occupant behavior in buildings, thermal discomfort analysis, sustainable residential buildings in rural areas, green building standards development, and the introduction of IEA ECBCS–Annex 59, an international collaborative effort on energy efficient cooling and heating methods.

ACKNOWLEDGMENTS

The editors thank all the contributing authors and participants in the workshop for making this book publication possible. Special thanks go to the research assistants and associates at the University of North Texas, Robert Xiong, Dr. Junghyon Mun, and Dr. Tingzhen Ming for their assistance in editing this book. We thank the U.S. National Science Foundation (NSF) for funding the workshop activities under Award No. 1207807. This successful workshop paved the path toward another U.S. NSF award, Research Coordination Network in Science, Engineering and Education for Sustainability (RCN-SEES): Predictive Modeling Network for Sustainable Human-Building Ecosystems (SHBE) under Award No. 1338851. The authors of this book are continuing to be active members of this research collaboration network. We note that NSF has indicated that any opinions, findings, and conclusions or recommendations expressed in this publication are those of the principal investigators and do not necessarily reflect the views of the National Science Foundation. NSF has not approved or endorsed its content.

The authors contributing to this book have received research funding from other U.S. and China funding sources, including the U.S. Department of Energy, the China Ministry of Housing and Urban-Rural Development, the Ministry of Science and Technology, industries, and other agencies. Their collective supports are greatly appreciated.

CHAPTER 1

Challenges in U.S.-China Building Research Collaboration

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1.1 INTRODUCTION

With the increased growth of the world's population and rapid urbanization, the share of building energy consumption in the energy sector is accelerating at a faster pace. If the trend continues, by 2025, buildings will be the top consumers of energy worldwide. Almost a third of the world's energy is now consumed by buildings. In the United States, 40% of the energy is consumed by residential and commercial buildings [1]. China's energy consumption in buildings has a similar share in its national energy portfolio. To match the increasing energy demand worldwide, there is no alternative but to look for a potential solution of low energy use for buildings.

Building energy consumption varies from country to country, and developed countries usually consume much more than developing countries. Figure 1.1 shows a comparison of building energy consumption in some typical countries. It is obvious that the United States and Canada consume the most energy, which is about five times the Chinese energy consumption per capita [1].

With the rapid economic growth in China, the building energy consumption (BEC) is surging in the past 10 years. At the same time, the energy consumption in developed countries has become constant, and even comes to a slight drop, as shown in Fig. 1.2. It is a big challenge for China to achieve sustainable development with better living conditions at the same time. How to improve the indoor environment without a significant increase in building energy usage is one of the key issues in China's sustainable development.

In 2009, the U.S. Department of Energy and the Chinese Ministry of Urban Rural Development (MOHURD) announced a joint agreement to foster collaboration in the development of more efficient building designs [2, 3]. As a follow-up initiative, the U.S.-China Clean Energy Research Center (CERC) was established. One of the four programs was on energy-efficient building technologies. Under this program, the United States and

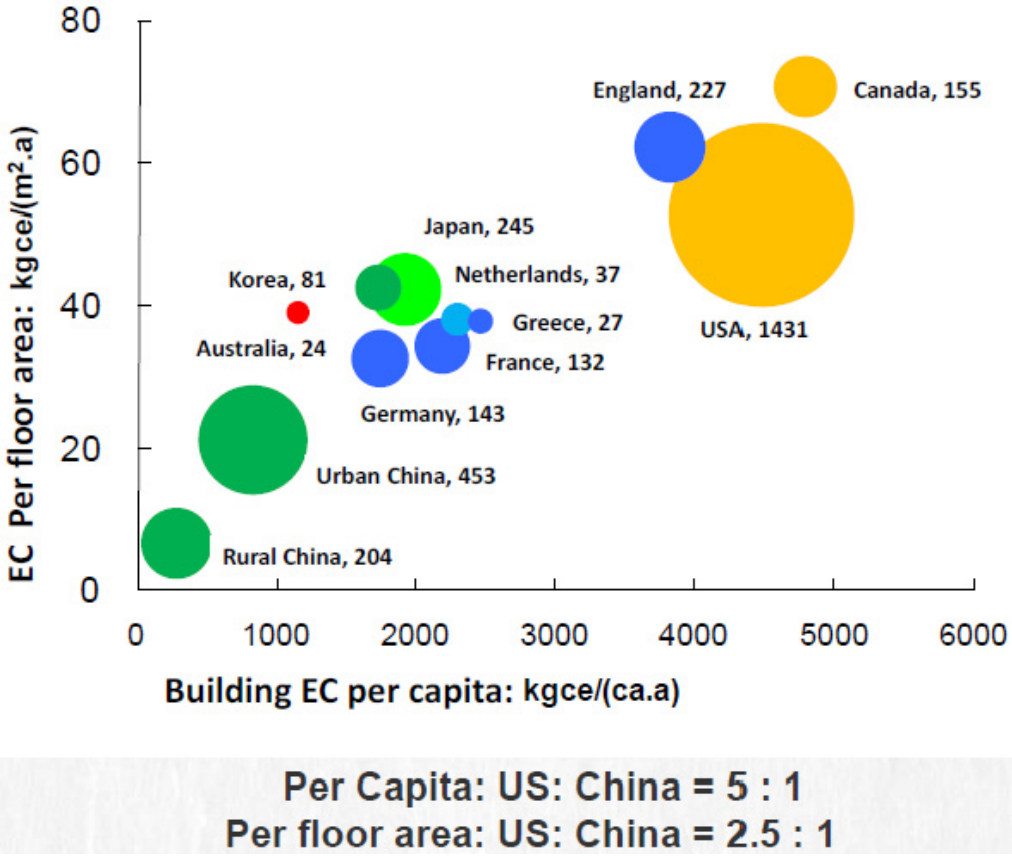

FIG. 1.1: Annual energy consumption (EC) per floor area in m^2 versus EC per capita: 1 kgce = 7000 kcal (Reprinted with permission from Y. I. Jiang) [1].

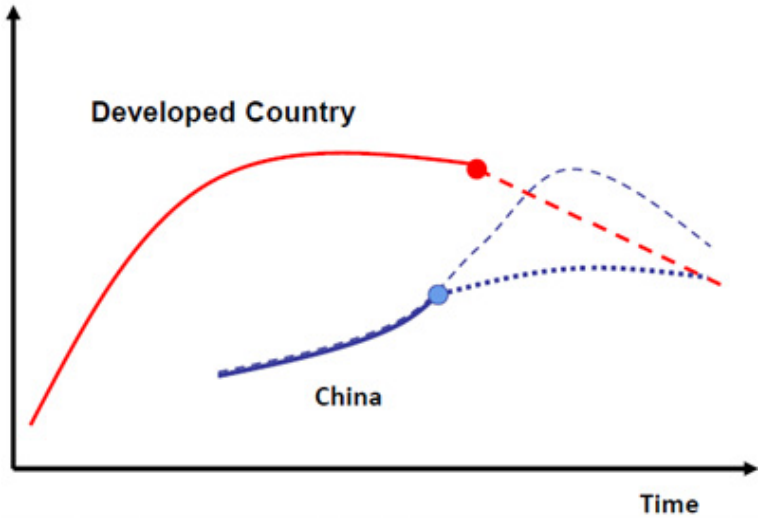

FIG. 1.2: Trends in building energy consumption (BEC).

China would exchange experts who would share their understanding of efficient building technologies, including high-performance HVAC, insulation, lighting, cold storage, geothermal heat pumps, building-integrated photovoltaics, and solar thermal systems. In particular, researchers from the United States and China have been and will continue to conduct analyses on the lessons learned from their combined experience related to energy-efficient buildings and communities.

1.2 CHALLENGES AND TARGETS

The main goal of the China-U.S. research collaboration is to reduce the overall building energy consumption and related carbon exhausted. The challenges are mainly to understand what baseline that reduction is coming from. For example, there are large differences in the energy usage patterns between buildings in the United States and China. The China-U.S. collaboration in studying those differences provides a unique opportunity to compare the data and better promote building energy efficiency practices in the two countries and finally encourage and promote the industries and businesses related to building energy products and services so that the two countries could become leaders in world market.

1.3 DIFFERENCES IN CHINA-U.S. BUILDING CONSUMPTION DATA

Researchers at Tsinghua University have conducted a series of analyses comparing the energy consumption data of some typical buildings in the two countries. Figure 1.3 shows several selected office buildings in China and the United States with the floor areas ranging from 4650 m^2 to 64,000 m^2 and the annual total energy consumption per building ranging from 34 kWh/m^2/year to 364 kWh/m^2/year. It can be seen from those seven buildings that all buildings in China consumed much less energy than those in the United States. Even the largest building studied here, the 287,000 m^2 Shanghai Office Tower, consumed 215 kWh/m^2/year while the two U.S. buildings consumed 364 and 356 kWh/m^2/year, respectively. Excluding the Shanghai Office Tower, all the other China buildings consumed less than 120 kWh/m^2/year, about a third of U.S. office buildings' energy consumption.

To find out further why such a huge difference exists in energy consumption between two countries, researchers in Tsinghua compared buildings of two university campuses: Tsinghua University in China and the University of Pennsylvania (U. Penn) in the United States. As shown in Fig. 1.4, the two campuses are located in climate zones that have very similar annual outdoor temperature profiles with nearly the same latitude (39.9139°N in Beijing and 39.9500°N for Philadelphia.) The results for energy consumptions of 94 buildings in Tsinghua and 53 buildings at U. Penn are presented in Fig. 1.5. At the University of Pennsylvania, the average annual electricity of 94 buildings is 231 kWh/m^2/year, heating energy is 0.9 GJ/m^2/year, and cooling energy is 1.1 GJ/m^2/year. The Tsinghua University's 53 buildings exhibit the average annual electricity of 63 kWh/m^2/year, and heating of 0.3 GJ/m^2/year. Their cooling energy consumption is included in electricity.

- Small magnetic suspense, oil-free turbine compressor.
- Heat pipe based thermal control.
- Temperature and humidity separated air-conditioning systems.
- Sensors and wireless sensor network.

1.7 SUMMARY

In this chapter, we point out a few key issues related to the research collaboration in the area of building energy between the United States and China. The opportunities exist for researchers from the two countries to understand the significant differences in building energy utilization and the needs to explore the reasons behind the differences. By focusing on the differences and investigating the comparative reasons, it will allow the research communities to invest their time and efforts effectively to arrive at the solutions that could minimize the uncertainties in predicting building energy consumptions. It has been suggested that building occupant behaviors is a significant factor contributing to such uncertainties. The technologies developed, targeting the efficient or reduction of building energy usage, should center on the human comfort tolerance and behaviors directly impacting energy consumption. The resulting new technology solutions will then be better in aligning with human needs and environments they are associated with.

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