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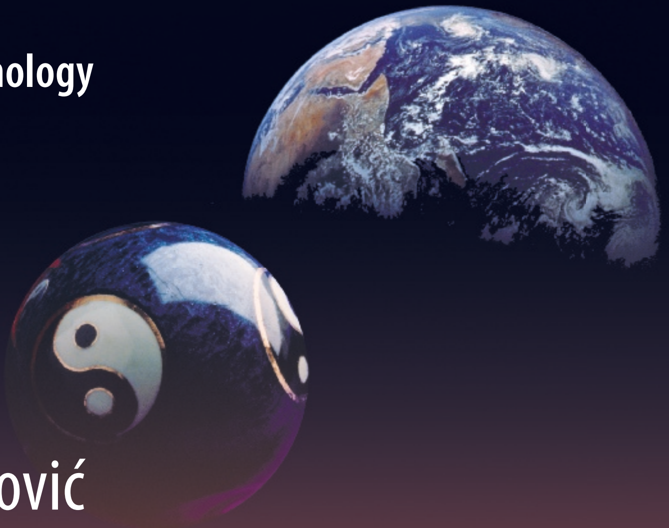

Benjamin Duraković

PCM-Based Building Envelope Systems

Innovative Energy Solutions for Passive Design

Springer

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Foreword

I feel very much delighted to write foreword for this new book titled *PCM-Based Building Envelope Systems: Innovative Energy Solutions for Passive Design*. My past experience has given me the opportunity to work in the area of phase change materials for various thermal applications. During this journey of my research, I have been able to benefit from the novel work of the author of this book "Benjamin Durakovic" on various aspects of phase change materials. Dr. Benjamin is an eminent faculty member of International University of Sarajevo. He is known for his research work that encompasses energy storage using phase change materials for passive building design, building energy efficiency, design of experiments, and data analysis. His tremendous contributions in more than 20 research and development projects in Bosnia and the USA, which lead to the publications of various important research papers in leading world-class journals in aforementioned fields, merit him as the best candidate to compile this book for the benefit of students, faculty members, engineers, researchers, and scientists working in building envelope systems around the globe.

This book is a ready reference to access details of energy storage passive design techniques and mathematical models using phase change materials. This book with eight unique chapters; in the opening chapter, first introduces the emerging problem of depleting resources and emphasizes on the significance of the building energy demands for heating and cooling purposes. Chapter 2 details about the various types of available phase change materials with their application limitations. Chapters 3–6 with pivotal significance provide details on the passive solar heating and cooling concepts. PCM-heat modulation with emphasis on thermal mass and free cooling is further discussed. The use of PCM directly in the building structures and components with possible methods is provided in Chaps. 4 and 5. Chapter 6 discusses the use of PCM as separate heat storage modules. In the later part of the book, the final chapter enlightens the reader with the physics of the processes involved during the heating and cooling of PCMs. Chapter 7 greatly contributes to discuss the heat transfer modes and mechanisms involved and finally elaborates the work on available simulation and modeling tools for PCM-based building envelope systems.

In a nutshell, this book will prove to be a complete guide for those already working in the domain of building envelope systems and looking for innovative energy solutions using phase change materials. For the beginners in the field of building envelope systems, this book will provide a complete walk through to the various stages and will help the reader to advance to the next level with detailed fundamental and applied knowledge.

October 2019

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Preface

Introduction

This book provides the latest research in the field of thermal energy storage technologies applicable for solar heating and cooling with the aim of reducing fossil fuel dependency. Particularly, the book discusses issues and advantages of common PCMs applicable for buildings as a more efficient novel solution for passive solar heating/cooling strategies. Up-to-date PCM-based energy storage solutions within building structure (wall, floor, ceiling, façade), components (windows, shading devices), and separate heat and cold storage devices are discussed in details. With the aim of building energy performance assessment, the book provides advanced modeling and simulation tools as theoretical base for the analysis of PCM-based building envelope in terms of heat storage and transfer.

Audience

This book will be of great value to those who deal with building energy analysis such as students, researchers, and professionals involved in the field of mechanical and civil engineering as well as architectural design.

The Aim of the Book

In the last few decades, world energy demand based on limited non-renewable sources was rapidly increased. The participation of the building sector through heating and cooling in global energy consumption is notable and takes up to 40%. To reduce building energy demand and carbon emission, it is necessary to implement innovative design concepts such as passive strategies. Heat storage plays one of the most important roles in building energy demand reduction. Emerging technologies based on the application of phase change materials (PCMs) in building envelope enhance the thermal performances of buildings and reduce energy demand.

Passive building design based on PCM is very active research area and new results and techniques become available almost on the continuous basis. The aim of this book is to present the state of the art in this research field including novel achievements based on the application of PCMs. Therefore, the book represents a collection of novel methods, techniques, and the recent research results including own research. Key problems and possible solutions were discussed.

Book Structure

In this book, *PCM-Based Building Envelope Systems: Innovative Energy Solutions for Passive Design*, passive design techniques based on phase change materials for energy storage as well as basics of the mathematical models were discussed. Each chapter has abstract, body, and conclusion. Graphical explanations and tables were used within the body to present key information in a quick way. Figure 1 represents graphical structure of the book.

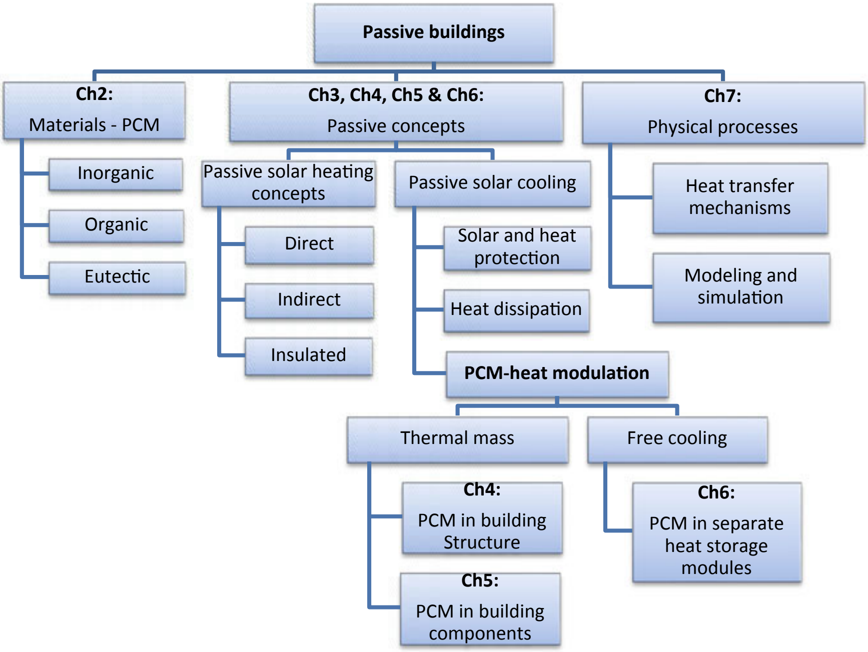

Fig. 1 Book structure

The book is organized into three major areas that are important for passive building design. In the first part, phase change materials and its properties, and advantages, disadvantages, and possibilities to be used for heat storage in passive building concepts were discussed in Chap. 2. In the second part, passive design techniques for heating and cooling were discussed. Particularly, the working principle of each technique was discussed with recent research developments and application. The part that deals with PCM-based energy storage techniques within the building structure was discussed in detail in Chap. 4; the PCM-based energy storage within building components was discussed in details in Chap. 5, and the PCM-based energy storage in separate heat storage modules was discussed in Chap. 6. Finally, the basics of the mathematical models for heat transfer modes and numerical simulation were introduced in Chap. 7.

Special attention was paid to the glazing systems as the weakest point of buildings in terms of heat gain/loss. Therefore, the aim in this case is to search for new technologies to reduce the energy consumption demand in buildings by considering different glazing system designs as responsive building elements and applying new materials. These systems contribute in reducing on-peak energy demand. Special focus is on the advantages of surplus heat gains made at midday stored in the thermal mass and its availability to the load offset later in the day when the outside temperature drops in winter/summer mode. In addition, to conduct comparative study of glazed systems performances for those based on the conventional technologies versus responsive glazed system technology with the aim of identifying the most appropriate system as a design solution.

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Special thanks to Dr. Hafiz Muhammad Ali for taking his valuable time to read the manuscript and write the book foreword. Special recognition is due to my family who constantly has much patience with me and has contributed greatly toward success of this book.

About This Book

In the last few decades, world energy demand based on limited non-renewable sources was rapidly increased. The participation of the building sector through heating and cooling in global energy consumption is notable and takes up to 40%. To reduce building energy demand and carbon emission, it is necessary to implement innovative design concepts such as passive strategies. Heat storage plays one of the most important roles in building energy demand reduction. Emerging technologies based on the application of phase change materials (PCMs) in building envelope enhance the thermal performances of buildings and reduce energy demand. These materials use latent heat of fusion to store relatively large amounts of energy for later usage, at narrow temperature ranges.

This book provides the latest research in the field of thermal energy storage technologies applicable for solar heating and cooling with the aim of reducing fossil fuel dependency. Particularly, the book discusses issues and advantages of common PCMs applicable for buildings as a more efficient novel solution for passive solar heating/cooling strategies. Up-to-date PCM-based energy storage solutions within building structure (wall, floor, ceiling, façade), components (windows, shading devices), and separate heat and cold storage devices are discussed in detail. With the aim of assessment of building energy performance, the book provides advanced modeling and simulation tools as theoretical base for the analysis of PCM-based building envelope in terms of heat storage and transfer.

This book will be of great value to those who deal with building energy analysis such as students, researchers, and professionals involved in the field of mechanical and civil engineering as well as architectural design.

Benjamin Duraković

Contents

About the Author

Benjamin Duraković is Assistant Professor at Faculty of Engineering and Natural Sciences, International University of Sarajevo. His research interests are energy storage using phase change materials for passive building design, building energy efficiency, design of experiments, and data analysis. He has authored or co-authored many research papers in the aforementioned topics and published in a variety of leading journals including *Sustainable Cities and Society, International Journal of Low-Carbon Technologies, Journal of Materials and Environmental Science*. He teaches courses at both undergraduate and post-graduate levels in the above-mentioned areas. Apart from this, he has completed or participated in more than 20 R&D innovation projects with Bosnian and US companies. He is actively involved as reviewer for leading journals including *Energy conversion and management, Energy and Buildings, Construction and Building Materials*, and he is Journal Editor of *Periodicals of Engineering and Natural Sciences*. e-mail: bdurakovic@ius.edu.ba

Chapter 1
Introduction

Strong economic and population growth in the last three decades caused a rapid increase in the world energy consumption producing an enormous amount of greenhouse gases (GHG). Fossil fuels are primary sources of CO_2, which take a share of about 65% in total GHG. Nowadays, there is a global trend of reducing greenhouse gasses. This reduction is primarily based on research and investigation of different innovative technologies that would positively affect GHG reduction. As one of the main contributors to the production of greenhouses is buildings and construction sector through energy consumption, building energy demand reduction is being directed toward research and development of innovative technologies that would decrease fossil fuel consumption.

Today, energy conversion and electricity generation are mainly based on burning fossil fuels and nuclear power (fission or fusion), which all rely on finite resources generating waste end products in an irreversible cycle Fig. 1.1. Fossil and nuclear fuel reserves are limited and generate huge amounts of waste and pollutant emissions. At the current consumption rate, coal reserves will run out in about 130 years, natural gas in about 60 years, and oil in about 40 years [1].

Based on Fig. 1.1, about three-quarters of power generation comes from non-renewable sources, which have very limited reserves. Building energy takes about 40% of global energy demand. Applying passive design strategies can contribute to the reduction in building energy demand.

1.1 Depletion of the Non-renewable Energy Resources

Coal consumption has never stopped increasing and has been the world's fastest-growing energy source in recent years—faster than gas, oil, nuclear, hydro, and renewable energy as shown in Fig. 1.2 [3]. This trend will continue in the future where coal will be a key component of the energy mix. Total world coal production

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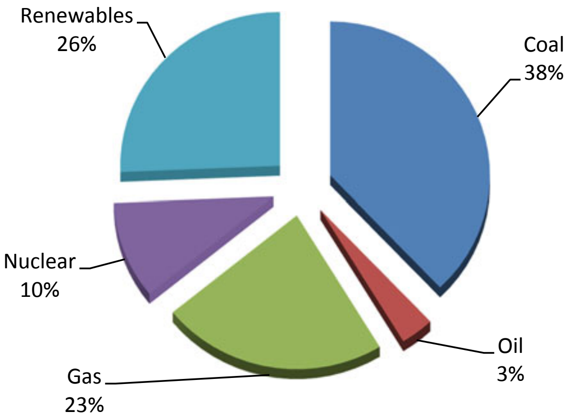

Fig. 1.1 World electricity production from all energy sources in 2018 [2]

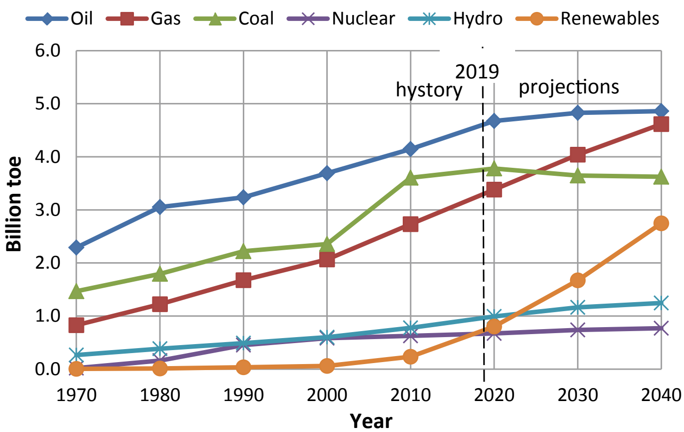

Fig. 1.2 World energy consumption by 2040 [2]

reached a record level in 2012, increasing by 2.9% in comparison with the previous year. Coal plays a key role in power generation and currently fuels 38% of the world's electricity. The figure is much higher in some individual countries. South Africa relied on coal for 94% of its electricity and Poland for 81% in 2014 [2] (Fig. 1.3).

In fact, it is expected that the share of the coal in electricity generation will be reduced below 30%, while the renewables will overtake gas and coal as the most used form of primary energy as of 2040.

World oil consumption is well reflecting the increase in the consumer demand for petroleum products, and it is on track to become critically low in 40 years. This means humankind cannot afford to wait 40 years, and must urgently conduct energy-saving programs and transition to alternative energy sources in the following

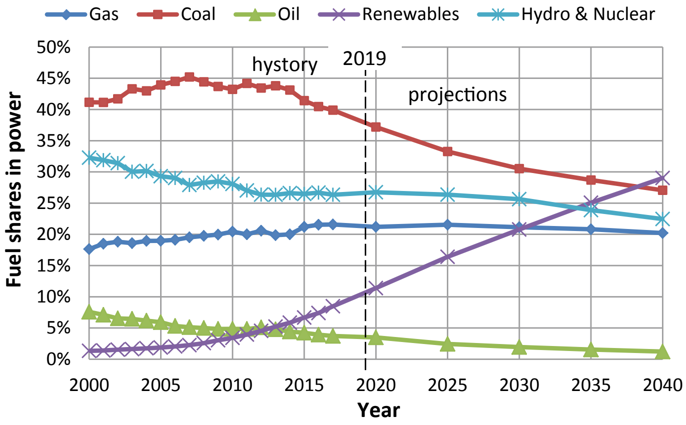

Fig. 1.3 Fuel shares in world electricity generation [2]

two decades. While this figure is hotly debated, what is clear is that oil has a host of useful industrial applications and to irreversibly burn oil endangers the future. World crude oil demand has been growing at an annualized compound rate slightly in excess of 2.0% per year recently. Demand growth is highest in the developing world, particularly in China and India. High demand growth is primarily caused due to rapidly rising consumer demand for transportation via cars and trucks powered with internal combustion engines. For economic and/or political reasons, this high demand growth component did not exist in most of the developing world even a decade ago [4].

Natural gas consumption is the fast-growing fossil fuel with estimated reserves for 60 years. Total world consumption of natural gas for industrial uses increases by an average of 1.5% per year through 2040, and consumption in the electric power sector grows by 2.0% per year. Growth in consumption occurs in countries outside of the Organization for Economic Co-operation and Development (OECD) member countries, where demand increases more than twice as fast as in OECD countries. Growth in natural gas consumption is particularly high in non-OECD countries, where economic growth leads to increased demand over the projection period. Consumption in non-OECD countries grows by an average of 2.2% per year through 2040, more than twice as fast as the 1.0% annual growth rate for natural gas demand in the OECD countries [5].

Oil, gas, and coal are a precious resource that humankind cannot afford to burn completely, thus consumption of these resources must be slowed down. Someday, currently unknown sources of fossil fuels may be discovered, but it would be irresponsible to base today's energy decisions on such an uncertain prediction. One is sure that continuation of oil burning can harm the viability of the future because oil is needed for lubricating the machines of the world for years to come, as well as to secure its continued use in the petrochemical industry [6]. Thus, we do need to sustain these fossil-based industries for their industrial applications, rather than as primary sources of energy.

How to meet extra energy demand in upcoming decades and on the other side reduce building energy demand with the aim of preserving fossil fuels will be challenging in the future.

1.1.1 Energy Consumption in Buildings

In recent years, the demands in building thermal comfort rise increasingly, which correspondingly cause a substantial increase in global energy consumption. For instance, in industrialized countries, building heating and cooling (residential and commercial energy consumption) participate between 20 and 40% in total energy consumption [7]. Windows can account for between 30 and 50% of the energy losses in buildings [4]. Opposed to other industrialized countries, building heating was accounted for 63% of natural gas consumed in US homes; the remaining 37% was for water heating, cooking, and miscellaneous uses [4]. In the European Union, the building sector is consuming 40% of the global energy, and two-thirds of this energy consumption is due to the heating, ventilation, and air-conditioning (HVAC) systems. Therefore, it is critical to reduce the energy demand of the buildings [8].

To reduce energy demand in buildings and contribute to preserving fossil fuels can be achieved by passive building design, using renewable energy sources, improving the thermal insulation of building envelope and storing energy for later usage. Solar energy is one of the most considered energy sources for building space heating, cooling, or solar hot water between 2010 and 2020, and generation from renewables grows 5.2% per year, compared with 3.9% per year between 2000 and 2010. Estimated global electricity generation from renewable energy sources will grow 2.7 times between 2010 and 2035 [9].

Solar heating systems use solar energy to heat the interior space or to store the energy in a storage system for later use. The heat is transferred by a heat transfer fluid (HTF), which can be either liquid or air. Liquid systems are more often used when storage is included and are well suited for radiant heating systems, boilers with hot water radiators, and even absorption heat pumps and coolers. Solar space cooling is an innovative technology that converts heat collected from the sun into useful cooling for applications such as building space conditioning. Obtained heat through the use of solar collectors is converted into cold using a “sorption” cooling process. The resulting cold is delivered to the application using an HTF (chilled water or dry cool air). Solar hot water is a simple and relatively inexpensive way to reduce energy consumption in residential and commercial buildings. The solar hot water system is comprised of solar collectors and an automatic control unit that work together. By harnessing the power of the sun, the systems can reduce the need for electricity 25–50%. In case that the solar system cannot provide adequate space heating, an auxiliary system provides the additional heat.

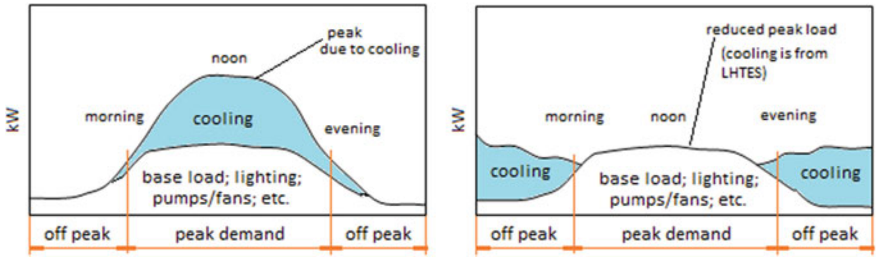

Fig. 1.4 Electrical profile—conventional building using chillers versus TES electrical profile

Different shading devices, solar attic cooling, and façade cooling can reduce energy demand in buildings as well. Hot attics cause the entire house to be warmer. Attic air temperatures can reach over 70 °C. Super-hot air gets trapped and collects in attics and causes heat to back up in the building.

Emerging technologies that improve building envelope performance have significant potential to reduce building energy consumption. Actual savings from these technologies will depend heavily upon their performance in diverse climate and operational conditions. Performance levels are determined to overcome existing window technologies as well. Overall heating and cooling savings depend mostly on how well solar heat is blocked [10].

Energy and its storage are one of the biggest technology challenges of the upcoming decades. Thermal energy storage (TES) systems as responsive building elements can contribute to reducing on-peak electricity demand. Latent heat thermal energy storage (LHTES) is an attractive technique for accumulating energy because it provides a high-energy storage density per unit of mass at constant or near-constant temperature. Thus, LHTES requires a smaller amount of phase change material (PCM) for the same amount of stored energy. The principle of PCM is a simple endothermic and exothermic reaction.

Referring to Fig. 1.4, the largest moveable portion of the building's electrical load can be shifted from high-cost "on-peak" hours to low-cost "off-peak" hours. TES/LHTS system is charged by capturing low-cost ("off-peak") electricity from the power grid during the night and then using this captured energy for cooling over the following day ("on-peak" hours). Another way is capturing solar heat over the day and using it over the night for heating in the wintertime.

As Fig. 1.4 shows, in conventional systems, the chiller must be run only when the building occupants want cool air. In a thermal energy storage system, the chiller can be run at times other than only when the occupants want cooling, as much as half of the energy consumed in a commercial building is used for cooling and heating. By using properly designed TES solutions, often up to 30–40% of this energy use can be saved [11]. The ability to store energy for use at peak demand is a challenge for delivering efficient innovative technologies and solutions.

Based on the recommendations given in IEA ECBCS (*International Energy Agency, Energy Conservation in Buildings & Community Systems*) Annex 44, and