IEEE Press Series on Systems Science and Engineering
MengChu Zhou, Series Editor

Energy Conservation in Residential, Commercial, and Industrial Facilities

edited by
Hossam A. Gabbar

IEEE PRESS

WILEY

ENERGY CONSERVATION IN RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL FACILITIES

IEEE Press
445 Hoes Lane
Piscataway, NJ 08854

ENERGY CONSERVATION IN RESIDENTIAL, COMMERCIAL, AND INDUSTRIAL FACILITIES

Edited by
HOSSAM A. GABBAR

Systems, Man, & Cybernetics Society

IEEE PRESS

WILEY

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

Library of Congress Cataloging-in-Publication Data is available.

ISBN: 978-1-119-42206-8

Cover design: Wiley
Cover image: © WangAnQi/iStockphoto

Printed in the United States of America.

10 9 8 7 6 5 4 3 2 1

I dedicate this book to my wife Naila Gaber for her great support, and to my son John Gaber and daughter Sophia Gaber for inspiring and motivating me to complete the book.

TABLE OF CONTENTS

PART II ENERGY SYSTEMS

PREFACE

Energy consumption in infrastructures represents almost one-third of total energy demand. As energy is linked to greenhouse gas emissions, which is linked to climate change and global warming, it is important to provide intelligent systems to support both energy conservation and energy supply in infrastructure systems.

This book shows business model and engineering design framework for practical implementation of energy conservation in infrastructures such as buildings, hotels, public facilities, industrial facilities, transportation, and water/energy supply infrastructures. Key performance indicators are modeled and used to evaluate energy conservation strategies and energy supply scenarios as part of the design and operation of energy systems in infrastructures. The proposed system approach shows effective management of building energy knowledge, which supports the simulation, evaluation, and optimization of several building energy conservation scenarios. Case studies are used to illustrate the proposed energy conservation framework, practices, methods, engineering designs, control, and technologies.

This book will offer the following new concepts:

- Infrastructure energy modeling
- Building envelope modeling
- Energy conservations methods
- Energy semantic networks (ESN) superstructures
- Energy conservation strategies and performance measures
- Examples in HVAC, lighting, appliances, storage, and machines

- Energy conservation optimization techniques
- Risk-based life cycle assessment
- Control strategies and systems for energy conservation
- Advanced energy audit systems

This book is structured into four parts:

Part I Energy Infrastructure Systems
Part II Energy Systems
Part III Energy Conservation Strategies
Part IV Resiliency, Protection, Control, and Optimization Systems

This book will help technology providers, infrastructure support industries, construction companies, municipalities, and regulatory institutions to study and manage energy conservation in infrastructures that include residential buildings, industrial facilities, transportation, and city infrastructures.

University of Ontario Institute of Tech, Ontario, Canada Hossam A. Gabbar

AUTHORS' BIOGRAPHY

Onur Elma received his M.S. and Ph.D. degrees in Electrical Engineering from Yildiz Technical University (YTU), Istanbul, Turkey, in 2011 and 2016, respectively. He worked as a project engineer in the industry between 2009 and 2011. He has been employed as Research Assistant in Electrical Engineering Department in YTU since 2011. He has been in Smart Energy Research Center (SMERC) at University of California, Los Angeles (UCLA) as a visiting researcher from 2014 to 2015. Currently, he is working as a post-doc researcher at University of Ontario Institute of Technology (UOIT). He has participated in many national and international projects and also has to his credit more than 25 papers. His research interests include smart grid, electric vehicles, home energy management systems, and renewable energy systems.

Hossam A. Gabbar is a full Professor in Faculty of Energy Systems and Nuclear Science at University of Ontario Institute of Technology (UOIT), and cross appointed in the Faculty of Engineering and Applied Science, where he has established both the Energy Safety and Control Lab (ESCL) and Advanced Plasma Engineering Lab. He is the recipient of the Senior Research Excellence Award for 2016, UOIT. Dr. Gabbar obtained his B.Sc. (Honors) degree in 1988 in first class from the Faculty of Engineering, Alexandria University (Egypt). In 2001, he obtained his Ph.D. degree from Okayama University (Japan) in Safety Engineering. From 2001 to 2004, he worked at Tokyo Institute of Technology (Japan), and from 2004 to 2008, he was Associate Professor in the Division of Industrial Innovation Sciences at Okayama University (Japan). From 2007 to 2008, he was a Visiting

Professor at the University of Toronto. He has more than 210 publications to his credit, including patents, books/chapters, journals, and conference papers.

Shibo Luo was born in Hunan, China, in 1977. He is currently pursuing the Ph.D. degree in Shanghai Jiao Tong University, Shanghai, China. He participates in many national projects, such as National Natural Science Foundation of China, National "973" Planning of the Ministry of Science and Technology, China, and so on. His research interests include SDN network security, network service composition, and so on.

Farayi Musharavati is currently Associate Professor in Department of Mechanical and Industrial Engineering, Qatar University. He obtained his Ph.D. in Manufacturing Systems from University Putra Malaysia in 2008. He holds MSc degree in both Manufacturing Systems and Renewable Energy and a B.Tech. (Honors) degree in Mechanical and Production Engineering from the University of Zimbabwe, Zimbabwe. Research interests include manufacturing systems, energy management, sustainability, waste management, life cycle assessment, applications of computational intelligence, smart water and smart energy, and renewable energy applications.

Ahmed M. Othman is Associate professor at Zagazig University, Egypt. He worked as a postdoctorate fellow at University of Ontario Institute of Technology (UOIT), Canada. He obtained his B.Sc. and M.Sc. degrees in electrical engineering from Zagazig University, Egypt in 2002 and 2004, respectively, and received his Ph.D. degree in electrical engineering from Aalto University, Finland in 2011. His current research areas include power quality issues, DFACTS technology, distributed energy resources interface and control and application of artificial intelligent techniques on power systems, microgrid, and renewable energy.

Shaligram Pokharel is a professor of Mechanical and Industrial Engineering at Qatar University, Doha, Qatar. Prior to joining this university, he held academic positions in Nanyang Technological University, Singapore. He holds B.E. (Honors) in Mechanical Engineering from the Regional Engineering College (Kashmir, India) and M.A.Sc. and Ph.D. in Systems Design Engineering from the University of Waterloo, Ontario, Canada. His research areas are focused in energy planning and modeling, low carbon supply chains, engineering management, reverse logistics, and emergency and humanitarian logistics.

Jason Runge obtained his M.A.Sc degree in Electrical Engineering in 2016 and a Bachelor of Engineering in Energy Systems Engineering in 2014 from the University of Ontario Institute of Technology. Currently, he is working toward his Ph.D. in Building Engineering at Concordia University. His research interests include energy forecasting, energy management, building management systems, and renewable energy systems.

Khairy Sayed received his B.S. degree in Electrical Power and Machines in 1997 from Assiut University, Assiut, Egypt. He obtained his Master's degree from the Electrical Energy Saving Research Center, Graduate School of Electrical Engineering, Kyungnam University, Masan, Korea, in 2007. He received his Ph.D. degree from Assiut University in 2013. He is working as Assistant Professor in the department of Electrical Engineering, Sohag University, Egypt. His research interests include soft switching converters, solar PV, wind energy, fuel cell, power conditioners for renewable energy sources, smart energy grids, protection, and control of smart microgrids. He has more than 10 years of experience in SCADA/DMS during his work in Middle Egypt Electricity Distribution company as a system integrator for control center project. He was a Visiting Scholar in University of Ontario Institute of Technology (UOIT) in 2016. At present he is working as a head of electrical department in Assiut Integrated Technical Education Cluster (ITEC), Assiut, Egypt.

Kartikey Singh is a final year student in electrical engineering and visiting student at the Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, where he worked on a research project in the area of transportation electrification and supported research tasks related to heuristic approaches for central control system design for resilient microgrids in transportation electrification applications.

Jun Wu received the Ph.D. degree in Information and Telecommunication Studies from Waseda University, Japan, in 2011. He was Post-Doctoral Researcher at the Research Institute for Secure Systems, National Institute of Advanced Industrial Science and Technology (AIST), Japan, from 2011 to 2012. He was Researcher at the Global Information and Telecommunication Institute, Waseda University, Japan, from 2011 to 2013. He is currently Associate Professor of the School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, China. He is also the Vice Director of National Engineering Laboratory for Information Content Analysis Technology, Shanghai Jiao Tong University, China. He is the chair of IEEE P21451-1-5 Standard Working Group. His research interests include advanced computing, communications and security techniques of software-defined networks (SDN), information-centric networks (ICN) smart grids, and Internet of Things (IoT) on which he has published more than 90 refereed papers. He has been Guest Editor of the *IEEE Sensors Journal*. He is Associate Editor of the IEEE Access. He is a member of IEEE.

Aboelsood Zidan was born in Sohag, Egypt, in 1982. He received his B.Sc. and M.Sc. degrees in electrical engineering from Assiut University, Egypt, in 2004 and 2007, respectively, and his Ph.D. in electrical engineering from University of Waterloo, Waterloo, Ontario, Canada in 2013. He is currently Assistant Professor at Assiut University, Egypt. His research interests include distribution automation, renewable energy, distribution system planning, and smart grids.

LIST OF CONTRIBUTORS

ONUR ELMA, Department of Electrical Engineering, Yildiz Technical University, Istanbul, Turkey; Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada

HOSSAM A. GABBAR, Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology; Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, Canada

SHIBO LUO, School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China

FARAYI MUSHARAVATI, Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, Doha, Qatar

AHMED M. OTHMAN, Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada; Electrical Power and Machines Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt

SHALIGRAM POKHAREL, Department of Mechanical and Industrial Engineering, College of Engineering, Qatar University, Doha, Qatar

JASON RUNGE, Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, Canada

KHAIRY SAYED, Sohag University, Egypt; Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada

KARTIKEY SINGH, Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada

JUN WU, School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, Shanghai, China

ABOELSOOD ZIDAN, Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada

ACKNOWLEDGMENTS

The editor would like to thank all contributors to this book, and the research team at the Smart Energy Systems Lab (SESL) at UOIT for their full dedication and quality research. Also, the editor would like to thank IEEE SMC for providing the chance to publish this work. We acknowledge UOIT for their continuous support to the research work at SESL.

PART I

ENERGY INFRASTRUCTURE SYSTEMS

CHAPTER 1

ENERGY IN INFRASTRUCTURES

HOSSAM A. GABBAR[1,2]
[1]Faculty of Energy Systems and Nuclear Science, University of Ontario Institute of Technology, Oshawa, Canada
[2]Faculty of Engineering and Applied Science, University of Ontario Institute of Technology, Oshawa, Canada

1.1 INFRASTRUCTURE SYSTEMS

As measured in 2015, around 1.2 billion people, constituting 17% of the global population, do not have electricity, and 2.7 billion people, constituting 38% of the global population, have risks on their health due to the reliance on the traditional use of biomass for cooking [1].

In order to discuss energy systems and conservation strategies in infrastructures, it is essential to analyze the infrastructure physical systems and their types, classifications, and energy requirements. It is possible to find a suitable definition of infrastructures as the fundamental facilities and systems that serve a region, area, community, city, or country, including the support facilities such as utilities, services, and transportation that are necessary for the economic development and perform all necessary functions. There are number of ways to classify infrastructures, such as size, criticality, use, occupancy, location, and surroundings. Infrastructures can support residential functions, commercial and public functions, transportation functions (including land, sea, air), and industrial functions. Infrastructures can be viewed as system of systems; for example, infrastructures include communications and cyber security, computational/technological, waste management, emergency and disaster management, defense and military, and other supporting infrastructures. The better we understand infrastructures, the better we design and operate energy systems in these infrastructures. Infrastructure modeling should support design and operational activities, with appropriate and comprehensive performance measures to evaluate design and operation features

Energy Conservation in Residential, Commercial, and Industrial Facilities, First Edition.
Edited by Hossam A. Gabbar.

and alternatives. Requirement analysis of infrastructures should include energy demand, risk management, performance, and sustainability requirements.

1.1.1 Infrastructure Classifications

Energy use in infrastructures can be controlled and optimized based on the nature of loads and energy systems implemented in these infrastructures. For proper planning, design, and operation of energy systems to support these infrastructures, it is important to analyze the classifications of infrastructures. Figure 1.1 shows hierarchical classification of infrastructures based on nature, type, use, function, and energy requirements. There are interrelations among these infrastructures, for example, water infrastructures are linked to residential, industrial, and commercial. Similarly, energy and waste are linked to all other infrastructures.

In order to understand energy consumption in different regions, power consumption in Ontario has been selected, as presented in Figure 1.2, where it shows the consumption in residential, commercial, industrial, electric vehicle, transit, and others. Power consumption in residential is very close to that consumed in commercial, while industrial is the third dominating sector for power consumption.

1.1.2 Infrastructure Systems

Infrastructure system includes technical and technological infrastructures to support all functions and the management of life cycle activities in infrastructures including flow and control of information across all elements of the infrastructure systems. Modeling of processes of infrastructure systems includes players, roles,

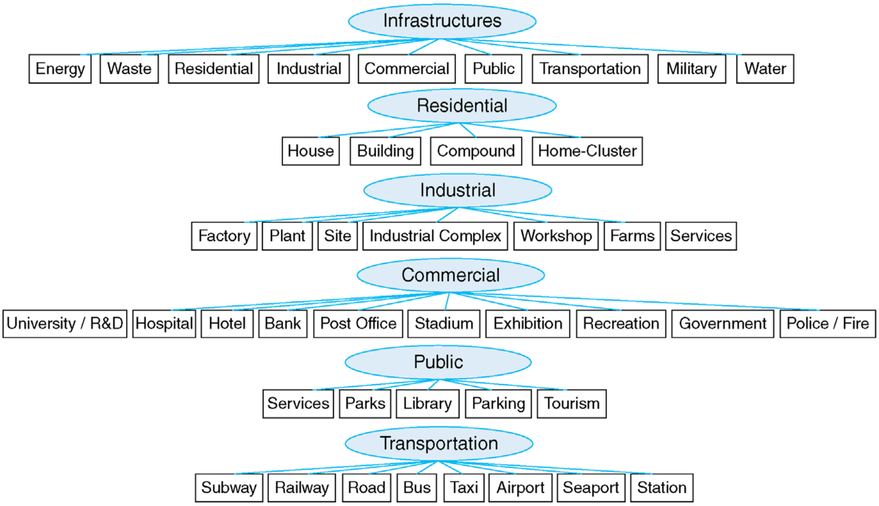


FIGURE 1.1 Infrastructure classifications.

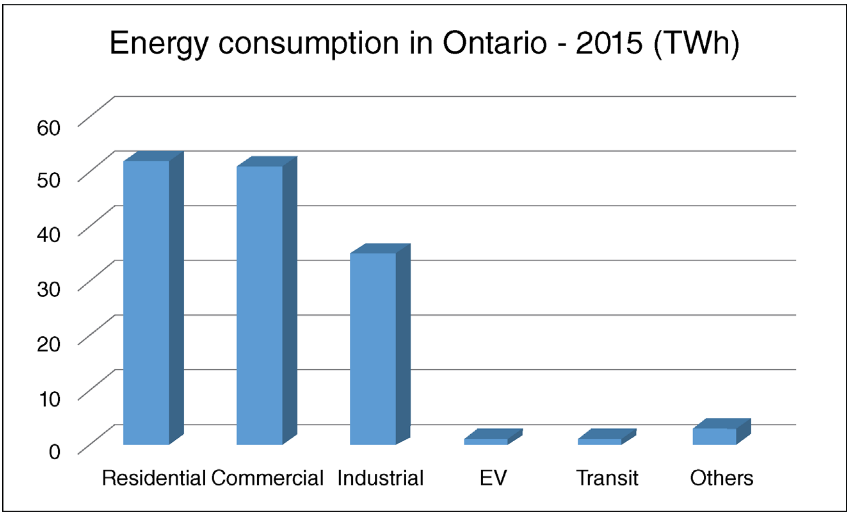


FIGURE 1.2 Power consumption in Ontario – 2015.

physical systems, functional modeling, financial modeling, planning, engineering design, operation, and management practices. One major component of infrastructure systems is the safety and protection systems to ensure the resiliency against hazardous, emergencies, and disaster situations and to sustain the stated target functions from the infrastructure systems.

1.2 ENERGY SYSTEMS IN RESIDENTIAL FACILITIES

Energy consumption in residential facilities constitutes one of the largest consumption of energy in cities and communities in Canada and worldwide. In 2015, energy consumption in residential facilities in Ontario is 52 TWh, which represents 36% of total energy consumption. Energy consumption in residential facilities include heating/cooling, electric loads, water heating, laundry, dishwashing, refrigerators and freezers, cooking, TV, lighting, and computer-related equipment, as shown in Figure 1.3. The highest energy use is in heating and cooling and ventilation, where it is clear the reduced use from 2013 to 2040. This can be justified by improved heating and cooling technologies and efficiencies. Electric loads and water heating are second largest energy use in the residential sector. Energy conservation strategies are widely adopted by utilities to reduce energy demand from utilities in residential facilities. Typically, utility grids supply energy to residential facilities. Energy conservation can represent around 1–3% of total energy demand in residential facilities. With the penetration of local distributed generation, energy can be supplied by

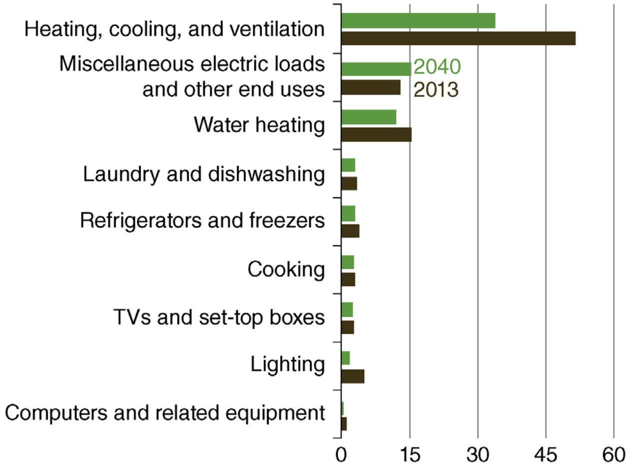


FIGURE 1.3 Residential sector delivered energy intensity for selected end uses in the Reference case, 2013 and 2040 (million Btu per household per year) [2].

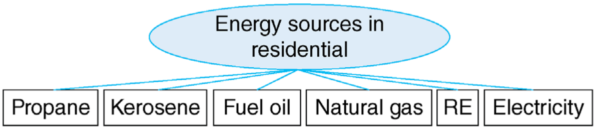
renewable energy technologies such as PV, energy storage, wind, gas generators, fuel cells, and geothermal systems.

There are a number of energy systems and technologies that are adopted in residential facilities, such as gas-fired water heaters, oil-fired water heaters, electric water heaters, heat pump water heaters, instantaneous water heaters, solar water heaters, gas-fired furnaces, oil-fired furnaces, gas-fired boilers, oil-fired boilers, room air conditioners, central air conditioners, air-source heat pumps, ground-source heat pumps, gas-source heat pumps, electric resistance furnaces, electric resistance unit heaters, cordwood stoves, wood pellet stoves, refrigerators-freezers, freezers, natural gas cooktops and stoves, clothes washers, clothes dryers, and dishwashers. Among the factors that are used to evaluate these energy systems are capacity, efficiency, energy factor (EF), combined energy factor (CEF), annual energy use, annual water use, average life, retail equipment costs, installation costs, and maintenance costs. These factors are used to evaluate the different energy systems in residential facilities to ensure most effective technology that can be applied in different regions and weather conditions.

Energy consumption in residential facilities can be viewed as in Figure 1.4, where it shows different types of energy sources, such as propane, kerosene, distillate fuel oil, natural gas, renewable energy, and electricity.

It is clear that electricity and natural gas represent the highest consumption from 2012 and projected till 2040. It is also noted that losses are quite high and energy conservation strategies will be essential for effective savings.

Energy prices for residential use are shown in Figure 1.5, which shows price of natural gas (NG) is the lowest, while electricity price is the highest.



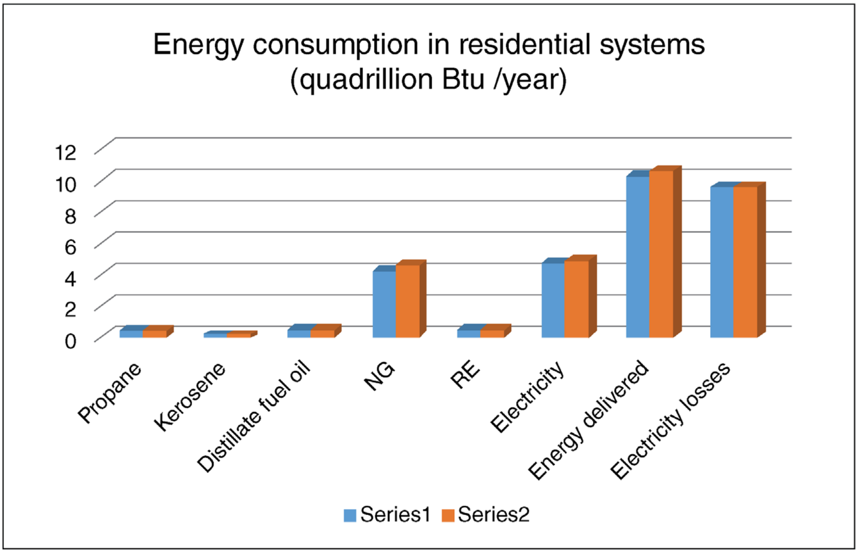


FIGURE 1.4 Energy consumption in residential systems, quadrillion Btu per year in the United States, 2012: gray, 2020: dark gray [2].

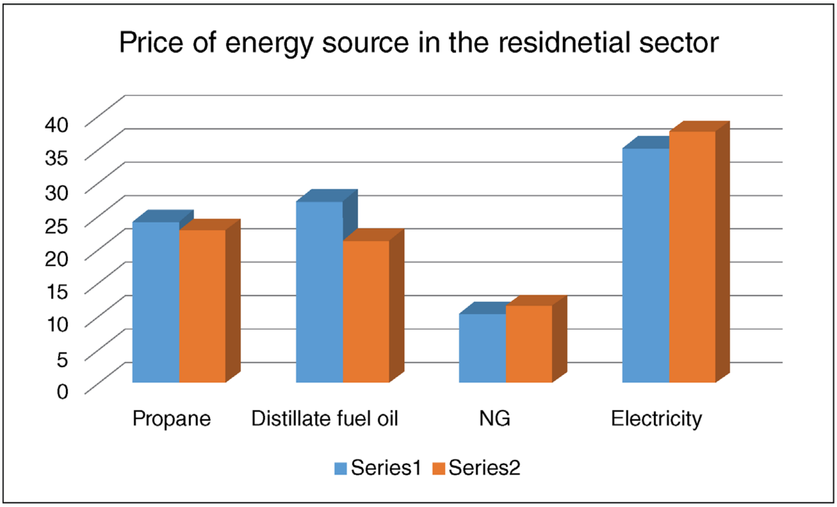


FIGURE 1.5 Energy prices in the residential sector, dollars per million Btu in the United States, 2012: gray, 2020: dark gray [2].

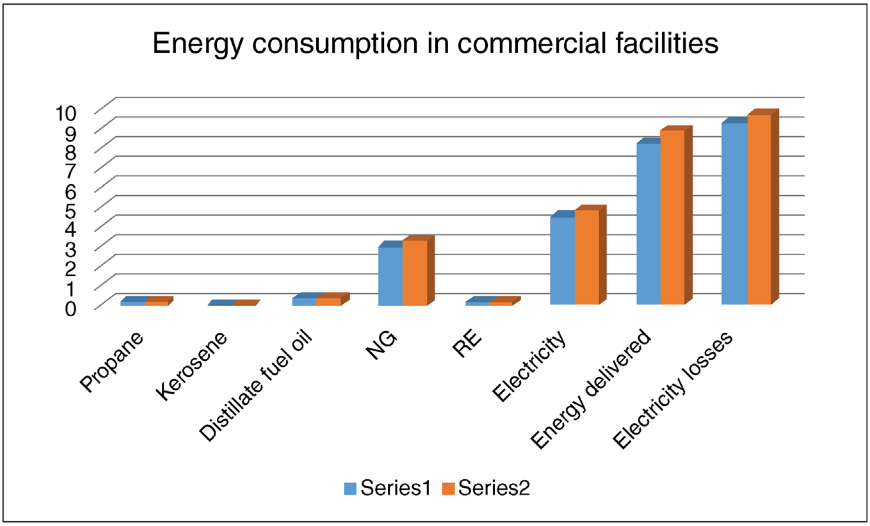


FIGURE 1.6 Energy consumption in commercial facilities in the United States, 2012: gray, 2020: dark gray [2].

1.3 ENERGY SYSTEMS IN COMMERCIAL FACILITIES

Energy consumption in commercial facilities, as stated by Department of Energy (DOE) [2], is shown in Figure 1.6. Electricity consumption is higher than NG use. While NG is cheaper than electricity, it is possible to provide better solution with increase in NG penetration in commercial use.

Also, energy prices in commercial facilities are shown in Figure 1.7.

It is shown that NG price for the residential sector is higher than NG price for the commercial sector.

1.4 ENERGY SYSTEMS IN INDUSTRIAL FACILITIES

In the industrial sector, Figure 1.8 shows the consumption from 2015 [2].

Also, energy prices in the industrial sector are shown in Figure 1.9, which shows the NG as the lowest clean energy source for the industrial sector.

1.5 ENERGY SYSTEMS IN TRANSPORTATION INFRASTRUCTURES

It is widely known that greenhouse gas (GHG) emission from transportation sector is high. The proper analysis of energy consumption in the transportation is important to address issues related to energy conservation with sustainability considerations, as shown in Figure 1.10.

Energy prices in the transportation sector are shown in Figure 1.11.

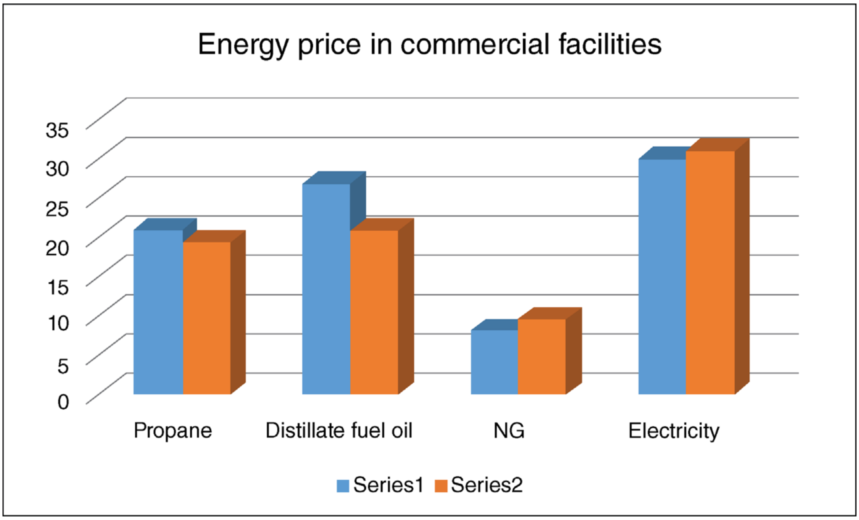
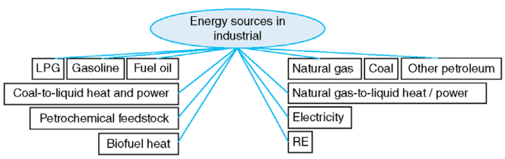


FIGURE 1.7 Energy prices in the commercial sector, dollars per million Btu in the United States, 2012: gray, 2020: dark gray [2].



Sector and source	Reference case							Annual growth 2013–2040 (%)
	2012	2013	2020	2025	2030	2035	2040	
Industrial[4]								
Liquefied petroleum gases and other[5]	2.42	2.51	3.20	3.56	3.72	3.69	3.67	1.4%
Motor gasoline[2]	0.24	0.25	0.26	0.26	0.25	0.25	0.25	0.0%
Distillate fuel oil	1.28	1.31	1.42	1.38	1.36	1.34	1.35	0.1%
Residual fuel oil	0.07	0.06	0.10	0.14	0.13	0.13	0.13	2.9%
Petrochemical feedstocks	0.74	0.74	0.95	1.10	1.14	1.17	1.20	1.8%
Other petroleum[6]	3.33	3.52	3.67	3.80	3.83	3.89	3.99	0.5%
Petroleum and other liquids subtotal	8.08	8.40	9.61	10.24	10.44	10.47	10.59	0.9%
Netural gas	7.39	7.62	8.33	8.47	8.65	8.76	8.90	0.6%
Natural-gas-to-liquids heat and power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--
Lease and plant fuel[7]	1.43	1.52	1.87	1.98	2.10	2.18	2.29	1.5%
Natural gas subtotal	8.82	9.14	10.20	10.44	10.75	10.94	11.19	0.8%
Metallurgical coal	0.59	0.62	0.61	0.59	0.56	0.53	0.51	–0.7%
Other industrial coal	0.87	0.88	0.93	0.95	0.96	0.97	0.99	0.4%
Coal-to-liquids heat and power	0.00	0.00	0.00	0.00	0.00	0.00	0.00	--
Net coal coke imports	0.00	–0.02	0.00	–0.01	–0.03	–0.05	–0.06	4.5%
Coal subtotal	1.47	1.48	1.54	1.53	1.48	1.44	1.44	–0.1%
Biofuels heat and coproducts	0.73	0.72	0.80	0.80	0.80	0.81	0.86	0.6%
Renewable energy[8]	1.51	1.48	1.53	1.60	1.59	1.58	1.63	0.4%
Electricity	3.36	3.26	3.74	3.98	4.04	4.05	4.12	0.9%
Delivered energy	**23.97**	**24.48**	**27.42**	**28.58**	**29.10**	**29.29**	**29.82**	**0.7%**
Electricity related losses	6.87	6.72	7.51	7.88	7.88	7.83	7.85	0.6%
Total	**30.84**	**31.20**	**34.93**	**36.46**	**36.98**	**37.12**	**37.68**	**0.7%**

FIGURE 1.8 Energy consumption in the industrial sector [2].