

TECHNOLOGIES FOR SUSTAINABLE LIFE CONCISE
MONOGRAPHS SERIES

Advanced Energy Efficient Building Envelope Systems

Moncef Krarti
Zhiqiang (John) Zhai
Benjamin Park
Kathleen Menyhart
Vinay Shekar
Jenna L. Testa
Saleh Nasser AL Saadi
Mohamed El Mankibi
Robert Slowinski

© 2017, The American Society of Mechanical Engineers (ASME), 2 Park Avenue, New York, NY 10016, USA (www.asme.org)

All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a database or retrieval system, without the prior written permission of the publisher.

INFORMATION CONTAINED IN THIS WORK HAS BEEN OBTAINED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS FROM SOURCES BELIEVED TO BE RELIABLE. HOWEVER, NEITHER ASME NOR ITS AUTHORS OR EDITORS GUARANTEE THE ACCURACY OR COMPLETENESS OF ANY INFORMATION PUBLISHED IN THIS WORK. NEITHER ASME NOR ITS AUTHORS AND EDITORS SHALL BE RESPONSIBLE FOR ANY ERRORS, OMISSIONS, OR DAMAGES ARISING OUT OF THE USE OF THIS INFORMATION. THE WORK IS PUBLISHED WITH THE UNDERSTANDING THAT ASME AND ITS AUTHORS AND EDITORS ARE SUPPLYING INFORMATION BUT ARE NOT ATTEMPTING TO RENDER ENGINEERING OR OTHER PROFESSIONAL SERVICES. IF SUCH ENGINEERING OR PROFESSIONAL SERVICES ARE REQUIRED, THE ASSISTANCE OF AN APPROPRIATE PROFESSIONAL SHOULD BE SOUGHT.

ASME shall not be responsible for statements or opinions advanced in papers or . . . printed in its publications (B7.1.3). Statement from the Bylaws.

For authorization to photocopy material for internal or personal use under those circumstances not falling within the fair use provisions of the Copyright Act, contact the Copyright Clearance Center (CCC), 222 Rosewood Drive, Danvers, MA 01923, tel: 978-750-8400, www.copyright.com.

Requests for special permission or bulk reproduction should be addressed to the ASME Publishing Department, or submitted online at <https://www.asme.org/shop/books/book-proposals/permissions>

ASME Press books are available at special quantity discounts to use as premiums or for use in corporate training programs. For more information, contact Special Sales at CustomerCare@asme.org

Library of Congress Cataloging-in-Publication Data

Names: Krarti, Moncef, editor, author.

Title: Advanced energy efficient building envelope systems / [compiled by] Moncef Krarti, Zhiqiang (John) Zhai, Benjamin Park, Kathleen Menyhart, Vinay Shekar, Jenna L. Testa, Saleh Nasser AL Saadi, Mohamed El Mankibi, and Robert Slowinski.

Description: New York : ASME Press, [2017] | Includes bibliographical references and index.

Identifiers: LCCN 2017002517 | ISBN 9780791861370 (alk. paper)

Subjects: LCSH: Insulation (Heat) | Exterior walls. | Roofs. | Buildings--Energy conservation.

Classification: LCC TH1715 .A38 2017 | DDC 693.8/32--dc23

LC record available at <https://lccn.loc.gov/2017002517>

Table of Contents

Preface	v
Abstract	vii
1. Dynamic Insulation Systems	1
1.1 Introduction	1
1.2 Description of DIM Technology	4
1.3 Model for DIM Systems	6
1.4 Optimal Control Strategies for DIM Systems	12
1.5 Comparative Analysis of Control Strategies	21
1.6 Sensitivity Analysis	22
1.7 Impact of Climate	26
1.8 Economic Analysis	26
1.9 Summary and Conclusions	31
References	35
2. Dynamic Cool Roofing Systems	39
2.1 Introduction	39
2.2 Cool Roof Properties	40
2.3 Performance of Static Cool Roofs	43
2.4 Current Cool Roof Energy Standards	53
2.5 Other Benefits and Challenges	55
2.6 Advances in Switchable Roof Coatings	56
2.7 Evaluation of Dynamic Cool Roofs Performance	59
2.8 Economic Analysis of Dynamic Cool Roofs	63
2.9 Summary and Conclusions	65
References	70
3. Breathing and Living Walls	75
3.1 “Breathing Wall” Concept	75
3.2 “Living Wall” Concept	77
3.3 State of the Art	78
3.4 Prototypes and Products	80
3.5 Modeling Advanced Façade Systems	82
3.6 Testing Advanced Façade Systems	85
3.7 Thermal Performance of Single-Layer Breathing Wall	89
3.8 Thermal Performance of Advanced Multi-Layer Walls	94
3.9 Thermal Performance of Buildings with PCM-Enhanced Walls	101
3.10 Thermal Performance of Buildings with Advanced Multi-Layer Walls	115
3.11 Summary on Single-Layer Breathing Wall	121
3.12 Summary on Advanced Multi-Layer Living Wall	122
References	127
Authors Biography	131

Preface

Building heating and cooling energy use accounts for up to 40% of the total energy consumption in developed countries. Heat losses and gains through the building envelope greatly contribute to thermal heating and cooling loads and subsequently to the overall energy performance of buildings. Several advances in building technology have been made that continue to transform building energy performance and promote new and innovative construction techniques and challenges traditional practices. In fact, some of the existing systems that are often required by energy efficiency codes and standards may not provide the optimal energy performance and indoor air quality (IAQ). For instance, leaky buildings traditionally perform very poorly in terms of energy consumption, but in general, their IAQ—as a result of the incoming outside air—is fairly good. For the sake of energy efficiency, the trend has been tighter, more effectively sealed buildings, which in turn has led to more IAQ, mold, and sick building syndrome problems. As the push for improved energy performance points designers and builders towards tighter construction, the very principle that reduces the building's energy consumption—reduced infiltration—is a net loser for indoor air quality.

In this monograph, some advanced technologies of building envelope are presented to challenge the existing paradigms for high performance buildings. Specifically, four building envelope systems are described in three chapters to showcase their ability to enhance the energy efficiency and optimize the IAQ of buildings. These advanced building envelope systems include:

- *Dynamic Insulation Materials*: These materials are assemblies that can change their thermal resistance through for instance, a controlled exchange of liquid or gaseous media, and are applied to the exterior walls and roofs of buildings. When applied and optimally controlled, these materials can save significant annual heating and cooling energy use for both residential and commercial buildings (Chapter 1).
- *Variable Reflectivity Cool roofs*: These systems are associated with coatings that can change their reflective properties over time depending on desired controlled strategies. It is well known that

static cool roofs can save energy use during cooling periods but may increase energy consumption during swing or heating seasons due to lower solar heat gains. The variable reflectivity coatings allow the reduction in heating penalty associated with conventional cool roofs (Chapter 2).

- *One-Layer Breathing Walls:* These systems provide air ventilation through the walls while recovering thermal energy. Essentially using heat exchanging mechanism, filtrated fresh air is introduced through the walls from outside to inside and is heated or cooled by the thermal energy wasted by conduction and convection with the walls (Chapter 3).
- *Multi-Layer Living Walls:* These walls utilize basic biomimetic principles to adapt to the change in climatic conditions. In particular, these climate-adaptive intelligent walls have embedded systems of air, water, and phase change material and can be controlled to maintain acceptable indoor environment under changing outdoor conditions (Chapter 3).

In all three chapters, an overview of the basic operating concepts of these advanced envelope systems is first provided. Then, their energy performance is summarized based on reported results using either experimental or modeling analyses.

It should be noted that the main goal of this monograph is to promote innovative ideas and disseminate the ongoing research and development related to the theme of sustainable buildings. It is a small contribution to the ASME initiative on Integrated and Sustainable Building Equipment and Systems (ISBES).

Moncef Krarti, PhD, PE, LEED-PE, ASME Fellow
Guest Editor

Abstract

This monograph presents the latest research developments of innovative building envelope systems. These systems have the ability to allow building structures to be responsive to changes in outdoor conditions to ensure comfortable indoor environment and acceptable indoor air quality at higher energy efficiency compared to conventional systems. In particular, the monograph overviews the basic operation principles and thermal performance of four technologies described in three chapters: (i) dynamic insulation materials that can change its thermal properties in order to better adapt the building envelope with its outdoor environment and reduce building heating and cooling thermal loads, (ii) variable reflectance coatings for application on roofs to lower and even eliminate the energy penalties associated with reduced solar heat gains during heating operation of buildings, (iii) single layer breathing walls to recover energy wasted from heat transmission inside the walls and provide air ventilation to indoor spaces, and (iv) multi-layer living walls to apply biomimetic principles and phase-change materials to adapt building envelope properties with the changing outdoor conditions.

Guest Editor:
Moncef Krarti, PhD, PE, LEED-AP

