PennState

PHRC

2020

RESIDENTIAL BUILDING DESIGN & CONSTRUCTION CONFERENCE PROCEEDINGS

MARCH 4–6, 2020

THE PENN STATER HOTEL & CONFERENCE CENTER
STATE COLLEGE, PENNSYLVANIA, USA

This page left intentionally blank for printing.

2020
RESIDENTIAL BUILDING DESIGN & CONSTRUCTION CONFERENCE PROCEEDINGS

MARCH 4–6, 2020

THE PENN STATER HOTEL & CONFERENCE CENTER

State College, Pennsylvania, USA

Edited by
Dr. Ali M. Memari
Sarah Klinetob Lowe

Department of Architectural Engineering
Department of Civil & Environmental Engineering
The Pennsylvania State University, University Park, Pennsylvania, USA

PennState College of Engineering | PENNSYLVANIA HOUSING RESEARCH CENTER

ISBN 978-1-62307-007-6

Editing by Ali M. Memari, Sarah Klinetob Lowe
Book design by Rachel Fawcett

Printed in the United States of America
First printing September 2020

Published by the Pennsylvania Housing Research Center (PHRC) at The Pennsylvania State University

Visit www.phrc.psu.edu/Conferences/Residential-Building-Design-and-Construction-Conference/index.aspx

Ali M. Memari
Director, Bernard and Henrietta Hankin Chair in Residential Building Construction
PHRC
222 Sackett Building
University Park, PA 16802

CONFERENCE ORGANIZATION

CONFERENCE CHAIR

Dr. Ali Memari
Bernard and Henrietta Hankin Chair in Residential Building Construction

Department of Architectural Engineering, Department of Civil & Environmental Engineering, PHRC, Penn State
amm7@psu.edu

CONFERENCE ORGANIZER

206B Sackett Building
The Pennsylvania State University
University Park, PA 16802
T: 814-865-2341
phrc@psu.edu

CONFERENCE SECRETARIAT

Sarah Klinetob Lowe
Housing Systems Specialist, PHRC
SKLowe@psu.edu

CONFERENCE COORDINATOR

Rachel Fawcett
Budgets & Publications Coordinator, PHRC
RFawcett@psu.edu

INTERNATIONAL SCIENTIFIC COMMITTEE

Clinton Aigbavboa
University of Johannesburg, South Africa

Somayeh Asadi
Penn State University, USA

Naomi Beal
passivhausMAINE, USA

Ben Bigelow
Texas A&M, USA

Melissa Bilec
University of Pittsburgh, USA

Ryan Bradley
University of the Witwatersrand, South Africa

Silvia Brunoro
University of Ferrara, Italy

Arindam Chowdhury
Florida International University, USA

José Pinto Duarte
Penn State University, USA

Jim Freihaut
Penn State University, USA

Antonio Garcia-Martinez
University of Seville, Spain

Karim Hadjri
University of Sheffield, UK

Dan Hindman
Virginia Tech, USA

Eric Holt
University of Denver, USA

Patrick Huelman
University of Minnesota, USA

Lisa Iulo
Penn State University, USA

Bohumil Kasal
Fraunhofer Wilhelm-Klauditz-Institute WKI, Germany

Thomas Kenney
Home Innovation Research Lab, USA

Mei Yung Leung
City University of Hong Kong, Hong Kong, China

Carlos Martín
Urban Institute, USA

Andrew McCoy
Virginia Tech, USA

Wendy Miller
Queensland University of Technology, Australia

Mahua Mukherjee
IIT Rourkee, India

Isabelina Nahmens
Louisiana State University, USA

Esther Obonyo
Penn State University, USA

Cilisia Duarte Ornelas
University of Porto, Portugal

Shiling Pei
Colorado School of Mines, USA

David O. Prevatt
University of Florida, USA

Georg Reichard
Virginia Tech, USA

Awni Shaaban
Sultan Qaboos University, Oman

Ryan Smith
Washington State University, USA

Matt Syal
Michigan State University, USA

Fitsum Tariku
British Columbia Institute of Technology, Canada

Sam Taylor
Joint Committee on Building Science Education, USA

Theresa Weston
DuPont, USA

PREFACE

While home builders are continuously challenged to consider various criteria such as affordability, energy efficiency, sustainability, serviceability, aesthetic, utility, and resistance to natural hazards among others, there are varying degrees of adherence to such objectives. The more efforts are made for technology transfer and providing the residential construction industry with the latest advancements in construction materials, tools, methods, and code requirements, the more receptive will be the mainstream builders to incorporation of technological advancements. As always, the Pennsylvania Housing Research Center (PHRC) at The Pennsylvania State University considers knowledge sharing and dissemination of the results of recent advancements in the field as one of its primary responsibilities and is pleased to continue organizing the Residential Building Design and Construction Conference series to serve the housing and residential construction industry for this purpose.

It is with great pleasure that we share the proceedings of the 2020 Residential Building Design and Construction Conference that was held on March 4–6, 2020 at The Penn Stater Hotel and Conference Center in State College, Pennsylvania. As in the past four RBDC Conferences, this 5th conference provided an opportunity for researchers, design professionals, manufacturers, builders, and code officials to exchange the latest advancements in research and practice and to discuss and share their own findings, innovations, and projects related to residential buildings.

The 2020 RBDC Conference hosted 132 attendees and included 56 papers and 102 presentations on various issues related to residential buildings, which encompass single- and multi-family dwellings, mid-rise and high-rise structures, factory-built housing, dormitories, and hotels/motels. Papers and presentations related to the following areas and topics were invited in the conference call:

- Aging-in-Place and Senior Living Housing
- Alternative Renewable Energy Generating Systems
- Building Information Modeling (BIM) Application in Residential Construction
- Building Integrated Photovoltaic Systems
- Building Performance Assessment/Metrics/Verification Methods and Occupant Behavior
- Building Science and Building Enclosures
- Energy Efficient Building Components
- Fire Damage and Protection
- High Performance Residential Buildings
- Indoor Air Quality
- Innovations in Green Roofs and Façade/Envelope Systems
- Innovations in Residential Architecture and Design
- Innovations in Modular and Manufactured Housing
- Innovative and Emerging Housing Construction Methods/ Systems
- Innovative Wall, Floor, Roof, Window, and Siding Systems

- Learning from the Performance of Residential Buildings under Natural Disasters
- Low-Income and Affordable Housing
- Panelized Building Components
- Passive House Design Approach
- Resilient New Design and Retrofit of Existing Buildings under Natural Disasters
- Retrofit of Existing Buildings for Energy Efficiency
- Rural Housing Materials and Construction
- Serviceability and Life Safety Damage Aspects
- Smart Home Technologies, Design, and Construction
- Sustainable Housing Construction Materials and Methods
- Temporary Housing for Disaster Situations
- Whole Building Design Approach
- Zero-Net Energy Homes

As the following Conference Schedule and Table of Contents of these proceedings show, many of the above areas were among the papers and presentations at the conference. In particular, there was considerable interest in Passive House Design and Retrofit, Disaster Resilient Design, Building Envelope and Building Science, and Construction using Cross Laminated Timber. The conference also hosted six Special Session panel discussions, three evening networking events, and a tour of the Building Enclosure Testing Laboratory (BETL) and the ADDCON Laboratory for 3D Printing of concrete, both located in Civil Infrastructure Testing and Evaluation Laboratory (CITEL) at Penn State University.

Two keynote speakers were invited for the conference: David O. Prevatt, Ph.D., PE, FASCE, Associate Professor of Civil & Coastal Engineering, Associate Director NSF - NHERI Experimental Facility at University of Florida and Lois B. Arena, PE, Director of Passive House Services at Steven Winter Associates, Inc. Professor Prevatt discussed his presentation titled "Wind Hazard Resilient Residential Communities—When Engineering Isn't Enough." Lois B. Arena shared her presentation titled "Passive House: A Proven Path Toward Resilient, Affordable & Energy Efficient Housing." The conference also hosted a closing plenary session by Jay Arehart, Senior Research Fellow at Project Drawdown and Tom Richard, Director of Institutes Energy & the Environment at Penn State, entitled "Buildings as a Drawdown Solution: Getting to Zero and Beyond."

We wish to thank the members of the International Scientific Committee of the conference for their contributions in promoting the conference. The support of the PHRC staff for logistics is gratefully acknowledged. In particular, special thanks goes to Rachel Fawcett for her contribution as the Conference Coordinator.

Proceedings Editors:
Ali M. Memari and Sarah Klinetob Lowe
March 2020

CONFERENCE SCHEDULE

WEDNESDAY, MARCH 4

8:30am - 10:15am | ROOM 207

KEYNOTE David O. Prevatt | University of Florida
"Wind Hazard Resilient Residential Communities—When Engineering Isn't Enough"
Opening Remarks: Dr. Sez Atamturktur | Department Head, Architectural Engineering, Penn State

10:45am - 12:15pm — **Conference Sessions A**

	Disaster-Resilient Design | Rm. 203	Building Envelope | Rm. 204	Adaptation & Retrofits | Rm. 205	The Big Picture | Rm. 211	Building Science/Education | Rm. 218
10:45-11:15	**Perceptions for Residential Resilience** *Sandeep Langar | University of Texas at San Antonio*	**Innovative Construction Products: From Qualification and Performance Assessment to Quality Control** *Marzieh Riahinezhad, J-F Masson, Peter Collins, Bruno Di Lenardo, Jocelyn Johansen, & Michael Lacasse | National Research Council of Canada & CSL Silicones, Inc.*	**Sustainability Charrettes and Penn State's Residence Halls Renovations: Improving Building Performance and the Student Experience** *John Bechtel & Yumna Kurdi | Penn State*	**Discussing Innovation in Residential Construction at the National Scale** *Frederick Paige, Andrew McCoy, & Carlos Martín | Virginia Tech & Urban Institute*	**Introductions + Overview** *Sam Taylor | Energy & Resource Efficiency*
11:15-11:45	**Single-Family Housing Construction Vs. Hazard Mitigation Cost Data In The State Of Kentucky Using Model-Based Cost Calculation** *Marlie Reneau & Fatemeh Orooji | Western Kentucky University*	**ASHRAE 90.1: Codified Condensation for Cold Climates** *David Finley & Manfred Kehrer | Wiss, Janney, Elstner Associates, Inc.*	**Passive House Retrofit: Breathing New Energy into Old Dorms** *Benedict H. Dubbs & William Trout | Murray Associates Architects*	**Building Industry: Trends in Sustainability and Building Science Applications** *Dorothy Gerring, Rob Wozniak, Thomas Brooks, Evan Klinger, Cole Moriarty, Jeffrey Sementelli, & Michael "Tanner" Reif | Pennsylvania College of Technology*	**Building Science Education: Evolving Approaches and Resources** *Sam Taylor | Energy & Resource Efficiency*
11:45-12:15	**Evaluation of Various Retrofit Strategies for Existing Residential Buildings in Hurricane Prone Coastal Regions** *Mehrshad Amini & Ali Memari | Penn State*	**Wall Upgrades for Deep Residential Energy Renovation: Interim Results from a Multi-Year Study** *Chrissi Antonopoulous, Cheryn Metzger, Jian Zhang, Michael Baechler, A.O. Desjarlais, Pat Huelman, & G. Mosiman | Pacific Northwest National Laboratory, Oak Ridge National Laboratory, & University of Minnesota*	**Trends and practices of retrofitting existing residential buildings to Passive House criteria and similar standards.** *Sophia Welch, Esther Obonyo, & Ali Memari | Penn State*	**A Path to Zero Energy Ready Home Construction** *Theresa Gilbride, Michael Baechler, & Kiere Degrandchamp | Pacific Northwest National Laboratory & High Performance Homes*	**50 Shades of Building Science Education** *Georg Reichard, Zach Gould, & Dominick DeLeone | Virginia Tech*

12:15pm-1:15pm — **LUNCH | PRESIDENTS HALL 1 & 2**

1:15pm - 2:45pm — **Conference Sessions B**

	Disaster-Resilient Design | Rm. 203	Building Envelope | Rm. 204	Adaptation & Retrofits | Rm. 205	MEP | Rm. 211	Building Science/Education | Rm. 218
1:15-1:45	**Assessing the Performance of Elevated Wood Buildings in the Wake of Hurricane Michael** *Jae Kim, Elaina Sutley, & Thang Dao | University of Kansas & University of Alabama*	**High-Performance Windows – More than just a Pretty Hole in the Wall** *Katherine Cort & Theresa Gilbride | Pacific Northwest National Laboratory*	**Market Transformation: How Far, How Fast** *Rob Bernhardt | Passive House Canada*	**A New Standard to Evaluate the Installation Quality of Residential HVAC Systems** *Dean Gamble | EPA ENERGY STAR Certified Homes*	**Teaching Passive House in Academia** *Walter Grondzik, Alison Kwok, Mary Rogero, & Katrin Klingenberg | Ball State University, PHIUS, University of Oregon, & Miami University of Ohio*
1:45-2:15	**Wind Induced Effects on Roof-to-Wall Connections of Residential Buildings** *Amal Elawady, Arindam Chowdhury, & Ehssan Sayyafi | Florida International University*	**Low-Slope Roofing Systems for Multi-Story Residential and Commercial Buildings** *Rowland Smith | Wiss, Janney, Elstner Associates, Inc.*	**Repurposing Everyday Buildings: Extraordinary Renovations of Ordinary Structures** *Eric Fisher & Bea Spolidoro | Fisher ARCHitecture*	**Monitoring HVAC System Performance for Affordable Housing Units** *Fatemah Ebrahim, Frederick Paige, Farrokh Jazizadeh, & Quinton Nottingham | Virginia Tech*	**NAHB Career Pathways: Early Career Home Builders Findings & Mapping Career Pathways in Homebuilding** *Eric Holt | University of Denver*
2:15-2:45	**Wind hazard resilient construction mitigation decision-making framework** *Fatemeh Orooji | Western Kentucky University*	**Thin shell concrete enclosures in residential buildings** *Pablo Moyano Fernandez | Washington University in St. Louis*	**OPEN BUILDING: Planning Multi-unit Residential Buildings for Change** *Stephen Kendall | Council on Open Building*	**Indoor Air Quality and Energy Use in Passive Houses** *Xinyi Lily Li & Donghyun Rim | Penn State*	**One Book with Many Topics: But Are They Enough?** *Walter Grondzik | Ball State University*

3:00pm - 4:30pm — **Conference Sessions C**

	Disaster-Resilient Design | Rm. 203	Senior Housing | Rm. 204	Adaptation & Retrofits | Rm. 205	Lab Tour	Building Science/Education | Rm. 218
3:00-3:30	**UN Sustainable Development and the Cool Roofs Challenge** *Kariuki Mbugua | Steam Plant Ltd*	**Tailoring Environments for Active Life Engagement (TEALE) Study: Preliminary Findings on Older Adults' Perceptions of the Functionality of their Housing Environment** *Angela L. Sardina, Shyuan Ching Tan, & Alyssa A. Gamaldo | University of North Carolina Wilmington & Penn State*	Presentation and Q&A Forum : **Scalable Retrofit Strategies for Net Zero Energy Performance in the United States & Beyond** *Moderator: Sarah Klinetob Lowe | Penn State* *Panelists:* *Lois B. Arena | Steven Winter Associates* *Saul Brown | RetrofitNY* *Dario Giandomenico | Green Building Alliance*	**Tour of Building Envelope Testing Laboratory (BeTL) + AddCon Lab Tours** [offsite + preregistration required] Meet at the Hotel Lobby at 3:00pm Return to Penn Stater by 5:00pm	**Mojave Bloom: Designing a Net-Zero Veteran's Transitional Home** *Eric Weber & Dak Kopec | University of Nevada Las Vegas*
3:30-4:00	**Modelling tropical cyclone vulnerability and the development of new insurance coverage programs for housing in Fiji** *Daniel J. Smith & Geoff Boughton | James Cook University, Cyclone Testing Station*	**Educating for Energy Efficiency: Educating Senior Residents Towards Net Zero Energy Goals** *Frederick Paige | Virginia Tech*			**Experiences with the Race to Zero/Solar Decathlon Design Challenge** *Tom Collins & Walter Grondzik | Ball State University*
4:00-4:30	**Kentucky Flood Resistant House: Integrating Resilience into Architectural Design** *Kyle Choate & Fatemeh Orooji | Western Kentucky University*	**Housing for Adults Facing Shifting Demographics in Japan** *Yoko Crume | Consultant (Aging & Society)*			**High Performance for Habitat for Humanity: Penn State's 2018-2019 Solar Decathlon Design Competition Entry** *Puja Bhagat & Jonathan Wong | Penn State*

6:00pm - 8:30pm — **HAPPY HOUR ON THE EXHIBIT FLOOR | PRESIDENTS HALL 1 & 2**

THURSDAY, MARCH 5

8:30am - 10:15am | Presidents Hall

KEYNOTE: Lois B. Arena | Steven Winter Associates
"Passive House: A Proven Path Toward Resilient, Affordable & Energy Efficient Housing"
Opening Remarks: Dr. Christopher Rahn | Associate Dean for Innovation, Penn State College of Engineering

10:45am - 12:15pm — **Conference Sessions D**

	Concrete | Rm. 203	Building Envelope | Rm. 204	Passive House | Rm. 205	Microgrids | Rm. 218
10:45-11:15	**Hempcrete as a Residential Construction Material: State-of-the-art and Challenges** *Hojae Yi, Corey Griffin, Ali Memari, David Lanning, & James Dooley | Penn State & Forest Concepts LLC*	**Long-Term Exposure Data Analysis of Residential High Performance Wall Assemblies Exposed to Real Climate** *Michal Bartko, Travis V. Moore, & Michael A. Lacasse | National Research Council of Canada*	**Panelized Multifamily Passive House: Less Cost & More Profit Than Code** *Paul Grahovac | Build SMART, LLC*	**The Mycorrho-grid: A Blockchain-based Mycorrhizal Model for Smart Solar Microgrids** *Zachary Gould, Susan Day, Georg Reichard, Ikechukwu Dimobi, & Arjun Choudhry | Virginia Tech & the University of British Columbia*
11:15-11:45	**Accounting for the carbon sequestration potential of concrete systems: OPC and Hempcrete** *Jay Arehart | University of Colorado Boulder*	**Multifamily case study in Midland, MI compares different construction strategies for cost, durability, energy transfer and comfort.** *Brian Lieburn | DuPont Performance Building Systems*	**FRONT FLATS: A Net Positive, Carbon-Neutral, Multi-Family Experiment……and Fashion Statement** *Timothy McDonald | Onion Flats*	**Mining the Impact of Urban Form on Energy Performance in Community Microgrids** *Mina Rahimian | Penn State*
11:45-12:15	**Mitigating pyrrhotite-induced damage in residential concrete construction** *Jonathon Piasente & Aleksandra Radlinska | Penn State*	**Field Evaluation of an Affordable Solid Panel Structural Building System** *Pat Huelman, Tom Schirber, Garrett Mosiman, Dan Hendeen, & Rolf Jacobson | University of Minnesota*	**Bridging the Communication Gap Between Design and Construction** *Thiel Butner | Pando Alliance*	**TBD**

12:15pm-1:15pm — **LUNCH | PRESIDENTS HALL 1 & 2**

1:15pm - 2:45pm — **Conference Sessions E**

	Occupant Behavior| Rm. 203	Wood & CLT | Rm. 204	Passive House | Rm. 205	Community Design | Rm. 211	Building Science/Education | Rm. 218
1:15-1:45	**Personalizing occupant comfort using bio-sensing techniques** *Erica Cochran & James Katungyi | Carnegie Mellon University Center for Building Performance & Diagnostics*	**Mid-Rise Wood Frame Construction: A Good Idea or Are We Asking for Trouble?** *Derek Hodgin | Construction Science & Engineering, Inc.*	**A Couple's Passive House - Environmental Sustainability Without City Living** *Gary Gardner | Passive House Western PA*	**Participatory Design in Housing** *Joe Colistra & Nilou Vakilbahrami | University of Kansas*	**Introductions & Reflections** *Sam Taylor | Energy & Resource Efficiency* **IEA EBC Annex 74: International Information-Sharing Platform for Building Competitions and Living Labs** *Holly Carr | US Department of Energy*
1:45-2:15	**Message Design for Residential Energy Feedback** *Wendell Grinton & Frederick Paige | Virginia Tech*	**Using Truss Rafting to Create Safer, More Efficient Construction Sites** *Daniel Hindman | Virginia Tech*	**Master Planning a Phased Passive House Retrofit** *Laura Blau | BluPath Design*	**Green Social Services Buildings in Japan: Engaging Clients and Inspiring the Community** *Richard Crume | American Public Health Association*	**Solar Decathlon winning design entries - how to get projects built** *Paul Crovella, Michael Schmidt, & Noah Townsend | SUNY ESF*
2:15-2:45	**Energy Efficiency Rebate Programs: An assessment of investment behaviors by homeowners** *Celso Santos & Kristen Cetin | Iowa State University & Michigan State University*	**Resurrecting Fire-Damaged, Glued Laminated Beams from Beyond the Grave: A Pilot for Attaining Serviceability Requirements** *Cole Moller & Brian Kukay | Cushing Terrell & Montana Technological University*	**On the Way to Zero: Exploring A Path to Cost Efficient, Energy Efficient Affordable Housing** *Mike Steffen | Walsh Construction*	**Penn State Initiative for Resilient Communities (PSIRC): pilot study for community flood resilience** *Lisa D. Iulo | Penn State*	**Envelope and Systems Synergy for High Performance, Affordable Housing** *Michael Gibson & Paul Karr | Kansas State University*

3:00pm - 4:30pm — **Conference Sessions F**

	Healthy Homes | Rm. 203	Wood & CLT | Rm. 204	Passive House | Rm. 205	3D Printing & Modular | Rm. 211	Building Science/Education | Rm. 218
3:00-3:30	**Residential Indoor Air Quality Update – Contaminant Exposures, Standards, & Control Technologies** *William Bahnfleth | Penn State*	**The Burwell Center: A CLT Construction Case Study on the Campus of The University of Denver** *Eric Holt | University of Denver*	**PHFA Passive House Addition | The Design – Product Research and Existing Modeling** *Benedict H. Dubbs, Jr. & Wade Romberger | Murray Associates Architects & Pennsylvania Housing Finance Agency*	**The Potential of Additive Manufactured Housing** *Joe Colistra & Paola Sanguinetti | University of Kansas*	**Building Science Education Panel Discussion** *Moderator: Sam Taylor | Energy & Resource Efficiency* *Panelists: Holly Carr | US Department of Energy* *Chrissi Antonopoulous | Pacific Northwest National Laboratory* *Pat Huelman | University of Minnesota* *Georg Reichard | Virginia Tech*
3:30-4:00	**Residential Indoor Air Quality Assessment: An Evaluation of the Built Environment and Quality of Life in Communities** *Jessica Vaden & Melissa Bilec | University of Pittsburgh*	**Mass Customized Cross-Laminated Timber Elements for Residential Construction** *Daniel Hindman & Ali Memari | Virginia Tech & Penn State*	**PHFA Passive House Addition | The Documentation – "The Devil is in the Details"** *Benedict H. Dubbs, Jr. & Wade Romberger | Murray Associates Architects & Pennsylvania Housing Finance Agency*	**Market Driven Collaboration & Innovation in Modular Construction** *Frank Yang | ADL Ventures*	
4:00-4:30	**Barriers in Implementing Material Transparency in LEED® v4.0 projects** *Susan Thomas & Paul Crovella | SUNY ESF*	**Shake Table Testing of a 10-story Mass Timber Building with Nonstructural Components** *Keri Ryan, Shiling Pei, & Tara Hutchinson | University of Nevada Reno, Colorado School of Mines, & University of California San Diego*	**PHFA Passive House Addition | The Build – Contractor Selection, Sequencing and Collaboration** *Benedict H. Dubbs, Jr. & Wade Romberger | Murray Associates Architects & Pennsylvania Housing Finance Agency*	**TBD**	

6:30pm - ? — **RELAX & UNWIND DOWNTOWN | SPONSORED BY THE GLOBAL BUILDING NETWORK**

FRIDAY, MARCH 6

8:30am - 10:00am   Conference Sessions G

	Affordable Housing | Rm. 203	Building Envelope | Rm. 204	Passive House + Education | Rm. 205	Energy Usage | Rm. 218
8:30-9:00	**Evaluating Inclusionary Zoning in Centre County, PA as a Tool to Increase the Supply of Affordable Housing Stock and to Mitigate Housing Segregation** *Rachel Fawcett | Penn State*	**Stucco – the Once and Future Cladding: Design Options to Meet Industry Codes and Standards** *Theresa Weston | DuPont Performance Building Systems*	Panel Discussion & Moderated Forum : **Passive House & the Nexus between Academia, Practice, Construction, and Research** *Moderator: Walter Grondzik |PHIUS & Ball State University* *Panelists:* *Laura Blau | BluPath* *Tim McDonald | Onion Flats* *Mary Rogero | Miami University* *Mike Steffen | Walsh Construction*	**Characteristics of Typical Occupancy Schedules for Residential Buildings in the United States** *Debrudra Mitra, Nicholas Steinmetz, Yiyi Chu, & Kristen Cetin | Iowa State University & Michigan State University*
9:00-9:30	**The Challenges of Creating Resilient Housing at Affordable Cost – A "Lessons Learned" Report on The Field of Dreams EcoCommunity** *Jörg Rügemer | University of Utah*	**Performance of PCMs in Different Building Envelope Configurations, Climate Zones and Building Operating Scenarios** *Hyejoo Koh & Fitsum Tariku | British Columbia Institute of Technology*		**An Evaluation of Electrical Energy Usage Comparing Homes With and Without Building Code Enforcement** *Ben Bigelow & Melina Cedillo | University of Oklahoma & Holder Construction*
9:30-10:00	**Integrating Flexible Human-Activity in Modular Space Design for Affordable Mass Housing in Asia** *Atul Biltoria & Uttam Roy | Indian Institute of Technology Roorkee*	**The Interface** *Adam Ugliuzza | Intertek*		**The Home as a Concrete Example for Energy Education** *Frederick Paige | Virginia Tech*

10:15am - 11:45am   Conference Sessions H

	Disaster-Resilient Design | Rm. 203	3D Printing on Mars | Rm. 204	Local Communities + Education | Rm. 205	High Performance Housing | Rm. 218
10:15-10:45	**Wind Pressure Distribution on Single-Story and Two-Story Elevated Structures** *Nourhan Abdelfatah, Amal Elawady, Peter Irwin, & Arindam Chowdhury | Florida International University*	**An Overview of the Execution of 3D-Printed Subscale Habitat on Mars: A Case Study to Exemplify the Automated Construction Process** *Shadi Nazarian, Jose Duarte, Sven Bilén, Ali Memari, Naveen Kumar Muthumanickam, Nathan D. Watson, Aleksandra Radlinska, Negar Ashrafi, & Maryam Hojati | Penn State*	Panel Discussion & Moderated Forum : **Community-University Partnerships for High Performance Homes** *Moderator: Dr. Meghan Hoskins | Penn State* *Panelists:* *Ilona Ballreich | Penn State* *Jasmine Fields | State College Borough* *Lisa D. Iulo | Penn State* *Sarah Klinetob Lowe | Penn State* *Colleen Ritter | State College Community Land Trust* *Maureen Safko | State College Borough* *Alan Sam | State College Borough*	**Managing Building Pressure Differentials in High-Performance, Low-Load Homes** *Pat Huelman & Marilou Cheple | University of Minnesota*
10:45-11:15	**Conceptual Geometric Design for U.S. Coastal Homes to Resist Hurricane Surge Forces** *Julie Bates & Ali Memari | Penn State*	**Structural Analysis of Full-Scale and Sub-Scale Structure for Digitally Designed Martian Habitat** *Keunhyoung Park, Ali Memari, Shadi Nazarian, Jose Duarte & Maryam Hojati | Penn State & University of New Mexico*		**Whole Building Airtightness Testing at Penn State** *Adam Ugliuzza | Intertek*
11:15-11:45	**Performance of Residential Buildings in Hurricane Prone Coastal Regions and Lessons Learned for Damage Mitigation** *Mehrshad Amini & Ali Memari | Penn State*	**Experimental Testing and Finite Element Modeling of 3D-Printed Reinforced Concrete Beams** *Keunhyoung Park, Ali Memari, Maryam Hojati, Mehrzad Zahabi, Shadi Nazarian, and Jose Duarte | Penn State & University of New Mexico*		**A Method for Evaluating Whole-building Energy Use of Two Adjacent Multifamily Residential Buildings in Pennsylvania: A Comparative Case Study on Passive House and Conventional Buildings** *Homeira Mirhosseini, Xinyi Lily Li, Lisa D. Iulo, & Jim Freihaut | Penn State*

11:45am-12:45pm   LUNCH | THE GARDENS RESTAURANT (PENN STATER)

12:45pm - 2:15pm   Conference Sessions I

	Infrastructure | Rm. 203	BIM | Rm. 204	Global Communities + Education | Rm. 207
12:45-1:15	**Role of Infrastructure in the Success of Urban Housing Developments** *Shay Chakraborty, M.G. Matt Syal, & Sinem Mollaoglu | Michigan State University*	**BIM for parametric problem formulation, optioneering, and 4D simulation of 3D-printed Martian habitat: A case study of NASA's 3D Printed Habitat Challenge** *Naveen Kumar Muthumanickam, Keunhyoung Park, Jose Duarte, Shadi Nazarian, Ali Memari, & Sven Bilén | Penn State*	Panel Discussion & Moderated Forum : **Global Building Network Panel Discussion** *Moderators: Dr. Esther Obonyo & Sarah Klinetob Lowe | Penn State* *Panelists:* *Rob Bernhardt | Passive House Canada* *Jenna Cramer | Green Building Alliance* *Richard Crume | American Public Health Association* *Dario Giandomenico | Green Building Alliance* *Dr. Esther Obonyo | Penn State*
1:15-1:45	**Improving the User Experience (UX) of Green Building Certification Resources for Multifamily Housing Units** *Dwayne Jefferson & Frederick Paige | Virginia Tech*	**The Value and Use of National Building Information Modeling Standards** *John Messner | Penn State*	
1:45-2:15	**TBD**	**TBD**	

2:30pm - 4:00pm   CLOSING PLENARY & CLOSING REMARKS | ROOM 207

"Buildings as a Drawdown Solution: Getting to Zero *and* Beyond"

Jay Arehart | Project Drawdown & Tom Richard | Penn State

Opening Remarks: Dr. Patrick Fox | Department Head, Civil & Environmental Engineering, Penn State

TABLE OF CONTENTS

CONFERENCE SESSIONS A

TRACK 1 | DISASTER-RESILIENT DESIGN

TRACK 2 | BUILDING ENVELOPE

TRACK 3 | ADAPTATION & RETROFITS

NO PAPERS *(See presentations at PHRC.psu.edu/Publications/Past-Conference-Proceedings.aspx)*

TRACK 4 | THE BIG PICTURE

TRACK 5 | BUILDING SCIENCE / EDUCATION

NO PAPERS *(See presentations at PHRC.psu.edu/Publications/Past-Conference-Proceedings.aspx)*

CONFERENCE SESSIONS B

CONFERENCE SESSIONS C

CONFERENCE SESSIONS E

CONFERENCE SESSIONS F

CONFERENCE SESSIONS I

TRACK 1 | INFRASTRUCTURE

TRACK 2 | BUILDING INFORMATION MODELING (BIM)

TRACK 3 | GLOBAL COMMUNITIES + EDUCATION

NO PAPERS *(See presentations at PHRC.psu.edu/Publications/Past-Conference-Proceedings.aspx)*

PROCEEDINGS ONLY

ASCE JAE : SPECIAL COLLECTION

The American Society of Civil Engineers' (ASCE) Journal of Architectural Engineering (JAE) is running a Special Collection on Housing and Residential Building Construction. This peer-reviewed Special Collection covers various aspects of residential buildings, such as single- and multi-family dwellings, mid-rise and high-rise apartment buildings, dormitories, and hotels/motels, and includes technical research and development, technology transfer, case studies, and state-of-the-art review types of papers. See published papers here,

https://ascelibrary.org/page/jaeied/specialcollectionhousingandresidentialbuildingconstruction

If you would like to convert your RBDC Conference paper to a journal paper for this JAE Special Collection, go to the following site: *http://www.editorialmanager.com/jrnaeeng/*. When you see the "Additional Information" section, in response to the following question: "Is this manuscript part of a Special Issue? If yes, please provide Special Issue title and guest editor name.," type the following in the dialogue box: "Housing and Residential Building Construction; Ali Memari". For more information, contact Dr. Ali Memari, *amm7@psu.edu*.

PENNSYLVANIA HOUSING RESEARCH CENTER

The Pennsylvania Housing Research Center (PHRC) collaboratively engages with the residential construction industry to catalyze advancements in homebuilding through education, training, innovation, research, and dissemination. The PHRC envisions a residential construction industry equipped with the knowledge, skills, and technology to build better homes. Administered within the Department of Civil & Environmental Engineering at Penn State, you can learn more at *phrc.psu.edu*.

206B Sackett Building
The Pennsylvania State University
University Park, PA 16802

T: 814-865-2341
phrc@psu.edu

PHRC.psu.edu

@PHRCPennState

Director | **Ali Memari**
Associate Director | **Brian Wolfgang**
Housing & Land Development Specialist | **Chris Hine**
Housing Systems Specialist | **Sarah Klinetob Lowe**
Training & Events Coordinator | **Tracy Dorman**
Budgets & Publications Coordinator | **Rachel Fawcett**

PennState College of Engineering | PENNSYLVANIA HOUSING RESEARCH CENTER

Double-skin ventilated glass façades. An overview of concepts, product systems, realized examples.

S. Brunoro[1]

[1]Researcher, Department of Architecture, University of Ferrara, via Ghiara 36, Ferrara, Italy, 44121. + 39 0532 293633, silvia.brunoro@unife.it.

ABSTRACT

Double skin façade systems are employed increasingly, mainly in high profile buildings being touted as an exemplary green building strategy. It is a new technology that is more often found in North European countries, even if in the last ten years also in Mediterranean Countries this totally glazed envelope had large diffusion.
The aim of the paper is to improve the definition of the double-layer ventilated glass façade concept, illustrate a proposal for the classification of the concept technologies and ventilation criteria, supported by existing examples, in order to improve the understanding of the general principles of the double skin façade system and the possibility of application both in cold than in hot climates.

INTRODUCTION

A Double Skin Façade is based on the notion of exterior walls that respond dynamically to varying ambient conditions, and that can incorporate a range of integrated sun-shading, natural ventilation, and thermal insulation devices or strategies. Early solar passive design exemplified in the "*trombe*" wall, can be considered as a precursor to modern double skin systems [*Diproise et altr.,1999*].
A typical double glass envelope system comprises a layer of single glass and a layer of double-glazing, separated by an air space. Each of these two façade is commonly called skin. The ventilated air cavity - having a width that can range between several centimeters to about a meter – is located between these two skins. The air cavity can be heated by the sun to create a warm buffer zone that protects interior zones in winter, or can be configured to function as a thermal chimney in summer utilizing the stack effect to remove excess heat. The Double Skin Façade is based on the notion of exterior walls that respond dynamically to varying ambient conditions, and that can incorporate a range of integrated devices: operable sun-shadings, natural or forced ventilation devices, heat absorber. [*Loncour et altr., 2004*]
From perspectives of both knowledge and budget, double skin systems are often beyond the scope of most commercially driven projects. The question arises as to whether or not double skin buildings truly are more environmentally responsible and sustainable, mainly in the Mediterranean climate context where summer overheating is the main issue, and where cooling requirements are higher than the insulation ones.
Before the energy crisis of the 1970's, the use of glass in envelopes was mainly focused on aesthetics, as it was estimated that they didn't need to be ecologically responsive to

the environment. Since energy costs were low, the inefficiency of the fully glazed building, with large heat gain and heat loss, resulted in more operation for the heating or the air-conditioning system.

Following the oil crisis of the 1970's, the fully glazed envelope was criticized due to its energy inefficiency: this led the building industry to develop new products such as photosensitive and photochromic glass, and new coatings such as reflective or selective (Low-E), anti-reflection, angular selective, etc. Many of these new technologies have helped in reducing energy consumption in buildings with large glass area. Moreover, glass has become an important feature in architecture: its many desirable qualities, including light transmission, and aesthetic appearance, make glass one of the almost indispensable materials in use today. With this belief, the intelligent double layer glass façade is being used frequently in Europe [*Krewinkel, 1998*].

Figure 1. A fully-glazed double-skin ventilated glass façade in the refurbishment of an existing building. Torno International Headquarters in Milan (Italy)

The main purpose of the double glass envelope is to balance the desire for daylight and outdoor view with the concerns for heat gain and loss. The air cavity is heated by the sun to create a warm buffer zone that protects interior zones in winter, while in summer it is configured to function as a thermal chimney utilizing the stack effect to remove excess heat.

In addition to the energy savings, the double envelope system has other potential benefits such as acoustic control, water penetration resistance, and improved office atmosphere because of the view and utilization of daylight. The double skin system also offers a choice for renovation of existing building facades to transform into more energy efficiency buildings (Figure 1).

A double skin façade can be classified according to: building construction, kind and direction of ventilation in the air cavity [*Oesterle et altr., 2001*]. The purposed classification is below summarized in the next two sections. The aim of this paper is to provide an advancement of knowledge in the field of the dynamic high-efficient envelopes, that can improve the overall energy balance of the building by reducing thermal losses, gaining solar energy and provide passive cooling: the so -called ventilated double skin glass façades.

CLASSIFICATION OF DOUBLE SKIN FAÇADE SYSTEMS BY TYPE

In a double layer façade configuration, glass "skins" are separated by an air corridor. The main layer of glass is usually insulating. The air space between the layers of glass acts as insulation against temperature extremes, winds, and sound. According to the typologies of constructions, double layer façades can be classified in three types: Full – height façades, Divided by space (corridor) façades, and Single-elements (cells) façades [*Brunoro,2006*].

Full – height (undivided) façades
In full height façades, the air space is undivided: the air cavity is vertically continuous across the entire facade to draw air upward using natural physics principals (hot air rises – Figure 2).

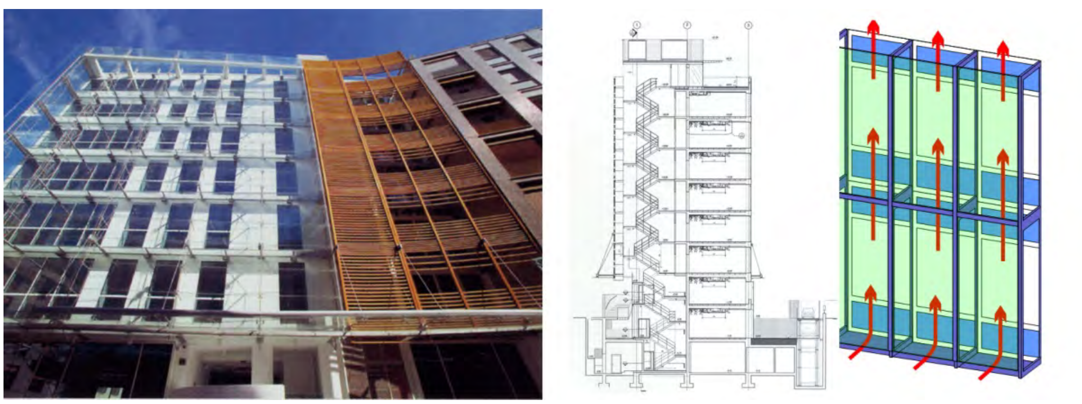


Figure 2. Full height façade

The undivided façade benefits from the stack effect. On warm days, hot air rises at the top of the air space. Openings at the top of the cavity throw out warm air and cooler replacement air is drawn in from the outside. However, in very hot and humid climates, offices on the top floors can suffer from overheating due to the low pressure and accumulation of hot air in the cavity adjacent to their space. For this reason, mechanical devices such as engines are desirable. In this configuration, the interior windows can be operable for ventilation or not. In most cases, some windows are fully opened, or “vasistas”, this favors the inlet of natural fresh air in the rooms. Generally the undivided air space can be practicable allowing people to occupy this environmentally variable interstitial space. The atria/air cavity can be used for maintenance, and also programmatically for green balconies: plants are used in these spaces to filter and moisten the air as well as act as shading devices.
In the continuous cavity, grates at each floor level allow the access to the interior of the space for cleaning. Any louvers that are located within the cavity must be able to be moved to facilitate access. These still permit airflow through the space but provide a

platform upon which to stand when cleaning the cavity floor by floor. In some instances, where there has to be occupation of the air space for cleaning, the interior clear dimension is usually in the 600 to 900 mm range.

Corridor façades

Corridor façades (Figure 3) are divided into vertical or horizontal bays across the wall, to optimize the stack effect, by drawing air across the façade through openings allowing better natural ventilation. In this typology, the divided air space can reduce over-heating on upper floors as well as noise, fire and smoke transmission.. However, the shaft façade becomes problematic for fire-protection, sound transmission and the mixing of fresh and foul air.

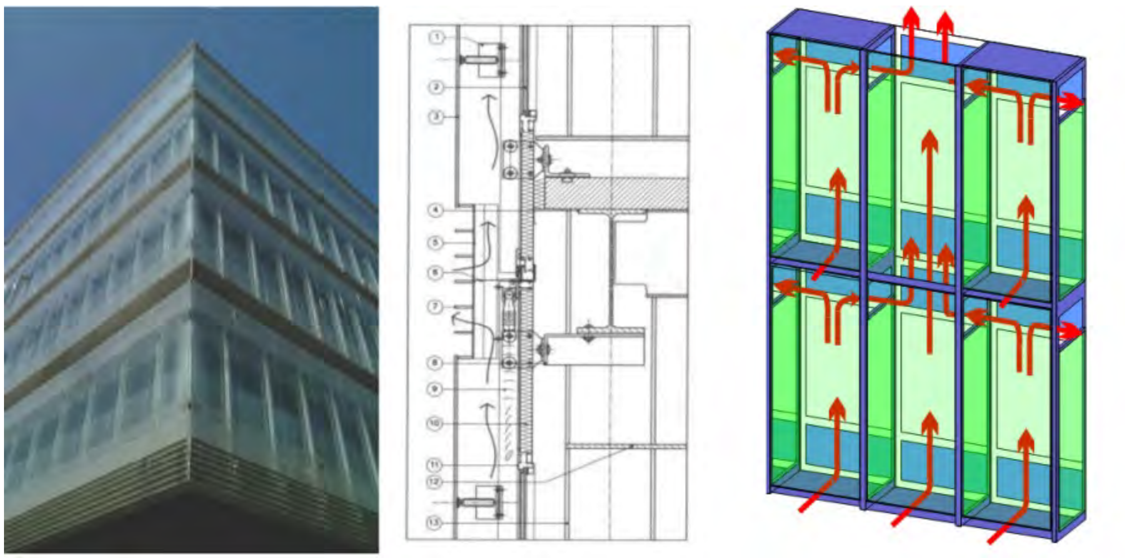


Figure 3. Corridor façade

Single-elements (cells) façades

A typical strategy of the double skin façade is to compartmentalize the buffer zone into separate regions with air supplied by grilles or vents at each level or individual zone (Figure 4).

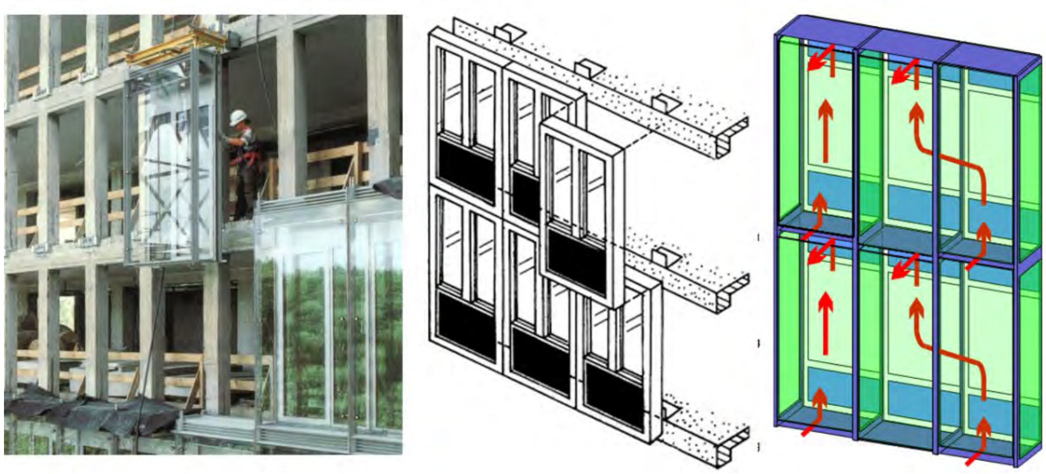


Figure 4. Cell façade

Double layer façades made by cells have a high prefabrication grade, as in general, single elements (one floor high) are ready to be installed. Floor-by-floor divisions add construction simplicity of a repeating unit and in turn can produce economic savings. Cell façades have fresh air and exhaust intakes on every floor allowing for maximum natural ventilation. This compartmentalization eliminates the impact of noise, sound, smoke and heat transfer from one section, level or room to the next area. This is more desirable also for fire-security, as the air cavity is divided into small zones. The use of vents or grilles allows for the control of the incoming air by reducing air speed, protecting from rain and reducing noise transmission from the exterior. It is this control that allows occupant access to natural ventilation in high-rise constructions.
In this type of façade, the dimensions of the air cavity is small (about 20 to 35 cm): this is because of the floor- height and the correct proportion for the stack effect. Cleaning is done from within the office space and requires that interior window panels open fully to provide adequate access for cleaning.

CLASSIFICATION OF DOUBLE SKIN FAÇADE SYSTEMS BY VENTILATION

The stack effect (or chimney effect) is a phenomenon related to the rising of hot air, which is lighter than cold air. Applied to a double skin glass façade, the concept of stack effect is expressed by the air movement in the cavity between the two skins. The air in the cavity is hotter than outside, and has a tendency to escape at the top of the cavity. The ventilation of the cavity may be totally natural, fan supported (hybrid) or totally mechanical. The width of the cavity can vary as a function of the applied concept between 10 centimeters to more than 1 meter. The width influences the physical properties of the façade and also the way that the façade is built.

Natural ventilation can provide an environmental friendly atmosphere and reduce the requirement for mechanical ventilation. On the other hand, natural ventilation may create a door-opening problem due to pressurization. Besides, if the air path is not appropriately designed, the solar heat gain within the façade cavity will not be removed efficiently and will increase the cavity temperature. This is mainly true in Mediterranean climates, where the risk of overheating is tangible.

Natural ventilation

In the naturally ventilated double façade system, the air flows into the cavity by two means: wind pressure and/or the stack effect [*Ding et altr.,2005*]. Wind pressure typically dominates the airflow rate. If properly designed, wind flowing over the façade can create pressure differences between the inlet and outlet inducing air movement. Without wind, the cavity can still be ventilated due to the stack effect. As air flows into the lower inlet, it is heated and becomes less dense and lighter. As a result, air will flow into the inlet and out the outlet while removing heat. Because there is the potential for stack-driven and wind-driven pressures to be counteractive, the air path and exterior openings need to be correctly sized and configured to insure the stack effect pressures and wind-driven forces are additive. A correct ratio is estimated in 1:2 (outlet the double of inlet). Otherwise, the preheated airflow in the cavity will tend to radiate to the interior, and opening the inner layer window in summer will introduce a burst of hot air

These are comprised of a single layer of glazing placed on the exterior the main façade of double-glazing. The single-glazed outer skin is used primarily for protection of the air cavity contents (shading devices) from weather. With this system, the internal skin offers the insulating properties to minimize heat loss. The outer glass skin is used to block/slow the wind in high-rise situations and allow interior openings and access to fresh air without the associated noise or turbulence. Windows on the interior façade can be opened or not. In general they are openable, while ventilation openings in the outer skin moderate temperature extremes within the façade.

Mechanical ventilation
In urban environments, natural ventilation systems may also experience significant problems of noise transmission and pollution and may result in uncomfortable indoor environments in extreme weather conditions. Therefore, a natural ventilation system is more suitable in suburban areas with temperate weather where the airflow in the cavity will be close to the indoor air condition.
In double layer glass façades with mechanical ventilation, the air space between the two layers of glazing becomes part of the HVAC system. Air is forced into the cavity by mechanical devices: the air rises and removes heat from the cavity and continues upwards to be expelled or re-circulated. The heated "used" air between the glazing layers is extracted through the cavity with the use of fans and thereby tempers the inner layer of glazing while the outer layer of insulating glass minimizes heat-transmission loss. Fresh air is supplied by HVAC and precludes natural ventilation. Air is not pumped in directly from the outdoors, for this reason there is potentially less risk of condensation and pollution in the cavity. Also, because the forced ventilation systems allow the building to be sealed, they provide more protection from traffic noise than naturally ventilated systems. In areas with severe weather conditions or poor air quality, the forced ventilation system can keep conditions in the buffer zone nearly constant to reduce the influence of the outdoor air to the indoor environment.

The placement of the glass can vary, depending on the ventilation system. The choice of the glass type for the interior and exterior panes depends on the typology of the façade. In case of a naturally ventilated façade, an insulating pane (= thermal break) is usually placed at the interior side and a single glazing at the exterior side. In case of a façade ventilated with indoor air (mechanical ventilation), the insulating pane is usually placed at the exterior side, the single glazing at the interior side.
Because of the different ventilation source, the thermal performance, like cavity heat removal rate and glass surface temperature, of these two systems may vary as well.

Hybrid ventilation
There is also a “compromise” between natural and mechanical ventilated double layer façades: hybrid systems. In general, in this type of ventilation, natural ventilation is used as far as possible, and the mechanical ventilation is only triggered when the driving forces of the natural ventilation become inadequate and no longer make it possible to achieve the desired performances. Generally, a remote system permits the shift to one type of ventilation to another in an automatic manner, on the basis of a controlled an algorithm.
On Figures 5-6-7 Different types of ventilation of Double skin façade are showed.

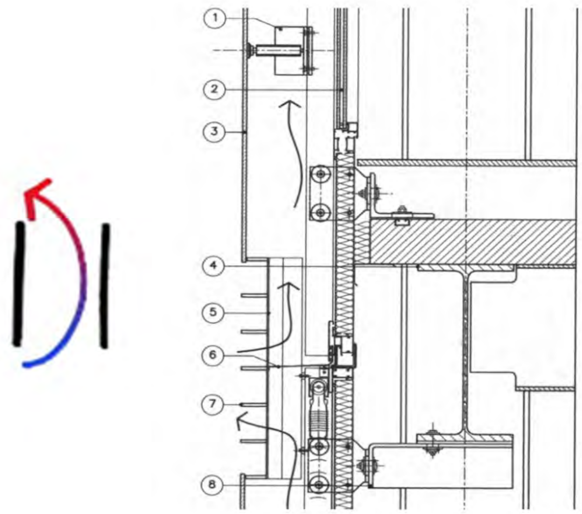


Figure 5. Naturally ventilated façade. The air in the cavity flows for wind pressure or chimney effect. Inner skin can be openable or not.

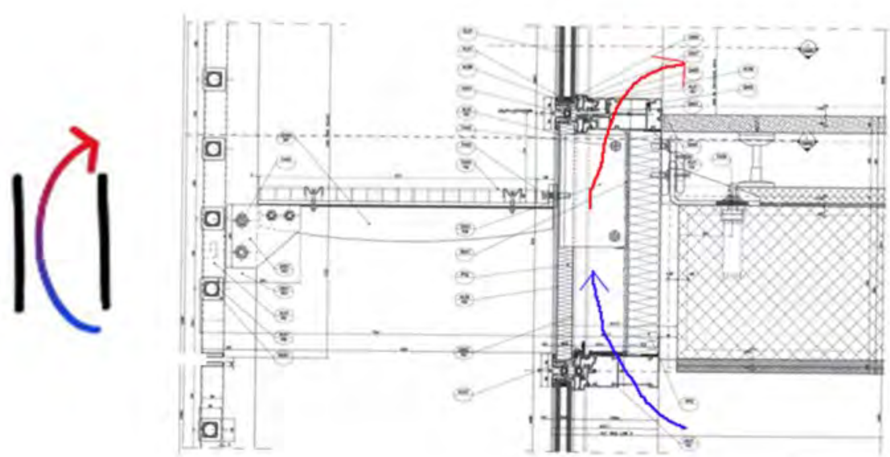


Figure 6. Mechanical ventilated façade. Air is forced into the cavity by mechanical devices: the air rises and removes heat from the cavity and continues upwards to be expelled or re-circulated.

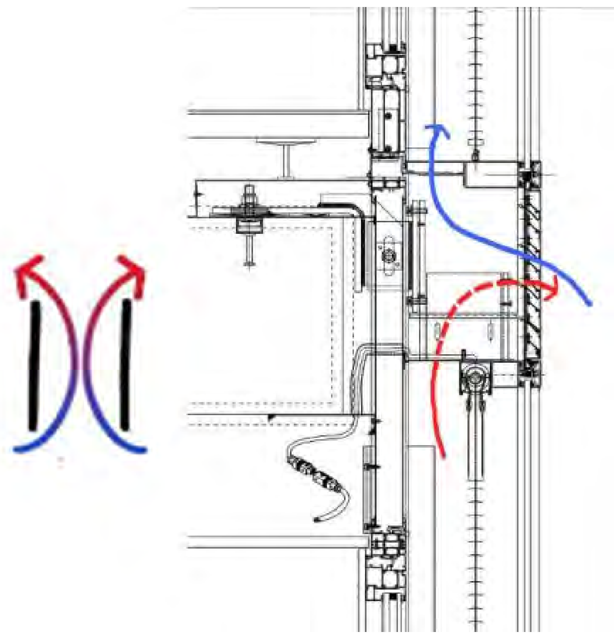


Figure 7. Hybrid ventilation, when both conditions are mixed.

Ventilation direction in the cavity

Another criterion of classification is the ventilation direction, that refers to the origin and the destination of the air flowing in the ventilated cavity. This can be applied to the type of ventilation (natural, mechanical, hybrid) above mentioned.

There are different approaches:

1. A building with its own separate heating, cooling and ventilating system, where a second skin is added to the façade. The cavity of the double skin façade is only ventilated to the outside and is built to reduce noise, contain solar shading and light redirection devices.
2. A building, where the heating, cooling and ventilating system of the building is integrated into the double skin façade, e.g.: by ventilating the building using the cavity of the double skin façade.

It is also possible that a façade can adopt several ventilation directions at different moments, depending on what devices integrated into the façade permit it (for example operable openings). The following ventilation directions can be listed:

Outdoor - Outdoor

In this ventilation mode, the air introduced into the cavity comes from the outside and is immediately rejected towards the outside. The ventilation of the cavity therefore forms an air curtain enveloping the outside façade.

Indoor -Indoor

The air comes from the inside of the room and is returned to the inside of the room or via the ventilation system. The ventilation of the cavity therefore forms an air curtain enveloping the indoor façade.

Mixed ventilation Outdoor –Indoor (Air supply) or Indoor - Outdoor (Air exhaust)

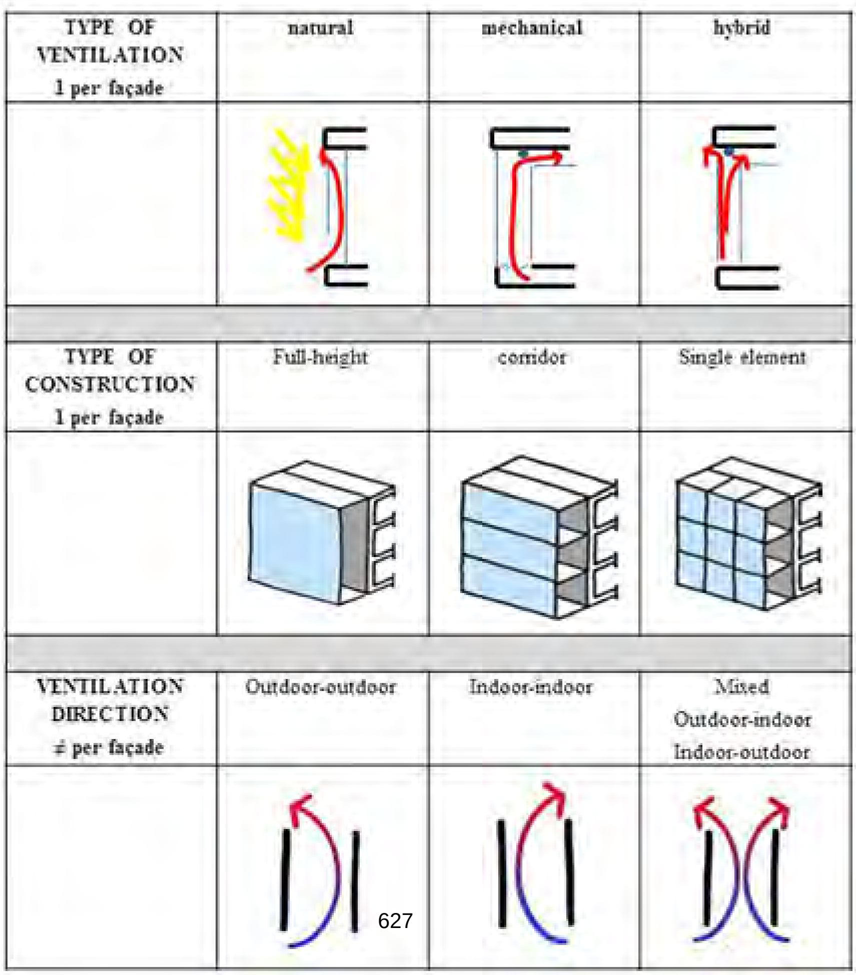
In the case of mixed ventilation, the air movement of the façade is created with outdoor air. This air is then brought to the inside of the room or into the ventilation system. The ventilation of the façade thus makes it possible to supply the building with air.
In indoor-outdoor systems, the air comes from the inside of the room and is evacuated towards the outside. The ventilation of the façade thus makes it possible to evacuate the air from the building.
Combinations between different kinds of classification (by type, by ventilation, by direction) are illustrated in Figure 8.

TYPE OF DEVICES

Solar shadings

"*Good lighting of the workplace is one of the main factors of indoor comfort that can positively influence health and productivity of office personnel. Natural light, its variations and its spectral composition are of great importance for well-being and mental health. Natural light is a fundamental component of our life, helping our body to produce vitamin "D", an important anticancer element*." [*Straube, 2001*]

The control of solar heat gain in a double skin glass façade is obtained through the use of shading devices in the air cavity, typically horizontal blinds. Blinds are situated in the cavity of the double skin facade and protect the building from the solar heat gains or play the role of the pre-heater for the ventilation air. The absorbed solar energy is transformed to the passing air by convection or by radiation to the neighboring surfaces. Several configurations for these horizontal blind shading devices exist; they



can either be fixed elements or operable units that are either controlled by the occupant or by sensors within the building. External shading devices are the most efficient means of reducing solar heat gain, but they are expensive because of installation costs and safety concerns, anyway the totally full-glazed façade aesthetic is changed.

Figure 8. Classification of Double layer lass façade by type

Moreover, they are typically fixed and not usually effective for all sun angle conditions especially with low sun angles in the morning or late afternoon. Also to reduce maintenance, the air cavity offers protection for the shading devices.

The geometry (mainly width and height of the cavity) and the properties of the blinds (absorbance, reflection and transmission) may affect the type of air flow in the cavity. When designing a Double Skin Façade it is important to determine type, size and positioning of interior and exterior openings of the cavity since these parameters influence the type of air flow, the air speed and the temperatures in the cavity.

The double skin façade with its increased glazing coverage improves the access to daylighting in the space. Also important to daylight penetration is floor to ceiling height and floor plan depth. The increased daylighting component of the completely glazed façade can introduce excessive glare and heat at certain times of the day. These increases require further measures in design to combat their negative effects. Solar shading devices are designed into the air space to decrease solar heat gain through the glazing and reduce the amount of glare caused by the increased access to daylighting.

Green in the cavity

In general the temperature of the blinds is high, which is an advantage in the cold period but disadvantage in the hot period. To decrease the cooling loads of the building new ideas for shading system are considered. Green in the cavity has the ability to dissipate absorbed solar radiation into sensible and latent heat. These are mostly related to the thermal, aesthetic, psychological, comfort level, and sound attenuation point of view. In general green in the cavity create more effective shading system than blinds. A research project at TU Delft aimed in defining the thermal performance of the double skin façade with plants. [*Stec W.J, et altr, 2005*]

Further simulations of the total building proofed that plants can contribute to the creation of comfortable indoor climate and saving energy.

The study proves that the Installation of plants in the double skin facade allows for reduction of the cooling capacity by almost 20%. A similar result was noticed for the energy consumption of the cooling system.

Figure 9. Different kind of solar shadings in Double skin glass façades. On the

left: venetian blinds (Johnson wax building, Milan, Italy) In the center: textile curtains (Gsw Headquarters, Berlin, Germany) On the right: green shadings (Bayerische landesbank, Frankfurt)

DOUBLE LAYER GLASS FACAES IN MEDITERRANEAN CLIMATE

The concept of regional response in building design leads to solutions that would further enhance concepts of sustainability by promoting climatic responses such as solar availability, weather patterns, urban design considerations, and other issues that deal with specific regional differences versus a technological solution that operates on universal conventions.

The double layer glass façades system is a sustainable design solution born in Northern Europe to maximize daylighting with integral solar heat gain control, to heat production and exchange by potential green house effect in the buffer zone. Overheating, as a minor problem, is solved by blinds and buffer zone. Natural ventilation reduces air-conditioning loads. This is why it is necessary to question if the system is exportable with good results in Mediterranean Countries.

The thermal performance of double façade systems depends on many factors. Because the interactions among these variables are complex, the energy savings and cost/benefit of these systems are not well established.

For the climate of Mediterranean Countries, the control of solar gains in the building design is important during the summer periods. Therefore double skin facades may lead to overheating during the summer months if there is no appropriate façade design, ventilation technique building orientation and provision of shading. [*Hamza, 2004*]

The Mediterranean climate encourages the use of natural ventilation. However, in the last decades, it is noted an increased use of air-conditioning due to high ambient air temperatures and high internal gains both in large office buildings than in residential buildings.

The buffer zone allows for the increased use of the perimeter zone of the space that typically requires heating or cooling mechanisms against the exposed glazing. Also, with the use of improved solar heat transmission values for glazing the absorption and reflection of heat can be manipulated to minimize solar heat gain. This can be accomplished through the use of what is referred to as 'spectrally selective glazing'.

The increased daylighting component of the completely glazed façade introduces excessive glare and heat at certain times of the day. These increases require further measures in design to combat their negative effects. Solar shading devices are designed into the air space to decrease solar heat gain through the glazing and reduce the amount of glare caused by the increased access to daylighting.

The air space and integrated solar shading devices control the solar heat gains that would typically require the use of mechanical means of air conditioning and air extraction.

Another problem that can occur in hot and humid climate regards naturally ventilated façades where the low pressure can reduce the stack effect in the air cavity. In Mediterranean Countries, the warm and wetter climate compared to the Northern European Countries, makes it difficult to think of the possibility of exploring a natural ventilated façade in all its performance potential. [*Hamza, 2005*]

Sometimes, to avoid overheating and condensation phenomena, electrical fan are provided to favor the flow of ventilation in the case of low-pressure and air stagnation

at the top of the air cavity. Due to the warm and humid climatic conditions typical of the Mediterranean area, it is preferred to avoid the natural ventilation trough the cavity, keeping the inner skin closes and obtaining the comfort conditions through the air conditioning (indoor-indoor) [*Brunoro,2006*]:
The maximum performance obtainable from a double-skin façade in Mediterranean climate is strongly linked to the integration with HVAC system. The main advantage will result in lower operating costs, due to the increased thermal performances of the envelope.

CONCLUSIONS

"*A double-skin façade also reduces heat losses because the reduced speed of the air flow and the increased temperature of the air in the cavity lowers the rate of heat transfer on the surface of the glass. This has the effect of maintaining higher surface temperatures on the inside of the glass, which in turn means that the space close to the window can be better utilized as a result of increased thermal comfort conditions*" [*Compagno, A., 1995, p. 94*]

The thermal performance is a primary consideration of selecting a double envelope system. Because of the different ventilation source and directions, the cavity heat removal rate and glass surface temperature, may vary as well.
Main conclusions on adopting high-performing double layer glass envelopes can be listed as follows:

- All types of Double Skin Façade offer a protected place within the air gap to mount solar shading and daylight enhancing devices, which then can be used whenever necessary and thereby reducing the cooling load;
- One of the main advantages of the Double Skin Façade systems is that they may allow natural (or fan supported) ventilation, which will reduce the use of electricity for ventilation;
- In winter the cavity forms a thermal buffer zone which reduces heat losses and enables passive thermal gain from solar radiation, which will reduce the heating load;
- May enable natural ventilation and night time cooling of the building's thermal mass, which will reduce the use of electricity for ventilation and the cooling load;
- Noise reduction from motor traffic, enabling natural ventilation without noise problems.

REFERENCES

Brunoro S. (2006). "Efficienza energetica delle facciate, Maggioli, Rimini

Compagno, A. (1995*), "*Intelligent Glass Facades; Material, Practice, Design", Birkhauser, Basel, Switzerland

Ding, W., Hasemi, Y. and Yamada, T. (2005). “Natural ventilation performance of a double-skin façade with a solar chimney”, *Energy and Buildings* .Vol. 37. Pp. 411-418

Diprose, P. R., Robertson, G. (1999). “Towards A Fourth Skin?”, *Sustainability And Double-Envelope Buildings*, Department of Architecture, University of Auckland, Auckland, New Zealand.

Hamza, N. (2004). “The performance of double skin facades in office building refurbishment in hot arid areas”, PhD thesis, University of Newcastle Upon Tyne, UK

Hamza N., Underwood C. (2005). “CFD supported modelling of double skin facades in hot arid climates”, Ninth International IBPSA Conference Montréal, Canada August 15-18

Krewinkel, H. (1998). “Glass Buildings”, Birkhauser, Basel, Berlin, Boston

Loncour, K., Deneyer, A., Blasco, M., Flamant, G., Wouters, P-, (2004). “Ventilated Double façade. Classification & illustration of façade concepts”, Belgian Building research Institute, Department of Building Phisics, Indoor climate & Buidling Services

Oesterle, E., Lieb, R., Lutz, M., & Heusler, W. (2001). “Double Skin Facades, Integrated Planning”, Prestel.

Stec W.J., van Paassen A.H.C., Maziarz A. (2005), “Modelling the double skin façade with plants”, *Energy and Buildings*, Vol. 37, pp. 419–427

Straube, J., & Straaten, R. v. (2001). “The Technical Merit of Double Skin Facades for Office in cool humid climates”, http://www.civil.uwaterloo.ca/BEG/Downloads/DoubleFacadesPaper.pdf