PennState

PHRC

2020

RESIDENTIAL BUILDING DESIGN & CONSTRUCTION CONFERENCE

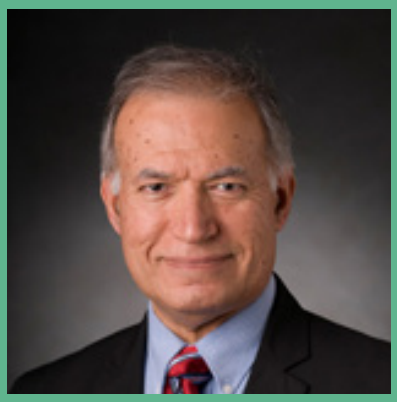
MARCH 4–6, 2020

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

WELCOME

REGISTRATION OPENS AT 7:30 AM

Dear 2020 Residential Building Design and Construction Conference Attendees,



It is my great pleasure to welcome you to the 2020 Residential Building Design and Construction (RBDC) Conference held March 4-6 at The Pennsylvania State University in State College, Pennsylvania. This fifth biennial conference is organized by the Pennsylvania Housing Research Center (PHRC) at Penn State and is being held in conjunction with the 28th Annual PHRC Housing Conference at The Penn Stater Hotel & Conference Center.

The Annual PHRC Housing Conference has been a successful PHRC program for 28 years with emphasis on topics of interest to developers, builders, remodelers, design professionals, planners, regulatory and code officials, modular and HUD code builders, and housing product manufacturers. On the other hand, the Biennial RBDC Conference that is being held for the fifth time is a program organized by the PHRC to provide a forum for researchers, design professionals, manufacturers, builders, and code officials to exchange knowledge and understanding on the latest research and development advancements and to discuss and share their own findings, innovations, and projects related to residential buildings.

At the 2020 RBDC Conference, we are very excited to have two keynote speakers: 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 will share his presentation titled "Wind Hazard Resilient Residential Communities—When Engineering Isn't Enough." Lois B. Arena will present her presentation titled "Passive House: A Proven Path Toward Resilient, Affordable & Energy Efficient Housing."

Most of the presentations at the conference are by university professors, researchers, graduate students, architects, consulting engineers, product manufacturers, and product related associations / councils. For this conference, we have also organized a special closing plenary on "Buildings as a Drawdown Solution: Getting to Zero *and* Beyond" by Jay Arehart, Project Drawdown researcher, and Tom Richard of Penn State. Also, you will not want to miss Friday's panel discussions on passive house & education; local communities & education; and global communities & education.

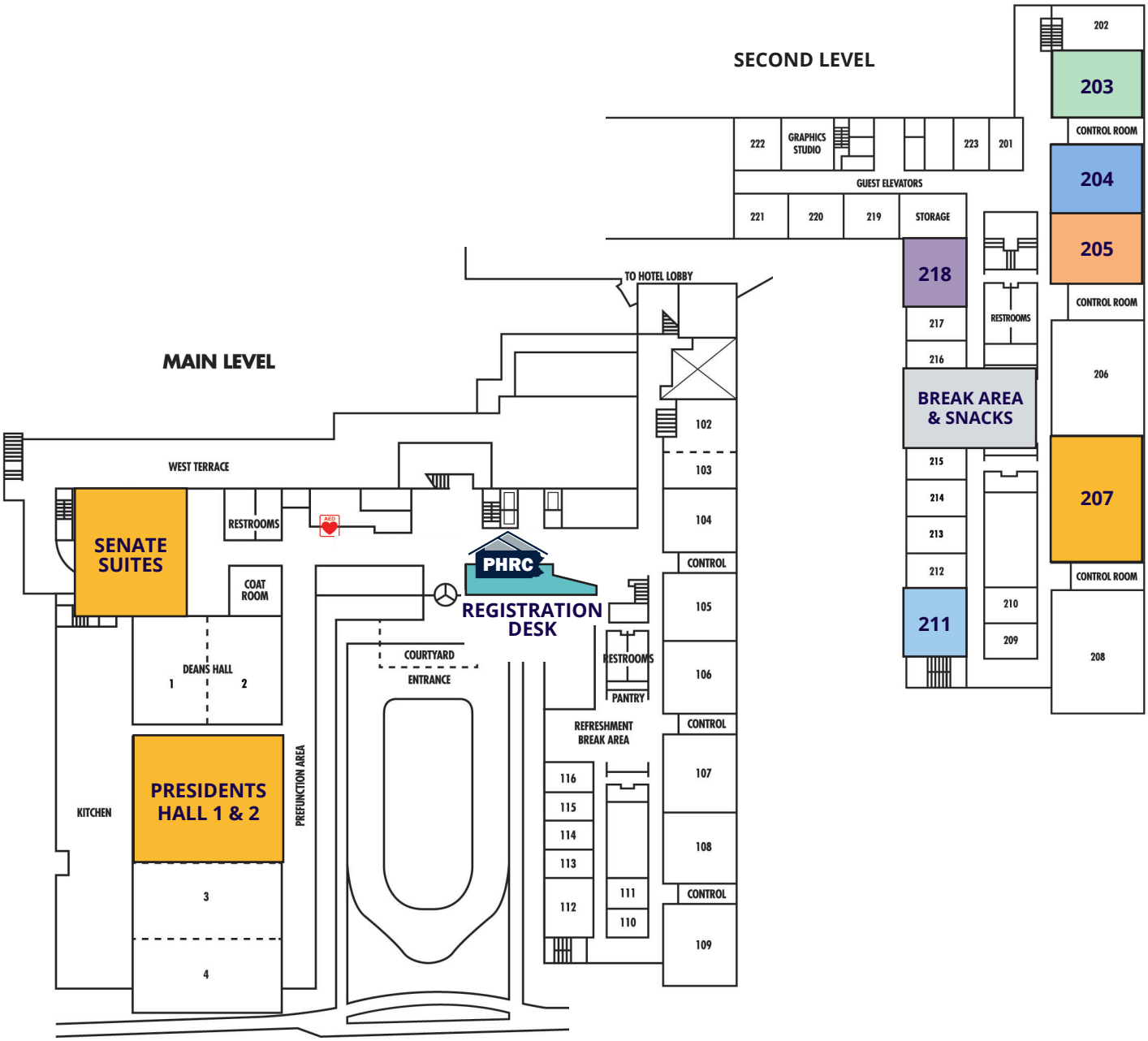
The details of most presentations in the form of full papers can be found in the proceedings of the conference. The conference proceedings and slide presentations can be found at this Dropbox link, *http://bit.ly/2020RBDCCPresentations* and on the PHRC website after the conference. As in the past four RBDC conferences, the authors of papers are invited to consider expanding/ enhancing their papers to submit for possible publication in the ASCE Journal of Architectural Engineering, Special Selection on Housing and Residential Building Construction. I hope that you find the technical content of the conference beneficial and you enjoy the opportunities for interaction and networking with colleagues.

Ali M. Memari, Ph.D., P.E., F.ASCE, Professor

2020 RBDC Conference Chair
Bernard and Henrietta Hankin Chair in Residential Building Construction
Director, The Pennsylvania Housing Research Center (PHRC)
Department of Architectural Engineering and Department of Civil and Environmental Engineering
The Pennsylvania State University

Conference Papers & Presentations

FACILITY MAPS



	WEDNESDAY	THURSDAY	FRIDAY
PRESIDENTS HALL 1 & 2	Lunch Happy Hour on the Exhibit Floor	Breakfast, Keynote Lunch	N/A
ROOM 207	Breakfast, Keynote	N/A	Track 3, Plenary
ROOM 203	Track 1	Track 1	Track 1
ROOM 204	Track 2	Track 2	Track 2
ROOM 205	Track 3	Track 3	Track 3
ROOM 211	Track 4	Track 4	N/A
ROOM 218	Track 5	Track 5	Track 4
HOTEL LOBBY	BeTL & AddCon Lab Tour	Relax & Unwind Downtown	N/A

SCHEDULE

TUESDAY, MARCH 3

6:30pm-8:30pm — **CONFERENCE WEEK KICKOFF RECEPTION | SENATE SUITES**

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 Martin | 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**

SCHEDULE

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

KEYNOTE

WEDNESDAY | 8:30 AM – 10:15 AM | ROOM 207

WIND HAZARD RESILIENT RESIDENTIAL COMMUNITIES — WHEN ENGINEERING ISN'T ENOUGH

DR. DAVID O. PREVATT, F.SEI, F.ASCE, PE (MA)

ASSOCIATE PROFESSOR OF CIVIL & COASTAL ENGINEERING, ASSOCIATE DIRECTOR NSF - NHERI EXPERIMENTAL FACILITY, *UNIVERSITY OF FLORIDA*

The 2011 tornado season was a wake-up call because over 250 persons were killed and $7 Billion in property damage occurred in just two tornado outbreaks. It galvanized the wind engineering community to produce its first tornado-resilient design guide, which is included in ASCE 7-16. Although the United States on average expects between 1,000 to 1,200 or more tornadoes per year, only one local jurisdiction exists in the U.S., out of 89,000, that has specifically legislated building design provisions to mitigate tornado-induced wind damage and injury. Residential construction suffers a disproportionately high degree of wind damage in hurricanes and tornadoes, too often attributed to "An Act of God," rather than to woeful lack of appropriate engineering.

Tornadoes and hurricanes have many similarities in the extreme winds that produce building damage, which makes the dearth of tornado design guidelines even more confounding. This talk discusses the impact of wind load design provisions for hurricanes and tornadoes on the vulnerability of residential construction and societal economic losses. Why provisions for tornado design were not included in minimum building load design standards is discussed, coupled with how weaknesses in the structural load paths of light-framed wood construction contributed to the widespread, catastrophic failures of tracts of houses in tornadoes. The talk will highlight some important research leading to development of the tornado design guide and it also suggests future research needs to create a path towards truly tornado-resilient residential communities.

Dr. David O. Prevatt is an Associate Professor (Civil & Coastal Engineering) in University of Florida's Engineering School of Sustainable Infrastructure and the Environment. He is also the Associate Director of NSF's NHERI Wind Engineering Experimental Facility at the University of Florida.

For over twenty years, Dr. Prevatt's research sought to address a widening gap between poor performance of residential structures in high wind events and the limited structural engineering associated with these structures. His research identified technologically feasible engineering solutions available to reduce wind damage to buildings. He has also addressed means to increase the limited implementation of these solutions in our communities. In particular since 2011, Dr. Prevatt has led a renewed thrust among engineers to develop tornado-resilient structural design standards. Dr. Prevatt applied his training and professional expertise in forensic engineering, wind engineering and analytical and experimental research to develop procedures for estimating tornado wind loads and the structural resistance of building systems.

Of greatest benefit, has been his focus on resilience of single-family residential structures, which lags behind improvements seen in commercial and industrial buildings. Not only has he focused on the engineering solutions but also in communication of those advances to the public, from the US Congress, to international wind engineering conferences, to students and the public. His efforts have served to galvanize the engineering community and construction professionals to develop building codes that provide tornado-resilient mitigation at reasonable economic costs. Dr. Prevatt strongly advocates for unifying wind design guides for all buildings and the development of performance-based wind design provisions for all structures. His goal is to make research more accessible by communities impacted by winds and promote philosophies for tornado-resilient residential communities.

After earning his MS and PhD degrees from Clemson University, Prevatt joined the Boston-based ENR500 consulting engineering firm, Simpson Gumpertz & Heger Inc. in 1998, focusing for seven years on building envelope system design and remediation for contemporary and historic buildings.

Dr. Prevatt won international recognition for his research by receiving the 2012 Silver medal from the Republic of Trinidad and Tobago's National Institute of Higher Education, Research, Science and Technology (NIHERST). In 2017, he received the Doctoral Dissertation Advisor / Mentoring Award from the Herbert Wertheim College of Engineering. As a professional engineer, Dr. Prevatt has testified before US Congressional Subcommittees on wind engineering related topics, and he served as a member of ASCE's Wind Load Task Committee that is developing the ASCE 7-16 wind load standard provisions, ASCE's EF-Scale Committee on Tornado Wind Speeds, and ASCE's Infrastructure and Research Policy Committee. Dr. Prevatt is an active researcher, who has published two monographs, and 80 articles, many in peer-reviewed journals and conference proceedings.

PROGRAM | SESSIONS A

WEDNESDAY | 10:45 AM – 12:15 PM

TRACK 1: DISASTER-RESILIENT DESIGN | 203

PERCEPTIONS FOR RESIDENTIAL RESILIENCE

AUTHOR: Sandeep Langar, *University of Texas at San Antonio*
SPEAKER: Sandeep Langar, *University of Texas at San Antonio*

The state of Texas has suffered the most Billion-Dollar Weather and Climate Disasters in the last two decades, making it the state with the highest disaster incident rate in the nation, followed by Illinois and Georgia. Given the intensity and frequency of natural disasters impacting the state, it is imperative to ensure that residential units/houses are resilient to natural disasters. The initial step in creating residential structures that are resilient to natural disasters is assessing current perceptions and adoption trends among homeowners and developers. The study uses a survey method to benchmark the resiliency paradigm among Homeowners and Home Builders in the state. The research involved the following steps: sample selection (homebuilders and homeowners), survey instrument development (online), pilot testing the instrument, survey administration, data collection, and data analysis. The results were statistically analyzed to identify the perceptions among homeowners and Home Builders for resiliency within the state of Texas.

SINGLE-FAMILY HOUSING CONSTRUCTION VS. HAZARD MITIGATION COST DATA IN THE STATE OF KENTUCKY USING MODEL-BASED COST CALCULATION

SPEAKER: Fatemeh Orooji, *Western Kentucky University*

Many homeowners may be aware of potential hazard mitigation building practices. However, uncertainties, primarily about cost and schedule increases, often cloud decision making and may lead to low adoption of proven strategies. Homeowners whose properties are in a natural hazard prone area (e.g. flood) need technical and economic guidance to support their decision about implementing mitigation that reduces future damage to their home. To address this critical need, this project proposes to advance the state-of-the-art understanding of construction and hazard mitigation cost through the integration of building information modeling (BIM) and model-based cost calculation to provide homeowners, stakeholders, and decision-makers additional information relevant to the upfront construction costs that may increase the adoption of hazard-resistant construction practices in the State of Kentucky. Building Information Modeling (BIM) is used to rapidly apply the analysis methodologies to multiple configurations of single family buildings to develop generalized cost data for wood-framed homes. Building information modeling manages all essential project data in digital format throughout the building's life-cycle. This advance technology integrates multi-disciplinary information within one model and creates an opportunity to optimize performance analyses and resiliency throughout the design process. This conclusion can be used by designers, builders, and owners to make comparisons and simplify the mitigation decision-making process. To demonstrate the methodology, a case study of a typical residential building is considered.

EVALUATION OF VARIOUS RETROFIT STRATEGIES FOR EXISTING RESIDENTIAL BUILDINGS IN HURRICANE PRONE COASTAL REGIONS

AUTHORS: Mehrshad Amini & Ali Memari, *Penn State*
SPEAKER: Mehrshad Amini, *Penn State*

Among hurricane related hazards, surge and subsequent flood waves due to high wind are the most destructive and costly phenomena during hurricanes for residential buildings in coastal areas. This potential damage has been increased over the past 30 years due to increase in intensity of storms, residential population, and age of existing homes in coastal regions. This paper presents a review of the performance of retrofitted residential buildings in past hurricanes, and potential wind and flood-induced damage and subsequent risk mitigation techniques are discussed. The results show that structural characteristics such as superstructure or foundation system type, specific flood-prone zone construction, and total cost play a prominent role in selecting the appropriate retrofit method by homeowners and engineers. Study of actual damage shows that although elevating the house can potentially reduce the direct damage from flood and surge, it can impose severe wind-induced damage to roof structural members, envelope systems, and foundation due to higher lateral wind loads and subsequent higher overturning moment. The performance of breakaway walls below the BFE strongly depends on connections between the wall and structural members. Furthermore, the performance of houses with dry floodproofing depends on several factors, including quality of materials below the BFE, appropriate installation (sealant and shield systems), and drainage system for potential seepage. Last but not least, regardless of retrofit strategies, the lack of flood damage-resistant material below the BFE and ongoing maintenance cause severe damage to residential buildings in coastal areas during the hurricanes.

TRACK 2: BUILDING ENVELOPE | 204

INNOVATIVE CONSTRUCTION PRODUCTS: FROM QUALIFICATION AND PERFORMANCE ASSESSMENT TO QUALITY CONTROL

AUTHOR: Marzieh Riahinezhad, J-F Masson, Peter Collins, Bruno Di Lenardo, & Michael Lacasse, *National Research Council of Canada*; Jocelyn Johansen, *CSL Silicones, Inc.*
SPEAKER: Marzieh Riahinezhad, *National Research Council of Canada*

Air barrier systems (ABS) are essential elements in the performance of building envelopes and they are specified in National Building Code of Canada (NBC) to control the risk of condensation. Since the publication of the Energy Code of Canada in 2014, more attention has been given to the importance

of ABS to control both heat flow and air transfer through the building envelope, which both contribute to rising costs of energy use in buildings. Recently, the Canadian Construction Material Centre (CCMC) developed performance criteria for liquid-applied ABS. The CCMC is a recognized accreditation body that provides guidance to building officials with respect to the conformity of innovative products as alternative solutions to the NBC. In this presentation, four key items are presented. First, a brief overview of liquid-applied ABS, their components and functions, and the motivation for use of this product in the construction industry will be reviewed. Second, the qualification process for this innovative product against requirements for compliance with the NBC in Canada and its market acceptance will be discussed. In doing so, the strategy recently adopted by the CCMC in the evaluation of innovative liquid-applied ABS will be reviewed. Third, the key performance criteria and the durability assessment for an expected 25 years of acceptable service life will be discussed. Finally, the quality control process for acceptable field applications will be mentioned.

ASHRAE 90.1: CODIFIED CONDENSATION FOR COLD CLIMATES

AUTHORS: David Finley & Manfred Kehrer, *Wiss, Janney, Elstner Associates, Inc.*
SPEAKER: David Finley, *Wiss, Janney, Elstner Associates, Inc.*

To comply with the energy code, designers often utilize the Prescriptive Building Envelope Option described in ASHRAE 90.1 when determining the minimum amount of insulation required within a wall assembly. In cold climates, the minimum R-Value requirement for framed wall assemblies allows designers to utilize a split insulation arrangement to meet code requirements. However, these designs often carry an elevated risk of condensation which is not explained in the text of the standard and may lead a designer to unknowingly promote detrimental insulation combinations with regard to convective condensation. A design tool has been developed based on psychometrics and ASHRAE 90.1 requirements which illustrates the ratio of continuous insulation to total insulation. The design tool currently assumes a high leakage rate; therefore, values along the pass-fail line may be overly conservative. In order to incorporate a more realistic air leakage rate and develop a more defined pass-fail criteria, our research uses software tools, like WUFI, to study the requirements offered by 90.1 to evaluate the hygrothermal performance of insulation combinations for framed wall assemblies based on the simplified exfiltration model. Hygrothermal engineering principals and the results will be presented with future publication of the design tool for the design industry.

WALL UPGRADES FOR DEEP RESIDENTIAL ENERGY RENOVATION: INTERIM RESULTS FROM A MULTI-YEAR STUDY

AUTHORS: Chrissi Antonopoulous, Cheryn Metzger, Jian Zhang, & Michael Baechler, *Pacific Northwest National Laboratory;* A. O. Desjarlais, *Oak Ridge National Laboratory*; Pat Huelman & G. Mosiman, *University of Minnesota*
SPEAKER: Chrissi Antonopoulous, *Pacific Northwest National Laboratory*

The Pacific Northwest National Laboratory, Oak Ridge National Laboratory and the University of Minnesota are conducting a three-year, multipart study on residential retrofit wall assemblies. The project is funded by the U.S. Department of Energy's Building Technology Office and will identify, test and verify wall assemblies for hygrothermal performance in retrofit applications. The study includes a comprehensive literature review and expert advisory group, which inform wall selection. Selected wall assemblies are then thermally simulated using EnergyPlus and THERM, and hygrothermally simulated using WUFI, to model both thermal and moisture performance of the wall assembly. Eight wall assemblies are then experimentally tested in an in-situ laboratory environment at the University of Minnesota, with a typical residential wall used as a baseline. The in-situ experiment looks at the physical hygrothermal performance of each assembly. The simulation and experimental results will be combined with an economic analysis to produce a techno-economic study of residential wall systems for deep energy retrofits. This paper presents progress after year one of the study.

TRACK 3: ADAPTATION & RETROFITS | 205

SUSTAINABILITY CHARRETTES AND PENN STATE'S RESIDENCE HALLS RENOVATIONS: IMPROVING BUILDING PERFORMANCE AND THE STUDENT EXPERIENCE

SPEAKERS: John Bechtel & Yumna Kurdi, *Penn State*

The investment in green buildings goes beyond economic and environmental impacts. Reducing the energy cost of operation and reducing the building's carbon footprint are obvious returns with green buildings. But green buildings can also have a larger impact on occupants' quality of life and well-being. Educational institutions such as Penn State realize that the impact of green buildings have a unique potential to impact students' sustainability experience and behavior. Adopting sustainability strategies early in the design process can have great impact on the building design. The Office of Physical Plant in their ongoing effort to evolve the Penn State sustainability policy in design and construction are exploring the possible impact of pre-design sustainability charrettes on the residence halls renovation process. By involving a third party sustainability facilitator, exploring several sustainability rating systems and the adoption of sustainability behavior strategies, the goal of this initiative is to evolve the design of residence halls to impact the students' quality of life and well-being.

PASSIVE HOUSE RETROFIT: BREATHING NEW ENERGY INTO OLD DORMS

SPEAKERS: Benedict H. Dubbs & William Trout, *Murray Associates Architects*

According to The College Board, 40 percent of full-time college students at public universities and 64 percent at private universities live on campus. Of those, 23 percent reside in purpose-built, near-campus student housing, and 22 percent are in on-campus dormitories, most of which are 50+ years old. When retrofitting rather than replacing older housing stock is the only option, employing Passive House design principles and certified building components to do so is an inspired alternative. To date, no U.S. college dormitory has been renovated to Passive House standards. In fact, of the 317 PHIUS (Passive House Institute US) certified projects, only 17 are retrofits. Murray Associates Architects, designed the Dauphin Hall Student Residence at Penn State affiliate Penn College of Technology, also designed the Passive House addition and renovation to the Pennsylvania Housing Finance Authority (PHFA). Utilizing Dauphin Hall as the subject and the PHFA renovation as an archetype, PHIUS WUFI® Passive 3.2 energy modeling software and related methods will demonstrate how Passive House principles can be applied effectively to a real-life college dormitory retrofit, for long-term energy savings and Passive House "trailblazer" status for an institution.

TRENDS AND PRACTICES OF RETROFITTING EXISTING RESIDENTIAL BUILDINGS TO PASSIVE HOUSE CRITERIA AND SIMILAR STANDARDS

AUTHORS: Sophia Welch, Esther Obonyo, & Ali Memari, *Penn State*
SPEAKER: Sophia Welch, *Penn State*

Passive House is a green building standard that is becoming more commonplace. As a standard heavily dependent on passive design aspects, it is well suited for new construction. With the rise in popularity, building techniques and technologies have advanced to levels that place the cost of a new passive house within 10% of a typical new house. This difference can be made up in less than 20 years with the energy savings that are the hallmark of Passive Houses. In addition to the energy savings, many banking institutions are providing financial perks, like reduced interest rates, that will further reduce the payback period, making monthly payments for new Passive Houses cheaper than those for new typical homes. However, the bulk of the housing stock is not new construction. Retrofits are inherently more difficult for passive house design since many design decisions have already been made simply by the building already existing. This can create built-in inefficiencies and leaves fewer components of the house to make up the required energy savings. Things become even more difficult when dealing with historic and culturally significant buildings. This paper looks at the trends of retrofitting existing houses to Passive House standards and explores the challenges and effort required to achieve it. It also explores retrofits to less strict standards, such as target heating and cooling load.

TRACK 4: THE BIG PICTURE | 211

DISCUSSING INNOVATION IN RESIDENTIAL CONSTRUCTION AT THE NATIONAL SCALE

AUTHORS: Freddy Paige & Andrew McCoy, *Virginia Tech*; Carlos Martín, *Urban Institute*
SPEAKER: Freddy Paige, *Virginia Tech*

Nationally, energy efficiency goals are changing and to facilitate the execution of improved standards and practices conversations about federal agency's involvement are evolving. This study highlights a national housing workshop sponsored by Housing and Urban Development (HUD) which has begun the process of increasing communication and collaboration between federal and private housing stakeholders. Media, research, industry, and manufacturing stakeholders collaborated to discuss strategies for improving housing innovation in the United States specifically focused on innovation for housing affordability, sustainability, and resiliency. This paper outlines the process of facilitating this discussion and providing an opportunity for housing stakeholders to move towards action. Key problems and solutions such as data availability and federally moderated databases are presented to describe the plan for the United States towards a sustainable future. By connecting workshop findings to systematic literature review data, further analysis of suggested solutions is provided in hopes of learning from past events and policies. The workshop discussed in this paper can and should be duplicated for years to come to create a more comprehensive understanding of contemporary issues in the sustainable buildings sector. As climate change impacts become more severe, the frequency of these strategic conversations will need to increase in response to natural disasters, energy scarcity, and affordability. Our technological advancements have outpaced the ability for our current socio-political infrastructure to deliver housing innovations. Through collaboration and strategic investment, the housing industry can catch up to other industries which use big data analytics and public private partnerships to shorten innovation cycles.

BUILDING INDUSTRY: TRENDS IN SUSTAINABILITY AND BUILDING SCIENCE APPLICATIONS

AUTHORS: Dorothy Gerring, Rob Wozniak, Thomas Brooks, Evan Klinger, Cole Moriarty, Jeffrey Sementelli, & Michael "Tanner" Reif, *Pennsylvania College of Technology*
SPEAKERS: Dorothy Gerring, Rob Wozniak, Thomas Brooks, Evan Klinger, Cole Moriarty, Jeffrey Sementelli, & Michael "Tanner" Reif, *Pennsylvania College of Technology*

This study was done to help identify how the building industry is learning about issues related to sustainability and building science. Interviews were completed in the fall of 2019 by students enrolled at Pennsylvania College of Technology of 23 alumni concerning where they are currently working. The firms were diverse, representing a broad sector of the design and construction industry, many located in Pennsylvania. The major findings were that firms rely heavily on industry publications and material suppliers to stay up-to-date. Firms are working to improve standard details for performance but 26% are not addressing achieving a continuous thermal envelope. Firms that are doing energy modeling are hiring consultants for this work (87%). The greatest challenges for the future were identified as costs and sustainability. The study shows that there is still a gap in the industry for application of building science performance issues and in fully understanding sustainability issues in a way that proves their value.

A PATH TO ZERO ENERGY READY HOME CONSTRUCTION

AUTHORS: Theresa Gilbride & Michael Baechler, *Pacific Northwest National Laboratory*; & Kiere Degrandchamp, *High Performance Homes*
SPEAKER: Theresa Gilbride, *Pacific Northwest National Laboratory*

While the number of zero energy homes constructed in the U.S. has grown dramatically, increasing nearly 400% since 2015, zero energy homes still accounted for less than 1% of all U.S. homes constructed as of December 2018. Concerns about high costs or implementation challenges have kept many builders from attempting zero energy home construction. However, builders participating in the U.S. Department of Energy's Zero Energy Ready Home Program are showing that zero energy ready home construction can be achieved simply and cost effectively with off-the-shelf equipment and materials and common construction techniques. Construction methods used by builders in the DOE program are compared with those used in just-to-code new homes and existing homes for several key components, including wall assemblies and HVAC systems. Examples of cost-effective assemblies used in the Mid Atlantic states are provided.

TRACK 5: BUILDING SCIENCE / EDUCATION | 218

INTRODUCTION & OVERVIEW

SPEAKER: Samuel Taylor, *Energy & Resource Efficiency*

This session will introduce and review the progress to date on efforts related to building science in education to kick off the Building Science/Education track at the 2020 RBDCC.

BUILDING SCIENCE EDUCATION: EVOLVING APPROACHES AND RESOURCES

AUTHOR: Samuel Taylor, *Energy & Resource Efficiency*
SPEAKER: Samuel Taylor, *Energy & Resource Efficiency*

Current advances in building science teaching resources & approaches are addressed that support the introduction and expansion of building science education in universities. These include infusion of building science into traditional architecture and construction management courses, as well as dedicated building science courses. An expanded description of resources is provided based on recent work supported by NREL, ORNL and others. In 2019, NREL supported a task order with the University of Minnesota to identify building science teaching resources and provide an annotated bibliography. Supplemental and supporting resources were also identified. Additionally ORNL supported development of an online Building Science Advisor to assess moisture risks of different building envelopes. They also supported the development of a new edition of the Moisture Control Handbook and the development of an open source 2-D hygrothermal analysis model (THERM). During the 4th RBDCC, we had a Building Science Education (BSE) track with 8+ speakers, a forum, and a tour of a RTZ design house under construction. Further faculty advisors at the April 2018 DOE Race to Zero judging and awards weekend at the National Renewable Energy Lab in Golden, CO recognized the need for resources to support the introduction and expansion of building science education in universities. In the 2019 Design Challenge weekend on April 12, 2019, this need was also emphasized as well as the need for the DOE SD Design Challenge (former Race to Zero competition) to give greater emphasis to good building science.

50 SHADES OF BUILDING SCIENCE EDUCATION

SPEAKER: Georg Reichard, *Virginia Tech*

The Solar Decathlon Design Student Competition, which emerged from the former Race to Zero Student Competition, was originally created to meet the lacking educational needs of building science education across the A/E/C disciplines. The organizing committee set out to engage and challenge students and faculty to apply sound building science principles to create cost-effective, market-ready designs. While the standard, quality, and extent of winning submission has dramatically increased over the years, concerns have emerged that student teams have lost sight of the original goals and that sound building science criteria are not met by a significant number of submissions. This presentation examines and extracts metrics from past competition guidelines as they relate to building science topics and assesses available project submissions of winning teams on those criteria across the years. The goal of this presentation is to facilitate a discussion on how building science criteria could be sharpened and possibly expanded in future competition guidelines.

SESSIONS B

WEDNESDAY | 1:15 PM – 2:45 PM

TRACK 1: DISASTER-RESILIENT DESIGN | 203

ASSESSING THE PERFORMANCE OF ELEVATED WOOD BUILDINGS IN THE WAKE OF HURRICANE MICHAEL

SPEAKER: Jae Kim, *University of Kansas*

There is a great appeal in the development of communities in coastal regions, despite the numerous, well-recorded historical disaster events caused by the high winds and storm surge flooding by hurricanes and other storms. Single-family residential structures may be the most vulnerable in these types of hazards, especially manufactured housing units and homes located directly on the shoreline. Given the general propensity to continue development in coastal regions, various disaster-mitigation techniques have been proposed and tested for such residential structures. Hurricane Michael was the strongest hurricane to hit the continental U.S. since Hurricane Andrew in 1992. Measured peak wind gusts were observed at 129 mph, where the gauge broke; real wind speeds may be even higher. Hurricane Michael presented a unique and important opportunity to investigate wind performance of residential buildings, given that recorded wind speeds reached and exceeded design winds at the coast and further inland. This work presents the findings from an NSF-funded RAPID reconnaissance in the Florida Panhandle following 2018 Hurricane Michael that investigated the performance of two types of elevated residential buildings, namely, site-built and manufactured housing. Two primary structural mitigation strategies were observed to minimize damage to these structures, including elevating homes above surge and flood levels, and using anchored tie downs on the manufactured homes. Identified trends in the levels and locations of damages sustained by the buildings, as a function of wind speed and physical building characteristics, are presented. Results are used to establish recommendations for improving the design standards of vulnerable hurricane-prone residential structures.

WIND INDUCED EFFECTS ON ROOF-TO-WALL CONNECTIONS OF RESIDENTIAL BUILDINGS

SPEAKER: Amal Elawady, *Florida International University*

Wind hazards are of the most hazardous events that frequently occur in the United States. Hurricane Irma left majority of damage concentrated on low-rise buildings and wooden construction. Roof-to-wall connections play an important role in the behavior of wood-frame buildings when exposed to wind induced loadings. These connections help in resisting wind induced uplift pressures experienced by roofs. Steel is the most common material used to manufacture these connectors such as in hurricane clips and straps. A steel-wood connection requires intrusion of screws or nails into the wooden members, which weakens the wooden members and creates a pathway for water penetration and subsequent damage to the interior of buildings. An alternative to such intrusive connections is non-intrusive bonded connections such as Fiber Reinforced Polymer (FRP) sheet connections. FRP connections are advantageous as they are nonintrusive and corrosion resistant, and offer better wind driven rain resistance. However, wind actions on roof-to-wall connections have not been adequately estimated yet. An extensive large-scale aerodynamic testing study is conducted at the NSF-Natural Hazard Engineering Research Infrastructure (NHERI) Wall of Wind (WOW) Experimental Facility (EF) to investigate wind actions resulting from simulated hurricane winds on a gable wood frame building model, with roof-to-wall connections. The model was installed on the WOW 16-ft diameter turntable and tested under different wind directions and under varying wind speeds, and two different enclosure configurations were considered to assess different internal pressure scenarios. The results were compared to pressure coefficients recommended by ASCE-7 10 and 16 versions for the cases of Component and Cladding and Main Wind-Force Resisting System. The experimental results showed a better match with the ASCE loadings based on the Component and Cladding case. Moreover, a set of tests was carried out for increasing wind speeds to observe failure, if any. The wind speed causing failure of the connections closely matched the estimated failure wind speed.

WIND HAZARD RESILIENT CONSTRUCTION MITIGATION DECISION-MAKING FRAMEWORK

SPEAKER: Fatemeh Orooji, *Western Kentucky University*

As a result of the increasing trends in wind frequency, intensity, and losses in the United States over the past 50 years, studies have focused on best practices and code-plus practices, and a variety of residential wind hazard mitigation methods have been suggested; however, implementing mitigation requires an initial investment which varies from several hundred to tens of thousands of dollars. Additionally, and more importantly, the economic benefit of mitigation (e.g. avoided loss) may not provide a positive return on investment. The optimal strategy of resilient residential construction should consider multiple objectives such as avoided financial losses and cost of mitigation considering the hazard spatial domain, building configuration, and economic aspects. This study develops a novel method to enhance the mitigation decision-making process. This multi-objective algorithm is developed to maximize wind hazard loss reduction of residential buildings by implementing a variety of mitigation methods that can be customized based on location, years of interest, and building configuration. These conclusions simplify the mitigation decision-making process, ultimately enhancing reliability and reducing risk. To demonstrate the model, a case study of a typical wood frame, one-story, single-family house is considered.

TRACK 2: BUILDING ENVELOPE | 204

HIGH-PERFORMANCE WINDOWS – MORE THAN JUST A PRETTY HOLE IN THE WALL

AUTHORS: Katherine Cort & Theresa Gilbride, *Pacific Northwest National Laboratory*

SPEAKER: Katherine Cort, *Pacific Northwest National Laboratory*

As more stringent building energy codes and better insulation products conspire to yield better performing walls, the inefficiency of the windows is coming into sharper focus. The U.S. Department of Energy has supported several projects through its national laboratories to improve the thermal performance of windows. At the Pacific Northwest National Laboratory in Richland, Washington, the PNNL Lab Homes, two fully monitored identical side-by-side manufactured homes, have been used to test the performance of several window improvements including triple-pane windows, storm windows with low-emissivity coatings, smart automated interior insulated shades, and exterior shading products. Findings will be presented on these studies,

along with impacts. For example PNNL's Lab Home research on low-e storm windows has helped to support a new ENERGY STAR certification, industry standards, and utility incentives. Preliminary findings will also be presented on the latest Lab Home windows study -- performance testing of a thin triple-pane window that uses a thin center layer of glass and krypton gas fill for windows that are no thicker or heavier than a standard double-pane window but provide R-5 or better insulation levels. The session will also present findings from related field studies and a market assessment of thin triple-pane windows conducted by PNNL.

LOW-SLOPE ROOFING SYSTEMS FOR MULTI-STORY RESIDENTIAL AND COMMERCIAL BUILDINGS

AUTHORS: Rowland Smith, *Wiss, Janney, Elstner Associates, Inc.* & Ali Memari, *Penn State*
SPEAKER: Rowland Smith, *Wiss, Janney, Elstner Associates, Inc.*

What exactly does failure mean? While many think of "building failure" as catastrophic condition where the structure collapses, the most frequent failures are serviceability level failures, i.e. some components stop functioning and cause problems for occupants or for building durability. By this definition, we can classify roofing issues as one of the most common building failures. One of the most basic goals for building owners is to keep the building dry, especially for roofing systems. This goal cannot be achieved if the building is experiencing roofing failures and, therefore an emphasis must be placed on the basis of design. By understanding the fundamentals of low-slope roofing systems that are common to multistory/high-rise residential and commercial buildings, one can begin to piece together the components that create and control a given system. For example, a building owner might ask "How will storm water be managed on my roofing system?" or "How does the climate of my building's location affect my roofing system?". The answers lie within the analysis of the components in these roofing systems. The goal of this paper is to provide basic review of the most commonly used low-slope roofing systems. The most efficient way to avoid roofing failures is by not having them in the first place. Instead of discussing patches and fixes to existing issues, this paper is meant to offer some guidelines that can be useful in the selection process of the roofing system.

THIN SHELL CONCRETE ENCLOSURES IN RESIDENTIAL BUILDINGS

AUTHOR: Pablo Moyano Fernandez, *Washington University in St. Louis*
SPEAKER: Pablo Moyano Fernandez, *Washington University in St. Louis*

Building enclosures fulfill different functions at different scales. They define, connect and separate indoor and outdoor environments while controlling the thermal flow to create habitable spaces. In addition to performing as the air, water, moisture and temperature barrier between exterior and interior conditioned space, building skins can also serve as part of the building's structural system. But most importantly, the outermost layer of the exterior wall is the component of the building that receives the greatest exposure to natural forces. Therefore, it needs to perform effectively over the lifetime of the building. As a physical interface of spatial and environmental exchange, the design of building enclosures must be comprehensively assessed in terms of function, aesthetics, feasibility, durability, maintenance and cost. Consequently, building enclosure systems are sophisticated assemblies generated through complex processes that merge design, science, technology and craft. Concrete has a long history as a building material. Recently precast concrete flourished to become a viable and competitive alternative. Yet, precast concrete is still rarely used in the single-family residential market in United States. With new technological advancements, concrete has seen several improvements, including reduced thickness. Today, concrete has achieved unprecedented thinness, diminishing its weight and still maintaining its strength and integrity. This paper discusses the use of Ultra High Performance Concrete (UHPC) in thin shell concrete assemblies as a performative component of residential building envelopes. The CRETE House, Washington University in St. Louis's proposal for the 2017 Solar Decathlon, is introduced as a case study of the use of an innovative precast concrete wall assembly in a single-family residence.

TRACK 3: ADAPTATION & RETROFITS | 205

MARKET TRANSFORMATION: HOW FAR, HOW FAST

SPEAKER: Rob Bernhardt, *Passive House Canada*

Global commitments have been made to improve building energy efficiency to address climate change and meet the worlds sustainable development goals by providing better buildings. The energy use intensity of buildings must not only be reduced by about 60%, but tomorrow's buildings must also deliver an improved quality of life in terms of comfort, health, resilience and affordability. Renewable energy sources are to meet the remaining energy needs of buildings and the carbon embodied in the construction of buildings must be minimized. How can these goals be achieved, and are jurisdictions succeeding in doing so? This presentation outlines global targets and norms, explaining how they were arrived at and how they can be achieved. Examples of market transformation initiatives will be highlighted, including Brussels, China, Vancouver, Canada, New York City, the EU and others, comparing the strategies adopted in each. Change is never easy and resistance to market transformation is endemic. This session will share insights and strategies on how to build sufficient momentum to overcome the inevitable inertia, inviting questions and engagement from session participants.

REPURPOSING EVERYDAY BUILDINGS: EXTRAORDINARY RENOVATIONS OF ORDINARY STRUCTURE

SPEAKER: Eric Fisher, *Fisher ARCHitecture*

Attendees will learn why architects are now expanding the use of adaptive reuse strategies to include buildings that would previously have been overlooked and demolished. First the presenters will review the history of adaptive reuse. Then they will introduce examples of extraordinary renovations and additions to everyday buildings. The talk will conclude with the introduction of creative, affordable, practical ways for architects to put these strategies to use.

OPEN BUILDING: PLANNING MULTI-UNIT RESIDENTIAL BUILDINGS FOR CHANGE

AUTHOR: Stephen Kendall, *Council on Open Building*
SPEAKER: Stephen Kendall, *Council on Open Building*

Buildings need to be planned for change; adopting an infrastructure model of buildings helps. Change of standards, life-style preferences and demographics are inevitable, during the initial planning and construction of buildings but also over time. An infrastructure model of buildings dis-entangles the long-lasting parts from the parts that change faster. In multi-unit residential buildings, this means disentangling the parts and spaces of the building that are shared by all inhabitants from those decided per unit of occupancy. The name given to these emerging practices is Open Building. This paper presents one case in the Netherlands and one in China. PATCH22 in Amsterdam was initiated by an architect / developer. Using an access floor technology for routing horizontal services, each floor in the 7-story building can be divided into between two and eight units. Each floor and each dwelling can be different at no additional cost. The Chinese case is UNITY TECH. They have delivered more than 60,000 infill packages in the last three years, fitting out spaces one-unit-at-a-time in large multi-unit residential towers left empty by the general contractor. Each four-person installation team completes an apartment in seven days. Every apartment type is accounted separately. Unity Tech saves 50% in time and 65% on materials waste and offer a 3-year warranty. Using their product offers savings on repair/remodeling for developers, who money and time. Other companies in China are offering a similar service. Lessons from these cases are drawn for application in the United States.

TRACK 4: MEP | 211

A NEW STANDARD TO EVALUATE THE INSTALLATION QUALITY OF RESIDENTIAL HVAC SYSTEMS

SPEAKER: Dean Gamble, *EPA ENERGY STAR Certified Homes*

The efficiency of over 200,000 new homes in the United States is evaluated each year using the Energy Rating Index (ERI), as defined in ANSI/RESNET/ICC Standard 301. However, under the current standard, one of the largest influences of a home's energy performance – the HVAC equipment – is still rated solely based on nameplate information, and not impacted by how the equipment was designed and installed. RESNET and EPA have drafted a new standard to change this by rewarding high-quality HVAC design and installation with ERI points. Not only will this make proper design and installation more valuable than ever before, it will significantly re-unify the process of doing an ERI rating and earning the ENERGY STAR for new homes. This presentation will discuss the key concepts behind the new draft standard, how many ERI points a properly installed system may earn, and when it will likely be available for use.

MONITORING HVAC SYSTEM PERFORMANCE FOR AFFORDABLE HOUSING UNITS

AUTHORS: Fatemah Ebrahim, Frederick Paige, Farrokh Jazizadeh, & Quinton Nottingham, *Virginia Tech*
SPEAKER: Fatemah Ebrahim, *Virginia Tech*

HVAC systems are a top contribution to residential building energy consumption and thermal performance. This study demonstrates the ability for property managers of affordable housing units to monitor the performance of their HVAC systems across their building stock using smart devices and cloud computing. This paper presents a case study of an affordable housing development in Virginia which was recently renovated to improve and explore HVAC system performance with high financial precision to meet evolving federal regulations. Real-time building energy usage at the circuit-level, resident perceptions, property manager perceptions, and building specifications are all combined to provide a detailed understanding of current and future practices for wirelessly monitoring HVAC equipment. This paper focuses on HVAC performance describing the selection, utilization, and performance of appropriately sized and comparable one stage, two-stage, and variable speed HVAC systems. Preliminary data analysis has shown great potential for updating previous processes to calibrate inaccurate perceptions of behavior-driven energy use; leverage cloud computing for data analytics and visualization to improve data accessibility; and the inclusion of socio-political impacts into decision-making tools. We have also found a critical need to better incorporate the variability of system performance due to the high potential for installation errors and user errors. The findings of this study transfer beyond the context of HVAC systems to various building systems which can be connected to the internet of things (IoT). The methodology of this study also provides guidance for better academic-industry-citizen engagement for the real-world testing and design of engineered infrastructure systems.

INDOOR AIR QUALITY AND ENERGY USE IN PASSIVE HOUSES

SPEAKER: Xinyi Lily Li, *Penn State*

A Passive House certified under the Passive House Institute (PHI) standard has been reported to reduce up to 80% of space heating energy and 50% of primary energy consumption by building highly airtight and thermally resistive building envelopes and adopting passive conditioning technologies such as energy recovery ventilation. This talk presents an up-to-date review on Passive House performance and literature, and the latest measurement data on both indoor air quality and energy use of a Passive House in Pennsylvania.

TRACK 5: BUILDING SCIENCE / EDUCATION | 218

TEACHING PASSIVE HOUSE IN ACADEMIA

AUTHORS: Walter Grondzik, *PHIUS & Ball State University*; Alison Kwok, *University of Oregon;* Mary Rogero, *Miami University of Ohio*; & Katrin Klingenberg, *PHIUS*
SPEAKERS: Walter Grondzik, *PHIUS & Ball State University* & Mary Rogero, *Miami University of Ohio*

The Passive House Institute US (PHIUS) conducts an active training program for professionals who wish to become proficient in passive house design and analysis. This training is provided via the CPHC (Certified Passive House Consultant) credentialing process. PHIUS has similar certifications for builders and raters, but the CPHC certification and related training is the core of its educational strategy. Historically, PHIUS CPHC training was delivered via face-to-face workshops. More recently the CPHC training adopted a blended delivery format; with both online and face-to-face components. The target audience for PHIUS training has traditionally been those seeking advancement or initial credentials via a continuing education experience. This has predominantly meant post-school adults. Even more recently, PHIUS made its CPHC training curriculum available for delivery through academic institutions. This allows students enrolled in a higher education program (most commonly architecture) to engage the CPHC training materials while a student and under the aegis of his/her university. This academic engagement can result in a CPHC certification for students who successfully pass the PHIUS certification exams. The certification can then be taken into practice upon graduation. This paper presents the rationale behind PHIUS offering its proprietary training to students and describes experiences with conducting such training within an academic institution, including reports from Miami University of Ohio, the University of Oregon, and Ball State University. These reports from three universities address universal concerns (enrollments, schedule, and student success rates) as well as institution-specific insights.

NAHB CAREER PATHWAYS: EARLY CAREER HOME BUILDERS FINDINGS & MAPPING CAREER PATHWAYS IN HOMEBUILDING

SPEAKER: Eric Holt, *University of Denver*

The demand for young professionals entering the home building industry continues to outpace the number of young professionals entering the. At the same time, homebuilding associations struggle to attract young professional members. Competition is high for the young professionals most valuable resource: time. What worked yesterday for associations is not working for the next generation of membership. Associations of every industry, type, and size are struggling to engage their next generation of membership. The young home builders have less industry experience, less power within their community, and are much more likely to leave the home building industry. However, they are vital to the long-term legacy of the National Association of Home Builders (NAHB). In 2018, NAHB provided a research grant to the University of Oklahoma and the University of Denver to conduct a study to increase engagement with young home builders. In this study, Young Home Builders (YHB) were defined as residential builders and remodelers between the age of 18-45 years old. To gain a better understanding of the YHB and to provide recommendations for increased engagement with YHBs, a 3-part study was conducted. The study included a survey of current NAHB members, a scan of benefits within peer associations, and a focus group study with recent recipients of the Professional Builder's 40 under 40 awards. This presentation discusses the finding and mapping career pathways young professionals can take in the homebuilding industry.

ONE BOOK WITH MANY TOPICS: BUT ARE THEY ENOUGH?

SPEAKER: Walter Grondzik, *Ball State University*

Through the development and distribution of a number of curriculum guides, the US Department of Energy has expressed an opinion regarding what an appropriate grounding in building science principles should look like. One such repository of basic principles resides in the "Building Science 101 Model Curriculum" that is part of the Building America Building Science Education Roadmap. Another, substantially independent, expression lies in the topics selected for the building science training that was an integral part of the 2019 Solar Decathlon-Design Challenge student competition. Mechanical and Electrical Equipment for Buildings (13th edition / MEEB; in production) is an 1800+ page compendium of information on building systems and assemblies—much directly related to building science. Many architecture students in North America get much of their information about building science from MEEB as it is commonly adopted by instructors of building systems and environmental technology courses. There are certainly other very influential texts (such as those by Lechner, Allen and Iano, Ching), but these are not the focus of this analysis. The objective of this presentation is to map (or cross-correlate) the essentials of USDOE-promoted building science education knowledge against the content of the 13th edition of Mechanical and Electrical Equipment for Buildings. The presentation will flag the gaps between the expected (DOE) and the delivered (MEEB) knowledge sets and provide suggestions for bridging such gaps.

SESSIONS C

WEDNESDAY | 3:00 PM – 4:30 PM

TRACK 1: DISASTER-RESILIENT DESIGN | 203

UN SUSTAINABLE DEVELOPMENT AND THE COOL ROOFS CHALLENGE

SPEAKER: Kariuki Mbugua, *Steam Plant Ltd*

Run by the Kigali Cooling Efficiency Program in collaboration with the Global Cool Cities Alliance Sustainable Energy for All, and Nesta's Challenge Prize Center, the Cool Roofs Challenge is a $2 million program to promote energy efficiency and reduce heat stress through the use of highly reflective solar cool roofs, primarily in low income countries. Speaker Kariuki Mbugua was recently selected as one of ten finalists who received a $100,000 grant to put their proposal into action. The best sustainable and transferable model will win $1 million in 2020 to further implement their project. This presentation will highlight and review Mbugua's Cool Roof Challenge project proposal.

MODELLING TROPICAL CYCLONE VULNERABILITY AND THE DEVELOPMENT OF NEW INSURANCE COVERAGE PROGRAMS FOR HOUSING IN FIJI

SPEAKER: Daniel J. Smith, *James Cook University Cyclone Testing Station*

In 2016 Category 5 Tropical Cyclone (TC) Winston swept through the Pacific region. It affected 62% of the Fijian population and caused over FJ$1.8 billion in damage and loss. An estimated 60% of losses were from damage to residential buildings, but an estimated 94% of the damaged houses were uninsured against tropical cyclones. The lack of insurance placed a heavy burden on the Government of Fiji to provide finance for the repair or reconstruction of damaged uninsured housing. There is limited availability of homeowners insurance in the domestic insurance market in Fiji because there is limited regulation of house construction and the resistance to cyclone damage is not well understood for many of the different types of housing. To address this knowledge gap and broaden the availability of insurance to homeowners in Fiji, the Cyclone Testing Station at James Cook University was commissioned by the World Bank to investigate the structural details of various typical Fijian housing types, develop vulnerability models and provide mitigation upgrades to improve performance. The project provided the engineering basis for a classification system that could make insurance cover available for more Fijian houses and mixed-use buildings. The proposed classifications will allow development of three commercial insurance options with the policy premium, excess and cover adjusted to reflect the level of risk associated with each level. This paper presents an overview of how the varying levels of structural vulnerability for different types of construction were assessed in the field study, the development of engineering models that produced damage curves for the three classifications, and how the project contributed to a significant revision of house insurance programs for Fiji.

KENTUCKY FLOOD RESISTANT HOUSE: INTEGRATING RESILIENCE INTO ARCHITECTURAL DESIGN

SPEAKER: Kyle Choate, *Western Kentucky University*

Flood is one of the most common and devastating natural hazards worldwide. Almost 75% of all federal disaster declarations are related to flood events. Every year in the world, flooding affects millions of people. Property damage from floods is a major economic concern for federal agencies, local governments, and individual homeowners. Federal agencies and researchers have focused on the best practices and code-plus practices and have suggested a variety of residential natural hazard mitigation methods. In this context, architects have a great responsibility and role to design resilient building environments that can better adapt to natural disasters. The goal of this project is to integrate resilience into the architectural design to develop a flood-resistant house. This research demonstrates the possible flood mitigation strategies with a specific focus on in the state of Kentucky. Each strategy built on mitigation efforts recommended by the Federal Emergency Management Agency (FEMA) researchers, and engineers. Furthermore, the study develops a new design solution for flood mitigation that did not compromise the convenience and the aesthetic of the home for its function. The design solution includes the foundation and structural sub-frame of the building, and waterproof materials. To demonstrate the proposed mitigation concept, a case study of a typical single-family house in the Bluegrass Region in the state of Kentucky is designed and illustrated.

TRACK 2: SENIOR HOUSING | 204

TAILORING ENVIRONMENTS FOR ACTIVE LIFE ENGAGEMENT (TEALE) STUDY: PRELIMINARY FINDINGS ON OLDER ADULTS' PERCEPTIONS OF THE FUNCTIONALITY OF THEIR HOUSING ENVIRONMENT

SPEAKERS: Angela L. Sardina & Shyuan Ching Tan, *University of North Carolina Wilmington* & Alyssa A. Gamaldo, *Penn State*

With the burgeoning older adult population, there will be an increasing demand for housing developments that are conducive to the interests and needs of older adults from diverse backgrounds of varying functional abilities. Thus, the study team developed and piloted the Home Usability Tool (HUT), which is designed to explore the usability of the home environment, or perceptions regarding the functionality of the using space and how this space hinders or supports everyday functioning for older adult populations. Trained research assistants met with participants in Wilmington, NC and State College, PA to administer the HUT as well as demographic, physical and cognitive health, and psychosocial questionnaires. The primary purpose of this pilot study was to implement the HUT to explore older residents' perceptions of the physical and social attributes of their housing complexes and their surrounding community, and to examine how these perceptions may vary by sociocultural, cognitive, psychosocial, and health characteristics. Preliminary findings suggested that older residents, particularly in lower income households, reported usability challenges with their home environment. Additionally, reported usability challenges were associated with health and well-being.

EDUCATING FOR ENERGY EFFICIENCY: EDUCATING SENIOR RESIDENTS TOWARDS NET ZERO ENERGY GOALS

SPEAKER: Frederick Paige, *Virginia Tech*

Policies in Virginia have increasingly committed to sustainable housing principles by incentivizing green building certifications, training, and construction processes. Included in recent policies, is a push for resident education on building systems which are becoming more complex. The purpose of this study is to better understand the impact of occupant education on energy consumption for energy-efficient, affordable housing units. Technological energy efficiency improvements are often crippled by occupant behavior such as improper use and substandard maintenance. More work is needed to fully explore the most effective educational processes and their effects on occupant behavior. The Virginia Center for Housing Research is in phase three of a longitudinal study that evaluates a 39-unit subset of our 300+ unit data set. Residents who received a targeted education on their energy consumption did not change their energy behaviors in the long term but their understanding of energy shifted by participating in this study. In addition to a quantitative analysis of energy use and perceptions of energy, the data uniquely utilizes a multi-method approach through interviews and "next-generation" energy monitors to reveal the appropriate occupant understanding required to optimize affordable energy-efficient housing. The senior residents in this study provided detailed insights on how education must be specifically tailored to their lifestyles and not just building components. It was also found that building components constrained residents' ability to save energy comfortably. The findings from this study provide evidence for refining residential energy efficiency policies for investments in education, incentives, and building components.

HOUSING FOR ADULTS FACING SHIFTING DEMOGRAPHICS IN JAPAN

SPEAKER: Yoko Crume, *Consultant (Aging & Society)*

Japan recently entered a new era demographically, with the overall population now declining. This is primarily due to the continuing trend of a low fertility rate that cannot sustain a stable population size. Meanwhile, Japanese life expectancy continues to rise. Due to the combined effects of these phenomena, Japan has become the most aged nation in the world. The proportion of those over age 65 has already reached 27.7 percent of the population and is expected to increase to 38.4 percent by 2065. Clearly, one of the most important challenges facing Japan today and in the foreseeable future is how to preserve quality of life for older adults at a time when the number of younger caregivers is declining while healthcare resources for older adults are in greater demand. In Japan, these challenges are described in terms of the three Ks: Kenkō (health), Kane (money), and Kodoku (loneliness). This presentation describes the changing housing conditions, trends, and programs in super-aged Japan, focusing on the development of community-based services and multi-generational programs.

TRACK 3: ADAPTATION & RETROFITS | 205

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*

Inspired by the European Energiesprong program, the Rocky Mountain Institute (RMI) and RetrofitNY are spearheading initiatives for scalable residential retrofit strategies across the United States. This presentation and Q&A forum will introduce the Energiesprong program, discuss Rocky Mountain Institute's national REALIZE program, and explore RetrofitNY's work across the state of New York to advance and catalyze large scale residential retrofits. Following the presentation will be a Q&A and panel discussion for participants to explore how to advance retrofit initiatives in their own locales.

TRACK 4: LAB TOUR | HOTEL LOBBY

BETL & ADDCON LAB TOURS (PRE-REGISTRATION REQUIRED)

SPEAKER: Ali Memari, *Penn State*

This session will offer an opportunity to attend an off-site tour of the Building Enclosure Testing Labs (BeTL) and the Additive Construction Lab (AddCon) at Penn State's CITEL facility. These facilities will allow attendees to learn about some of the latest in building enclosure research through the BeTL tour including hot box testing of residential wall assemblies and infrared evaluation of existing wall systems. The AddCon facility tour will provide a snapshot of the ongoing research into advanced 3D printing technologies using materials such as concrete and clay as filament. Tour hosts will provide context regarding the goals of the research program and how these initiatives will impact the construction industry in the future.

TRACK 5: BUILDING SCIENCE / EDUCATION | 218

MOJAVE BLOOM: DESIGNING A NET-ZERO VETERAN'S TRANSITIONAL HOME

AUTHORS: Eric Weber & Dak Kopec, *University of Nevada Las Vegas*

SPEAKER: Eric Weber, *University of Nevada Las Vegas*

Our team is incorporating emerging technology that support health outcomes and personal wellbeing into a design that supports energy efficient building design. This unique proposal has implications for empirical research and home design, and the important potential to address issues of health and affordable housing facing the southwest region's fast-growing population, our efforts center on supporting the reintegration of veterans into our community. Dubbed Mojave Bloom, this prefabricated net-zero energy transitional home for returning veterans affected by varying degrees of amputation and/or struggling with PTSD will assist its residents in developing skills required for successful reintegration into civilian life.

WEDNESDAY | 3:00 PM – 4:30 PM

EXPERIENCES WITH THE RACE TO ZERO/SOLAR DECATHLON DESIGN CHALLENGE

AUTHORS: Tom Collins & Walter Grondzik, *Ball State University*
SPEAKERS: Tom Collins & Walter Grondzik, *Ball State University*

Our institution has participated in three Race to Zero/Solar Decathlon Design Challenge competition cycles. During this time, we have worked with ten student teams, seen eight teams invited to present their projects in Colorado, and celebrated more than one team award. The Race to Zero student design competition, renamed the Solar Decathlon-Design Challenge for the 2019 cycle, has provided a range or opportunities and challenges for our accredited architecture program. Several of these elements will be presented in this paper. The primary driver for our initial and continued participation in this USDOE-sponsored event is the framework for integrated design that it offers and demands. In our situation, this integration involves the expansion of design boundaries beyond traditional "architectural" considerations into technical systems and operational performance. The desire for more integrated design thinking is achieved by expansion of horizons among architecture studentsrather than by the active involvement of additional disciplines in the day-to-day workings of the design studios. This may not be ideal, but it works. The structure of the competition requires that our students learn and understand more about buildings than they would in a studio with a less diverse range of systems engagement. In this paper we will describe the structure and context of our studio; the infusion of building science into the studio setting; working with external partners and consultants in studio; and observations regarding successes and challenges. The main focus will be what makes this experience different from conventional studios and the role that the competition plays in demanding such differences.

HIGH PERFORMANCE FOR HABITAT FOR HUMANITY: PENN STATE'S 2018-2019 SOLAR DECATHLON DESIGN COMPETITION ENTRY

AUTHORS: Puja Bhagat & Jonathan Wong, *Penn State*
SPEAKERS: Puja Bhagat & Jonathan Wong, *Penn State*

Since 2014, members of the Pennsylvania Housing Research Center and the Energy Efficient Housing Research Group at Penn State have collaborated to support student design teams to compete in the Department of Energy (DOE) Race to Zero and Solar Decathlon competitions. This annual design competition challenges interdisciplinary undergraduate and graduate student teams to design an affordable, marketable, net zero-energy ready home that meets the DOE Zero Energy-Ready Home standard and incorporates sound building science principles. Each year, Penn State students have gone beyond baseline competition requirements to partner with a Pennsylvania-based housing organization. These partnerships provide a real site, context, and design constraints for the students' submission, and have opened opportunities for greater community impact and industry partnerships. In 2019, Penn State's team partnered with Habitat for Humanity of Greater Centre County (HFHGCC) in order to develop an affordable, net zero-energy ready housing design strategy that adapted to any site and family. This design strategy would allow HFHGCC to provide families with houses that were tailored to their specific needs, while still being environmentally responsible. This case study paper will describe the Penn State team's overall organizational approach and integrative design process, as well as the technical design of the housing system created for the 2018-2019 Penn State Solar Decathlon submission.

HAPPY HOUR ON THE EXHIBIT FLOOR

WEDNESDAY | 6:00 PM – 8:30 PM

Enjoy delicious food & drinks with great company! Network with conference attendees from the PHRC Housing Conference & the Residential Building Design & Construction Conference, industry exhibitors, and the next generation of housing professionals. Included in your evening are heavy hors d'oeuvres (carving station, mashed potato bar, passed appetizers, & more) and two drinks! Be sure to stop by our Exhibitors' tables, and learn more about their products and services to assist you.

PRE-REGISTRATION REQUIRED, *SEE TRACY AT THE REGISTRATION DESK BY 3:00 PM.*

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KEYNOTE

THURSDAY | 8:30 AM – 10:15 AM | PRESIDENTS HALL 1 & 2

PASSIVE HOUSE: A PROVEN PATH TOWARD RESILIENT, AFFORDABLE & ENERGY EFFICIENT HOUSING

LOIS B. ARENA, PE

DIRECTOR OF PASSIVE HOUSE SERVICES, *STEVEN WINTER ASSOCIATES, INC.*

The Passive House (PH) building standard is the most stringent energy efficiency standard in the world. It is quickly being identified as one path to achieving the carbon reduction goals set forth by a multitude of states and municipalities around the country and the world. Several affordable housing authorities in the US are currently including it or are preparing to include it as one of the sustainability options in their applications for funding. Projects range in size from single family dwellings to high-rise structures as tall as 33 stories in the US with millions of square feet and tens of thousands of units completed, under construction and in design.

The benefits of the PH building standard for affordable housing owners and occupants far exceed energy savings. Comfort, resilience, affordability and durability are just a few. This presentation will explore how and why this standard has made such inroads into the affordable housing market, how it is helping achieve climate action goals in the US and the financial case for widespread implementation. Case studies of completed projects will be reviewed and compared to cost data and financial and energy savings.

Lois B. Arena, Director of Passive House Services at Steven Winter Associates, Inc., possesses over 25 years of experience in the building science field and has extensive experience with new and existing buildings. Lois holds both US and international Passive House consultant certifications and is currently consulting on some of the largest and most difficult Passive House projects in the world. She has co-authored and presented training programs about energy efficient building practices to professionals in all sectors of the building industry and is regularly invited to present at conferences and private firms around the world to discuss the benefits of and road blocks to PH adoption.

TRACK 1: CONCRETE | 203

HEMPCRETE AS A RESIDENTIAL CONSTRUCTION MATERIAL: STATE-OF-THE-ART AND CHALLENGES

AUTHORS: Hojae Yi, Corey Griffin, & Ali Memari, *Penn State*; David Lanning & James Dooley, *Forest Concepts LLC*
SPEAKER: Corey Griffin, *Penn State*

Given that over 95% of buildings are residential dwellings, for any meaningful global impact on CO2 reduction, locally sourced materials, and easy to construct methods are needed for energy-efficient and low-carbon residential buildings. One such promising material is industrial hemp (Cannabis sativa L.). Hemp stalks from fiber varieties and crop residues from CBD oil varieties contain long, high-strength fibers, which enable processing into industrial biomaterials such as additives for hempcrete. The hempcrete mixture may be made up of bio-fiber hemp hurd as aggregate and mineral binder hydrated lime to adhere hemp hurd pieces together. Hempcrete has been shown to have potential in residential construction applications to improve insulation of masonry walls, reduce consumption of carbon-intensive concrete, and reduce the weight of cement-based structures. Considering that the cultivation of industrial hemp is newly reinstated, hempcrete and related construction materials should be developed as a market-ready product that considers the supply chains, processes, and manufacturing facilities that are to be established in the United States. This paper highlights a state-of-the-art review of hempcrete for affordable and sustainable home building and describes key research needed for this composite material to be a successful alternative to conventional wood-frame residential building construction.

ACCOUNTING FOR THE CARBON SEQUESTRATION POTENTIAL OF CONCRETE SYSTEMS: OPC AND HEMPCRETE

SPEAKER: Jay Arehart, *University of Colorado Boulder*

Focus of the building design community has shifted to not only reducing operational energy consumption, but also to reduce the carbon emissions from construction materials. Some construction materials, such as ordinary portland cement (OPC) concrete and hempcrete, have the ability to store carbon dioxide through a chemical carbonation process, offsetting a portion of their initial emissions, often referred to as embodied carbon. In this session a simple mathematical model will be presented that can be used by building designers to quantify the quantity of carbon dioxide that cementitious construction materials can reabsorb over their lifespans. The model will be explored in the context of a life cycle assessments of an OPC column, and hempcrete insulation system that utilize a variety of mix designs (including both hydraulic and pozzolanic binders). Key takeaways from this session include (1) an understanding of how to design cementitious materials to minimize their net lifecycle emissions and (2) the tools to quantity the carbon sequestration potential of cementitious materials used in residential construction.

MITIGATING PYRRHOTITE-INDUCED DAMAGE IN RESIDENTIAL CONCRETE CONSTRUCTION

SPEAKER: Jonathon Piasente, *Penn State*

Pyrrhotite damage has devastated residential communities in northern United States and Canada. Cracking in housing basements and other concrete elements has resulted in water intrusion, mold growth, and loss of load-bearing capacity. The reported damage has been so severe that the houses lost their entire value and many are deemed unusable and unsellable, resulting in the worst construction defect on record in Canada. More cases are being identified in the U.S. and Europe, including 2017 investigation of FEMA and Army Corps of Engineers into cracking observed eastern part of Connecticut, where over 30,000 homeowners are affected. In this research, reaction kinetics of pyritic aggregate was evaluated using mortar mini bars. Samples (12.7×12.7×139.7 mm) were cast and stored in environmental chambers set at a range of temperatures (5 to 60oC), RH (50 to 95%), and elevated O2 levels (up to 35%). After reaching equilibrium, the mini-bars were be moved into the oxygen enhanced chambers. Length and mass measurements were performed at regular time intervals. The nitrogen-purged environment allowed for separating drying shrinkage and mass loss from the subsequent expansion and mass gain due to O2 uptake. In parallel, sacrificial specimens were tested using SEM/EDS + quantitative image analysis to determine the degree of sulfide oxidation and damage accumulation in mortar over time. The results were used to establish “acceleration factors”, which quantify how temperature, RH, and O2 levels impact the rate of pyrrhotite reactivity.

TRACK 2: BUILDING ENVELOPE | 204

LONG-TERM EXPOSURE DATA ANALYSIS OF RESIDENTIAL HIGH PERFORMANCE WALL ASSEMBLIES EXPOSED TO REAL CLIMATE

AUTHORS: Michal Bartko, Travis V. Moore, M. Ghobadi, G. Ganapathy, & Michael A. Lacasse, *National Research Council of Canada*
SPEAKER: Michal Bartko, *National Research Council of Canada*

This paper presents comparison of test results of residential, highly insulated, zero energy wall assemblies. Three wall assembly specimens were installed and instrumented at the NRC’s Field Exposure Wall Test Facility in 2016. The wall assemblies consist of 1) a high R-value (R-29) retrofit assembly with continuous external foam insulation and poly-ethylene vapor barrier on the interior side; 2) a Passive House, R-43 double stud assembly with wood based insulation; and 3) a stud wall assembly with external insulation (R-29) and wood based oriented strand board vapor control on interior side. The specimens, installed on a west facing wall of the FEWF, were exposed to real climatic conditions, in Ottawa, Ontario, Canada. Prior to climate exposure, the assemblies were exposed to high humidity and high pressure difference from the interior side for several weeks to induce moisture inside the

specimens. Hourly values of temperatures, pressure, relative humidity and moisture presence have been monitored and recorded during all four seasons. Temperature, moisture and pressure sensors were placed on both interior and exterior sides, as well as within the assemblies at multiple locations where the potential for condensation and mold growth was considered high. The present study reports on the behavior of all three specimens over a three year period of year-round exposure and data monitoring. The water content was recorded locally and intermittently in the wall assemblies. The moisture presence corresponds with major rain events and always evaporated previous to causing deterioration in the wall assemblies. Comparison of yearly runs of pressures differences, temperatures and humidity results together with dew point and mold growth calculations results show that after the long-term exposure, no visible or calculated failures occurred in any of the three specimens. Additionally, as of the writing of this paper, no indication of reduction in long term performance has been observed.

MULTIFAMILY CASE STUDY IN MIDLAND, MI COMPARES DIFFERENT CONSTRUCTION STRATEGIES FOR COST, DURABILITY, ENERGY TRANSFER AND COMFORT

SPEAKER: Brian Lieburn, *DuPont Performance Building Systems*

Two identical multifamily buildings were built side by side in Midland, MI (CZ5) to compare different construction strategies designed to exceed energy code requirements. The buildings were constructed in 2016 and are being monitored for a 5-year period. This case study compares 2x4 continuous insulation (ci) against 2x6 cavity only insulation. The study also compares Frost Protected Shallow Foundation (FPSF) to footing and stem wall foundation. Data will be presented on cost of construction methods, hygrothermal performance of wall assemblies and energy transfer.

FIELD EVALUATION OF AN AFFORDABLE SOLID PANEL STRUCTURAL BUILDING SYSTEM

SPEAKER: Pat Huelman, *University of Minnesota*

Our team has completed a multi-year field demonstration and evaluation of a Solid Panel Structural (SPS) (studless) building system for affordable housing. The system is intentionally designed to support the use of exterior control layers for improved building performance, including energy efficiency, durability, and resilience. The building system is site fabricated and designed for quick erection using a single enclosure contractor to improved quality control of the construction process, in particular to maintain the integrity of the structural system and control layer sequences. This approach reduces cycle time, especially to dry-in, reducing the builder's costs and risks. Furthermore the simplicity of the building system and sequence can take advantage of less skilled labor. An affordable housing developer built three identical house plans using three different building approaches: the Solid Panel Structural (SPS) building system built to Zero Energy Ready Home (ZERH) requirements, a Hybrid 2x4 Wall System also built to ZERH, and a more conventional 2x6 Base Case Wall built to meet Energy Star v3. These houses were analyzed to compare constructability, costs, and performance. Software models were used to assess energy and hygrothermal performance prior to construction. Following construction, a monitoring package was deployed to measure energy use, temperatures, relative humidity, and moisture contents. Construction cost and assembly analysis was used to identify opportunities for system optimization. In addition, this field demonstration provided insitu construction feedback through on-site observation, field notes, and contractor interviews. These "real world" insights pointed out several opportunities for improvement of both the building and delivery system.

TRACK 3: PASSIVE HOUSE | 205

PANELIZED MULTIFAMILY PASSIVE HOUSE: LESS COST & MORE PROFIT THAN CODE

AUTHOR: Paul Grahovac, *Build SMART, LLC*

SPEAKER: Paul Grahovac, *Build SMART, LLC*

Passive House certified wall panels with factory-installed Passive House certified windows have been causing houses and apartment buildings constructed with them to surpass Passive House air tightness requirements on the very first blower-door effort. For one of these instances, a single blower door unit with a single fan was used to pressurize and test an apartment building of 52,781 sqft in a single whole-building test. The architect-contractor design-build developers of the system attribute the air tightness performance to the fluid-applied detailing materials that are used to line the rough opening and secure the window to the lined rough opening as well as to the fluid-applied material used to seal the panels at the floor, the top, and to each other. No tapes or self-adhered membranes are used. The Passive House energy performance on the Affordable Housing project resulted in a $300,000 increase in mortgage funding and a $300,000 increase in developer fees – the non-profit developer says this allows them to build more Affordable Housing. Financial projections hypothesizing the same structure built for the unsubsidized market to code-only standards and for comparison to Passive House show private-sector developers can increase their cash flow significantly by building to Passive House and paying tenant utilities. The payback period is less than a third than for blue-chip stocks and occurs without stock-market risk. If the speed of panelized construction is accounted for along with avoiding the customary 20-year window replacement because of the high quality of Passive House windows, the payback goes to 4.92 years.

FRONT FLATS: A NET POSITIVE, CARBON-NEUTRAL, MULTI-FAMILY EXPERIMENT……AND FASHION STATEMENT

SPEAKER: Timothy McDonald, *Onion Flats*

Front Flats is a 28 unit apartment building with ground floor commercial space located in the heart of the Kensington section of Philadelphia. Completed in 2019 and built to the rigorous Passive House standard at an affordable cost, this project is an experiment in not simply affordable carbon-neutral design and construction but also treats solar panels both as an energy producing technology, as well as a "material". The roof, East, South and West facades are covered in bifacial solar panels lending a pristine, somewhat guarded aesthetic to the building directly adjacent to the Market-Frankford elevated train. Unique, heating/cooling/dehumidification systems along with a surprisingly simple, cost-effective and incredibly efficient semi-centralized hot water system will be discussed in detail in this lecture. Front Flats is the development/design/build collective, Onion Flats', most recent and affordable attempt at making carbon-neutral buildings standard.

BRIDGING THE COMMUNICATION GAP BETWEEN DESIGN AND CONSTRUCTION

SPEAKER: Thiel Butner, *Pando Alliance*

You've committed to Passive House certification. Now what?! Are you ready deliver a cutting-edge, cost-effective new project? The handoff from design team to construction team is often full of miscommunication and missed opportunities. Builders often feel frustrated by details that they believe can't be built. Architects are equally frustrated that builders don't build what they've drawn. How can this transition be made seamlessly? How can the design intent be communicated to the builder? How can the builder find a voice to ask clarifying questions? Your PHIUS Rater or Verifier can facilitate this communication because they are well-versed in both design review and field implementation. This presentation will share specific, real-world examples of details that contributed to a project's ultimate failure to certify. In reviewing these lessons learned, you'll step into your next design with increased confidence and reassurance.

TRACK 4: MICROGRIDS | 218

THE MYCORRHO-GRID: A BLOCKCHAIN-BASED MYCORRHIZAL MODEL FOR SMART SOLAR MICROGRIDS

AUTHORS: Zachary Gould, Georg Reichard, Ikechukwu Dimobi, & Arjun Choudhry, *Virginia Tech*; Susan Day, *University of British Columbia*

SPEAKER: Georg Reichard, *Virginia Tech*

The Mycorrho-grid is a blockchain-based microgrid inspired by the way trees collect and distribute resources through mycorrhizal networks in the forest. It was first developed in conjunction with Virginia Tech's grand-prize winning TreeHAUS entry in the 2019 Solar Decathlon Design Challenge and is expanded upon here with a focus on further potential for biologically inspired functionality. The baseline case as simulated in the competition is a 12-unit multi-family microgrid with a shared 50kW rooftop solar array and fixed price return from the grid. A framework derived from literature in mycorrhizal networks and the mathematical modeling of mycelial growth is developed to help transition the Mycorrho-grid from phyto-centric operation, where resources are exchanged based on the needs of the trees (energy producing and consuming households), to myco-centric operation, where resources are exchanged based on the needs of the fungal energy storage and distribution mechanism (local battery and centralized grid) with a larger environmental awareness. This transition helps introduce an element of altruism into the larger grid network that the authors believe could improve overall reliability in response to regular outages and resilience in response to major outages. Degrees of decentralization and their implications for the security and fault tolerance of critical infrastructure are discussed along with strategies for simulating the efficacy of a mycorrhizal dynamic pricing algorithm moving forward.

MINING THE IMPACT OF URBAN FORM ON ENERGY PERFORMANCE IN COMMUNITY MICROGRIDS

SPEAKER: Mina Rahimian, *Penn State*

This presentation discusses the impact that the spatial structure of urban form has on the amount of energy consumed for community building operations. Using artificial neural networks, this study factors in the many spatial dimensions of urban form and explores their combined effect on community-wide net energy consumption. Nineteen indicators of urban form have been measured for all zip codes in San Diego and their monthly values of energy consumption have been acquired through the county's utility company, SDG&E. Inference on the resulting predictive model has been done using Shapley values showing that the most influential indicators of urban form on energy consumption are related to the compactness, passivity, shading, and diversity of a community in the context of the case study. The results of this study contribute to the larger research of this paper on adding a spatial dimension to the existing technical discourse on improving the energy performance of community microgrids.

SESSIONS E

THURSDAY | 1:15 PM – 2:45 PM

TRACK 1: OCCUPANT BEHAVIOR | 203

PERSONALIZING OCCUPANT COMFORT USING BIO-SENSING TECHNIQUES

SPEAKER: James Katungyi, *Carnegie Mellon University Center for Building Performance & Diagnostics*

Energy conscious homeowners already use programmable thermostats to achieve indoor comfort when they are at home and to minimize energy consumption when they are away. Newer 'smart' thermostats like the Nest and Ecobee automate the setpoint schedule by 'learning' the homeowner's use habits, and they allow homeowners to change settings on their phones and talking to Google and Alexa. This is excellent for capturing just the right settings for home and away, however, occupant comfort when they are home may also vary over time. Indoor temperature settings based on schedule alone often result in low satisfaction and high energy consumption. With changes in activity, a single setpoint temperature cannot meet the occupant's comfort needs. With changes in sunshine and cold or hot radiant temperatures from windows, a single setpoint may not ensure comfort. Moreover, as occupants age, the ability to adjust temperatures as needed may become burdensome. On the other hand, biosignals such as skin temperature and heart rate variability will recognize changes in activity, clothing or building conditions and may become the control for the future. Biosignals are objective indicators of an occupant's response to the thermal environment and can therefore be relied upon to optimize thermal conditions for the occupant's comfort needs. This presentation introduces controlled research on the effectiveness of occupant skin temperature biosignals captured through smart wearables or non-intrusively, by infrared cameras, to ensure individual occupant comfort in real time, or to negotiate between occupants that share a space to identify optimal temperature setpoints. Based on the findings of several PhD dissertations completed in the Center for Building Performance and Diagnostics at Carnegie Mellon, it is becoming clear that biosignals offer significant gains in indoor environmental control and energy savings.

MESSAGE DESIGN FOR RESIDENTIAL ENERGY FEEDBACK

AUTHORS: Wendell Grinton & Frederick Paige, *Virginia Tech*
SPEAKER: Wendell Grinton, *Virginia Tech*

Energy feedback messaging is an emerging sociotechnological approach to improving the efficiency of energy consumption in homes. Annually, nearly $40 billion of electricity is squandered by U.S. residents on end uses, which do not improve well-being. Residents are underinformed on how their personal behavior and increased number of in-home devices have dampened the impact of efficiency gains of individual technologies. Currently, the ability for energy monitoring devices to act as two-way communicators between energy providers and consumers is being underutilized. Real-time energy use data can be leveraged to create behavior influencing messaging. Utility companies have begun to leverage standard utility meters and enhanced energy bills to provide messages, with varying levels of success. Recently, energy monitoring devices have improved to become more detailed and "smart" but feedback techniques are lagging. To identify the impacts of the design of energy feedback messages, this study measures the neural activation of participants using a functional near-infrared spectroscopy (fNIRS) device. The fNIRS device quantifies neurocognition, which describes the function of one or more specific areas of the brain. To enrich the brain activity data, a post-task survey gathers data on participants' willingness to change energy consumption behaviors after seeing messages. Lastly, study participants' suggestions for personalizing messages to evoke a behavioral response are captured via semi-structured interviews. Through understanding the cognitive and behavioral response to energy feedback messages, the effectiveness of energy feedback messaging can be enhanced to optimize energy consumption with minimal physical changes to a home. The findings from this study are transferable to a variety of energy feedback mechanisms and provide insights for meeting new residential building standards which require resident education.

ENERGY EFFICIENCY REBATE PROGRAMS: AN ASSESSMENT OF INVESTMENT BEHAVIORS BY HOMEOWNERS

AUTHORS: Celso Santos, *Iowa State University* & Kristen Cetin, *Michigan State University*
SPEAKER: Celso Santos, *Iowa State University*

Nowadays, there has been a growing concern regarding the carbon footprint associated with buildings. In the U.S., buildings alone account for over 40% of CO2 emitted, with the vast majority due to energy consumption. To encourage homeowners to invest in energy-efficient technologies for their homes, many utilities have implemented residential rebate and incentive programs. However, few studies have examined homeowners' needs and their associated energy efficiency investments. The aim of this study is to describe the investment behaviors of homeowners associated with energy-efficient technologies. This study focuses on data collected for homes in Cedar Falls, Iowa, which has significant seasonal climate variations, a variety of building ages, and a long-standing residential efficiency rebate program. Based on the rebate program data collected from 2013 to 2016, of the homeowners who purchased energy-efficient technologies, the most common technologies invested in were efficient lights, central air conditioning systems, and insulation. Approximately 65% of investments in new, efficient cooling systems were due to inoperable or broken existing systems, while 30% were still working but less efficient; heating or cooling system replacement is also among the most common first energy efficiency technology investment that households make, potentially serving as a common gateway to interest in and knowledge by households of energy efficiency programs. Efficient lightings are financially attractive investment for homeowners when considering the total cost of investment versus the rebate received. The results of this research can be used to benefit and improve the effectiveness of energy efficiency rebate programs.

TRACK 2: WOOD & CLT | 204

MID-RISE WOOD FRAME CONSTRUCTION: A GOOD IDEA OR ARE WE ASKING FOR TROUBLE?

SPEAKER: Derek Hodgin, Construction Science & Engineering, Inc.

Recent changes in the building code helped fuel the current surge in mid-rise wood frame construction projects. Over the past several years, there has been an increasing number of water intrusion claims in relatively new mid-rise wood frame buildings. While the code requires the building envelope to provide protection from the weather, it does not provide the details necessary for designers and/or contractors to meet this requirement. Typical construction details, that have had limited success on 1 to 3 story wood frame buildings, are even more problematic on taller buildings. Specifically, vertical and lateral movements, caused by frame compression, shrinkage, external loads and material incompatibility, can compromise the function of flashing and waterproofing details. Differential movements between the wood framing and exterior cladding components can cause physical damages to building envelope components that increases the extent of water intrusion. Once the water reaches the wood framing components, significant damages such as rot, corrosion and mold can result. Additionally, once compromised, the effectiveness of products used to meet fire resistance requirements is unknown. If our design and construction of the building envelope does not incorporate "best practices", mid-rise wood frame buildings may become the "black eye" of the construction industry.

USING TRUSS RAFTING TO CREATE SAFER, MORE EFFICIENT CONSTRUCTION SITES

AUTHOR: Daniel Hindman, *Virginia Tech*
SPEAKER: Daniel Hindman, *Virginia Tech*

Worker falls in residential construction are a common source of accidents and injuries. Of particular concern is the construction stage of setting roof trusses on a top plate, where there are few opportunities for the workers to tie off to for fall protection. One possible tool to help prevent some of these hazardous situations is the use of truss rafts, or groups of trusses built on the ground and craned into position. Truss rafts allow workers to create roof systems on the ground, or on the roof using the truss raft as a fall arrest anchor. Currently, few construction companies use truss raft systems. This presentation will collect several interviews with building contractors who use rafting systems and attempts to collect vital knowledge to conduct rafting and identify areas of future research needed to help more contractors use rafting methods.

RESURRECTING FIRE-DAMAGED, GLUED LAMINATED BEAMS FROM BEYOND THE GRAVE: A PILOT FOR ATTAINING SERVICEABILITY REQUIREMENTS

AUTHORS: Cole Moller, *Cushing Terrell* & Brian Kukay, *Montana Technological University*
SPEAKER: Cole Moller, *Cushing Terrell*

There continues to be a need for restoring the flexural capacity of fire-damaged, glued laminated beams. In general, fire-damaged wood members result in reduced cross-sections, delamination, and other effects. Where warranted, the residual flexural capacity estimates are determined through a combination of post-fire assessments, white paper calculations, and engineering judgement. Thereafter, decisions are made for individual members: specifically, to remain as-is; to be repaired; or to be replaced. The focus of this research is on restoring serviceability to individual members unequivocally categorized for replacement. Fire damage, extinguishment, and loading to maximum capacity all occur before applying carbon fiber reinforcement and conducting additional tests (in order to capture the worst-case scenario through this pilot study). The proof of concept derives from testing and pairing of 24F-V-8 DF/DF glued laminated beams. The measured values obtained from destructive and non-destructive test data facilitate the calibration of computer-generated models. The measured values also compare to the National Design Specifications for Wood Construction (NDS). Once restored, the worst-case scenario beam not only exceeds the flexural requirements for beams in good condition using the NDS, but also produces a ductile failure once it is reloaded to maximum capacity. For these reasons, the methodology surrounding this feasibility study will also be of interest to others, including but not limited to residential building design and construction professionals.

TRACK 3: PASSIVE HOUSE | 205

A COUPLE'S PASSIVE HOUSE - ENVIRONMENTAL SUSTAINABILITY WITHOUT CITY LIVING

AUTHOR: Gary Gardner, *Passive House Western Pennsylvania*
SPEAKER: Gary Gardner, *Passive House Western Pennsylvania*

Many choose to live in the city as an environmentally responsible course of action. However, not everyone feels that city life is for them. The owners chose to live in a less dense place and to use the Passive House design concept. The intent of the project is to walk as softly on the earth as possible by greatly reducing energy consumption, harvesting on-site renewable resources, restoring the former alfalfa field, unused for fifty years, and to aid in carbon emission mitigation (GWP reduction). The presenter will share the challenges of designing a PHIUS+ compliant house that is not in an optimally compact three-dimensional configuration, particularly with regard to the building envelope. Designing walls and a roof with the very high required R-values and a high degree of airtightness proved to be challenging. This will be discussed. Actual utility charges plus the contribution of solar panels for the all-electric house will also be shared. The electrical usage of the house will be compared with PA 2009 Code compliant usage, PA RECS averages and HERS. The presentation will address the differential costs between those of the one-story house and a house of the same square footage constructed in a two-story configuration. In addition to the house, goals for a low impact landscape design will be examined.

MASTER PLANNING A PHASED PASSIVE HOUSE RETROFIT

SPEAKER: Laura Blau, *BluPath Design*

America's building stock requires a massive overhaul to meet the demands of a low-carbon sustainable future. Buildings are renovated every 25-75 years. Besides lost energy savings, half-baked decisions today create negative impacts for the foreseeable future where the importance of do-it-right-

the-first-time is paramount. Sam Rashkin, developer of Energy Star for the DOE, emphatically stated at previous high-performance building conferences "EnergyStar is not good enough". He proposed that retrofit strategies with constrained budget should partially implement full-measures rather than fully implement half-measures. A keen awareness of the building-science challenges of each building is required to accomplish a phased retrofit. The industry need to educate clients, professionals and contractors of the risks in implementing unanalyzed enhancements without accounting for building dynamics that develop over time. Each building has a unique set of opportunities and constraints based on climate, orientation, condition, structure and material attributes. Without an intelligent science-based plan, naïve and well-intentioned efforts can exacerbate moisture, condensation, freeze-thaw and IAQ problems, along with their negative health and durability risks. This seminar provides a set of master-planning tools and a decision tree to guide the analysis and develop strategies for each property. Beginning with the client's budget and objectives, these tools provide a value-based process for setting overarching goals tempered with diagnostic data derived from the building. A series of prioritized steps coupling interventions that are required and tasks that can be implemented as discrete projects will then be developed.

ON THE WAY TO ZERO: EXPLORING A PATH TO COST EFFICIENT, ENERGY EFFICIENT AFFORDABLE HOUSING

SPEAKER: Mike Steffen, *Walsh Construction*

Mike will discuss the challenge that continuously escalating construction costs present to those who develop and operate affordable housing, and will review how housing developers and their architect/contractor teams can effectively address that challenge by working with more discipline to drive greater efficiencies into the design and construction process. Rather than envisioning the use of so-called disruptive new technologies such as modular construction and mass timber framing, Mike will outline an approach to achieving more cost efficient projects through the use of more inherently efficient building design, advanced wood framing, and a greater degree of standardization and repetition of the basic building components and systems used in affordable housing construction. Several project case studies will illustrate the application of these ideas, and the results in terms of cost reduction. Effective application of cost efficient design can lead to much higher levels of energy efficiency through improved design of building form and layout, and by allowing space in the project budget for the incorporation of higher quality, high performance components and systems.

TRACK 4: COMMUNITY DESIGN | 211

PARTICIPATORY DESIGN IN HOUSING

AUTHORS: Nilou Vakilbahrami & Joe Colistra, *University of Kansas*
SPEAKER: Joe Colistra, *University of Kansas*

This paper describes a participatory development strategy used to empower community. When residents in an historic residential neighborhood of Denver, Colorado learned of a plan to build speculative housing, they tapped architects to assist them in pooling resources and expertise in order to build a project they felt would be more congruent with the scale and character of their neighborhood. Recognizing that only those affected by an environment have any right to its determination, forty-two long-time residents all living within a few blocks of the project put their own homes up for collateral in order to secure construction loans for this development. The design and development process described contests the traditional roles of both the architect and client. Architects often view broad participation with skepticism, believing that participatory design that aspires to operate in a way that might be categorized as emancipatory cannot possibly yield the same level of design quality afforded projects that are not shackled by the marginalization of a shared vision or "design by committee." Sharing resources allowed community members to become active participants in their built environment. The willingness to invest in one's own neighborhood reflects a willingness to invest in oneself and the belief that these actions can allow a group to act strategically and critically to restructure a world they cannot wholly remake. This self-development model generated a great sense of pride and accomplishment as the neighborhood witnesses the emergence of a community asset shaped with their own ideas and resources.

GREEN SOCIAL SERVICES BUILDINGS IN JAPAN: ENGAGING CLIENTS AND INSPIRING THE COMMUNITY

SPEAKER: Richard Crume, *Governing Councilor with the American Public Health Association*

The green building revolution has been slow to take hold among social services agencies due to tight budgets and the perception that high-tech building designs are often incongruent with disadvantaged clients. Yet, the Japanese have discovered that solar, energy-efficient social services buildings can engage their clients in renewable energy activities and inspire enthusiasm in the surrounding community. These facilities help create a positive image of their clients, and for both clients and their caregivers, they are fun to live and work in too. This presentation examines three such facilities: a community workshop for developmentally disabled adults, a group home providing residential care for children up to high school age who come from troubled families, and a similar facility housing younger children, including infants. These bright and cheerful facilities are centrally located in their communities, and one includes a bakery and café that attracts passersby. Lessons learned from these facilities that can be applied around the world are discussed.

PENN STATE INITIATIVE FOR RESILIENT COMMUNITIES (PSIRC): PILOT STUDY FOR COMMUNITY FLOOD RESILIENCE

SPEAKER: Lisa D. Iulo, *Penn State*

Urban centers and agrarian communities in the Susquehanna River basin are facing increased risks of floods — resulting in economic, environmental, and social stresses. These threats disproportionately affect low-income households, threaten municipal tax revenue, and undermine the river's potential as a cultural and recreational resource. Launched in January 2019, the Penn State Initiative for Resilient Communities (PSIRC) provides an environment of shared discovery where stakeholders, decision-makers, designers, and researchers spanning multiple disciplines come together to address local resilience challenges related to flood risk in small, riverine communities. Starting with a pilot project in partnership with the Borough of Selinsgrove, the tools, methods, and lessons learned will be generalized to inform decision-making for sustainability and resilience to riverine flooding in communities throughout the Chesapeake Bay Watershed and beyond.

TRACK 5: BUILDING SCIENCE/EDUCATION | 218

IEA EBC ANNEX 74: INTERNATIONAL INFORMATION-SHARING PLATFORM FOR BUILDING COMPETITIONS AND LIVING LABS

SPEAKER: Holly Carr, *US Department of Energy*

The International Energy Agency's (IEA) Energy in Buildings and Communities Program (EBC) has created Annex 74 with the goal of setting up an authorized international platform for the evolution and linking of existing building competitions and living labs as well as discussing new concepts. The concepts may encompass the building as well as the district level including sustainable mobility. The international character of the IEA EBC brings together building scientists from all over the world to share information about. This presentation will outline the progress of the Annex to date, anticipated future activities, and opportunities to participate.

SOLAR DECATHLON WINNING DESIGN ENTRIES - HOW TO GET PROJECTS BUILT

AUTHORS: Paul Crovella, Michael Schmidt, & Noah Townsend, *SUNY ESF*
SPEAKERS: Paul Crovella, Michael Schmidt, & Noah Townsend, *SUNY ESF*

This presentation will follow the history of two DOE competition entries (2014 Race to Zero grand prize winner - single family detached, and 2019 Solar Decathlon Design Challenge first place winner in the mixed-use multifamily). For both of these entries, the teams choose to work very closely with potential owners to ensure that their work would be considered for construction. The 2014 entry took almost four years to get built, and the 2019 entry is currently beginning the process for consideration. This presentation will distill the critical lessons from working with real clients and melding these requirements in to the DOE competition requirements. The post competition need to build coalitions, engage with public and private entities, and ultimately accept the modifications needed for a project to produced will be discussed. Students from both teams plan to participate in the presentation.

ENVELOPE AND SYSTEMS SYNERGY FOR HIGH PERFORMANCE, AFFORDABLE HOUSING

AUTHORS: Michael Gibson & Paul Karr, *Kansas State University*
SPEAKERS: Michael Gibson & Paul Karr, *Kansas State University*

The Net Positive Studio is an interdisciplinary research and design effort in the College of Architecture, Planning, and Design at Kansas State University seeking to develop housing prototypes that are affordable, safe, high-quality, environmentally sensitive, and functional while demonstrating broad tenants of sustainability: energy and environmental conservation, economic tenability, and positive social and community impact. In the Net Positive Studio's first iteration, the team partnered with the Mattie Rhodes Center, a community organization in Kansas City, to develop and build a single-family infill housing prototype, in a community known as Indian Mound, intended to be constructed for near $100/ft2 while achieving an EUI (energy use intensity) lower than 15 kBtu/ft2 per year. The project and the studio team are also participants in the current Solar Decathlon Build Challenge, sponsored by the U.S. Department of Energy. In the design, a high-performance building envelope was integrated with a strategic approach to maximizing the efficiency of the home's environmental control systems. This paper elaborates in detail upon innovations in the building envelope and heating and cooling systems, describing how these systems work together. Using computational fluid dynamics simulation, the Indian Mound prototype's operation is compared to contemporary approaches to envelope and HVAC systems common in affordable housing. In summary, the project's design and the analyses presented in the paper show that critical improvements in envelope design can work in sync with modern HVAC technology, resulting in a solution that is both more affordable and better-performing than today's contemporary affordable housing solutions.

SESSIONS F

THURSDAY | 3:00 PM – 4:30 PM

TRACK 1: HEALTHY HOMES | 203

RESIDENTIAL INDOOR AIR QUALITY UPDATE - CONTAMINANT EXPOSURES, STANDARDS, & CONTROL TECHNOLOGIES

SPEAKER: William Bahnfleth, *Penn State*

The presentation will provide an update on issues relevant to design and operation of residential buildings to achieve good indoor air quality. It will summarize the current state of knowledge regarding indoor pollutant sources and exposures - gases, particulate matter, and microorganisms, air quality standards and guidelines - in particular, ASHRAE Standard 62.2-2019 and the WELL Building Standard and its multifamily residential pilot addendum, and developments in control technology for the major contaminant classes.

RESIDENTIAL INDOOR AIR QUALITY ASSESSMENT: AN EVALUATION OF THE BUILT ENVIRONMENT AND QUALITY OF LIFE IN COMMUNITIES

SPEAKER: Jessica Vaden, *University of Pittsburgh*

Air pollution, which is known to degrade building materials and infrastructure, has a similar impact on health and quality of life (QOL) in communities. Our study aimed to explore both indoor and ambient air pollution, and social and environmental factors, within communities and the effect on overall QOL. Indoor and ambient air quality analysis was performed in 13 low- to middle-income homes in Pittsburgh, Pennsylvania, during the heating and cooling seasons, from November 2016 to July 2018. Each home was monitored for 7-21 days collecting continuous samples of carbon dioxide (CO_2), radon, particulate matter (PM), black carbon (BC), relative humidity (RH), temperature, formaldehyde (HCHO), and total volatile organic compounds (TVOCs). A QOL survey was also developed and implemented in each home. Indoor air quality results show indoor concentrations of HCHO, radon, and PM, exceeding recommended levels published by the U.S. Environmental Protection Agency (USEPA). Current work includes combining the results with data from a local citizen science initiative (n=50) and examining the interaction effect of air pollution on respondent's QOL score. Preliminary QOL survey results show a relationship between mental health outcomes and living in a safe and secure environment ($X^2(12) = 26.02$, $p < .01$). Compared to the research devoted to the physical health effects of air pollution, studies on psychological consequences and quality of life are less represented. This research aims to fill this gap.

BARRIERS IN IMPLEMENTING MATERIAL TRANSPARENCY IN LEED V4.0 PROJECTS

AUTHORS: Susan Thomas & Paul Crovella, *SUNY ESF*

SPEAKER: Susan Thomas, *SUNY ESF*

Americans, on an average, spend approximately 90% of their time indoors (U.S. EPA, 1989) where the concentrations of some pollutants are often 2 to 5 times higher than typical outdoor concentrations. (U.S. EPA, 1987). Materials make the built environment possible and the choice of which materials to use can have significant consequences for human health and the ecosystem that we all share. Information about impact of materials on human health and environment is becoming more prominent. However, lack of guidelines and potential tools that could help us access this data makes the process of material selection difficult for designers. This difficulty can be reduced through disclosure of material ingredients and its impacts. The Material and Resource category in LEED® v4.0 has placed more focus on material transparency through the Building Product Disclosure and Optimization credits under the Material and Resources category and the Low Emitting materials credit under the Indoor Environmental Quality category. Out of 1573 projects certified by 12/17/2018 under the LEED® v4.0 Building Design and Construction rating system, 404 projects (25.6%) have scorecards available for evaluation and 162 (40%) of the 404 projects have achieved one or more points for these credits. This background study and previous studies indicate barriers in implementing material transparency. The research identifies gaps in information as well as gaps in access to or availability of transparent material ingredient documentation that will help material producers better understand the needs of designers who are responsible for green material selection. It will also help to identify future research opportunities related to the development and evaluation of sustainable materials and material transparency.

TRACK 2: WOOD & CLT | 204

THE BURWELL CENTER: A CLT CONSTRUCTION CASE STUDY ON THE CAMPUS OF THE UNIVERSITY OF DENVER

SPEAKER: Eric Holt, *University of Denver*

Cross Laminated Timber (CLT) is a mass timber material that has the potential to expand the wood building market in the U.S. However, sustainable building design requires careful planning and design with many design iterations to meet building owner/architect expectations. These design iterations include cost effective analysis examining multiple technologies in the building envelope and heating, ventilation and air conditioning (HVAC) systems using multiple simulation tools. However, there is a technical gap in CLT as there are sparse studies done in this area. The objective of this project is to support wide adoption of CLT in multi-story residential and commercial building markets by filling the knowledge gap on CLT energy consumption, optimization, and comparison with other building assemblies doing: (1) on-site monitoring of a CLT buildings, (2) whole building energy model simulations, (3) optimization of the performance and design for CLT buildings and (4) comparison with traditional building envelopes. The University of Denver is building a CLT building on campus to be a living laboratory and career center for the campus. The Burwell Center's structure and building envelope is comprised of CLT walls and floors, with traditional exterior metal stud framing with an overlay of sheathing and a spray-applied weather barrier system. The building is currently scheduled to finish in Mid-July of 2020 with a goal of LEED Platinum certification. DU is partnering with the Colorado School of Mines for an ongoing research study of energy performance of this CLT Building.

MASS CUSTOMIZED CROSS-LAMINATED TIMBER ELEMENTS FOR RESIDENTIAL CONSTRUCTION

AUTHORS: Daniel Hindman, *Virginia Tech* & Ali Memari, *Penn State*
SPEAKER: Daniel Hindman, *Virginia Tech*

Cross-laminated timber (CLT) is a new building material rapidly expanding in use in the United States construction industry. Current CLT construction style has focused on exterior load bearing walls systems to create a range of buildings. CLT combines uses of modular construction and building information modeling (BIM) to create pre-manufactured elements which are easily and quickly assembled on-site, creating significant savings in construction labor costs. As CLT enters the building code and market to a higher degree, it may be helpful to examine other structural material systems currently in use where CLT materials could improve current systems. Specific areas discussed in this paper include the use of CLT for elevator shaft wall systems, wall segmentation placement to create open structures and the use of CLT products for tornado and storm shelters.

SHAKE TABLE TESTING OF A 10-STORY MASS TIMBER BUILDING WITH NONSTRUCTURAL COMPONENTS

AUTHORS: Keri Ryan, *University of Nevada Reno*; Shiling Pei, *Colorado School of Mines*; & Tara Hutchinson, *University of California San Diego*
SPEAKER: Keri Ryan, *University of Nevada Reno*

To advance the wood products market, new design solutions for tall wood buildings using mass timber products are being developed. In particular, post-tensioned cross-laminated timber (CLT) rocking walls have been proposed as a seismic resilient lateral system. To advance the seismically resilient CLT rocking walls for tall buildings, a comprehensive shake table test of a 10-story building with CLT rocking walls is planned for 2021 on the NHERI@UC San Diego outdoor shaking table. This test is the culmination of the NHERI TallWood Project that aims to develop seismic design methodology for resilient timber buildings. An essential aspect of building resilience is assurance that NCSs sustain minimal damage or are easily repairable; however, a number of aspects specific to rocking wall systems and their impact on NCSs are not well understood. In this presentation, preliminary plans for the shake table test will be described, and a vision for incorporating NCSs into the test program presented. Due to the lack of shake table test data of exterior skin systems with glazing, a key objective is to characterize the response of a variety of curtain wall and light-framed window wall type systems, and to validate industry standard racking tests as predictors of seismic performance. In addition, detailing improvements for stairs, interior partition walls, and suspended ceilings are proposed. The project team is actively seeking industry and academic collaborators for testing of various NCSs to capitalize on this opportunity.

TRACK 3: PASSIVE HOUSE | 205

PHFA PASSIVE HOUSE ADDITION:

Created in 1972 by the state legislature, the Pennsylvania Housing Finance Agency (PHFA) provides affordable homeownership and rental housing options for older adults, low- and moderate-income families, and people with special housing needs. In 2004, the non-profit had grown enough to warrant a 163,000-square-foot, 8-story headquarters building at 211 North Front Street in the state capital. The $21.3 million building is certified LEED Gold. Continued agency growth fueled a recent major expansion that was designed to Passive House and LEED Platinum sustainability standards—a first for an expanded corporate building on the East Coast. Murray Associates Architects is the architect of record for the 2005 headquarters and the 2019 expansion.

PHFA PASSIVE HOUSE ADDITION | THE DESIGN – PRODUCT RESEARCH AND EXISTING MODELING

SPEAKERS: Benedict H. Dubbs, Jr., *Murray Associates Architects* & Wade Romberger, *Pennsylvania Housing Finance Agency*

The project combined a new 8-story contemporary tower and a historic building to an existing building, located in the Capital Area Neighborhood's Historic District of the city. Detail development that connected the three structures while maintaining passive house envelopes will be presented. Researching products and materials that would "stand the test of time" was critical. Considerations included different types of renewable materials such as using synthetic products in addition to their origins, specific applications, thermal bridges, air tightness, environmental and health aspects and disposal. We will discuss the decision-making process and how the manufacturers data and current code requirements were translated into energy model input values plus how the material performances were compared to inform the design. Our whole-building energy and daylight analysis process will be discussed as to how we assessed passive efficiency strategies, reductions in cooling/heating loads, high-efficiency equipment, support savings verification, and identifying the most ideal operating conditions. How we optimized glazing sizes, orientation and shading to extend the period that the building can run passively will also be discussed. And finally, the reconciliation of the USGBC LEED Platinum and Passive House requirements will be presented.

PHFA PASSIVE HOUSE ADDITION | THE DOCUMENTATION – "THE DEVIL IS IN THE DETAILS"

SPEAKERS: Benedict H. Dubbs, Jr., *Murray Associates Architects* & Wade Romberger, *Pennsylvania Housing Finance Agency*

The drawings and details for this project were massive. Over 500 sheets were produced to carefully and clearly illustrate assembly junctions, sections and elevations. The details were accompanied by technical descriptions to ensure key principles were understood by the contractors. Our documentation process will be discussed for the building's physical data, construction material details, alternative construction materials etc. Quality Control, coordination and extreme use of BIM and 3Dviews will also be presented.

PHFA PASSIVE HOUSE ADDITION | THE BUILD – CONTRACTOR SELECTION, SEQUENCING AND COLLABORATION

SPEAKERS: Benedict H. Dubbs, Jr., *Murray Associates Architects* & Wade Romberger, *Pennsylvania Housing Finance Agency*

PHFA selected their contractors, as they utilized a multiple-prime, publicly bid procurement procedure, but the selected local contractors had no previous experience with constructing a passive house project. We will discuss how we assisted in their education to construct and review mock-ups and maintain progress of on-going construction by holding on-site informational workshops plus how we worked with the Owners' Rater to ensure construction achieved Passive Construction Certification. Our Construction Administration, or on-site time during the construction, was triple that of a "typical" code-built project to ensure details were built properly. We will review why this commitment in staff hours was critical, as any construction setbacks would have cost significant time and money in delays and even more to undo any select demolition. Finally, we will address the project's construction sequencing which included effect scheduling, ensuring materials were on site, weekly inspections of completed and ongoing work and PHIUS Inspections.

TRACK 4: 3D PRINTING & MODULAR | 211

THE POTENTIAL OF ADDITIVE MANUFACTURED HOUSING

AUTHORS: Joe Colistra & Paola Sanguinetti, *University of Kansas*
SPEAKER: Joe Colistra, *University of Kansas*

This paper will present emerging trends in additive manufactured housing (3D printed concrete) techniques that allow housing units to be delivered sustainably and affordably. Through case studies, we explore the potential for 3D printing Net Zero Energy housing units. Building envelope assemblies are compared to analyze the insulating capacity of concrete 3D printed walls and their predicted impact on energy consumption. The pros and cons of this emerging construction technique are discussed, including: speed of construction, energy efficiency, flexibility in housing module, constructability of complex geometries and associated layout limitations, code and inspection implications, incorporation with conventional building envelope components and systems, and marketability.

MARKET DRIVEN COLLABORATION & INNOVATION IN MODULAR CONSTRUCTION

SPEAKER: Frank Yang, *ADL Ventures*

Modular construction is experiencing unprecedented demand and investment, creating a unique set of opportunities, as well as challenges in aligning key stakeholders and streamlining design, construction, and financing processes. Cooperation driven directly by the needs of building owners and occupants will accelerate commercialization of innovative high-performance modular innovations. Using the highly successful semiconductor consortium Sematech as a model, ADL Ventures is, in partnership with MBI, Rocky Mountain Institute, and other industry partners, launching a national collaborative to develop, standardize, and mass produce cutting-edge modular / pre-fab innovations, including new materials, production tools and software. The presentation will highlight our work with major building owners to create new "market pull" mechanisms, including both successful case studies as well as yet-to-be-broken market barriers.

TRACK 5: BUILDING SCIENCE / EDUCATION | 218

BUILDING SCIENCE EDUCATION PANEL DISCUSSION

MODERATOR: Sam Taylor, *Energy & Resource Efficiency*
PANELISTS: Holly Carr, *US Department of Energy*; Chrissi Antonopoulous, *Pacific Northwest National Laboratory*; Georg Reichard, *Virginia Tech*; & Pat Huelman, *University of Minnesota*

Faculty advisers for Solar Decathlon Design Challenge and the DOE Race to Zero have raised issues regarding the perceived decline in emphasis of building science education of the DOE student design competitions. The early Race to Zero competitions emphasized priority building science, including hygrothermal performance. The following issues will be addressed by the panel: 1) Approaches to improve the emphasis and value of building science education in the Design Challenge competition, and the academic courses (lecture and/or studio) paired to the competition; 2) Teaching resources (primary and supplemental) and approaches to support the paired academic building science courses (as well other university building science education); and 3) Other design competitions, capstone projects, and related experiential projects that can also provide building science experiential learning. 4) Optional, particularly relevant to revised Thursday track - BSE role in integration of priority outcomes [quality, high performance buildings that are safe, healthy, durable (i.e. good hygrothermal performance, IEQ, disaster resistance & energy efficient) plus sustainable, affordable, resilient, and optimized for grid-integration]. The Panel would include the DOE BSE Program Manager, NREL/PNNL (staff for BSE competitions and resources) and competition judges involved in the DOE design competition, and BSE session speakers concerned with enhanced building science education. The panel would provide possible approaches for achieving the objective of enhancing the building science education value of the DOE design competitions and paired academic courses.

RELAX & UNWIND DOWNTOWN

THURSDAY | 6:30 PM – ?

More information on the back cover. Thank you to the Penn State / UNECE Global Building Network for sponsoring the event!

SESSIONS G

FRIDAY | 8:30 AM – 10:00 AM

TRACK 1: AFFORDABLE HOUSING | 203

EVALUATING INCLUSIONARY ZONING IN CENTRE COUNTY, PA AS A TOOL TO INCREASE THE SUPPLY OF AFFORDABLE HOUSING STOCK AND TO MITIGATE HOUSING SEGREGATION

SPEAKER: Rachel Fawcett, *Penn State*

One in three households in the United States lives in housing that is unaffordable to them from the Aspen EPIC's 2020 research primer, "Strong Foundations: Financial security starts with affordable, stable housing." Lack of affordable housing opportunities for low- to moderate-income people in Pennsylvania continues to be an issue throughout the Commonwealth and can create economic, racial, and social barriers to an equitable, inclusive community. Focusing on Centre County, inclusionary zoning is assessed as a tool to increase the supply of affordable housing stock and to mitigate housing segregation. Seven municipalities throughout the county maintain inclusionary zoning ordinances of greatly varying degrees in regards to requirements, incentives, intended population served, administration, and overall goals. Each ordinance has differed in terms of implementation and effectiveness for creating new housing and preserving its affordability. Existing conditions and ordinances were assessed and compared to the local housing market in an effort to craft future recommendations for the region and specific municipalities.

THE CHALLENGES OF CREATING RESILIENT HOUSING AT AFFORDABLE COST – A "LESSONS LEARNED" REPORT ON THE FIELD OF DREAMS ECOCOMMUNITY

AUTHOR: Jörg Rügemer, *University of Utah*
SPEAKER: Jörg Rügemer, *University of Utah*

Field of Dreams EcoCommunity [FoD] is a collaborative effort to re-imagine the affordable housing typology in the U.S. Southwest. It consists of twenty units, of which two are already finalized in close proximity to Salt Lake City, Utah. Underlying principles of how we live and the types of spaces we need to accommodate these desires were re-examined, challenging the contemporary notion that quantity of space supersedes quality of space and design clarity, with the goal of providing a high quality of living within an optimized, moderate footprint that is sensitive to both inhabitants and the local environment. FoD was planned to be the synthesis of modern technology and vernacular principles -- unlike traditional modern buildings, FoD utilizes what is immediately available onsite as the primary energy source in form of passive winter solar heat gain; it supplements only what cannot be generated onsite to meet modern standards of comfort through technological means. To become net-zero, remaining energy requirements can be offset through optional photovoltaic solar systems. Traditional ideas of orientation, passive energy design, thermal massing and aspects of daylighting are key elements in the outward expression of the building's massing. This strategy creates an energy-efficient building with a high resilience factor, thus making survival in extreme conditions possible without external energy sources, also reflected by supporting occupants with their own food supply by offering produce production onsite. This paper describes the development and design process of FOD, to continue with a "lessons learned" section that focuses on the construction-specific challenges.

INTEGRATING FLEXIBLE HUMAN-ACTIVITY IN MODULAR SPACE DESIGN FOR AFFORDABLE MASS HOUSING IN ASIA

AUTHORS: Atul Biltoria & Uttam Roy, *Indian Institute of Technology Roorkee*
SPEAKER: Atul Biltoria, *Indian Institute of Technology Roorkee*

In the contemporary fast changing world, with urbanization as an inevitable process for economic development of nations, it is often forgotten that Housing is one of the basic human rights. Migration of people to urban centers occurs in search of better career opportunities, in lieu of which citizens are forced to live in sub-standard housing. Due to increased demand of affordable housing, Governments in Asia needs to provide livable shelters to its people urgently. Livability leads to activity spaces, like behavioral pattern and flexibility. A design of housing space, which compliments its users with healthy spaces is the quest. Psychological and social needs of people living in urban multi-storied buildings need to be taken care of, by design intervention and integration of robust system of modular grid planning, capable of assembling various components of housing construction. Modular construction with prefabricated materials has the enormous capability of reducing the ever increasing gap between supply and demand of affordable mass housing due to faster construction process. Primary and secondary case studies were conducted to gauge such activity spaces. Interesting plots on space and time matrix, which reflects usage of space by each family member are obtained. These results correlates to research gap found earlier in literature study, as evident by primary survey conducted on urban population as respondents. This Paper aims to understand patterns of urban living in urban housing through Time-space matrix and links it with flexible housing design.

TRACK 2: BUILDING ENVELOPE | 204

STUCCO – THE ONCE AND FUTURE CLADDING: DESIGN OPTIONS TO MEET INDUSTRY CODES AND STANDARDS

SPEAKER: Theresa Weston, *DuPont Performance Building Systems*

Stucco has been used since ancient times and it has survived by evolving to meet evolving design criteria. In North America, stucco is a widely used and growing exterior cladding in residential construction, comprising 24% of the US primary exterior wall material in 2015, up from 16% in 1995, according to the US Census Bureau. Despite stucco's popularity over the last 20 years, stucco systems have been associated with several performance questions, including cracking and water intrusion. Additionally, industry energy efficiency codes are challenging traditional wood-frame stucco assembly design. This presentation reviews the latest energy and building code requirements relating to stucco applied over wood based substrates.

PERFORMANCE OF PCMS IN DIFFERENT BUILDING ENVELOPE CONFIGURATIONS, CLIMATE ZONES AND BUILDING OPERATING SCENARIOS

AUTHORS: Hyejoo Koh & Fitsum Tariku, *British Columbia Institute of Technology*
SPEAKER: Hyejoo Koh, *British Columbia Institute of Technology*

This paper presents an innovative material, called phase change material (PCM). This material has been introduced in building construction but additional guidance is needed within the industry for selecting and installing PCMs. There are several factors influencing PCM performance in energy savings such as its characteristics, the weather, the type of building envelope it is integrated with and the building operation type. The report provides the results of numerical simulations with mat type PCMs installed within a wood framed wall assembly and presents the most effective PCM configuration for energy savings under different climates and mechanical system schedules. The PCMs with several melting points in the range of 21 to 27°C have been simulated under the climates such as, Vancouver (mild), Toronto (cold), and Houston (hot) on different building operation schedules. In most scenarios, the PCM performance is maximized when it is located near the indoor control space and its melting point is within the range of the indoor temperature in the control space. With the non-mechanical scenario, a single PCM can't provide the best performance all year around, indicating PCM performance changes as outdoor temperature fluctuates. With mechanical system operating scenarios, the maximum energy savings can be achieved when the indoor temperature fluctuates within the PCM melting point range. Vancouver has the maximum mechanical system energy savings during summer and fall while Toronto has them in shoulder seasons and Houston in winter and fall. A wall with PCMs does not save energy in extreme weather conditions since the PCMs do not experience a cycle of phase change.

THE INTERFACE

SPEAKER: Adam Ugliuzza, *Intertek*

Today's building construction must overcome complex building materials, multi-layer construction / multiple trades, limited on-the-job training, higher expectations, schedule, and are generally cost sensitive. In the past, building systems were simpler with fewer layers, there were many master tradesman, apprentice training, with less building performance expectations. Performance criteria (water air, vapor, and thermal) is readily available for most building enclosure materials and assemblies that are commonly used in the building construction industry today. However, performance criteria for the interface of materials and assemblies is not clearly defined or published and is often missed or misunderstood. Continuity of the environmental control layers is most vulnerable at the interface of building enclosure components. Without the proper interfacing, we cannot expect to achieve the laboratory tested performance of the materials and assemblies selected for the project. The relationship between components and trades that is required to ensure continuity of the environmental control layers may not be immediately apparent or intuitive if the contract documents are unsuccessful in presenting the building enclosure as a contiguous and cohesive assembly, composed of inter-related parts. Furthermore, if the contract documents fail to clearly represent the building enclosure's environmental control layers and trade relationships, the related subcontractor's obligation will be limited to the installation and performance of their system alone. This presentation will review building enclosure design and performance and the evolution of the materials and assemblies used in construction today. Typical assemblies and common transition/interface details will be reviewed along with case studies, computer modeling, laboratory certification testing and field performance testing. The discussion will also overlay the affects building enclosure material and assembly interfacing has on construction sequencing and schedule and overall building performance.

TRACK 3: PASSIVE HOUSE + EDUCATION | 205

PASSIVE HOUSE & THE NEXUS BETWEEN ACADEMIA, PRACTICE, CONSTRUCTION, AND RESEARCH

MODERATOR: Walter Grondzik, *Passive House Institute of the US (PHIUS) & Ball State University*
PANELISTS: Laura Blau, *BluPath Design*; Tim McDonald, *Onion Flats*; Mary Rogero, *Miami University*; & Mike Steffen, *Walsh Construction*

Passive house construction is taking off in the US and Canada--especially in the multi-family marketplace. This success is gratifying, yet poses questions and raises issues. Four exceptionally knowledgeable panelists will discuss current and future prospects for passive building in North America. The big-picture question to be addressed is: how can those in practice, in construction, in research, and in academia build synergies to build capacity and build quality in passive building? Each panelist will provide a perspective on this question and the panel will look collectively at several specific issues related to this question. There will opportunity for the audience to contribute to the discourse and/or pose questions to the panel.

TRACK 4: ENERGY USAGE | 218

CHARACTERISTICS OF TYPICAL OCCUPANCY SCHEDULES FOR RESIDENTIAL BUILDINGS IN THE UNITED STATES

AUTHORS: Debrudra Mitra, Nicholas Steinmetz, & Yiyi Chu, *Iowa State University*; & Kristen Cetin, *Michigan State University*
SPEAKER: Debrudra Mitra, *Iowa State University*

The overall energy performance of the residential building sector highly depends on the presence of occupants and how they interact with buildings' energy consuming systems. Therefore, in order to predict the energy performance of a residential building, it is important to utilize an occupancy profile that accurately represents occupants' behavior in a space. In current practice, most building energy simulation tools for residential buildings assume a standard 24-hour schedule, regardless of the home's or household's known characteristics. This demonstrates there is room for improvement in the modeling of occupancy schedules. In order to better represent the unique characteristics of residential occupancy profiles, 12 years of American Time Use Survey (ATUS) data was analyzed. Major classifiers that impacted the variation between schedules were obtained and compared. It was found

that there are two classifiers that significant impact occupancy schedules: (1) age of the occupant, and (2) type of day, i.e. weekday or weekend. To explore variations among these groups further, cluster analysis was performed on the daily occupancy profiles. For a majority of the age groups, the various occupancy schedules can be described using four major clusters for both weekdays and weekends. The results help generalize the variability of occupancy schedules into groups, while providing much more tailored occupancy schedules than the standard schedule currently utilized in energy modeling software. Overall, the results of this study provide a better understanding and more tailored prediction of the residential occupancy schedules, based on known occupant characteristics. This benefits both building energy modelers and researchers in sustainable residential building design.

AN EVALUATION OF ELECTRICAL ENERGY USAGE COMPARING HOMES WITH AND WITHOUT BUILDING CODE ENFORCEMENT

AUTHORS: Ben Bigelow, *University of Oklahoma* & Melina Cedillo, *Holder Construction*
SPEAKER: Ben Bigelow, *University of Oklahoma*

Homes account for 23% of energy consumption in the United States. However, most homeowners are less likely to invest in energy efficiency upgrades after construction. As a result, current building codes include energy efficiency requirements. The reduction in electrical energy usage because of code compliance has been documented, as well as the lack of any reduction in consumption based on year of construction when a building code is not enforced. This paper compares two studies that measured electrical consumption in homes. Using both data sets, the financial impact of electricity consumption in homes built to code, versus homes built to an older code or built without code enforcement are compared. The research suggests that more recently built homes do not consume less electricity in the absence of code enforcement. Not surprisingly, homes built with a code enforced were more efficient than homes without code enforcement. In fact, homes built without code enforcement in recent years were found to consume more electricity than homes built with a code enforced that were competed in the 1980's.

THE HOME AS A CONCRETE EXAMPLE FOR ENERGY EDUCATION

SPEAKER: Frederick Paige, *Virginia Tech*

By design, energy-efficient (EE) homes are influenced by the Energy Literacy rate of society. Across the general population, energy literacy is low adding complexity to the process of delivering energy-efficient housing that people demand and utilize optimally. A limiting factor in a person's ability to understand energy is energy's invisible presence, and varying form. This exploratory case study identifies how interactions with energy-efficient homes in the Greenville, South Carolina area influences the Energy Literacy of occupants and visitors. The specific Energy Literacy concepts targeted in this study are: human use of energy is subject to limits and constraints, conservation is one way to manage energy resources, electricity is generated in multiple ways, social and technological innovations impact the amount of energy used by society, and energy use can be calculated and monitored. Examples from this case study showcase how utilizing features of EE homes like utility bills and energy-efficient devices can make lessons on the energy more personally relevant, understandable, and applicable. This case report also introduces open-access educational materials for leveraging housing-related examples of commonly misunderstood energy concepts. Implications of this study apply to a variety of stakeholders such as educators, policymakers, engineers, and designers who collectively make up the energy-dependent society who need to be energy literate to address energy and climate issues. Grounded by an Energy Literacy framework developed by dozens of educational partners and federal agencies, this study focused on critical energy concepts that help housing stakeholders make informed energy-related decisions.

SESSIONS H

FRIDAY | 10:15 AM – 11:45 AM

TRACK 1: DISASTER-RESILIENT DESIGN | 203

WIND PRESSURE DISTRIBUTION ON SINGLE-STORY AND TWO-STORY ELEVATED STRUCTURES

AUTHORS: Nourhan Abdelfatah, Amal Elawady, Peter Irwin, & Arindam Chowdhury, *Florida International University*
SPEAKER: Amal Elawady, *Florida International University*

Along the shoreline, low-rise coastal structures are recommended to be elevated as a retrofitting way to reduce flooding hazards. FEMA provides guidance on the elevation needed for structures according to their location from the coastline, which can reach as high as 4.6m from the ground level. Besides the increase of wind speed with the increase in the structure's height, it is expected that aerodynamics of elevated structures will change and behave differently compared to the structure's slab-on-grade counterpart. As a result, structures elevated without careful consideration of the values and distribution of actual wind pressure are vulnerable to wind-induced damage. This agrees well with damage assessment observations made after Hurricane Irma and Michael. However, there are no available design guidelines or provisions pertaining to wind loading on the envelope or components of typical elevated buildings. In addition, very few studies in literature have considered investigating wind actions on elevated structures or mobile homes. Recently, two large-scale aerodynamic wind testing have been conducted on single-story and two-story elevated house models at the Wall of Wind (WOW) Experimental Facility at Florida International University. For each test case, the models were raised to four different elevations to investigate the effect of the floor underneath gap height on the wind pressure distribution on the models. The models were instrumented using densely distributed pressure taps to measure wind pressure time histories. This paper discusses the distribution of the peak and mean pressure coefficients on the building surfaces for each stilt height for the two test models. Comparisons showing the role of the roof mean height and the number of stories on the pressure distribution will be presented.

CONCEPTUAL GEOMETRIC DESIGN FOR U.S. COASTAL HOMES TO RESIST HURRICANE SURGE FORCES

SPEAKER: Julie Bates, *Penn State*

In the aftermath of hurricanes like Katrina and Harvey that have changed the landscape of the coastal U.S., it has become very important to effectively prepare for such natural disasters. Rebuilding from hurricanes is a slow process, with as much as 17 percent of damaged properties still needing substantial repairs five years after Katrina and Rita. If coastal homes continue to be built the same way, they will continue to be devastated by future hurricanes. However, there are a few different approaches and adaptations to the design of coastal residential buildings to help defend them. Some approaches focus on simply elevating the traditional home, while others focus on reinforcing the homes with stronger materials. Yet, another approach focuses on designing the shape and geometry of coastal homes to better withstand hurricanes surge effects. This presentation focuses on different ways that shape and structural configuration can help U.S. Coastal homes to resist hurricane surge forces, which are the forces associated with the high wind and surge water from the ocean. In particular, developing aerodynamic shapes that will reduce the effect of wave forces on the structure will be discussed. This presentation includes an introduction about how coastal homes have performed in past events and existing solutions. However, the main focus of this presentation is to discuss the development and analysis of a geometric approach to counter the effects of hurricane surge force. Ultimately, the result of the study will be presented in the form of a conceptual design.

PERFORMANCE OF RESIDENTIAL BUILDINGS IN HURRICANE PRONE COASTAL REGIONS AND LESSONS LEARNED FOR DAMAGE MITIGATION

AUTHORS: Mehrshad Amini & Ali Memari, *Penn State*
SPEAKER: Mehrshad Amini, *Penn State*

Coastal residential buildings are vulnerable to significant damage due to different hurricane hazards. Recent damage to such residential buildings illustrates poor performance of coastal structures as it relates to hurricane hazards. This could mean that recent standards and building code provisions need to be improved in terms of loading and design requirements. This paper reviews the evidence from actual damage in past hurricanes with respect to direct and indirect damage to different types of residential buildings in coastal areas. The results show that building materials other than wood have better performance during strong hurricanes. Regardless of building materials, residential buildings have mainly suffered extensive wind-induced damage to envelope systems and roofs more than the structural systems. Therefore, selecting adequate connection systems, suitable wind resistant materials, and appropriate installation methods for wall/roof covering can significantly reduce the level of direct and indirect wind-induced damage. Furthermore, many non-elevated or low-elevation buildings sustain severe flood damage in coastal areas. It can be concluded that elevating the structure and its supporting base on deep embedded piles above the BFE is the most effective method to reduce flood damage to residential buildings in coastal areas. However, it might increase the wind damage due to the fact that the house is exposed to higher wind pressures so that further measures should be considered. Last but not least, selecting the appropriate foundation system, enhancing foundation connections, and using flood-resistant materials below the BFE can also reduce flood-induced damage to residential buildings in coastal regions.

TRACK 2: 3D PRINTING ON MARS | 204

AN OVERVIEW OF THE EXECUTION OF 3D-PRINTED SUBSCALE HABITAT ON MARS: A CASE STUDY TO EXEMPLIFY THE AUTOMATED CONSTRUCTION PROCESS

AUTHORS: Shadi Nazarian, Jose Duarte, Sven Bilén, Ali Memari, Naveen Kumar Muthumanickam, Nathan D. Watson, Aleksandra Radlinska, & Negar Ashrafi, *Penn State;* & Maryam Hojati, *University of New Mexico*
SPEAKER: Shadi Nazarian, *Penn State*

Since 3D printing of structures is expected to reduce construction time, material, cost, and energy, the building industry has come to realize the relevance and importance of digital design and additive construction, paving the way for much-needed advancement in the construction industry. Furthermore, the automation implied in 3D printing technology could introduce newfound applications; for example, it makes possible in-situ construction in harsh conditions on Earth and extraterrestrial environments such as Mars and the Moon prior to the arrival of human explorers. This paper presents the dynamic and interrelated processes of design and development of materials, systems, and architectural constructs on a single BIM platform, on which the architectural design of a habitat, the tool-path design, and assembling and coordination of information regarding multiple interrelated variables such as materials properties, structural behavior, systems' transformation, costs, and logistics, can be systematically created, coordinated, managed, analyzed, and converged towards the common goal of automation in construction. We review the attempts made by the interdisciplinary team of Penn State faculty and students to print a sub-scale habitat for Phase III–Level 3 of NASA's 3DPrinted Habitat Challenge. NASA designed the multi-phase Challenge to catalyze research to advance the automated construction technology needed to create sustainable housing solutions for Earth and deep space habitats. This paper presents a framework to quantitatively understand the benefits of and changes that will trigger in construction and logistics, rather than a focus on qualitative consequences in terms of the inevitable transformations it will trigger in architectural language and practice.

STRUCTURAL ANALYSIS OF FULL-SCALE AND SUB-SCALE STRUCTURE FOR DIGITALLY DESIGNED MARTIAN HABITAT

AUTHORS: Keunhyoung Park, Ali Memari, Shadi Nazarian, & Jose Duarte, *Penn State*; & Maryam Hojati, *University of New Mexico*
SPEAKER: Keunhyoung Park, *Penn State*

Over the past few years, digital design and additive construction have been gaining recognition and acceptance for terrestrial construction, and their enormous potential coupled with automation is accordingly justified for space colonization programs. Building a habitat in deep space, in places such as Mars or Moon, would face challenges different from those encountered on Earth in terms of design, construction, and structural performance. 3D printing or additive manufacturing using robots enables us to build shelters autonomously using indigenous materials. For making a livable environment for humans on Mars, the habitat needs to be pressurized and provide enough protection against harsh solar radiation. In this study, a numerical finite element model (FEM) was constructed to conduct the analysis/design process of a Martian habitat using Revit by AutoCAD to coordinate the habitat design with the structural analysis and later the printing process. The geometry information of the habitat design was transferred from the design authoring program Revit by Autodesk to Autodesk Nastran through the Standard ACIS Text (SAT) and the stereolithography (STL) file format. The file format is also used to deliver data from the design authoring program to the printing system preparation process. Finite element (FE) modeling and analysis were used to study the structural performance of different schemes for the habitat design under relevant gravity loads and internal pressures. The optimized model was proposed for the printing process, and a subscale habitat was modeled and evaluated for actual construction. Portland cement mortar-based printing material was used as the construction material.

EXPERIMENTAL TESTING AND FINITE ELEMENT MODELING OF 3D-PRINTED REINFORCED CONCRETE BEAMS

AUTHORS: Keunhyoung Park, Ali Memari, Mehrzad Zahabi, Shadi Nazarian, & Jose Duarte, *Penn State*; & Maryam Hojati, *University of New Mexico*
SPEAKER: Keunhyoung Park, *Penn State*

The advantages of using Additive construction include the elimination of formwork and associated labor costs and enhancing the ability to create more complex shapes, surface conditions, new details, and make new spatial and architectural expressions possible. The structural behavior of these 3D printed concrete components is different from conventional cast elements due to the nature of 3D printing. This may result in either concrete with lower strength or printed material anisotropic with directionally dependent properties and with different mechanical behavior compared to cast concrete due to potentially less than perfect bond between filament (potential for cold joint) and tiny gaps between filaments. There is limited research on options to reinforce these elements and how to model them numerically since embedding reinforcing rebars in a printed beam would be quite different from reinforced cast beams as printed concrete exhibits lower tensile strength. In this study, two different rebar types, FRP and Steel, were used to reinforce 100×150×1200 mm beams, and their strengths were measured by conducting three-point bending flexural tests. Structural analysis was then performed on finite element models using Autodesk Nastran with the tetrahedron element of the beams to determine the response of printed beams. In this modeling, the printed concrete was assumed to be isotropic just as cast concrete. The experimental results indicate low bond strength between the printed material and embedded rebars causes the beams to fail under relatively low bending stress due to the separation of the reinforcement from the printed material (filaments).

TRACK 3: LOCAL COMMUNITIES + EDUCATION | 205

COMMUNITY-UNIVERSITY PARTNERSHIPS FOR HIGH PERFORMANCE HOMES

MODERATOR: Meghan Hoskins, *Penn State Sustainability Institute*

PANELISTS: Ilona Ballreich, Lisa D. Iulo, & Sarah Klinetob Lowe, *Penn State;* Jasmine Fields, Maureen Safko, & Alan Sam, *State College Borough*; & Colleen Ritter, *State College Community Land Trust*

Moderated by Penn State's Sustainability Institute, this session will highlight how Penn State has engaged in multiple community partnerships for high performance housing & sustainability work in local communities, including the 1) Sustainable Communities Collaborative which connects faculty, students, and staff with local communities to address sustainability challenges through an engaged, collaborative effort, 2) the Solar Decathlon Design Challenge Competition which partners with Pennsylvania housing entities for real-world Zero Energy Ready Home designs, 3) the GreenBuild project, which is an affordable duplex built to the Zero Energy Ready Home standard, and 4) the Energy+ initiative to retrofit existing affordable housing in State College.

TRACK 4: HIGH PERFORMANCE HOUSING | 218

MANAGING BUILDING PRESSURE DIFFERENTIALS IN HIGH-PERFORMANCE, LOW-LOAD HOMES

SPEAKER: Pat Huelman, *University of Minnesota*

Today's airtight homes combined with mechanical airflows (i.e. exhaust fans, duct leaks) can result in significant air pressure differentials. As building codes and improved construction practices dramatically reduce building enclosure leakage, air transport by mechanical systems can cause significant negative and positive pressures within the home and across the building enclosure. If left unmanaged these pressures can contribute to performance concerns including combustion safety, comfort, moisture transport, and entry of exterior pollutants (i.e. garage, soil, etc.). The proposed approach is a multi-step process. The first step reviews and identifies critical pressure differentials in terms of overall building performance (comfort, efficiency, durability, indoor air quality, etc.). Second, key equipment and operational contributors are identified that might result in significant pressure differentials in airtight, high-performance homes. Third, is to develop a categorization of the temporal and spatial nature of equipment use and resulting pressures. Last, using previously collected information, a set of proposed pressure management guidelines can be established for houses with different locations (climate zones), indoor conditions, and building configurations (combustion equipment, attached garage, radon risk, etc.). Ultimately these pressure management guidelines can lead to design procedures for make-up air (supply or exhaust) based on acceptable pressure levels and typical loads (air flows) created by various equipment selection. Several control strategies will be discussed, as well.

WHOLE BUILDING AIRTIGHTNESS TESTING AT PENN STATE

SPEAKER: Adam Ugliuzza, *Intertek*

This presentation will include case studies for whole building airtightness testing and diagnostic air leakage site detection at three buildings on Penn State University (PSU) main campus. Each case study will discuss scope, objectives, test results, and lessons learned. The goal of this presentation is to analyze these three (3) case studies to help guide PSU and the industry on the importance of airtightness, high-performance building construction, and the effort that is required to achieve building enclosure airtightness goals. The case studies include the following buildings. The Stuart Hall project in East Halls is a building renovation project. PSU Office of Physical Plant (OPP) expressed interest in better understanding airtightness of existing buildings as well as expectations for building enclosure performance for renovation construction projects. Whole building airtightness testing and diagnostic air leakage site detection was performed pre and post renovation. Steidle Hall, a recently completed PSU renovation project, is a forensic investigation that resulted from a sprinkler system pipe failure due to water freezing. PSU OPP suspected that air leakage through the enclosure was the likely cause for the failure. Whole building airtightness testing and diagnostic air leakage site detection was performed to help determine the cause of the freezing pipe and to identify other potential building enclosure issues. The Chemical and Biomedical Engineering Building is a new PSU construction project. Whole building airtightness testing and air leakage site detection was performed as part of the Building Enclosure Commissioning (BECx) Functional Performance Testing Plan to verify building enclosure airtightness performance.

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

AUTHORS: Homeira Mirhosseini, Xinyi Lily Li, Jim Freihaut, & Lisa D. Iulo, *Penn State*

SPEAKER: Homeira Mirhosseini, *Penn State*

Due to global warming concerns in recent years, there has been increasing interest to develop weather-dependent strategies to achieve energy efficiency and reduction of energy demands. Passive House is a solution for lowering the building energy demand by improving the performance of building envelope and reduce weather-related energy demands for heating and cooling. A review of previous research studies shows that although the initial construction costs are increased by using Passive House standards, the savings from utility costs over time make the use of Passive House beneficial for building owners. The objective of this research is to use a comparative method to validate the reduction in energy demand for heating and cooling loads over time in two adjacent multifamily residential affordable senior housing buildings with similar layouts and identical orientation in Philipsburg, PA (Climate Zone 5A) as case studies, one conventionally constructed and the other built according to Passive House standards. Whole building calibrated simulation approach will be used to compare the energy model developed based on software simulation in compliance with ASHRAE 99.1, 55, and 62.21 codes, and data-driven energy model based on data collection using ECMs and utility bills of the buildings. A calibrated Building Energy Model (BEM) will be used to determine the energy demand and savings of two buildings to validate whether designing a high-performance envelope can help to meet the energy reduction goals defined by Passive House Institute US (PHIUS).

TRACK 1: INFRASTRUCTURE | 203

ROLE OF INFRASTRUCTURE IN THE SUCCESS OF URBAN HOUSING DEVELOPMENTS

AUTHORS: Shay Chakraborty, M.G. Matt Syal, & Sinem Mollaoglu, *Michigan State University*
SPEAKER: Shay Chakraborty, *Michigan State University*

The infrastructure is an important part of the success of any residential development, but it takes on a critical role in the case of urban housing developments, both new and redevelopment projects. This research reviewed literature and several case studies nationwide to define supporting infrastructure for residential redevelopments. The review led to defining thirteen categories of infrastructure systems and each system was then divided into subsystem leading to a total of forty infrastructure subsystems. The infrastructure systems and subsystems, required for the success of a urban residential redevelopment, were separately prioritized with the help of structured interviews with six developers and four municipal/state government officials in Michigan. The data from each group was collected in the context of their perspective on development success criteria such as: Company / Municipal Success, Profitability, Primary and Secondary Project Success Aspects, and Branding. ELECTRE III, a multi-criteria decision-making model that effectively helps in prioritization or optimized ranking of alternatives, was used for data analysis. The results reflect that the top five priorities for developers are Digital Infrastructure, Utilities, Education, Transport and Green Infrastructures whereas the Municipal Officials preference list includes Digital, Employment, Utility, Transport, Retail in order of priority. Infrastructures like Renewable Energy, Green Space are yet to gain widespread popularity in the real estate industry. The authors believe that this analysis will be valuable in guiding the developers and municipal officials in prioritizing the infrastructure options for a given budget to get the most impact on the success of a residential redevelopment project.

IMPROVING THE USER EXPERIENCE (UX) OF GREEN BUILDING CERTIFICATION RESOURCES FOR MULTIFAMILY HOUSING UNITS

AUTHORS: Dwayne Jefferson & Frederick Paige, *Virginia Tech*
SPEAKER: Dwayne Jefferson, *Virginia Tech*

Designing complex sustainable infrastructure systems requires an abundance of expert knowledge. To improve the construction industry's capacity to deliver sustainable infrastructure, guidance on optimizing green building systems needs to be more accessible. Green infrastructure certifications are an emerging open access method for providing sustainable engineering guidance to designers. EarthCraft Multifamily (ECMF), an evolving green building certification, has been utilized to deliver more than 45,000 energy-efficient housing units. This study identifies the impact ECMF tools and resources have on enhancing project delivery for builder-developers. EarthCraft has been successful in increasing the delivery of energy-efficient affordable housing, and this study leverages user experience (UX) methodologies to understand how to further improve ECMF and replicate its success. The strengths and weaknesses of ECMF are identified through data collected from stakeholder interviews, user interviews, and usability analysis. Preliminary findings show potential for ECMF resources to evolve in their design, content, and delivery methods. Additionally, a usability analysis has revealed that the selection of sustainable design practices in new construction and renovation projects have been influenced by ECMF tools. ECMF resources have the ability to lower the level of expertise required for sustainable infrastructure delivery which can allow for the inclusion of a broader set of stakeholders. With accessible guidance, the agency of non-expert stakeholders is increased allowing them to better manage their role in delivering sustainable infrastructure. This study provides transferrable findings with implications for the improvement of existing practices, and the creation of new innovations for green infrastructure project delivery.

TRACK 2: BUILDING INFORMATION MODELING (BIM) | 204

BIM FOR PARAMETRIC PROBLEM FORMULATION, OPTIONEERING, AND 4D SIMULATION OF 3D-PRINTED MARTIAN HABITAT: A CASE STUDY OF NASA'S 3D PRINTED HABITAT CHALLENGE

AUTHORS: Naveen Kumar Muthumanickam, Keunhyoung Park, Jose Duarte, Shadi Nazarian, Ali Memari, & Sven Bilén, *Penn State*
SPEAKERS: Naveen Kumar Muthumanickam & Jose Duarte, *Penn State*

The design of buildings to be additively constructed using robots requires a paradigm shift during the design process. Using industrial robots to 3D print concrete structures imposes constraints on geometries that can be feasibly 3D printed. It is essential to consider the feasibility of 3D printing any geometrical structure during early stages of its design to avoid unnecessary revisions. Moreover, this new paradigm requires us to easily and efficiently compare and evaluate multiple design options to make informed decisions. These tasks mandate meticulous extraction of requirements from the design brief, parametric formulation of the design problem to include those requirements in the form of design variables and objectives; and generation and simulation of multiple design options and scenarios. This paper presents an overview of our efforts to leverage Building Information Modeling (BIM) for algorithmic problem formulation, optioneering, and 4D simulation in the process of designing a Martian habitat to be 3D printed as part of the NASA 3D-Printed Habitat Challenge Competition.

THE VALUE AND USE OF NATIONAL BUILDING INFORMATION MODELING STANDARDS

SPEAKER: John Messner, *Penn State*

As Building Information Modeling (BIM) continues to become more prevalent in the design and delivery of residential building projects, it is critical for

the industry to develop standard approaches and information exchanges to improve the value of adoption. The United States National BIM Standard (NBIMS-US), developed by the National Institute for Building Sciences, provides a core set of BIM standards. NBIMS-US includes standards related to planning the implementation of BIM on both a project and organizational level, measuring BIM implementation, and defining consistent information exchanges. This presentation will discuss the current content within NBIMS-US along with the future vision for expanding the national standards.

TRACK 3: GLOBAL COMMUNITIES + EDUCATION | 207

GLOBAL BUILDING NETWORK PANEL DISCUSSION

MODERATOR: Esther Obonyo & Sarah Klinetob Lowe, *Penn State*

PANELISTS: Rob Bernhardt, *Passive House Canada*; Jenna Cramer & Dario Giandomenico, *Green Building Alliance*; Richard Crume, *American Public Health Association*; & Esther Obonyo, *Penn State*

The emerging Penn State/United Nations Economic Commission for Europe (UNECE) Global Building Network (GBN) is a globally dispersed community of researchers, educators, and practitioners that crosses sectors, disciplines, and geographies that facilitate the training of the next generation of leaders in the built environment through the development of new educational programs & foundational open-access educational resources and mainstream the understanding of the multiple benefits of high performance buildings through broad public outreach & direct engagement with both the community & policymakers. The purpose of this panel is to take stock of what kind of transformation can be achieve through a consortium approach. Panelists will each provide a 10-15 minute presentation followed by a Q&A session. Presentation topics include an Overview of the Global Building Network (Dr. Esther Obonyo), an Overview of Health in Buildings (Richard Crume), Overview of Policy & Practice Needs for Transformation (Rob Bernhardt), and an Overview of UN Cities of Excellence (Jenna Cramer & Dario Giandomenico).

CLOSING PLENARY

FRIDAY | 2:30 PM – 4:00 PM | 207

BUILDINGS AS A DRAWDOWN SOLUTION: GETTING TO ZERO *AND* BEYOND

JAY AREHART
SENIOR RESEARCH FELLOW, PROJECT DRAWDOWN

TOM RICHARD
DIRECTOR OF INSTITUTES OF ENERGY AND THE ENVIRONMENT, PENN STATE

Buildings present one of the biggest opportunities for reducing greenhouse gas emissions and reversing climate change. Project Drawdown has identified a suite of solutions that can deliver emission reductions while increasing building performance, and shown through global analysis that these practical, commercially available drawdown solutions are not only high impact and affordable, but accrue multiple benefits into the future. A revolution is already underway in buildings and component technologies, including tighter envelopes with healthy and high performance ventilation, energy efficient heating, cooling and lighting, and control systems that create synergies with renewables through demand management and integrated thermal and electrical storage. As the energy load of building drops close to zero, building materials themselves become a bigger part of the carbon footprint – and can transform buildings into carbon sinks. Carbon negative materials offer opportunities for enhanced performance while creating a new home for atmospheric carbon at a gigaton scale.

But these opportunities will not become standard practice without effort. Research, development and demonstration must be accelerated, and we need educational efforts at every scale for building designers, tradespeople, regulators, owners, and occupants. We also need supportive policies that encourage rapid adoption at a global scale. The unabashed goal is to transform one third of the global economy, and deliver a future that is climate positive for our children and grandchildren. This is the future we desire, and they deserve.

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RELAX & UNWIND DOWNTOWN

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THURSDAY | 6:30 PM – ? | HYATT PLACE STATE COLLEGE

Explore and connect for a casual evening in downtown State College! Join conference attendees and the PHRC staff for appetizers at the new Hyatt Lounge from 6:30-8:30pm with the first drink on us. Afterwards, keep your networking going at one of State College's numerous downtown hot spots. Scheduled bus transportation at 6:00pm or 6:45pm to and from downtown will be provided, or easily catch an Uber, Lyft, taxi, or hotel shuttle to and from downtown around your own schedule. Appetizers, the first drink, and bus transportation to & from the event are included in your conference registration! RSVP is required with bus time selection. Note: please remember to bring your ID!

Penn State is coordinating the development of the Global Building Network (GBN) in partnership with the United Nations Economic Commission for Europe (UNECE). Learn more at *bit.ly/PennStateUNECE, iee.psu.edu, www.sedtapp.psu.edu.*

UNECE

PennState Institutes of Energy and the Environment

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ENGINEERING DESIGN, TECHNOLOGY, AND PROFESSIONAL PROGRAMS

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*.

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