2019 Buildings XIV International Conference

December 9-12, 2019

Clearwater Beach, Florida

Date: Sunday, December 8, 2019

8:30am - 12:00pm
Beach Room

Workshop 1: No Way, That's Impossible

Believe It or Not: Field Realities

Peter Spafford
Air Barrier Association of America (ABAA)

This session will use actual projects and demonstrate how easy it is for issues in the air and vapor barrier to arise in the field and why they occur. Examples of proper installations and provide key points for how to ensure proper installation of air and vapor barrier materials in the field.

Research: What Needs to Be Done

Laverne Dalgleish
Air Barrier Association of America (ABAA)

This session will discuss research projects that are needed to be done to increase our understanding of the building enclosure for durability, sustainability, and performance. In order to continue to reduce energy consumption and provide owners with healthy buildings, continue efforts in research is a must.

Whole Building Air Leakage Testing

Lee Durston
Morrison Hershfield

This presentation will review the process of testing a building and provide insights to lessons learned from having run hundreds of tests. As whole building airtightness testing is becoming mandated in some parts of the country and seen in our standards and codes, these insights on how to properly run the test will help everyone better understand this process.

Don't Let the Roof Destroy Your Walls

Roy Schauffele
Division 7 Solutions, Inc.

This presentation will look at the roof wall intersection and the various types of products used at this interface. The presentation will provide project examples of both good and bad intersections and include some solutions for the audience to be able to use after attending.

8:30am - 12:00pm
Gulf Room

Workshop 2: I Can See, Glazing

What is Going on with Glazing: Future of Glazing

Stanley Yee
Dow

This presentation will shed light on today's glazing systems and provide insight into what the glazing industry is doing to increase energy efficiency and other improvements moving forward.

Issues From the Field and How to Avoid Them

Anthony Santocono
Kawneer Company, Inc.

This presentation will focus on curtain wall and storefront window systems and discuss proper installation of these systems while using examples of what not to do in the field. The presentation will also provide guidance and suggestions for what to watch for as these systems are being installed to ensure they perform as expected.

Sealants - A Sticky Situation

Marcy Tyler
Tremco Commercial Sealants & Waterproofing

With so many chemistries, applications, and choices, sealants continue to confuse many people about where to use what? This presentation goes over the main types and chemistries of various Sealants and provides some recommendations on where and how they should be installed.

8:30am - 12:00pm
Palm Room

Workshop 3: We Know about Insulation

Session Chair: **Marcin Pazera**, PIMA

Facing the Enemy of Insulation - Thermal Bridges

Jay H. Crandell. P.E.
ARES Consulting/ Applied Building Technology Group, LLC

Thermal bridges are typically associated with framing elements within a building envelope assembly. These are well-known and are commonly addressed by use of recognized methods to determine a U-factor for an assembly. However, thermal bridges created at various interfaces between building envelop assemblies are less known and more often ignored. These types of thermal bridges include junctures between floor edges and walls, roof edges and walls, and fenestration and walls. While largely ignored in current codes and practice, poor detailing practices that fail to minimize thermal bridging and maximize insulation continuity (while maintaining structural continuity) at these building assembly interfaces can account for as much as 20 to 70 percent increase in heat flow through a building envelope. Thus, poor detailing has several building design implications including increased energy loss, potential error in estimating heating and cooling loads used to size equipment, localized moisture and durability risks, and reduced occupant comfort. These implications work against the fundamental purpose of insulation. Based in part on on-going work within the ASHRAE 90.1 standard committee, this presentation confronts a variety of thermal bridges and their impacts with methods of mitigation through improved detailing.

Optimizing the Thermal Layer within Low-Slope Roof Systems

James R. Kirby. AIA
GAF

Low-slope roofing assemblies include a wide range of insulation and membrane attachment methods. Often ignored is the effect of fasteners on the overall R-value of the system. This presentation discusses R-value differences based on fastener location within the system. There are different initial costs associated with fastening the first layer of insulation and adhering the upper layers versus mechanical attachment of an entire system. Different installation methods also have different thermal performance which affect energy costs over the life of the roof. Multiple roof system attachment methods are analyzed for initial cost, R-value and cost of long-term energy use.

Providing Design Professionals Insight Into Improved Prediction and Optimization of Building Envelope Thermal Performance

Jerry Phelan
Covestro, LLC

The information presented in this report sets forth the author's thorough examination, compiled results and findings/conclusions of the research conducted with the objective of providing guidance to design professionals for improving accuracy – and enabling optimization - of building energy performance.

Advanced Insulations that Evolved from the Knudsen Effect

David W. Yarbrough. PhD. P.E.
R&D Services, Inc.

The pressure dependence of gas-phase thermal conductivity that occurs as pressure decreases or regions for molecular collisions are limited is described by the "Knudsen Effect (1911)". The high thermal resistance of advanced products such as vacuum panel insulation and nano-scale insulations is due in part to reduction in gas-phase molecular collisions due to vacuum conditions or limited space for these collisions to occur in, for example, fine powders. The Knudsen effect and resulting advanced insulation products is discussed.

Polyiso Continuous Insulation Wall Systems: The Perfect Wall

Diana Fisler
Johns Manville

The exterior wall surface delivers many functions to the building structure. These including water and air resistance, thermal insulation and structural strength. This presentation discusses how each of these functions are traditionally delivered, and explores how and why these functions can be combined into a high functioning "perfect" insulating wall.

8:30am - 12:00pm
Bay Room

Workshop 4: Evaluating the Moisture Durability of Building Envelope Components

Session Chair: **Andre O. Desjarlais**, Oak Ridge National Laboratory

Evaluating the Moisture Durability of Building Envelope Components

Andre Desjarlais[1], **Achilles Karagiozis**[2]
[1]Oak Ridge National Laboratory/ ABAA; [2]National Renewable Energy Laboratory

This workshop will introduce the attendees to hygrothermal simulations and briefly cover the parameters that impact hygrothermal simulation and how the software accounts for these loads.

1:00pm - 4:30pm **Beach Room**	**Workshop 5: Fun in the Lab**
	Air and Moisture Leakage Calculator **Andre Desjarlais, Som Schrestha** Oak Ridge National Laboratory (ORNL) The Air & Moisture Calculator allows any user to input simple numbers and details about their project like location, size, architype, and then compare the energy use and potential moisture in the walls of a typically poorly built, air leaky building to a code-compliant building or buildings with leakage rates below code. **ASTM E331 on Steroids: Ultimate Wall Assembly Test** **Andrew Dunlap** SmithGroup o Many have felt ASTM E331 has needed to be upgraded to deal with today's assemblies. This presentation will go over the ABAA Standard which is being prosed to ASTM to improve upon wall assembly testing. **Technical News from ABAA** **Andrea Wagner Watts, John Posencker** Air Barrier Association of America (ABAA) ABAA's Technical Committee Chairs will provide insight to what ABAA is doing within industry and review a few of their latest Technical Documents focusing on the Building Enclosure. **Pull Adhesion Test Method** **Sarah Flock** Raths, Raths & Johnson, Inc. The pull adhesion test method has recently been updated by ABAA and ASTM. This presentation will review what the current method entails and provide insight as to why it was in need of these changes. **Potential Inaccuracies in Air Leakage Modeling** **Som Shrestha[1], Andre Desjarlais[1], Lisa Ng[2]** [1]Oak Ridge National Laboratory; [2]NIST This presentation will go over some of the concerns and issues with air leakage modeling in today's software.
1:00pm - 4:30pm **Gulf Room**	**Workshop 6: Don't Screw Up: There Is a Better Process**
	Building Enclosure Commissioning - Where it Came From and Why it is Needed **Fiona Aldous** Wiss, Janney, Elstner Associates, Inc. (WJE) Building Enclosure Commissioning (BECx) is one of the hottest buzz words in the enclosure industry. This presentation goes through the history and development of the process and provides reasons for why it is needed in our industry. **BECx Process in Action - The Process through Case Studies** **Melissa Payne** Tremco Commercial Sealants & Waterproofing This presentation will provide the audience a chance to witness the BECx process from start to finish using actual projects as examples to demonstrate this key process in our industry. **Codes and Standards: Today's Requirements for Tomorrow's Buildings** **Chris Mathis** Mathis Consulting Company With building enclosures becoming more complex and owners wanting durable, energy efficient buildings, our codes and standards must continue to develop and provide guidance for construction teams to be able to meet these demands. This presentation will look to the past and future of various building codes and standards regarding the building enclosure engaging you to think about what is needed for our buildings in the future.
1:00pm - 4:30pm **Palm Room**	**Workshop 7: Energy Efficient Buildings: Economy vs. Ecology** Session Chair: **Andreas Holm**
	Return of Investment (ROI) Calculations **Prof. Dr. Ing Andreas Holm** FIW Munchen Assessments of the economic viability of various measurements, given by industry, housing sector, owners but also by science, show significant differences. Besides climatic, building physics, geometrical and economic parameters, the results are also being influenced by the particular calculation method. Depending on the calculation approach, different statements concerning the amortization of energy-saving methods will be reached. This leads to a fierce public discussion.

Aspects of Embodied Energy

Prof. Dr. Ing Andreas Holm

FIW Munchen

Energy used to produce the building materials, the construction of the building and finally any disposal required are not yet included in the energy calculations. But at the same time the use of sustainable building and insulation materials is promoted by the governments. This part of the workshop sets out to compare the parameters of various external wall constructions and then also considers the extra consumption of primary energy which arises due to more stringent requirements for the energy efficiency of the building envelope.

1:00pm - 4:30pm

Bay Room

Workshop 8: DOE Building Envelope Research Projects on Fenestration and Grid Interaction

Session Chair: **Shailendra S**, Saint-Gobain Research India

The ARPA-E SHIELD Program: A Window into the Future of Novel Materials for Thermal Management

Marina Sofos

U.S. Department of Energy

The Advanced Research Projects Agency-Energy (ARPA-E) launched the SHIELD (Single-pane, Highly Insulating Efficient Lucid Designs) program in 2016 with the goal of dramatically improving the thermal properties of single-pane windows that account for roughly 2 quads of cold weather energy losses in the U.S. The vision for SHIELD is to go beyond conventional multi-pane insulated glass unit (IGU) approaches for energy efficient windows by developing solutions that are directly installed in retrofit projects to existing frames and sashes while minimizing impact on the appearance of the window and not adding substantial weight to the pane itself.

As such, the program has focused on addressing the challenge of developing novel materials and material combinations that go beyond current state-of-the-art super-insulating solid materials to meet thermal targets comparable to double-pane solutions, while also yielding optical metrics necessary to meet transparency requirements for window applications in both commercial and residential buildings. A variety of thermal barriers have been developed and explored, including both porous (e.g., aerogel) and non-porous materials. Product solutions have consisted of both films that can adhere directly to existing window panes along with manufactured panes with similar weight and thickness to current panes and that can be mounted into existing window sashes. Partial solutions that can enable either approach have also been investigated.

This session will include an overview of the program, including key findings and takeaways at a portfolio-level. Members of the SHIELD cohort will then highlight the teams' technologies and discuss next steps towards commercialization. Finally, industry stakeholders will discuss opportunities for next steps to transition meaningful advances towards commercially viable products into the single pane window retrofit and new/replacement window markets.

Grid-Interactive Efficient Buildings R&D Opportunities

Chioke Harris

National Renewable Energy Laboratory

Additionally, the DOE Building Technologies Office Windows and Opaque Envelope subprogram has been exploring technology challenges and gaps as part of the development of its Grid-interactive Efficient Buildings (GEB) and R&D Opportunity (RDO) reports. BTO will present a broader view of the R&D frontiers that can target these challenges and gaps in the windows and opaque envelope technology space, based on the GEB and RDO reports.

5:00pm - 6:30pm

Pool Grass

Sunday Social Event: Welcome Reception

Date: Monday, December 9, 2019

7:30am - 8:30am

Beach/Gulf Room

Breakfast

8:30am - 10:00am

Beach/Gulf Room

Keynote: Keynote Speakers, Lew Harriman and Hartwig Künzel

Metrics That Matter: A Modest Proposal for Improving Building Research Structure and Funding

Lew Harriman

Mason-Grant Consulting, United States of America

If building industry decision makers don't have key research results—in a form that is actionable—at their moments of decision, how can we justify the societal and financial costs of gaining that knowledge? The current political discourse provides evidence of contempt for scientific facts and methods on the part of a large percentage of university-educated decision makers. This must serve as a wakeup call for all who give a large portion of their lives to research and field investigations intended to make buildings better. If what we do does not really matter—and if it is not also understood to matter by the public and by decision makers—we won't be doing it much longer. We need to refocus our attention. History shows that effective information presentation and distribution is just as important as the research results. Based on examples of effective versus ineffective information transfer, this talk proposes radical suggestions for better project structure and funding allocation for building research.

Durable, Energy Efficient and Comfortable Buildings are No Science Fiction!

Hartwig Künzel

Fraunhofer IBP, Germany

The construction sector could do more to reduce our carbon footprint and to save our natural resources. This means saving energy for building operation and addressing the CO2-emissions released during manufacturing, construction, remodeling and demolition. Enhancing durability and focusing on renewable resources have become further key issues. Preserving and maintaining building constructions is a continuous fight against moisture. Water impairs the thermal performance of building materials and may cause mold growth, damage and degradation. High indoor air humidity is uncomfortable and poses health risks. Therefore, water penetration, condensation and unfavourable humidity conditions in the building and its envelope have to be limited or prevented altogether. Appropriate heat, air and moisture control should not only govern the envelope design and installation process, it should also be guidance for maintenance, repair and retrofit measures.

Climate change poses new challenges for our buildings. They should be resilient to natural disaster such as flooding, power outage, strong winds and heavy rain or snowfall. They should also be grid interactive and accommodate renewable power fluctuations as well as intermittent operation. The necessary preference for renewable or recycled building materials poses additional challenges due to their general moisture sensitivity. Assessing the dynamic hygrothermal behaviour of buildings and construction assemblies as function of different impact parameters may be a way to demonstrate the risks involved and to find adequate solutions for optimum building design and operation.

10:00am - 10:30am **Break**

10:30am - 12:00pm **Session 1: Impact of Changing Climate**

Bay Room

Session Chair: **Chris Mathis**, MC2 Mathis Consulting Company

Assessing Building Envelope Performance and Resiliency with Forcing Climate Projections (BLDG-19-001)

Thomas Zakrzewski, Kyleen Rockwell

HKS, Inc.

Anthropogenic influenced climate-warming trends over the past century directly related to greenhouse gases emissions lacks any consensus on adaptation strategies and solutions. The emissions associated with the built-environment, amounting to more that 39% of the total emissions in the United States, continue to rise with a “business as usual” design mentality with no regard to the consequences. Increasing concentrations of greenhouse gas emissions will continue to influence the warming of the Earth’s atmosphere and consequently, climate change adaptation strategies will become even more decisive in the overall design resiliency of a building. This climate change impetus requires that building energy codes adopt more stringent performance-based requirements to ensure that emissions associated with the built-environment are restrained and stabilized over time despite any uncertainty. Thus, this endeavor seeks to isolate and evaluate the performance and resiliency of the building enclosure with various forcing climate projections and normalized weather files. The predicted envelope performance factor (EPF), a Building Envelope Trade-off Option procedure which only considers building envelope components per Normative Appendix C, ANSI/ASHRAE/IES Standard 90.1, is first utilized to appraise prescriptive building envelope requirements, resulting EPF, for current and prior versions of Standard 90.1 (2004 thru 2016) specifically for ASHRAE Climate Zone 5A in response to normalized historical weather patterns using an industry standard reference EnergyPlus Weather (EPW) weather file. Secondly, the EPW file is “shifted” for 2026-2045, 2056-2075, 2080-2099 future years at RCP4.5 and RCP8.5 emission scenarios at 5% and 95% warming percentiles to determine equivalent EPF to stabilize emissions for a ANSI/ASHRAE/IES Standard 90.1-2016 compliant reference commercial prototype building model. Specific to the distribution climate model projections and emissions scenario considered, the experimental simulated results indicate targeted envelope performance factors that can be used as performance metrics earlier in the integrated design processes to reinforce or plan for building resiliency.

Building Energy Demand Under Future Design Condition: A Case of Philadelphia Office Buildings (BLDG-19-002)

Hamed Yassaghi, Simi Hoque

Drexel University, Philadelphia, PA 19104, United States of America

Assessing the impact of climate change on the building sector has many challenges and has gained attention among scholars and designers in recent years. To quantify the effect of climate on the building energy demand and to adequately size the HVAC equipment, the use of design condition (design day) is necessary. The current design day files available for the United States are updated to 2013 and few descriptions regarding the use of future scenarios for design day files are available. In this article, future design day files are developed using weather generators applying the IPCC emissions scenarios. Challenges associated with building current and future design day files and their discrepancies are identified, and a process for addressing the uncertainties is described. The future design day files are implemented into a practice study of DOE large office buildings in Philadelphia to assess the impact of the changing climate on the energy consumption and equipment sizing. The results are compared with outcomes obtained using the ASHRAE 2013 climatic design conditions as the base. Buildings in the city of Philadelphia, on average, are more than 60 years old and most were built before standard building regulations existed and are highly vulnerable to the changing climate. Using the most conservative design day strategy, for cooling purposes, the results show up to 25% increase, with a confidence level of 0.05, in the nominal capacity of the chiller for the A2 (most extreme emissions) scenario by the end of the century. This study aims to guide the development of design day files for future climate scenarios allowing Architects and Engineers to promote improved mitigation strategies towards climate change for building energy demand.

Effect of Climate Change on the Energy Performance and Thermal Conditions of a Single-Family Detached House in Canada (BLDG-19-003)

Fuad Mutasim Baba, Hua Ge

Concordia University, Canada

The Earth is already experiencing some of the effects of climate change, such as rising temperature, more frequent storms, increased precipitation, etc. British Columbia (BC), Canada has recently introduced the Energy Step Code for voluntary use as a measure to guide the industry to achieve consistent energy efficiency improvement from current building code to net-zero energy ready buildings by 2032. These measures will significantly reduce the energy consumption of buildings. However, with climate change, how these energy-saving buildings can perform under future weather data rather than historical weather data. This paper attempts to answer this question by investigating the effect of climate change on the energy consumption of a single-family house with different energy efficiency levels, i.e. bylaw to meet current National Energy Code of Canada for Buildings (NECB), and passive house (PH) to meet the PH requirements. Four climate zones in BC are simulated, i.e. zone 4 (Vancouver); zone 5 (Kamloops); zone 6 (Prince George); and zone 7 (Fort Nelson). SRES A2, RCP 4.5 and RCP 8.5 emission scenarios are used to generate future climate for 2020, 2050, and 2080. The simulation results show that for both bylaw and PH cases, heating energy consumption will be reduced 35-50% while cooling energy consumption will be increased. For bylaw case, the energy consumption will be decreased for four climate zones, while for PH case, the energy consumption will be increased for zone 4 & 5 and decreased for zone 6 & 7. In climate zone 5, the building fails to meet the PH requirements during 2050. Therefore, buildings designed based on historical weather data will perform differently under the changing future climates, thus the efforts should be made to design buildings that are adaptable to climate change.

10:30am - 12:00pm
Palm Room

Session 2: Design Tools

Session Chair: **Wahid Maref**, Ecole de Technologie Supérieure Montreal (University of Quebec)

NIST Infiltration Tools for Commercial Buildings (BLDG-19-004)

Lisa C. Ng[1], Som Shrestha[2], Brian Polidoro[1], W. Stuart Dols[1], Steven J. Emmerich[1]
[1]National Institute of Standards and Technology, United States of America; [2]Oak Ridge National Laboratory, United States of America

The Department of Energy estimates that infiltration through building envelopes accounted for 6 % of the total energy consumed by commercial buildings and 21 % of the heating and cooling energy. Air barrier requirements are now being included in ASHRAE Standards 90.1 and 189.1 and other construction requirements. The energy impacts of unintended infiltration on building energy use can be significant, but current energy simulation software and design methods are generally not able to accurately account for envelope infiltration and the impacts of improved airtightness. NIST has been developing tools to better account for infiltration in building energy models. The tools that will be discussed in this paper include: CONTAM Results Export Tool; weather-correlated infiltration inputs for prototype commercial buildings and the associated Open Studio Measures; and a web-based tool to evaluate the energy savings of building envelope airtightening, which was developed with the Oak Ridge National Laboratory and the Air Barrier Association of America. This paper briefly describes each tool, their applications, and the benefits of using each. All of the tools are publicly available at no cost.

Moisture Transfer in Commercial Buildings due to the Air Leakage: A New Feature in the Online Airtightness Savings Calculator (BLDG-19-005)

Som S Shrestha[1], Andre Desjarlais[1], Laverne Dalgleish[2], Lisa Ng[3], Diana Hun[1], Steven Emmerich[3], Gina Accawi[1]
[1]Oak Ridge National Laboratory; [2]Air Barrier Association of America; [3]National Institute of Standards and Technology

Air leakage through the building envelope is responsible for a larger amount of energy use. The DOE Windows and Building Envelope Research and Development Roadmap for Emerging Technologies states that in 2010 infiltration was responsible for 20% of primary energy consumption attributable to fenestration and building envelope components of commercial buildings. Despite this fact, improving airtightness is not always recognized by owners of commercial buildings, as they have been slow in acknowledging and diminishing the detrimental effects of air leakage on energy use.

The construction industry needs a credible, easy-to-use tool that estimates potential energy and financial savings in a standardized manner, so designers and contractors can give building owners compelling reasons to invest in reducing air leakage. In 2016-17, Oak Ridge National Laboratory, the National Institute of Standards and Technology, the Air Barrier Association of America, and the US-China Clean Energy Research Center for Building Energy Efficiency collaborated to develop an online calculator that is free to the public, user-friendly, and uses the simulation results of the best-in-class building energy simulation tool EnergyPlus and the whole building airflow simulation tool CONTAM. In 2018, the calculator was expanded to add moisture transfer calculations because air leakage through the building envelope can have a significant impact on the amount of moisture transfer. In addition, four more commercial building types were added to the existing database of three building types. This paper describes the procedure used to calculate moisture transfer due to air leakage and provides examples that demonstrate the energy impact and moisture transfer for each of the seven commercial building types that are currently part of the calculator.

The Building Science Advisor: Providing Expert Advice on Building Envelope Systems (BLDG-19-006)

Philip Boudreaux[1], Simon Pallin[1], Antretter Florian[1], Gina Accawi[1], Andre Desjarlais[1], Eric Werling[2]
[1]ORNL, United States of America; [2]U.S. Department of Energy

The overall performance of an envelope component such as a wall or roof is difficult to predict. Thermal and moisture performance depend on the combination of materials used in the structure, thermal bridges, individual materials, construction workmanship, climate, orientation, air tightness, and indoor conditions. Modern building codes are requiring more insulation and tighter construction to enable energy efficient buildings but provide little guidance about how to ensure these assemblies remain moisture durable. Furthermore, as new products and materials are introduced, builders are increasingly uncertain about the long-term durability of their building envelope designs.

The Building Science Advisor (BSA) is a rule-based expert system webtool that is free for anyone to use and guides the user in selecting energy efficient and moisture durable wall designs tailored for their specific climate. The current state of the tool required the combination of expert opinion and hygrothermal simulations and a clever grouping of building materials into different material property categories to build a concise rule-based database. We will present how this was accomplished and different use cases of the tool. Then we will outline new features that will be added to the BSA such as adding probabilistic hygrothermal simulation results for walls that experts have little experience with and the expansion of the tool to include retrofit capabilities.

12:00pm - 1:30pm **Lunch**

Rusty's

1:30pm - 3:00pm **Session 3: Advanced Building Envelope Materials**

Beach/Gulf Room Session Chair: **Diana Fisler**, Consultant

An Innovative Low-Cost Aerogel Blanket for Thermal Bridge Correction (BLDG-19-007)

Umberto Berardi, Rashmi Sharma
Ryerson University, Canada

Aerogel-enhanced products are often indicated as promising materials for increasing the thermal resistance of the building envelope. However, their high cost, typically related to the critical conditions needed for the synthesis of the aerogels, is often limiting their diffusion. This paper aims to present a new low-cost aerogel-enhanced blanket manufactured at Ryerson University using ambient pressure drying conditions in an effort to lower the cost of these products and to investigate possible applications of these products for the corrections of thermal bridges. In aerogel-enhanced blankets, fiber matrix bonds together the aerogel structure, compensating the low mechanical properties of the aerogels without reducing their exceptionally low thermal conductivity. Thermal characterization tests confirm the superior performance of aerogel-enhanced blankets, which show thermal conductivity values below 0.016 W/mK. Then, the utility of aerogel-enhanced blankets for correcting typical thermal bridges is assessed through simulations in twelve typical construction nodes, six concrete and six steel constructions. For the scope of thermal bridge correction, the inclusion of 10 mm and 20 mm thick aerogel-enhanced blankets were modeled in 2D and 3D. Among the investigated nodes, results show that the wall to balcony connection in concrete structures could have the greatest improvement in linear thermal transmittance (88% lower) if the thermal bridge is corrected with thin aerogel-enhanced blankets.

Review of Models to Evaluate and Guide the Development of Low Thermal-Conductivity Materials (BLDG-19-008)

Som S Shrestha[1], Amit Rai[1], Tianli Feng[2], Mingkan Zhang[1], Diana Hun[1], Kaushik Biswas[1], Andre Desjarlais[1]
[1]Oak Ridge National Laboratory; [2]Vanderbilt University

Developing insulation materials with low–thermal conductivity values is appealing for building envelope retrofits and new construction. Therefore, it is a priority research area for the US Department of Energy Building Technologies Office (BTO). Multiple institutions are exploring various methods to develop new insulation materials with a thermal resistivity ≥97 m·K/W (14 h·ft2·°F/Btu/inch). Current materials that provide such high thermal resistivity use micro- or nanoporous structures, as well as low–thermal conductivity gases and reduced pressure. Efforts to develop these new materials would benefit greatly from a tool that can numerically evaluate various options to optimize material design and achieve the desired thermal resistivity. The available models do not capture all modes of heat transfer through the complex structures required to achieve very high thermal resistivity. This paper presents a literature review of the existing models that have been used in the study of heat transfer mechanisms of insulation materials such as aerogels, foams, and fibrous materials. The review shows most of the models make some assumptions to simplify the analysis. Further, such models have not included important factors, such as the size effect and the interfacial effect, which could significantly affect heat transfer through insulation materials. Moreover, there is a lack of a database for the thermal accommodation coefficients of various insulation materials that are used to calculate gaseous thermal conductivity. In addition, this paper presents details regarding the development of new models. The new models will capture various factors that have been neglected in existing models (such as nanoscale heat transfer, interfacial thermal resistance). They will allow parametric studies that identify optimum design options for insulation materials and thus accelerate the achievement of BTO's goal of developing insulation technologies with thermal resistivity greater than ≥97 m·K/W (14 h·ft2·°F/Btu/inch).

Advanced Materials for Energy Efficient Building Envelopes: Performance, Limits and Opportunities (BLDG-19-009)

Stefano Fantucci, Valentina Serra, Marco Perino
Politecnico di Torino

In EU almost 40% of the final energy use is consumed by the building sector. For this reason, pushing towards high energy performing buildings can be one of the best solutions to address the next targets of 40% reduction of the emissions until 2030 (Paris agreement).

The increasing demand for very high new energy efficient buildings and the deep energy retrofit interventions on the existing building stock has determined a growing interest in advanced materials for the building envelopes. These materials (i.e. Super Insulating Materials, Advanced Thermal Plasters, Phase Change Materials, Low Emittance Materials and high reflective coatings) are characterised by very high thermal performance even if applied in thin layers. This feature makes them attractive since they seem to be particularly suitable for all the cases in which, for several reasons, usual insulation techniques cannot be easily applied, i.e. (space saving, critical nodes, technological and historical compatibility etc.)

Unfortunately, the building sector is a conservative market, and as a consequence, despite the great potentials of advanced materials, they are still poorly adopted, because of the high costs, the short durability (concerning the building lifetime) and the lack of knowledge about their actual thermal behaviour.

The presented study aims to analyse some of the barriers that limit the use of these materials in buildings and provide indications related to methodologies, tools, and guidelines for the correct design and the assessment of the thermal performance of building envelope components making use of advanced materials.

1:30pm - 3:00pm
Palm Room

Session 4: IEQ and Thermal Comfort

Session Chair: **Florian Antretter**, Fraunhofer Institute for Building Physics

Determining the Value of Occupant Comfort from Highly Insulating Windows (BLDG-19-010)

Robert Hart, Charlie Curcija, Stephen Selkowitz
Lawrence Berkeley National Lab, United States of America

Windows are known to be the weakest link in most thermal envelopes and are responsible for about 5 Quads, or approximately 10%, of building energy use in the US. Windows, therefore, offer a significant opportunity for building energy savings. Sales of high performance windows, such as triple glazing, though have comprised less than 2% of all US window sales for the last 20 years. The two most cited reasons for this slow market adoption are high initial cost and impractical returns on investment through energy savings. But these common metrics ignore some of the most valuable characteristics of highly insulating windows to consumers, such as reduced capital cost for HVAC equipment, load stability, and occupant comfort. In this paper, several metrics for occupant comfort concerning windows are presented and their sensitivity to window thermal performance is analyzed. The value of occupant comfort is then quantified through the HVAC energy savings and the usable floor space adjacent to the windows to help redefine the return on investment metric.

Occupant Perceptions of Thermal Comfort in Contemporary Condominium Buildings (BLDG-19-011)

Helen Stopps, Marianne F Touchie
University of Toronto, Canada

Thermal comfort significantly influences occupants' perception of the indoor environmental quality of their homes and can impact occupant health. Previous studies in North American high-rise post-war multi-family (MF) residential buildings have shown a high prevalence of thermal discomfort amongst occupants during both the summer and winter periods. However, despite the recent boom in high-rise condominium building construction, little is known about occupant thermal comfort in contemporary MF buildings. In this study, the occupants of 57 suites in two recently constructed high-rise condominium buildings, located in Toronto, Canada, were surveyed regarding their perception of the thermal comfort in their suites. Over half of all participants reported discomfort in one or more rooms of their suites in both the summer and winter months despite the presence of in-suite HVAC controls in all studied suites. Suite layout, floor number, orientation and HVAC sizing appear to influence occupant thermal comfort in the studied suites, indicating the importance of their consideration in future MF building design.

Your Psychrometric Chart Might Be Fake News: Comparing the Impact of the Exterior Envelope on Thermal Comfort Perceptions in Open-Plan Offices Before and After Retrofit to High Performance Buildings Standards (BLDG-19-012)

Ihab Elzeyadi[1], Stanley Gatland II[2]
[1]University of Oregon, United States of America; [2]CertainTeed Corporation, United States of America

An increasing marketing campaign by the green building industry and particularly the Leadership in Energy and Environmental Design (LEED™) certification system promotes linkages between LEED™ certified, high-performance buildings, and better indoor environmental quality (IEQ). Despite the favorability of this hypothesis, few studies have empirically proven the linkages between LEED™ certified green buildings envelope design and their impact on occupant's thermal comfort perceptions. This paper reports on an investigation of the relationship between better building envelopes design and thermal comfort performance with respect to occupant perceptions of a longitudinal study comparing a pre/post-occupancy move of 800 office employees from a traditional (Valley Forge, PA) to a LEED™ (Malvern, PA) platinum certified building. The specific question posed is whether moving from a traditional to a LEED™ certified green building have positive impacts on occupant perceptions of indoor thermal comfort? And if proven, what attributes of the LEED™ building have a positive effect on both physical and psychological perception of better thermal comfort and indoor environmental quality?

Continuous and intermittent measurements were performed and pre- /post-occupancy evaluation surveys were conducted. Results show strong correlations between improved visual, acoustical, and indoor air qualities of the retrofitted green environment that is well correlated with improved employee's productivity and satisfaction. A Perceptions of the thermal environment, however, varied between those positive and negative responses leading to little or no improvement. A detailed commissioning and measurements using a triangulation of research procedures were further employed to understand thermal shortcomings of the HVAC system and additional retrofits, as well as occupant's behavior, are recommended. Proving that, for high-performance buildings, both the occupants and the buildings require on-going dialogue to ensure the occupants are able to adjust to the building systems and achieve its desired levels of performance.

1:30pm - 3:00pm **Bay Room**	**Session 5: Whole Building Performance** Session Chair: **Cheryn Metzger**, Pacific Northwest National Laboratory
	Using Environmental Whole Building Life Cycle Assessment and Energy Modeling to Compare Lifetime Building Environmental Impacts (BLDG-19-013) **David Bliss, Mark Webster, Jennifer Williamson** Simpson Gumpertz & Heger, United States of America Increasingly, owners and design teams want to understand how their building choices will affect the environment. Environmental Life-cycle assessment (LCA) is a powerful, emerging tool for evaluating the environmental impacts of existing and new buildings – in particular, the embodied impacts of building materials. Building energy modeling (BEM) can help predict the energy consumption of buildings, but it is rarely combined with LCA to predict the overall environmental impacts of both building materials and energy consumption. Our study developed a methodology for comparing the environmental impacts of several design options. We then used the methodology to study a building retrofit project, modeling the following four cases to better understand the interaction between energy upgrades and lifecycle assessment: 1) an existing, 90-year-old building, 2) a code-compliant (standard energy) retrofit, 3) an advanced-performance (deep energy) retrofit, and 4) a new, high-performance building targeting net-zero energy use. For each case, we calculated the environmental impacts, including global warming potential and smog creation potential, for materials comprising the primary envelope and HVAC components. We also calculated the building's annual energy use and used that to calculate the associated environmental impacts. Finally, we combined the environmental impacts associated with the building's materials and a simplified annual energy use calculation. We compared the impacts for each case over a 75-year duration. We also evaluated global warming potential over a 20-year timeframe, due to the urgency to reduce greenhouse gas emissions in the near term. This study demonstrates a methodology for comparing the environmental impacts – both embodied and operational – of different building scenarios in combination, rather than separately. This will allow building designers and owners to make more informed decisions regarding environmental outcomes inherent in multiple design scenarios matching the energy and environmental goals of their organizations. **Assessing Resiliency and Passive Survivability in Multifamily Buildings (BLDG-19-014)** **Lisa White, Graham Wright** Passive House Institute US Resilient building design is becoming increasingly important as occurrence and duration of extreme weather events increase. These events cause disruptions in building operation and safety due to lack of electric power or fuel. Several resilient design strategies are known, many of which are also sustainable or energy saving design strategies. Specifically, passive building strategies that favor energy conservation in buildings also have a positive impact on the building's resilience. Passive survivability is a key element to resilience, which can be assessed using modeling software to simulate interior conditions during power outages. This can help inform building design to plan for a more resilient future. This presentation will address passive survivability metrics and assessment protocol for passive survivability including a proposed methodology to derive climatic resilience design weeks (similar to ASHRAE design conditions). It will discuss results of dynamic simulation completed in WUFIplus assessing passive survivability during power outages in varying multifamily building designs, and inform the audience on how building design influences its ability to maintain desirable interior conditions during outages. **Variables Influenced by Thermal Mass and its Impact on Energy Performance in Buildings (BLDG-19-015)** **Simon Pallin[1], Tyler Pilet[2], Renata Starostka[3]** [1]ORNL, United States of America; [2]Georgia Tech, United States of America; [3]Duke University, United States of America There is no question that thermal mass has an impact on the energy performance of buildings, both the peak energy demand and overall consumption. However, there are many variables that will contribute to and influence the impact of mass on energy performance. This paper is a result of an analytic study that evaluated thermal mass and associated building envelope energy performance for commercial and residential prototype buildings. Relationships between thermal mass, insulation levels, internal gains, outdoor climate, building usage and user preferences were studied. In this paper, authors analyze how these variables interact and investigate optimized conditions for utilization of thermal mass. It is also discussed how air conditioning operation, exterior and interior loads, and thermostat set points impact the usefulness of thermal mass in a building to favorably impact peak demand and energy savings. Existing methods and approaches to evaluate the impact of thermal mass are discussed and a preferred design approach is presented to estimate the impact of thermal mass on energy peak demand and overall energy consumption under both heating and cooling conditions.
3:00pm - 3:30pm	**Break**
3:30pm - 5:30pm	

Beach/Gulf Room

Session 6: Material Properties

Session Chair: **Diana Hun**, Oak Ridge National Laboratory

New Insights on Moisture Transport in Wood (BLDG-19-016)

Dominique Derome[1], Chi Zhang[2,5], Mingyang Chen[2,5], Benoit Coasne[3], Sinan Keten[4], Jan Carmeliet[2]

[1]Université de Sherbrooke; [2]ETH Zurich, Switzerland; [3]Laboratoire Interdisciplinaire de Physique (LIPhy) CNRS and University Grenoble Alpes, France; [4]Northwestern University, USA; [5]Empa, Switzerland

Wood is a well-used building material, for building structure, façade, windows, etc., where the capacity of wood to absorb water is not only an issue of dimensional stability and modified material properties, but also of durability. As water molecules are adsorbed into the hydrophilic matrix in the cell walls, the induced fluid-solid interaction forces result in swelling of these cell walls. The interaction of the composite polymeric material, that is the layer S2 of wood cell wall, with water is known to rearrange its internal structure, make it moisture sensitive and influence its physical properties.

As the origin of moisture-induced processes is found at the S2 cell wall layer, we study the coupled effects of water sorption on hygric and mechanical properties of different polymeric components. Our aim is to understand all the ramifications of this intricate nanocomposite, with the specific aim of upscaling the results to cellular and macroscopic scales. In order to study the behavior of S2 layer, we analyse the different configurations of cellulose microfibril aggregates and S2 matrix using Molecular Dynamics (MD) simulations. These atomistic simulations are used to mimic water adsorption and desorption in amorphous cellulose, make observations on hysteresis and relate the hygromechanical behavior as observed from the breaking and reforming of hydrogen bonds.

We upscale the observations using a poromechanical constitutive model. Further, upscaling to cellular scale is informed through accurate geometrical description using X-ray CT at different relative humidity. The ensemble of results documents the full co-occurrence of sorption and swelling. It shows swelling is reduced by the multilayer wall composition and the cellular structure of wood. This modeling methodology provides new insights in understanding wood material properties and behavior which cannot be directly determined from experiments and allows to explore new pathways for material development and durability improvement of wooden components.

Trends and Anomalies in Hygrothermal Material Properties from the ASHRAE 1696 Research Program (BLDG-19-017)

C. J. Schumacher[1], Claire Lepine[1], Kevin Zhang[2]

[1]RDH Building Science Inc., Waterloo ON Canada; [2]Ryerson University, Toronto ON Canada

Budget and time constraints preclude the determination of specific material properties for most energy and hygrothermal simulation and modeling tasks. Practitioners rely heavily on material property data included in computer program databases and/or from published resources such as Chapter 26 of the ASHRAE Handbook of Fundamentals (HOF), which has long been one of the best industry resources for thermal and moisture properties of insulations and building materials.

This paper presents an overview of the ASRHAE 1696 Research Project, “Thermal, Moisture and Air Transport Property Values for New Building and Insulating Materials.” Subject materials (15 new and 9 updated) are addressed; test methods for 10 hygrothermal material properties are summarized; and finally, trends and anomalies are highlighted.

Characteristics of Chloride and Sulfate Based Magnesium Oxide Boards (BLDG-19-018)

Stefanie Wøhler Nielsen[1], Tommy Bunch-Nielsen[2], Kurt Kielsgaard Hansen[1], Wofgang Kunther[1], Bent Grelk[1], Carsten Rode[1]

[1]Technical University of Denmark, Denmark; [2]Bunch Bygningsfysik

Sheathing boards based on magnesium oxide (MgO) have been widely used in the Danish market during the years 2010-2015. However, it was realized that they have a strong affinity to absorb humidity from ambient air, which easily leads to dripping of corrosive salt water from the boards, moisture uptake in adjacent structural members and degradation of the boards themselves. Such boards have now been banned from use in the Danish market, while damage cases valuing around 300 million USD need to be reconciled.

In the boards that were most often seen in the market, the binder was formed by chemical reaction between MgO and MgCl2. However, MgSO4 is an alternative offered by some manufacturers, and such boards may have such smaller moisture uptake that damages can be avoided.

This paper gives an account of recent attempts to determine some characteristics of MgO boards, which are based either on chloride or sulfate. The investigations comprise:

- Optical examination in microscope of thin sections for structure and composition.

- Analysis of atomic composition and distribution in Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDX).

- Identification of elemental composition with X-ray Fluorescence (XRF) and Energy Dispersive X-ray (EDX).

- Identification of crystalline components with powder X-ray Diffraction (XRD).

- Qualitative and quantitative methods for use in the field to determine the chloride content.

- Determination of moisture retention, including time evolution of moisture uptake and eventual sorption curve.

- Determination of water vapour permeability.

- Analysis of chemical composition of ions of leaked salty water with Inductively Coupled Plasma Optical Emission Spectrometry (ICP) and Ion Chromatograph (IC).

- Determination of dry mass loss and visual observation of decomposition after exposure to high humidity

- Corrosion test on zinc sheets, which are brought in contact with powder of MgO board.

Hygric Evaluation of Cement Plaster Wall Claddings in a California Coastal Climate (BLDG-19-019)

Justin deWolfe, **Caroline Klatman**
Simpson Gumpertz & Heger, Inc., United States of America

Portland cement plaster, or stucco, is a timeless cladding, yet industry changes are making it increasingly difficult for designers to specify. Three-coat stucco, lath, and two layers of building paper have been specified for exterior building walls in climates like coastal California for years — and still are today. However, the process for analyzing stucco walls is more complicated due to building code changes related to insulation requirements and the availability of multiple water-resistive barrier types. Designers often use WUFI 6.2 (WUFI; by the Fraunhofer Institute for Building Physics) modeling software to analyze the heat and moisture migration (i.e. hygrothermal) through building assemblies over time. This type of computer analysis can raise new questions and challenges.

WUFI provides a built-in material database that includes a stucco material, called “Regular Portland Stucco”. We have found modeling can calculate unreasonably high moisture contents in exterior wall building components when located in a California mixed climate with “Regular Portland Stucco” cladding and a vapor-permeable water-resistive barrier. This condition can overwhelm the exterior wall cavity with the excess moisture diffusion from the stucco, which fails the wall. The hygrothermal analysis results conflict with our experience that these wall assemblies perform well in this climate.

Based on these results, we set out to validate WUFI’s Regular Portland Stucco hygric material properties. We did this by performing laboratory testing on a large sample of common proprietary stucco mixes and configurations and comparing the lab-tested hygric properties with the properties for “Regular Portland Stucco” in WUFI. Our laboratory testing also takes a unique look at the hygric performance of several typical stucco finish coats.

This presentation provides design strategies, through case studies and model simulation, to help reduce high exterior wall moisture and provides guidance on how to approach a hygrothermal analysis of a stucco wall system.

3:30pm - 5:30pm
Palm Room

Session 7: Emerging Systems and Energy Performance

Session Chair: **Umberto Berardi**, Ryerson University

Installation Demonstration and Performance Evaluation of Composite Foam-Vacuum Insulation Boards in an Occupied Building (BLDG-19-020)

Kaushik Biswas[1], **Andre Desjarlais**[1], **Anthony Gehl**[1], **Jerald Atchley**[1], **John Letts**[2], **Jennifer Yao**[2], **Mike Hubbard**[2], **Russell Glowner**[2], **Douglas Smith**[3]
[1]Oak Ridge National Laboratory, United States of America; [2]Firestone Building Products Company; [3]NanoPore Incorporated

This article summarizes the installation demonstration of R25 composite insulation boards containing polyisocyanurate (polyiso) foam-encapsulated modified atmosphere insulation (MAI) panels. The R25 boards can achieve a thermal resistance of 25 hr-ft2-°F/Btu within 2 inches of thickness (or R12/inch). MAI represents a lower-cost version of vacuum insulation panels (VIPs), due to a simpler processing method. The R25 composite boards were developed by the project team of Firestone, NanoPore and ORNL, and their thermal performance has been verified via laboratory testing and previously reported.

This article focuses on the installation of the R25 boards on the roof of an occupied building by professional contractors. The roof originally contained a gravel built up roof (BUR) over foam insulation, wood fiber board and steel deck. An approximately 5000 square foot portion of the roof was replaced and retrofitted. The 5000 square foot section was further divided into four smaller sections containing different insulations with different attachment methods: (i) mechanically-attached 2 inch R25 composite boards, (ii) foam-attached (i.e. using adhesive) R25 composite board, (iii) mechanically-attached two layers of 2 inch regular polyiso boards, and (iv) foam-attached two layers of 2 inch regular polyiso boards. The latter two sections with two layers of polyiso boards served as baseline, with a similar R-value (R24 hr-ft2-°F/Btu) as the R25 composite boards. The article summarizes the installation details as well as feedback from the contractors and manufacturers. Further, temperature and heat flow sensors were installed in the different retrofitted sections to monitor the long-term performance of the R25 and polyiso sections. Preliminary data analysis suggested additional thermal mass-related benefits from the R25 boards due to its higher density and lower thermal diffusivity compared to regular polyiso.

Energy and Hygrothermal Analysis of Phase Change Materials in Exterior Wall Assemblies (BLDG-19-021)

Sajith Wijesuriya, **Paulo Tabares-Velasco**
Colorado School of Mines, United States of America

Thermal energy storage can potentially reduce electric demand in commercial buildings. Among different technologies, phase change materials (PCMs) embedded in the building envelope have the potential to shift cooling energy demand away from peak hours. Although many studies have studied the thermal performance of PCMs in building envelope, moisture transfer has not been effectively analyzed. Convective heat transfer between the envelope and air plays an important role on the overall hygrothermal performance. Furthermore, PCM encapsulation methods present different enclosure materials and therefore, influences the heat and moisture transfer across the envelope. This study is part of a larger project that empirically validates PCM models used in building energy modelling software for wall assemblies. This study validates WUFI using data from two walls having different PCM encapsulation types. Further analysis is done to investigate the hygrothermal behavior of an exterior wall with and without PCMs subjected to precooling. The results of the validation study indicate the importance of initial relative humidity values when comparing the heat and moisture transfer models with PCM inclusions. Based on the analyzed wall, results show that there is no risk of hygrothermal damage to the wall assembly and the application precooling doesn’t impact the drying potential.

Studying the Impact of Green Roofs and Living Walls on the Energy Performance of a Supermarket in a Semi-Arid Climate

Mauricio García[1,2], **Sergio Vera**[1,2], **Fabien Rouault**[3]

[1]Department of Construction Engineering and Management, School of Engineering, Pontificia Universidad Católica de Chile; [2]Center for Sustainable Urban Development (CEDEUS); [3]School of Construction, Pontificia Universidad Católica de Chile

Supermarkets and warehouse stores need to reduce operational costs due to increasing competition. Jamieson (2014) shows that big-box retail stores in USA potentially can reduce its energy consumption by up to 30%. Living walls and vegetative roofs emerge as envelope technologies able to reduce buildings energy consumption. This kind of buildings is ideal for implementing these vegetative envelopes because they have a large opaque surface where these technologies can be installed. However, there is a lack or absence of studies evaluating which strategy performs better in terms of reducing the energy consumption of supermarkets. For this reason, this paper aims to evaluate the impact of green roofs and living walls on the energy consumption of a supermarket building located in Santiago of Chile, which is characterized by a semiarid climate (Bsk according to Köppen-Geiger climate classification). Heat and mass transfer models (HMTM) for green roofs and living walls programmed in Matlab® are coupled with EnergyPlus® using MLE+®, an open-source Matlab/Simulink toolbox for co-simulation with EnergyPlus. The HMTM of Tabares-Velasco & Srebric (2012) is used for green roofs, and it is adapted for living walls. The validation of the green roof HMTM was done for different climates represented by the cities of Santiago (Chile), Melbourne (Australia) and Chicago (USA), while the living wall HMTM was validated only for Santiago (Chile). The validation shows very good agreement between the experimental and simulation data for substrate temperature and volumetric water content. A Prototype Retail Building will be simulated. Currently, we are running the Matlab-EnergyPlus co-simulation, thus this abstract does not show results. The full paper will include results comparing the energy consumption of the supermarket for living walls and green roofs as wells as evaluating the impact of different design parameters (i.e leaf area index, stomata resistance) of these vegetative envelopes on the energy consumption.

3:30pm - 5:30pm
Bay Room

Session 8: Test Methods and Applications

Session Chair: **Danko Davidovic**, Huber Engineered Woods LLC

Development of a Dynamic Hot-Box Test Setup with Variable Outdoor Climate

Oskar Ranefjärd[1], Eva Frühwald Hansson[1], Anders Rosenkilde[1,2]

[1]Department for Building and Environmental Technology, Lund University; [2]TMF- Swedish Federation of Wood and Furniture Industry

In Europe, all new houses built require an energy declaration showing the expected energy consumption during use. However, there is often a discrepancy between the calculated and the actual energy consumption. Some claim that in general the difference is on the positive side for wooden buildings, with real energy consumption being lower than predicted. This could be an effect of thorough and long-time work with energy related issues or it could be the bio-based material performing better than designed. The working hypothesis for this paper is that materials with moisture buffering capacity have better energy performance when used in real structures under real climatic conditions compared to standard test of thermal insulation performance.

The goal of this paper is therefore to develop an experimental procedure to test thermal insulation with different outdoor climates. The setup should also be suitable for various materials and different wall structures. With the objective to simulate a variety of outdoor climates, a Hot-Box test was set-up where one side of the experimental setup is a humidity- and temperature-controlled climate-chamber (outdoor side). The other side is a highly insulated box with temperature-controlled heating, where the energy required to maintain the temperature is measured (indoor side). As validation of the test setup, steady-state values (as an ordinary Hot-Box test) were compared against values obtained using a HotDisk apparatus. For common insulation materials as, mineral wool and XPS the results from Hot-Box and HotDisk tests were very similar whereas there were differences for bio-based insulation material. Dynamic outdoor climate with diurnal changes does not show apparent differences compared to the steady state Hot-Box test for the tested materials, but there is reason to believe there is a difference with longer cycles.

Thermal Resistance Measurements of Two- and Three-D Thermal Bridges Using an ASTM C177 Based Apparatus

John Frederick Straube[1], Joe Simonji[2], Chris Schumacher[3]

[1]University of Waterloo, Canada; [2]RDH Building Science; [3]RDH Building Science Labs

Thermal bridges, localized areas of building enclosures that allow higher heat flow, are recognized as an important source of heat loss/gain. Computer models are now widely used to quantify the impact of thermal bridges. However, few full-scale measurements of heat flow through thermal bridges have been undertaken to confirm and validate computer models. To allow for the measurement of specimens with complex 2D and 3D heat flows (i.e. thermal bridges a special large-scale guarded hot plate apparatus based on ASTM C177 was designed and constructed. This apparatus is capable of accepting specimens measuring 4’ (1219mm) by 4’ (1219mm) and up to 16” (406mm) thick. This paper describes the apparatus, its design, and the results of commissioning tests.

Computer modelling was used to estimate heat flow errors describing the characteristics and limitations of the apparatus. Once constructed, the apparatus was validated against a heat flow meter calibrated using a NIST-traceable calibration sample. The capability of the guarded hot plate to measure layered specimens with thermal bridges was demonstrated through the measurement of three specimens resembling typical wall assemblies. Measurements from the apparatus were compared against results from computer models and good agreement was found.

The Impact of Adjacent Zone Pressure on Whole Suite Airtightness Tests

Jason Douglas Gray

University of Toronto, Canada

Single-fan blower door testing is commonly used for estimating the airtightness of multi-unit residential building (MURB) suites, but current testing procedures and standards do not take into consideration the impact that adjacent zone pressures may have on test results. In two case study buildings, standard whole-suite airtightness tests were conducted with the adjacent zone pressures in two conditions. The first condition had the adjacent zones at the same pressure as

the atmospheric pressure, which was achieved by leaving the windows opened in these zones and monitoring interior pressures. The second condition allowed the adjacent zone pressures to reach a natural equilibrium with the test suite, while the windows were closed, resulting in interior pressures between atmospheric and the test suite pressure. The results of the tests showed that, in Building 1, air leakage at 50 Pascals (Q50) was changed by approximately 24% depending on the adjacent suite pressures, while the results from Building 2 showed no appreciable change in Q50. This higher percentage difference in Building 1 may be due to the higher interconnectedness between the suites, as compared to Building 2. Despite a small sample size of two suites, the effect of adjacent zone pressure appears to be highly variable and will likely change on a building-to-building basis. These tests highlight the importance of monitoring adjacent zone pressures during whole-suite airtightness tests in MURBs to ensure they are as close as possible to atmospheric pressure such that the test results can be more accurately interpreted.

Affecting Air and Water Barrier Effectiveness: Fixing the Fasteners?

Sarah Flock[1], Andrew Dunlap[2]
[1]ABAA / RRJ; [2]ABAA / SmithGroup

Building enclosure design involves balancing the demands of air, water and thermal considerations. Air and water barriers (AWB) are often incorporated to provide weather protection, but to perform successfully, require continuity. However, enclosure design also includes rainscreen cladding systems with numerous fasteners penetrating the AWBs (via attachments). Available guidelines for detailing and testing the installed AWB with the cladding attachments can be limited, and installation practices are not consistent from project to project. While improved installation methods and consensus standards for validating air and water tightness are needed, research is also required to assess detection approaches and the evaluation methodologies to employ. This session will discuss the research underway, as well as the background and context of the current practices related to penetrations of the AWB.

Date: Tuesday, December 10, 2019`

7:30am - 8:30am — **Breakfast**

Beach/Gulf Room

8:30am - 10:00am — **Session 09: Thermal Performance of Walls and Systems, Part 1**

Bay Room — Session Chair: **Dominique Derome**, Universite de Sherbrooke

Advanced Integrated Facades: Concept Evolution and New Challenges

Fabio Favoino, Marco Perino, Valentina Serra
Politecnico di Torino, DENERG, TEBE Research Group, C.so Duca degli Abruzzi n°24, ZIP 10129, Torino (Italy)

The exploitation of RES at the building scale, the possibility to perform the energy demand management and the ability to take the advantage of the opportunities offered by the outdoor environment are, today, key issues for achieving a satisfactory energy efficiency in buildings. It has been demonstrated that all these goals can be achieved through the adoption of the so-called Responsive Building Elements (RBEs). Among various concepts, Advanced Integrated Façades (AIFs) are probably one the most promising RBE technology, due to the important role that the building envelope plays in controlling the energy and mass flows between the building and the outdoor environment. In this paper the most significant outcomes of a twenty year long research activity, done on different types of AIF, will be presented. They are the results of both numerical and experimental investigations performed on various types of AIF, namely active double skin facades with various ventilation strategies (mechanical, natural, hybrid) and smart glazing systems. Morever, the present and future evolution of the AIF concept toward more comprehensive, up-to-date and visionary technological solutions will be discussed. They are the so-called Multifunctional Façade Module (MFM), like the ACTRESS prototype (ACTive, RESponsive and Solar) or the POWERSKIN+ system (Highly advanced modular integration of insulation, energising and storage systems for non-residential buildings). The ACTRESS prototype integrates high performance insulation systems (opaque and transparent) with energy storage capabilities (by using PCM latent heat). It hosts PV cells and the opaque submodule can be ventilated with various strategies. It is has been conceived and a prototype was built for monitoring its energy performance and its capability in providing optimal indoor environmental quality. POWERSKIN+ is an off-site prefabricated modular system, glazed and opaque, integrating smart material solutions to renovate existing facades of both double skin and advanced integrated curtain walls. It will be developed in a recently funded Horizon 2020 EU project.

Thermal Performance Evaluation of Slotted Metal Studs in Infill Wall

Katharina Rud-Olson[1], Maria Thörnqvist[1], Petter Wallentén[2]
[1]SKANSKA, Sweden; [2]Lund University, Sweden

Within the construction sector buildings are required to be more energy efficient than ever before. Tougher building regulations require ever more accurate energy demand calculations to ensure a building's operational performance. Heat transmission losses through a buildings envelope play a key role in the overall energy performance of the building. Underestimating these losses may lead to non-fulfilled energy requirements. Currently used standard methods for calculating the heat transmission losses of buildings are for the most part sufficient but lack in certain areas where current knowledge is inadequate and requires further investigation. One of these areas is wall constructions using slotted metal stud framing, where there currently is no simplified standard method of calculation. The thermal transmittance through a slotted metal stud creates a complex three-dimensional problem which has proven difficult to transfer into a more manageable model. This study analyzes some of the suggested methods of calculation for the thermal performance of slotted metal stud walls, where the results revealed that the suggested methods have a rather large margin of error in relation to 3D simulations. To solve this issue this study presents a new calculation method for the thermal performance of slotted metal stud walls. The new method of calculation is based on 3D simulations of the

heat flow through 117 different wall structures together with non-linear regression analyses. It suits a large variety of slotted metal stud wall structures and has a smaller margin of error than the current simplified methods of calculation.

Impact of Low-E WRB Facing an Air Cavity on the R-Value of a Wall System

Benjamin Meyer[1], **Maria Spinu**[2], **Theresa Weston**[2], **Helga Kuhlmann**[2]
[1]ECS Mid-Atlantic, LLC, United States of America; [2]DuPont Performance Building Solutions

The objectives of this study were to quantify the thermal benefit of low-E barriers adjacent to an airspace and to evaluate the thermal resistance of an airspace with and without airflow. The performance of wall systems with three types of weather resistive barriers (WRBs) facing the airspace were evaluated: WRB with Low-E metalized surface, white WRB, and conventional black building paper. This article discusses brick veneer walls which are installed with an air cavity behind the brick cladding.

The study covers simulations performed with different computer models which include WUFI®, FLUENT®, ABAQUS, and a mathematical Analytical Model developed in-house. The simulations were compared with experimental temperature profile measurements on 96"x96" instrumented test walls. The test wall assemblies were measured in accordance with ASTM C 1363-05, Standard Test Method for the Thermal Performance of Building Assemblies by Means of Hot Box Apparatus. A wall with a controlled introduction of outside air in the airspace was compared with a wall with encapsulated airspace (no airflow in the cavity).

The main finding, validated through both simulations and experimental data, indicate that Low-E WRB adjacent to an airspace with or without airflow will improve the thermal performance of the wall when compared to a similar wall with "regular" WRBs by reducing radiant heat flow through the air cavity. The CFD simulations show that for air cavities up to ¾" the effect of convection is minimal while convection dominates over conduction for air cavities above 3/4" for which there is an effect of airflow on the thermal performance of the wall.

An "R-Value Calculator" based on a mathematical Analytical Model was also developed and validated during this study. The model can be used to evaluate and compare the overall R-value for wall systems with Low-E WRB versus other WRBs for enclosed cavities.

8:30am - 10:00am
Palm Room

Session 10: Fenestration Systems and Energy Performance

Session Chair: **Bipin Shah**, WinBuild Inc.

Experimental and Modelling Study of the Energy Performance of New Types of Energy Smart Window Curtains

Ali Naman Karim, **Carl-Eric Hagentoft**
Chalmers University of Technology, Sweden

New types of energy smart window curtains, with the aim to reduce the heat losses through windows have been studied. By covering windows with these curtains, for instance when buildings are not occupied, the energy performance can be improved and becomes more economical and sustainable. The paper aims to evaluate the energy performance of the curtains by in-situ measurements and simulations. In this paper, two different designs of these curtains have been studied. Curtain design (A) has the aim to increase the overall thermal resistances of window constructions and by that decrease the heat losses through windows. Curtain design (B) has an additional solar collector function which is aimed to capture some part of solar radiation striking windows and warm up the indoor environment. Warmer air is forced into the indoor environment by small fans inside the curtain. The paper investigates also the possibilities to optimize the design of the curtains regarding the emissivity of the material used in the design, using analytical models. During a 27 days measurement campaign, interior and exterior temperatures, intensity of solar radiation and energy consumptions in three identical test huts are continuously measured. The interior temperatures are kept constant using radiators. Results from the pilot study show that the total U-values of windows can be improved by using the curtains. For the case studied in this project, using the curtain design (A) improves the U-value of the window by approximately 50 %. For Curtain design (A) a surface to surface resistance of 0.65 m2K/W and for design (B) a resistance of 0.38 m2K/W is estimated.

Field Study of Energy Savings Potential of Dynamic Facade Systems Using Low-E Fabric Attachment

Kalieshwar Chella Srinivasan Krishnan[1], **Bipin Shah**[2], **Ravi Srinivasan**[1]
[1]University of Florida, United States of America; [2]WinBuild, Inc.

The use of highly glazed façades is becoming a common design feature. This can have both positive and negative effects on the energy demand of the building. Façades that can be altered actively using controls have been known to help reduce the energy consumption of a building. An example of such a system is one that controls fenestration attachments (shading devices) along with interior lighting, known as a Dynamic Façade System (DFS). This field measurement study aims to determine the change in U-factor of a glazing system when DFS with low-E fabric attachment is placed on the interior of a window. Study also provides an understanding about the change in U-factor and daylighting with change in degree of openness of the fabric. Using this change in U-factor and daylighting, potential annual energy savings is calculated for an educational building (Rinker Hall, University of Florida, Gainesville, FL, USA). The DFS studied in this paper is primarily aimed as a retrofit.

Energy consumption reduction was primarily due to the reduction in U-factor due to the use of an active shading system and corresponding reduction in interior lighting energy consumption. The reduction in lighting energy consumption is calculated using data gathered from a lamp switching circuit. To calculate these potential annual energy savings, a detailed energy model of Rinker Hall was developed using eQuest. The baseline energy model represents the existing structure fitted with existing glazing. It was compared against

a simulated model with the U-factor of the new glazing system fitted with dynamic facade systems with special low-e fabric attachment. Results showed that DFS with low-e fabric attachment of varying degrees of openness reduced annual electrical energy consumption by 12% - 16% and lighting power density by 16%-21% depending upon degree of openness of fabric used. This resulted in reduction of cooling loads.

Assessment of Electrochromic Glazing Impact on Occupants Thermal Comfort and Building Energy Performance

Ahoo Malekafzali Ardakan
SageGlass, United States of America

Access to natural daylight and connection to outdoor environment is one of the key elements of contemporary architecture. This design concept is characterized in buildings by large area glazing. However, large openings without proper shading strategy can cause visual and thermal discomfort for occupants in building perimeter zones. Electrochromic glazing can dynamically tint and vary its visual and thermal properties. EC glazing can prevent large amounts of solar energy from passing into the building interior to prevent over-heating.

This study focuses on analyzing how Electrochromic (EC) glazing can affect: 1) occupant thermal comfort and 2) building energy performance. Advanced human thermal comfort model developed by UC Berkeley and Center for Built Environment (CBE) was used in this study to predict body comfort and sensation. The level of accuracy of advanced thermal comfort model which can predict comfort for local body parts makes it a unique tool for assessment of comfort under non-uniform environments which is common due to variation in solar angle and solar radiation intensity. Building energy performance was modeled using parametric modeling tool based on Energy plus simulation engine.

A higher education building was selected as a case study for whole building energy analysis comparing energy performance of the EC glazing versus low-e window. For assessing thermal comfort performance of the Electrochromic glazing, two identical offices spaces one with Electrochromic glazing in multi-zone configuration and one with low-e glazing were modeled. Thermal comfort and sensation of manikin were compared from both rooms at local and overall level. The analysis result showed that multi-zone Electrochromic glazing could significantly improve the thermal comfort levels of manikin model. Analysis result was reported in terms of color coded manikin and interior solar radiation model for selected hour that occupant receives direct sunlight penetration.

10:00am - 10:30am **Break**

10:30am - 12:00pm
Bay Room

Session 11: Thermal Performance of Walls and Systems, Part 2

Session Chair: **Hua Ge**, Concordia University

Use of Rigid Phenolic Foam Exterior Insulation for Renovation of Concrete Sandwich Walls

Tuomo T. Ojanen
VTT Technical Research Centre of Finland Ltd, Finland

Improving energy efficiency of the building envelope in renovations requires new technologies and materials. Additional exterior insulation system can improve the energy efficiency and indoor thermal comfort. Safe moisture performance of the additional exterior insulation assembly requires suitable properties for the materials.

Rigid phenolic foam insulation is a new product that offers several advantages. The thermal conductivity of the material can be 0.020 W/mK, allowing good thermal resistance with significantly thin layers. Low additional dimensions enhances the applicability of the exterior insulation system. Rigid phenolic foam has also relatively low water vapor diffusion resistance at high humidity levels where drying efficiency is needed.

This paper presents a numerical study about the moisture performance of the exterior thermal insulation systems applied on concrete sandwich walls under cold climate conditions (Finland). The renovation structure has exterior sheathing, ventilated cavity and additional thermal insulation. The main moisture load for the new insulation system is caused by the wet exterior layers of the old wall exposed to driving rain before renovation. The study compares the drying potentials and the humidity conditions of the renovation application using either mineral wool, expanded polystyrene or rigid phenolic foam insulation.

The results show that in the case of rigid phenolic foam the drying of the exterior concrete core from 97 % RH to 85 % RH average level took from 9 % to 13 % longer than with vapor open mineral wool, while with EPS this drying time was about 140 % longer. All the renovation cases improved the moisture safety of the structure from the original.

The paper will discuss the effect of the old wall materials, initial moisture contents and dimensions of the additional insulation. The presented renovation system with rigid phenolic foam can be safely applied and the technology is ready for implementation.

Thermal Evaluation of Masonry Shelf Angle Supports for Exterior-Insulated Walls

Adam Di Placido, Bailey Brown, Drew Chong, Chris Schumacher
RDH Building Science Inc.

Exterior insulation in above-grade wall assemblies is becoming more common as energy codes and voluntary energy efficiency programs continue to shift the building construction industry toward more stringent thermal performance standards. Exterior insulation can be effective for achieving high R-value walls; however, high-conductivity thermal bridges, such as cladding attachment systems, often penetrate the insulation and require careful consideration to avoid significantly degrading the insulation's thermal performance. Mitigating heat

loss from cladding attachment systems is of great interest for heavyweight anchored masonry veneer claddings, which require a robust structural attachment system to transfer cladding loads back to the primary structure.

Masonry veneer claddings are typically supported by the building structure using a combination of intermittent anchors and shelf angle bearing supports. This paper discusses computer-based three-dimensional thermal modeling calibrated with physical testing of a shelf angle support to evaluate the thermal performance of shelf angle support design options available for exterior-insulated anchored masonry veneer walls. Calibration of the model demonstrated that the contact resistance between the shelf angle support and the structure can significantly reduce the associated heat loss. Additionally, this paper considers the impact of two other common thermal modeling oversights: circular cross-sectional area sizing and galvanized steel material property selection.

The calibrated thermal modeling results of this study demonstrate that shelf angle support designs can significantly diminish the effectiveness of the exterior insulation by reducing the R-value of the exterior insulation by 50%. Notable thermal improvements can be achieved by using more thermally efficient shelf angle supports designed specifically for reducing thermal transmittance. The calibrated thermal modeling results demonstrate that such products improve upon the thermal losses of traditional designs, reducing the R-value of the exterior insulation by approximately 15%.

The results from this study demonstrate that with the appropriate selection of shelf angle support design, high R-value exterior-insulated masonry veneer walls are achievable.

Silicone Based Thermally Broken Anchors for Rain Screen Wall Application

Jie Feng[1], Lawrence Carbary[1], Ryan Asava[2], Andrew Dunlap[2]
[1]The Dow Chemical Company; [2]SmithGroup Building Technology Studio

In many commercial or industrial buildings, steel or aluminum anchors are used to attach external building components (e.g. cladding) onto internally positioned building components (e.g. structure walls, sub-frames). These anchors pass through seams in the insulation and transfer exterior generated loads (e.g. wind loads) and gravity loads from building enclosure components to the internal building structure. These load transfer mechanisms can act as a thermal bridge between the exterior and interior building components, which will reduce the overall building insulation façade performance (e.g. U value). To minimize the impact on the building enclosure's insulative performance through the use of fully metallic anchors, this study developed a unique silicone-based thermally broken anchor for back-ventilated/rain-screen wall application that provides structural load transfer capacity as well as thermal bridging mitigation potential. Silicone has been widely used in commercial building projects as structural glazing adhesives, weatherproofing sealants and joint components as a result of proven high durability and good insulation performance. However, anchor products on the market to-date have not incorporated silicone structural adhesives to achieve better thermal insulation performance. The silicone adhesive attachment introduced in this study has incorporated a unique design redundancy that will mitigate structural separation of the anchor in the event of a fire in the exterior wall cavity. Moreover, this study also demonstrates that a silicone-based thermally broken anchor can have sufficient structural capacity and acceptable manufacturability through injection molding. A lab scale insulation test was performed to compare anchors with and without silicone-based thermal break. Then, an injection molding tool was developed to verify its process feasibility for high volume manufacturing. These injection molded silicone-based anchors were tested to evaluate their structural capability with and without ageing. It is concluded that silicone-based thermally broken anchor can provide sufficient structural capability and improved thermal performance at same time.

10:30am - 12:00pm
Palm Room

Session 12: High Performance Buildings

Session Chair: **Mehdi Ghobadi**, National Research Council Canada

Feasibility Analysis of Net-Zero Energy Design in the Canadian Arctic

Carsen Jeffrey Banister, Adam Wills, Justin Berquist
National Research Council Canada

Several jurisdictions across the globe have begun to adopt net-zero energy or net-zero energy ready targets in their building codes in an effort to reduce energy consumption and greenhouse gas emissions. The majority of work designing and optimizing net-zero buildings has been undertaken for buildings outside the Arctic. Given the unique energy supply and climate challenges for northern buildings, there are potential economic and environmental benefits in considering net-zero energy buildings and systems in the North.

This study assesses the feasibility of designing and building to net-zero energy levels of performance in the Arctic. The study simulates the energy performance of two buildings considered for Nunavut. The first building is a multi-unit residential building (MURB) to provide affordable housing and the second building is a hotel considered for the same site. Both buildings were modelled in ESP-r to determine their space heating demands. ESP-r/TRNSYS co-simulation was then utilized to explore energy system concepts. Parametric simulations were performed to evaluate sizing of system components, control, and system operation.

Limited information and research is available for northern buildings. Given the unique environment of the North, net-zero solutions developed for southern climates are often not suitable. This paper identifies challenges to conventional net-zero building solutions due to renewable resource availability, harsh climate conditions, and higher costs for materials and maintenance. This study also provides an example of real-world application of detailed building performance simulation, the results of which yield a feasibility analysis technical solutions for realizing net-zero energy buildings in the Arctic.

Builder Choices for Zero Energy Ready Home Construction

Theresa Lee Gilbride, Michael C Baechler

Pacific Northwest National Laboratory, United States of America

Although the number of net zero energy homes constructed increased 75% from 2016 to 2017, net zero or zero energy ready homes still account for less than 1% of U.S. homes constructed in 2017. Concerns that it will cost too much or require too many complicated technologies 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 with a combination of off-the-shelf equipment and materials and common construction techniques implemented with training and verification. Construction methods used by builders in the program will be compared with those used in just-to-code new homes and existing homes for several key components, including wall assemblies and HVAC systems. Case studies of cost-effective assemblies in several climate zones will also be described, including specific examples of construction techniques developed by these zero energy ready home builders to meet net zero targets.

First-Year Operation Monitoring of a Six-Story Building in Vancouver Built for High Energy Performance

Jieying Wang
FPInnovations, Canada

A 6-story mixed-use building, with five stories of wood-frame residential construction on top of concrete commercial space at the first level was completed in Vancouver in early 2018. It is the largest building in Canada designed and built to meet the Passive House standard. A number of innovative technologies were used to reduce space heating energy consumption and to improve indoor air quality. For example, the exterior walls were built with double studs with the wall cavities filled with batt insulation; 2-in. thick polymer-faced expanded polystyrene (EPS) boards were installed between the two rows of wall studs to further improve thermal performance. The EPS, carefully taped at joints during the construction, is also a major component of an air and vapor barrier. High-efficiency heat recovery ventilators and electrical baseboard heaters were installed in the building. Space cooling was not integrated in the mechanical systems. The building was instrumented during the construction to measure building envelope performance, and indoor environmental conditions including temperature, relative humidity (RH) and CO2. Seven residential units including three south-facing units on floors 2, 4, and 6, respectively; three north-facing on floors 2, 4, and 6; and one west-facing unit on the 4th floor were selected for the monitoring. Sensors were installed in the exterior walls to measure the wood (wall stud, plywood exterior sheathing) moisture content, temperature, and RH across each assembly. These units were also monitored for indoor environment. About one year's post-occupancy performance was presented and discussed in this paper. The field monitoring found that overheating occurred from late spring throughout the summer of 2018. The indoor CO2 levels mostly remained below 1000 ppm. The exterior walls performed reasonably well in terms of moisture performance.

12:00pm - 1:30pm **Lunch**

Rusty's

1:30pm - 3:00pm **Session 13: Fenestration and Energy**

Beach/Gulf Room Session Chair: **Charlie Curcija**, Lawrence Berkeley National Laboratory

Human Centric Tools for Visual Comfort Assessment In Existing Buildings

Tatiana Séverin-Fabiani[1], Delphine Descloux[1], Thuillier Laura[2], Wuest Isabelle[1]
[1]Saint-Gobain Research Paris, France; [2]Saint-Gobain Research Compiègne, France

Providing comfortable, healthy buildings with high energy efficiency is a key challenge for the future. Solutions that combine both safety and comfort for the occupants with sustainable approaches to address the environmental challenges have to be implemented in construction field. In this frame, new methodologies to assess the comfort of occupants have to be developed.

However, if daylight is increasingly highlighted in new construction, it still represents a largely unexploited resource in existing buildings for saving energy and improving occupant's comfort. In this context, there is a need for extensive evaluation of the comfort, based on metrics and non-intrusive diagnostic but also on human experience and perceptions. Our work is focused on the development of indicators of comfort and on setting up the associated evaluation protocols. We have developed a set of tools to quantitatively assess visual comfort in existing places. The set of tools that will be detailed are measurements and simulation of daylighting performances in a room associated to an occupant satisfaction survey. The tools combined together aim at providing non-intrusive and quick assessment of occupied spaces. Our results are showing that those assessment tools are candidate for short to mid-term adoption of the tools outside of the research field and for internal campaigns. Our tools are particularly adapted to post-occupancy diagnostics that can be performed by design offices in the frame of labelling schemes.

The tools were already used in real case study to assess visual comfort in offices. Results of the measurements, simulations and surveys will be described in details.

Detailed Window Model for Hygrothermal Building Simulation

Jan Radon[2], Florian Antretter[1], Matthias Pazold[1]
[1]Fraunhofer Institute for Building Physics, Germany; [2]Agr. University of Cracow, Faculty of Environmental Engineering, Dept. of Rural Building

Windows and their dynamic performance have a huge impact on building energy demand and peak loads. To model windows in dynamic building simulation, several methods are available. Simplified methods take standard input parameters like overall U-value and SHGC into account, which are available from manufacturers. More detailed models account for the convective, radiative and conductive processes in

window panes and air/gas gaps and can represent various dynamic phenomena but require more comprehensive inputs. Detailed windows models which can compute the performance of new, innovative window technologies utilizing air spaces in windows to preheat/cool air and control direction of flow are currently missing for dynamic hygrothermal building simulation models.

This paper describes the creation of a new, comprehensive dynamic window model and its integration into a dynamic hygrothermal building simulation software. The new model includes options to simulate controlled and pressure difference driven air-flow in gaps between window panes with release of the air towards either side of the window. Dynamic changes of heat flow due to short- and longwave absorption and exchange, changes in surface transfer resistances depending on air velocities and conduction with different gas fillings are considered. Partial or full shading due to shading elements inside, outside or in between window panes contributes to dynamic heat flow numbers.

To quantify the effects of the new dynamic window model, a case study in a mixed-humid climate will be presented, which shows the energy impact but also changes in hygrothermal risk due to latent load from window ventilation control. Taking dynamic effects into account results in a significant change of predicted energy demand. Advanced window systems and window controls can be implemented and tested in the software to improve performance.

A New Analytical Approach for Evaluating Fenestration Impacts on Residential Building Performance

Jim Larsen
Cardinal Corporation, United States of America

Two-parameter linear regression analysis is used in this study to understand the interaction of window U-Factor and window solar heat gain (SHGC) on building energy performance. These regression techniques have been utilized by Lawrence Berkeley National Laboratory (LBNL) in support of the ENERGY STAR Windows program and have been further refined for guidance on the interaction window energy performance parameters across a variety of climates, building vintages, and HVAC systems/fuel supplies.

1:30pm - 3:00pm
Palm Room

Session 14: Energy Performance and Standards

Session Chair: **Ihab Elzeyadi**, University of Oregon

Advancing Best Practices for Energy and Indoor Environmental Quality for Multifamily

Sean Patrick Denniston[1], Chris Mathis[2]
[1]New Buildings Institute, United States of America; [2]MC2 Mathis Consulting Company

Multifamily buildings represent a major opportunity to advance the goals of improved building energy performance and better indoor air quality. ACEEE estimates that there are $3.4Billion per year in cost effective energy savings in the multifamily sector. But the energy performance of multifamily buildings has been relatively neglected in the broader industry push for high performance buildings, and many strategies for reducing energy use in this sector remain under-represented in new construction. Likewise, indoor environmental quality – especially indoor air quality – and ventilation strategies from other building sectors have not always translated well to multifamily buildings even as IEQ concerns in the multifamily market have grown.

In response to these needs and a booming multifamily market, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) launched a project to develop a new ASHRAE Multifamily Guide to begin to address this critical need for better information to support better practice in the design and operation of multifamily buildings. Unlike ASHRAE's Standards, this guide is not meant to provide minimum requirements for multifamily buildings, but rather to provide best practices to maximize the quality, performance and effectiveness of existing practices while simultaneously enabling and empowering practitioners to pursue the best and highest performance options.

This two-part paper will introduce readers to the ASHRAE Multifamily Guide and discuss the background behind its creation from the perspective of both the ASHRAE committee that oversaw its genesis and the team selected to create it. The first part will give the background for the project's creation from the perspective of the Chair of ASHRAE's Residential Building Committee. The second part will give the perspective of the project team and will discuss the subjects covered, how the content was structured to address the intended audience and how the more challenging subjects were handled.

PHIUS+ 2018 Passive Building Standard

Graham Wright, Lisa White
Passive House Institute US

PHIUS+ 2018 is a pass/fail, performance-based passive building standard. It includes prescriptive quality assurance requirements adopted from U.S. government programs, which ensures benefits that cannot be obtained by simply specifying energy targets, such as a comfort, health, and high indoor air quality. The main focus of the standard is energy savings. There are three main performance metrics: Limits on heating/cooling loads (on an annual and peak basis), source energy, and air-tightness criteria.

The heating/cooling load limits for PHIUS+ 2018 were developed based on a robust analysis to determine a sweet spot for investment in energy conservation measures. Optimization was done in BEopt, an EnergyPlus-based tool developed by NREL. A variety of building sizes and occupant densities were simulated in numerous climates, optimizing for the maximum source energy savings at the minimum cost point (up-front and operational costs considered). The result is passive building performance criteria that vary based on climate, energy price, building occupant density, and size (envelope to floor area ratio).

The source energy criterion is based on a building's "fair share" of carbon, with the goal to limit global warming to 2C. The residential limit is per-person, and the non-residential limit is floor-area-based. This annual net source energy target can be met with a combination of conservation measures, on-site renewables, and off-site renewables. This target is on a glide-path to 0 by 2030.

The air-tightness limit is based on a tolerable amount of air-leakage that will not compromise durability in the building envelope. Energy savings from air-tightness is an important secondary benefit.

PHIUS+ 2018 favors conservation measures to an economically feasible point, with a view toward a clean energy future. It provides a cost-optimized path for high performance and net zero energy building design and can help many jurisdictions meet their carbon reduction goals.

How Energy Codes Lead to Occupant Behaviors that Reduce Efficiency

Cheryl Saldanha, Sean O'Brien, Vince Cammalleri
Simpson Gumpertz and Heger, United States of America

As developers and building owners charge more to tenants for access to views, architectural trends have evolved to include large glazed areas on buildings. To offset this trend, energy codes and standards have incrementally limited the prescribed window-to-wall ratios and thermal performance requirements. To allow some design flexibility, energy codes and standards offer the trade-off and performance compliance paths as alternatives to complying with stringent prescriptive requirements. Given that internal loads typically outweigh the building envelope loads, it can be a simple exercise to use an energy model to demonstrate compliance with the performance path.

However, a poor performing building envelope (even one in a code-compliant building) can lead to higher operational energy consumption and costs, which a code-compliance energy model does not capture. Glazing systems with higher thermal transmittance values (i.e., U-factors) and solar heat gain coefficients (SHGC) have interior surfaces that are colder in winter and warmer in summer than the surrounding environment. The large temperature differences create radiation asymmetry conditions, which occupants perceive as thermal discomfort. Occupants then adjust thermostats and override preset controls that drive up energy use. Equipment is forced to operate outside efficient as-designed settings. Designers also often include perimeter heating and cooling dedicated to keep glazed surfaces warm or cool, which is an energy intensive strategy to address this issue.

In our paper, we will review the energy code performance compliance path requirements for modeling building envelopes. We will provide recommendations for changes to the code language for performance-based compliance.

1:30pm - 3:00pm
Bay Room

Session 15: Hygrothermal Performance of the Building Envelope

Session Chair: **Mikael Salonvaara**, Oak Ridge National Laboratory

Hygrothermal Performance of Cool Roofs Subjected to Hot and Humid Climates

Hamed H. Saber[1], Ali E. Hajiah[2], Wahid Maref[3]
[1]Department of Mechanical Engineering, Jubail University College, Royal Commission of Jubail and Yanbu, Jubail Industrial City 31961, Kingdom of Saudi Arabia; [2]Kuwait Institute for Scientific Research, Shuwaikh, Al-Jahidh , Kuwait; [3]Department of Construction Engineering, Ecole de Technologie Supérieure_ETS Montreal (University of Quebec), Canada

Cool (white) roofs use bright surfaces to reflect a significant portion of the incident short-wave solar radiation, which lowers the surface temperature compared to conventional (black) roofs. As such, white roofs help reduce the urban heat island effect during the summer. The questions are: (a) do white roofing systems lead to moisture-related problems in hot and humid climates?, (b) what are the amount of energy savings as result of using white roofing systems instead of black roofing systems of same insulation amount, and (c) what is the reduction in the amount of insulation in a white roofing system having the same energy performance as the black roofing systems? To answer these questions, numerical simulations were conducted for different types of roofing systems that are commonly used in low-rise buildings in order to asses and compare the energy and hygrothermal performance of white and black roofing systems. The roofing systems are subjected to hot and humid climates.

The results showed that black roofs always perform with lower moisture than white roofs, and no risk of condensation and mould growth occurred in different roofing systems. Also, the results showed that white roofs experienced an increase in the heating energy loads compared to that with black roofs. However, the decrease in the cooling energy loads for white roofs were typically much greater than the increase in the heating energy loads. The main outcome of this study has shown the capabilities of using reflective materials with different short-wave solar absorption coefficients for enhancing the energy performance of roofing systems and/or reducing the amount of insulation that resulted in same energy performance as black roofing systems. The results of this study can be used in future for upgrading the Building Codes so as to allow less roof insulation if cool roofing system is installed.

Application of a Cavity Ventilation Empirical Model for Hygrothermal Performance Assessment of Rain Screen Walls

Emishaw Iffa, Fitsum Tariku
British Columbia Institute of Technology, Canada

Moisture drying, wetting, and redistribution in wall components can be affected by several factors such as wind speed and direction, solar gain, wind-driven rain, indoor and outdoor humidity, air infiltration and exfiltration. One of the main reasons an air cavity ventilation is used in envelopes is to facilitate moisture control strategy. A computational model that combines a detailed CFD model for the air transport in the cavity

with a Heat-Air-Moisture (CFD-HAM) model is a useful tool to provide an accurate hygrothermal performance assessment of a rain screen wall. However, coupled CFD-HAM models can be computationally expensive and time-consuming. Recently, a simplified empirical model that accounts for the effects of wind and solar radiation on cavity ventilation is developed. In this study, the developed empirical model is used to study the hygrothermal performance of a wood frame rain-screen wall in British Columbia coastal climate. In addition, the empirical model performance is compared against other three existing models: considering the cavity as still air, an existing empirical model, and constant ACH values of 100ACH and 200 ACH and the heat and moisture sources and sinks added to the air layer. Results show that all models provide a similar result during wetting seasons. The wall system with a still-air cavity exhibits the highest moisture content on the plywood followed by the empirical model used from the literature. The newly developed empirical formula and the 100 ACH and 200 ACH give a similar estimation in most cases of the simulation period.

Energy and Hygrothermal Analysis of Cross Laminated Timber and Wood Framed Mid-rise Commercial Buildings.

Sajith Wijesuriya[1], Alejandra Nieto[2], Paulo Tabares-Velasco[1]
[1]Colorado School of Mines, United States of America; [2]Rockwool North America

Mass timber construction has recently seen worldwide interest and increased use due to its multiple benefits such as structural robustness and high level of prefabrication. Cross Laminated Timber (CLT) has established itself as a viable and environmentally friendly building technology in Europe and is seeing increased use in the rest of the world in medium rise to high rise buildings. However, CLT is not yet widely used in North America. While energy and hygrothermal performance of CLT buildings are important key aspects to consider, current literature mostly focused on structural and fire performance.

This study compares CLT and wood frame mid-rise commercial buildings in two cities (Boston, MA and Austin, TX) using hygrothermal performance and building energy simulations software WUFI and OpenStudio. Hygrothermal simulations investigate the drying capability of the multi-layer envelopes when different insulation products (such as mineral wool and extruded polystyrene, XPS) are used in exterior wall and roof applications following IECC 2015 code. Building energy modeling comprises parametric analysis including different ventilation modes, insulation systems, and HVAC setpoints. Results include recommendations on what combination of HVAC and envelope system produces highest energy savings and effectively controls moisture in the envelope for new mid-rise constructions with CLT inclusions.

3:00pm - 3:30pm **Break**

3:30pm - 5:30pm **Session 16: Window Attachments and Shading**
Beach/Gulf Room
Session Chair: **Marc LaFrance**, US Department of Energy

Maximizing Daylight and Energy Performance: Using Pareto Front Analysis for Multi-Objective Facade Shading Optimization

Cheryl Saldanha, Graham Cranston, Juhun Lee, Christian Sjoberg, Tat Fu
Simpson Gumpertz and Heger, United States of America

In building science, maximizing natural daylighting while minimizing solar heat gains is a multi-objective optimization problem. The Pareto efficiency method offers a solution for approaching the challenge.

Multi-objective optimization involves inherent tradeoffs between simultaneous competing goals. These include allocating shared resources and optimizing inversely correlated responses (e.g., fuel efficiency and power output). Each objective is usually a function of multiple parameters, but the existence of multiple parameters does not in itself result in a multi-objective optimization problem. The single objective of minimizing weight could be a function of material selection, geometry, etc., but a simultaneous competing objective, such as maximizing stiffness, is needed to form a multi-objective optimization problem.

Our team applied the Pareto efficiency method to the Vitta Center medical facility in Guatemala, where summer solar radiation is a significant concern. The challenge was to provide the architect with several arrangements of façade shading elements to maximize daylight and access to exterior views, while minimizing solar radiative gain. We performed a parametric analysis, varying the vertical fin shades' spacing and depth and the slab overhang depth, to quantify the daylight autonomy and solar radiative gain for a typical office space on each elevation independently. In this paper, we describe the modeling process, including determining constraints and permissible ranges for parameters, and developing tools to compare output from different software tools. We analyze the resulting data to develop a set of preferred solutions having comparable performance but varied aesthetic. The architect will use the preferred solutions to inform the design and layout of shading devices.

Impact of the Accuracy of Shading Calculation on Passive House Design and Certification

Lisa White[1], Andres Pinzon[1], Florian Antretter[2], Matthias Pazold[2], Jan Radon[3]
[1]Passive House Institute US; [2]Fraunhofer Institute for Building Physics; [3]Agr. University of Cracow, Faculty of Environmental Engineering, Dept. of Rural Building

Solar gain is a driving factor for the design of ultra-low energy buildings in all climate zones. Most building simulation models used to compute energy demand and peak loads for passive buildings do not take self-shading and shading from surrounding elements into account, or only do so in a simplified way. This leads to design decisions which are not cost effective and can cause comfort and overheating issues.

This paper will introduce a new method developed to compute monthly shading factors per window. The new method takes into account all shading interactions and is based on a geometrical representation of all elements that shade transparent building envelope elements. It is implemented in the PHIUS+ certification software WUFI® Passive and applied to a range of existing certified passive houses. The resulting energy demands and loads are compared to the values from the previous method to compute shading impact in passive building energy balance calculations.

Results show that changes in heating and cooling energy demand as well as in peak loads are significant between the old and new methodology - up to 15-20%. The paper will summarize guidance on how to fully utilize the capabilities of the new shading model in WUFI® Passive. The new method is not only faster but also more accurate, with results closer to real solar gains. Application of the method will lead to more cost effective and comfortable design solutions.

Experimental Setup for the Measurement of Detailed Heat Transfer in Window Attachments

Charlie Curcija, Robert Hart, Howdy Goudey
LBNL, United States of America

Heat transfer in window attachments typically involve multiple pathways that are challenging to measure and quantify. Normally, overall heat transfer in fenestration systems is measured in calorimetric instruments, known as hot box for U-Factor measurements (ASTM C1199, ASTM C1363, ASTM E1423, ISO 8990, ISO 12567) and Solar Calorimeter for SHGC measurements (NFRC 201, ISO 12567). While hot box measurement provide means to measure overall heat transfer, it is unable to distinguish between local heat transfer effects and different heat transfer pathways that may be taking place. In this paper we describe novel method to measure local heat transfer rates that enable us to determine spatial distribution of heat transfer and its individual components. The method utilizes the idea of heat flux meter in the form of a Calibration Testing Standard, or CTS. CTS methods was originally developed to aid in calibrating hot boxes for the measurement of fenestration products. We further expand on this idea by introducing second CTS that represents instrumented window attachment. While window CTS is normally sealed, window attachment CTS may or may not be sealed, where gaps between window frame/opening and window attachment may be intentionally introduced to simulate edge and top/bottom gaps that window attachments may form when installed over window. These gaps introduce air flow pathways, whose effects on heat transfer can thus be investigated. LBNL has developed several window attachment models, including for products such as cellular shades, pleated shades, vertical louvered blinds and perforated screens. In order to have confidence in the newly developed attachment models, these models are being validated through extensive testing using window attachment CTS method.

Energy Performance of Cellular Shades

Cheryn Metzger
Pacific Northwest National Laboratory, United States of America

Laboratory and field studies have demonstrated that the use of window attachments such as cellular shades can provide significant savings by reducing energy consumed for heating and cooling in homes. The degree to which this measure saves energy, however, depends on a number of factors including the type of cellular shade, the structural and orientation characteristics of the home, the characteristics of primary window on which it is attached, climate conditions, and operating schedules. This project, sponsored by Silicon Valley Power and the American Public Power Association's Demonstration of Energy and Efficiency Developments Program, examines the savings potential of cellular shades in 13 climate zones throughout California and the United States. The energy savings are modeled using EnergyPlus simulation software and include savings for three different prototype homes, two variations of window types and window area, and two different types of cellular shades. The model is validated using experimental data from the Pacific Northwest National Laboratory's Lab Homes. The results from this study provide valuable input for utility incentive programs around the United States.

Savings are most significant in smaller, existing homes with relatively high window-to-wall ratios. For these home types, energy savings associated with HVAC operation ranges from 10% to 34%.

3:30pm - 5:30pm
Palm Room

Session 17: Building Airtightness

Session Chair: **Graham Finch**, RDH Building Science

Nationwide Energy Impact of Envelope Air-Tightness in U.S. Commercial Buildings

Mahabir Bhandari, Som Shrestha, Andre Desjarlais, Melissa Lapsa
Oak Ridge National Laboratory

Air leakage in commercial buildings in the U.S. accounts for about one quad of energy annually. As the thermal resistance of commercial building envelopes continues to improve, the relative contribution of air leakage to heating and cooling loads has been increasing. To reduce air leakage in buildings, several manufacturers have developed advanced air barrier technologies and construction practices. Advances in easy to use tools for determining the impact of air leakage also helps in the market penetration of these advanced technologies. Oak Ridge National Laboratory, the National Institute of Standards and Technology, the Air Barrier Association of America, and the US-China Clean Energy Research Center for Building Energy Efficiency partnered to develop an online calculator that estimates the potential energy and cost savings in the major US, Canadian and Chinese cities from improvements in airtightness. The calculator estimates the energy and cost savings potential based on the pre and post-retrofit air leakage rates for prototype commercial buildings. These savings were extended to determine the national level energy savings potential by using the weightage of the type of commercial building in different ASHRAE climate zone locations. The base infiltration rates of 1.07

CFM/ft2 at 0.3 in. of water was assumed for these calculations and the savings were calculated for three different air infiltration target rates of 0.4 CFM/ft2(optional in most building codes), 0.25 CFM/ft2 ((as mandated by US Armey Corps of Engineers) and 0.06 CFM/ft2 (based on field tests of airtight of new constructions at 0.3 in. of water. The national source energy savings of 238, 283 and 313 TBtu respectively were estimated for these target air infiltration rates for seven type of commercial buildings considered in this study.

Automated House Sealing: Aerosol Envelope Sealing of New Homes

David Bohac[1], Curtis Harrington[2]

[1]Center for Energy and Environment; [2]UC Davis, Western Cooling Efficiency Center

A new aerosol sealing technology has been developed for automated house envelope sealing. The process involves briefly pressurizing the house while applying an aerosol sealant “fog” to the house interior. As air escapes through leaks in the envelope, the sealant particles are carried to the leaks where they impact and stick to seal the leaks. A standard blower door is used to facilitate the sealing process, and provide real-time feedback and a permanent record of the sealing.

This paper presents the results of project to identify methods to successfully integrate aerosol envelope sealing into the home building process. The project team worked directly with builders in California and Minnesota to identify the best stages for incorporating aerosol sealing from the perspectives of cost, performance, and seamless integration into the construction process.

One group of California used sealed attic construction with the first four houses using spray foam under the roof deck for insulation and air sealing. The two houses sealed prior to the application of spray foam had a tightness of 1.8 ACH50 prior to spray foam. This indicates that the air sealing of spray foam is not necessary when aerosol sealing is applied. When construction was complete the four houses aerosol sealed had an average tightness of 1.1 ACH50 which was 39% tighter than similar control houses. Two other houses with box netted insulation had an average tightness of 3.0 ACH50 after aerosol sealing and prior to drywall. A total of 13 of the 15 houses in Minnesota were sealed prior to drywall installation. They had an average tightness of 0.81 ACH50 and four were tighter than the passive house standard of 0.6 ACH50. For the first builder, at the end of construction the average tightness was 0.88 ACH50 which was 34% tighter than similar control houses.

Comparison of Several Air Sealing Methods for the Top Plate/Drywall Gap in Residential Walls

Michael Bowe

Dow Construction Chemicals, United States of America

One of the more difficult locations to air seal in wood framed construction is at the double top plate, especially with an attic or other unconditioned space above. Air can leak past the top plate both at exterior and interior walls. Practitioners of the airtight drywall approach have employed various methods to seal this gap. The oldest of these includes gun applied fluid beads such as caulk and drywall adhesive, and solid preformed gasket like sill sealer which can be stapled in place. Some installers have repurposed 1 component PU foam of the more compressible window and door formulations, and 1K or 2K PU foams have been applied from the attic onto the top of top plates. In the past decade, several spray applied foams or elastomeric formed in place gaskets have appeared on the market. More recently we have developed a water based 1 component gun foam which forms a compressible drywall gasket in place.

In this presentation we will compare and contrast these materials and methods for sealing this critical air leak. We will discuss their ease of use and limitations at the application stage, and then their impact on subsequent trades including their resistance to damage before the wall is closed and the materials are protected. We will select several of the methods whose air blocking performance we have measured on full sized walls, and show IR thermography from field trials.

Analysis and Lessons Learned from Whole-Building Air Leakage Testing of 250 Buildings

Medgar Louis Marceau[1], Alexander David Shrode[2]

[1]Morrison Hershfield Corporation, United States of America; [2]Morrison Hershfield Corporation, United States of America

Whole-building air leakage testing (WBALT) is a method of measuring air leakage through the building envelope of a completed building. It is used for code-compliance, construction quality assurance, and evaluating the performance of the air barrier. Uncontrolled air leakage contributes to higher energy use, thermal discomfort, poor indoor air quality, and degradation of building envelop materials. While most states and provinces require a continuous air barrier in new buildings, only Washington State requires that ALL new buildings be tested. Further, if the leakage rate exceeds 0.40 cfm/ft2, a visual inspection of the air barrier must be conducted and any leaks noted shall be sealed to the extent practicable.

The authors have collect a vast amount of data from performing WBALT over the past seven years, primarily in Washington State. This paper will present an analysis of the combined data from approximately 250 tested buildings from at least four testing companies: 40 from the authors’ and approximately 210 from three others.

The buildings tested consist of a wide range of building types: high-rise to low-rise; wood-framed and non-combustible construction; and residential and nonresidential. The cladding and fenestration systems also encompass a wide range of typologies: masonry veneer, mass concrete, rain-screen claddings, curtain wall, window wall, vinyl windows, vented and unvented roofs, and more. Among these cladding systems are various air barrier materials that include adhered membranes, fluid-applied membrane, and mechanically attached loose-laid sheets.

The data show many interesting trends such as:

• The measured leakage rate is decreasing over time due to contractor emphasis on air barrier quality control and due to lessons learned in properly preparing the building for testing.

• Certain building typologies, such as curtain wall, are intrinsically more air-tight then others; but even buildings with complex detailing and many different air barrier systems can be very air-tight.

3:30pm - 5:30pm
Bay Room

Session 18: Building Envelope Retrofit, Part 1

Session Chair: **Lisa White**, Passive House Institute US

Minimal Invasive Refurbishment of Post-War Buildings with a Multifunctional Façade Element

Michael Bayer, Markus Karnutsch, Matthias Gnigler, Thomas Reiter, Markus Leeb
Salzburg University of Applied Sciences, Austria

Aim of this paper is the description of the development of a prototype for the facade renovation of a multi-family residential building erected during the post-war period in Hallein. The prototype combines heating, insulation and sound absorption in one element. The façade serves as an example for buildings that are in need of renovation, while being minimally invasive and energy efficient.

The prototype was erected in December 2017. Relevant components of the prototype include an activated mortar layer in which the heating circuits for external wall activation have been placed, a composite wood panel, cellulose blown insulation, a wooden formwork, a rear ventilation gap and sound absorption panels.

During prefabrication process and the attachment of the façade element, component sensors were set for continuous monitoring of temperatures and relative humidity both in the façade element and in the existing outer wall.

Due to the activation from the outside, the heat dissipation systems in the interior become obsolete. A further interference with the private sphere of the residents is thereby prevented. The existing windows will be replaced by new windows. The U-value of the new overall construction is 0.18 W / m²K, which corresponds to a 120% improvement compared to the existing masonry.

The main heating circuit covers the wall part belonging to the measuring room, while the edge heating circuit covers the surrounding façade, in order to avoid transmission heat losses across the flanks. Both systems are recorded separately. The control strategy for water inlet temperature is driven by ambient temperature. Initial results show that a flow rate of 470 l / h at a maximum flow temperature of 35 ° C is sufficient to keep the measuring room at 22 ° C during the heating season. Additionally, accompanying simulations are carried out for the purpose of validation.

SIREN: A Comprehensive Framework for a Sustainable Renovation Process with a Holistic Approach

Petter Wallentén[1], Kristina Mjörnell[1,2]
[1]Dep. Building Physics, Lund University, Sweden; [2]RISE Research Institutes of Sweden

A comprehensive framework for a sustainable renovation process with a holistic approach to renovation has been developed within the swedish research project SIREN (Sustainable Integrated Renovation), taking into consideration the areas: technology, environment, economy, social values, architecture and cultural historical environment and construction management. The framework describes activities that will be carried out at different stages of the process, as well as charting who will be responsible for and performing these activities. The framework refers to available methods, tools and procedures that can be used for inventories, analyzes and decisions in the different stages of the renovation process to include all aspects that are essential for achieving sustainable refurbishment. After each stage (operating, planning, design, reconstruction and commission) in the renovation process a self-evaluation can be made to estimate to what extent each sustainability aspect has been considered and included. The framework has already been introduced to a number of real estate companies that have begun implementing parts or the entire framework in their operations. The purpose of the research project was:

• To create a framework for activities and methods with the goal of achieving sustainable refurbishment

• To document existing methods and tools such as routines, templates and checklists that can be used in therenovation process.

• Describe new methods and tools where they are missing.

• Provide good examples of how methods and tools can be used.

• To make the framework of activities and methods accessible to different actors in the renovation process.

Overall, all activities and methods contributes to long-term and life-cycle perspectives. The framework is not currently a national standard in sustainable renovation but it is a first step towards that.

Necessary Changes in the Residential Building Sector to Achieve the Climate Protection Aims for 2030/2050 in Germany

Andreas Holm
FIW-Munchen, United States of America

Moisture permeation is responsible for more than 90% of the ageing of VIPs with typical fumed silica cores. Reducing the moisture permeation by increasing the barrier properties of the multilayer plastic films is a well-established approach to enhance the service life of the fumed silica VIPs used in building applications. In addition, VIPs with fumed silica powders with slower increase of thermal conductivity in response to the absorbed moisture degrade substantially slower than others.

For this study, the sorption isotherms of several different fumed silica materials are measured together with other parameters, such as particle sizes and hydrophobization. This measured data is taken as input data for hygrothermal simulations of VIPs in summer and winter climates. Simulations of thermal conductivity

measurement setups in guarded-hot-plate apparatuses at different mean temperatures and with different temperature gradients are carried out to support the measurements and to better understand the thermal conductivity increases due to moisture distribution within the fumed silica powder.

The results are compared to the proposed method from the draft product standard for VIPs to determine the ageing of VIPs for building applications together with an estimation of the expected service life for VIPs with various powder formulations.

Retrofit of Masonry in Historic Buildings: Role of Climatic Loads and Material Parameters

Tessa K Hansen[1], Ruut H Peuhkuri[1], Søren P Bjarløv[2]
[1]Danish Building Research Institute, Aalborg University, Denmark; [2]Department of Civil Engineering, Technical University of Denmark

Historical buildings represent cultural, historic and aesthetic value, whether preservation worthy or not. For this reason, the concept of internal insulation has been introduced as a possible energy retrofitting measure for such buildings. The application of the thermal insulation on the interior side of the wall reduces the heating energy consumption and improves the thermal comfort. But it also changes the hygrothermal conditions of that wall reducing the drying potential and leaving the original wall colder and damper when compared to pre-retrofitting. This may lead to undesired consequences like interstitial condensation, mold growth, wood rot and the general deterioration of the façade materials and components.

The prediction of the hygrothermal performance of internal insulation solutions plays therefore an important role when designing successful retrofit measures. External loads, e.g. wind driven rain (WDR) and solar radiation, may vary largely depending the location and orientation and have a significant impact especially on historic buildings with porous masonry walls.

This paper presents assessment of the hygrothermal performance of internally insulated historic masonry by means of monitoring of case studies as well as by dynamic hygrothermal simulations. Simulations were used for detailed investigation of the effect of WDR on the hygrothermal conditions within the walls and which role other parameters play in the prediction of the performance.

The results from case studies showed no clear effect of the WDR on the performance of the internally insulated masonry. However, high loads from WDR inevitably increase the moisture content of the wall. The role of certain material parameters and orientation, including solar radiation in combination with WDR, was found in the simulations.

Date: Wednesday, December 11, 2019

7:30am - 8:30am — **Breakfast**

Beach/Gulf Room

8:30am - 10:00am

Bay Room

Session 19: Wind-Driven Rain

Session Chair: **Carsen Jeffrey Banister**, National Research Council Canada

Determining Moisture Source Due to Wind-Driven Rain for Input to Hygrothermal Simulations Using Experimental Methods

Travis V. Moore, Michael A. Lacasse, Maurice Defo
National Research Council Canada, Canada

Resilient building design is becoming increasingly important as occurrence and duration of extreme weather events increase. These events cause disruptions in building operation and safety due to lack of electric power or fuel. Several resilient design strategies exist, many of which are also sustainable or energy saving design strategies. Specifically, passive building strategies that favor energy conservation in buildings also have a positive impact on the building's resilience. Passive survivability is a key element to resilience, which can be assessed by simulating interior conditions during power outages in building energy modeling software. This paper will address passive survivability metrics and assessment protocol for passive survivability including a proposed methodology to derive climatic resilience design weeks. Additionally, it will cover simulation results from dynamic modeling completed in WUFIplus. These simulations assess passive survivability during power outages in varying multifamily building designs and inform the audience on how building design influences a building's ability to maintain desirable interior conditions during outages.

Impacts of Wind-Driven Rain Calculation Methods on the Moisture Performance of Wood-Frame Walls

Maurice Defo[1], Michael A. Lacasse[1], Sahar Sahyoun[2], Travis V. Moore[1]
[1]National Research Council Canada, Canada; [2]Concordia University

The semi-empirical wind-driven rain (WDR) calculation models in the ISO Standard (ISO) and the ASHRAE Standard 160P (ASHRAE), and the one by Straube and Burnett (SB) are compared with regard to their impacts on hygrothermal responses of four wood-frame walls differing by their claddings. Buildings of 2-storey, 4-storey and 10-storey located in suburban area were considered. Three Canadian cities belonging to different climate zones were selected for simulation: Ottawa (ON), Vancouver (BC) and Calgary (AB). Simulations were run for two years selected from a historical climate data set based on the moisture index. Water infiltration through the assembly was assumed to be 1% of the WDR as suggested by the ASHRAE Standard. Temperature (T) and relative humidity (RH) of the outer layer of OSB sheathing were compared amongst the three WDR models. The mould growth index on the outer layer of the OSB sheathing was used to compare the moisture performance predicted using the three WDR calculation methods. The total WDR sums obtained with the three models differ by city and building type (height). In most cases, the total WDR sums obtained with both ASHRAE and SB models are comparable and are higher than that obtained with the ISO model.

The differences observed in WDR results do not have impacts on the T profiles of the outer layer of the OSB Sheathing. For RH and mould growth risk, differences amongst the 3 models vary depending on whether or not the water infiltration is considered, the climate (city), the cladding and the building types. In general, both Straube and ASHRAE models give conservative results than the ISO model.

New Developments in Understanding Wind Driven Rain Deposition on Building Envelopes and its Consequences

Jan Carmeliet[1], Aytaç Kubilay[2], Jonas Allegrini[2], Dominique Derome[3]
[1]ETH Zürich, Switzerland; [2]Empa, Switzerland; [3]Université de Sherbrooke

Wind-driven rain (WDR) refers to rain droplets, driven by the wind, impacting on surfaces in the built environment, leading to wetting and drying processes affecting buildings and the urban microclimate. The proper understanding and management of WDR as water source in the built environment is required since evaporative cooling from wetted urban surfaces is a future avenue for mitigating urban heat island effects and heat waves, expected to increase due to climate change. A second reason is that WDR is a main agent of deterioration of building materials and, when climate change leads to more extreme weather events such as heavy rain, it is expected that building damage risks will increase in the coming decades.

The proposed methodology allows a better understanding and modeling of the different physical processes involved in WDR deposition on buildings. We have developed an Eulerian Multiphase CFD model for WDR prediction in complex urban environment. This model was validated with field rain measurements on multiple buildings and wind tunnel air flow measurements.

Studying rain deposition on facades, modulations such as roof overhang and balconies are shown to be effective at sheltering the facade from WDR, but are themselves exposed to higher amount of WDR compared to a flat façade. As the wind speed increases, the sheltering provided by roof overhang and balconies decreases as the raindrops move more horizontally. Windows sills are very effective at decreasing catch ratio and droplet impact speed. Contours of catch ratio on the ground show a high WDR intensity region around the building resembling a horse-shoe shape for wind direction perpendicular to the main façade. Finally, as a special case, we study the driving rain on a small train station shelter during a rain event and demonstrate the capabilities of our approach in informing designers.

8:30am - 10:00am
Palm Room

Session 20: Building Envelope Retrofit, Part 2

Session Chair: **Targo Kalamees**, Tallinn University of Technology

A Façade Retrofit Solution for Improving Energy-Efficient Thermal Comfort in Buildings

Vinay Kumar Natrajan, John Jose Pattery, Sasi Tallam, Shailendra S
Saint-Gobain Research India, India

A methodology for retrofitting of facades, via the addition of single- or double-glazings, has been developed in order to improve both the energy-performance of an existing building envelope and occupant comfort. This process of retrofitting is executed from the inside of the building, when the building is in use and with minimal disturbance to occupants. It also requires minimal intervention from the facilities team of the building, and does not involve de-commissioning of an office space during the retrofitting process. As such, this methodology of retrofitting is simpler and cheaper to execute when compared to the traditional method of re-installation of a new glazing from outside the building with/without- dismantling the existing glazing. The retrofitting solution has been launched at the pilot-scale, and has been demonstrated to reduce the heat-ingress from glazings by roughly 50%. Pre- and post- retrofit evaluation of the occupant thermal comfort in an office space, as quantified using spatial distributions of the operative temperature, revealed a significant improvement in the thermal comfort of the space close to the facade. Depending on the time of the day, the drop in the operative temperature is found to range from 1.5 to 4 degC at workstation locations closest to the façade. Additionally, an improvement in the acoustic comfort is also noted, and the peak noise levels measured close to the façade (inside the building), are seen to drop from 48dB for the pre-retrofit scenario to 36dB for the post-retrofit scenario.

Hygrothermal Performance of Mass Timber Wall Assembly with External Insulation Finish System

Villu Kukk, Jaan Kers, Targo Kalamees
TalTech University, Estonia

In terms of safe hygrothermal performance, the building envelope requires correct rain protection, air tightness, sufficient dry-out capacity and the correct location and tightness of the vapor barrier. The objective of this research was to evaluate the impact of the rainwater leakage and dry-out capacity on the hygrothermal performance of an MHM external wall with the ETICS system. Based on the validated hygrothermal simulation model, the hygrothermal performance of mass timber wall construction with ETICS was analysed in Delphin software. Estonian moisture reference year for mold growth as boundary conditions and wind-driven rain load with 1 % of leakage were used in the analysis. Hygrothermal performance of the studied wall was evaluated by the risk of mold growth on the material surface, which was measured with a mold growth index. The results of this study showed that using a vapor and airtight membrane between ETICS and MHM panels can prevent high humidity on the MHM panel surface in case of 1 % of rainwater penetration and thereby avoids the risk of mold growth on a wooden surface. The given solution works only if the thermal insulation composite system provides sufficient dry-out towards the exterior and EPS insulation is not recommended as it poses a high risk of mold growth on MHM panel surface. In addition, based on the results it was recommended to keep the initial moisture content in MHM panels below 19% to prevent an extended dry-out period and thereby prevent the possible risk of mold growth.

Hygrothermal Performance of Post-Retrofit Wood-Frame Building Envelopes with Added Rigid Exterior Insulation: Field Measurements and Simulations

Jieying Wang[1], Hua Ge[2], Lin Wang[2]
[1]FPInnovations, Canada; [2]Concordia University, Canada

This paper covers field measurements and hygrothermal simulation results about post-retrofit building envelope performance of two wood-frame multi-unit residential buildings with rigid exterior insulation added during the retrofitting in the coastal climate of British Columbia. Building No. 1 had 2 in. (50 mm) thick expanded polystyrene insulation boards installed in its exterior walls during re-cladding, and tapered polyisocyanurate insulation boards in thickness from 4 in. (100 mm) to 1 in. (25 mm) installed on its low-slope vented roof during re-roofing. Building No. 2 had 3 in. (75 mm) thick mineral wool insulation boards installed in its exterior walls. Moisture content and relative humidity sensors were installed in these wall and roof assemblies, at a total of 12 measurement locations to assess post-retrofit building envelope performance. The field measurements confirmed that the exterior insulation greatly reduced fluctuations in both temperature and relative humidity for the plywood exterior sheathing, and in particular, kept the sheathing warm and the relative humidity low in the cold and damp winter. The expanded polystyrene and mineral wool insulation boards installed in the exterior walls of these two buildings caused small differences in driving forces and potential directions of vapour flow, particularly under warm weather conditions. The hygrothermal simulations carried out for these assemblies produced results reasonably close to field measurements, therefore the hygrothermal models are considered validated. And the validated models can be used for assessing the hygrothermal performance of the retrofitted envelopes in other climate conditions.

10:00am - 10:30am **Break**

10:30am - 12:00pm
Bay Room

Session 21: Vacuum Insulation Panels

Session Chair: **Pär Johansson**, Chalmers University of Technology

Evacuated Spheres for Closed-Cell Vacuum Insulation

Diana Hun, Tomonori Saito, James Klett, Kaushik Biswas, Tolga Aytug, Kai Li, Bingrui Li, Shrestha Som, Soydan Ozcan
Oak Ridge National Laboratory, United States of America

Insulation materials with a thermal resistance that is higher than R6.5/in are needed for building envelope retrofits in which solutions with slim profiles are required because of minimal available space or because real estate has a premium cost. Vacuum insulation panels (VIPs) are the current state-of-the-art insulation material with a thermal resistance of about R35/in; however, their use in buildings has been hindered by the fact that damages to their protective film decrease their thermal resistance to ≤R8/in. Given the lack of robust, highly-insulating materials, we are exploring the development of evacuated spheres that can act as a closed-cell vacuum insulation, or simply put, miniature VIPs. The evacuated spheres will be assembled into 4×8 ft or larger boards that could attain a thermal resistance of ~R14/in. Advantages that evacuated spheres will offer over VIPs are that they will be more suitable for construction because punctures will only cause localized damage, and that the boards can be cut into customized shapes. We are currently investigating two distinct processes to evacuate spheres to produce polymeric vacuum insulation spheres (PVISs) and coated and evacuated insulation spheres (CEISs). PVISs involve the extrusion of economical polymers, blowing agents, and gas barriers. CEISs use naturally-occurring or synthesized hollow particles with porous shells that are evacuated and coated with a gas impermeable thin film. Both manufacturing processes are targeting to be scalable to very large throughputs to ensure cost-effectiveness and adoption by the construction industry. This paper discusses the manufacturing techniques that we are exploring and our progress to date.

Design of a New Moisture-Based Accelerated Ageing Procedure for Vacuum Insulation Panels

Alexander Thomas Hayes, Cynthia A Cruickshank, Christopher Baldwin
Carleton University, Canada

When retrofitting a building, or constructing to higher insulating levels, the finished thickness of the building envelope must be considered. To meet the energy and space saving requirements of today's market, builders are looking for new materials to insulate their walls that do not require new assemblies, new construction practices, or that require a large thickness to meet the desired insulating levels. Vacuum insulation panels (VIPs) have shown potential to meet or exceed today's high insulating levels while keeping the thickness of the building envelope down. Integrating VIPs within a building envelope can significantly decrease home heating requirements, especially in heating dominated climates. However, integrating VIPs into the construction market remains a challenge, as there is an unknown service life of the panels, which degrade over time, and no data on how different climate conditions affect panel lifespan. It has been presented in literature that moisture can diffuse into panels under humid conditions, resulting in a decrease in thermal resistance over time. Recent research has used varying climate conditions in accelerated ageing testing to determine the service life of VIPs, however, a disconnect remains between results obtained under laboratory conditions and the degradation in performance observed in actual applications. This paper presents a new method to link results obtained from accelerated ageing with real time degradation, using moisture as the principle ageing mechanism. To determine how moisture affects the thermal performance of VIPs, VIPs from two manufacturers were held in a Constant Temperature and Humidity Chamber (CTHC) at 30℃ (86°F) and 90% RH for 30 days. VIPs from the first manufacturer experienced a 0.2% mass increase from an initial mass of 840 g (29.63 ounce) due to moisture and a decrease of 5% in thermal resistance. VIPs from the second manufacturer experienced a 0.05% gain in mass from an initial 246 g (8.67 ounce) and a decrease of 6.5% in

thermal resistance. In finding that moisture gains within VIPs can cause a decrease in insulating capacity, the new accelerated ageing method links CTHC ageing to real time VIP degradation through moisture content of the panels.

Field Testing of Interior Super Insulation Materials on a Brick Wall in an Industrial Building

Pär Johansson[1], Paula Wahlgren[1], Petra Eriksson[2]
[1]Chalmers University of Technology, Sweden; [2]Uppsala University, Sweden

Conventional thermal insulation materials, such as fiber glass and EPS, demand a thick layer of insulation to reach the energy targets. Super insulation materials (SIM) are thermal insulation components with a 3-10 times higher thermal resistance than conventional insulation materials, such as vacuum insulation panels (VIP) and aerogel blankets (AB). They are efficient in increasing the thermal performance of walls when retrofitting, without significantly tampering with the wall thickness. Usually other measures such as changing windows or heating system are preferred before adding insulation to the walls, but to improve the thermal comfort and energy performance further, interior insulation is a possible alternative. In this study, an industrial building from 1896 with a 470 mm (1.5 ft) homogenous brick masonry wall is investigated regarding the hygrothermal performance and thermal inertia of the wall with interior insulation. Earlier research has shown that interior insulation decreases the drying-out capacity of the exterior wall and increases the risk for freeze-thaw damages in brick walls. In this study measurements from field investigations and simulations of a homogenous brick wall with 20 mm (0.8 in) interior VIP and 20 mm (0.8 in) aerogel blankets are compared to a non-insulated reference wall. The measurements showed that the wall was wet throughout the measurement period while the measured U-value was reduced with 82-83% for the AB and 81-84% for the VIP layers.

10:30am - 12:00pm
Palm Room

Session 22: Thermal Performance of Building Envelope Components

Session Chair: **Peter Adams**, Morrison Hershfield Ltd.

Improving the Energy Efficiency of Insulated Siding by a Factor of Five

Andre O. Desjarlais[1], Kaushik Biswas[1], Chris Johnson[2], Douglas Smith[3]
[1]Oak Ridge National Laboratory, United States of America; [2]Royal Building Products; [3]NanoPore, Inc

Retrofitting an existing wall assembly to make it more energy-efficient is probably the most difficult technical challenge facing the building industry. Common approaches used today include cavity fill techniques, adding continuous foam or fibrous insulation, or adding an insulated cladding or siding product.

Filling wall cavities with loose fill insulation is the most common practice, but conventional “drill and fill” techniques result in damage to interior gypsum board that is difficult to repair to hide the damage completely. Performing the task from the exterior side requires the removal and replacement of the cladding system and adds appreciable cost to the project. Even after the work is completed, the wall system is usually under-insulated by today’s standards. Continuous insulation can be applied to the outside of the exterior sheathing. Again, the removal and replacement of the cladding system and adds appreciable cost to the project. The addition of this amount of continuous insulation requires that all the architectural details be re-trimmed.

Today’s state of the art in terms of energy-efficient cladding is expanded polystyrene foam insulated vinyl siding with a minimum thermal resistance rating of R2 (hr-ft2-°F/Btu).This paper will report on a research project to produce vacuum-insulated vinyl siding that would represent at least a 5-fold thermal improvement from currently available insulated siding products. It has sufficient R-value to meet the continuous insulation requirements of the IECC in all climate zones and has a thin profile that will facilitate its application to existing homes without the need for expensive re-trimming of the architectural details. The paper will include issues associated with the design of the insulated siding, the development of prototypes, laboratory testing of the thermal performance of the cladding system, and field testing to measure the in-situ thermal performance and the durability of the cladding product.

Case Study: Wall Thermal Performance of the 3D Concrete Printed Affordable Homes

Paola Sanguinetti, Omar Abdulmughni Humaidan, Khaled Ali Almazam, Joe James Colistra
The University of Kansas, United States of America

Additive manufacturing (3D printing) is entering the construction market as an emerging technology that augments the sufficiency of manufacturing time and affordability of construction. However, more research is needed on the thermal performance of the 3D printed homes. The purpose of this study is to evaluate the potential of concrete 3D printing for the construction of Net Zero energy affordable homes in the Midwest region of the United States. The study examines the need for thermal insulation in this construction type and compares the predicted energy savings to the cost of the investment in 3D printed construction. The case-study consists of three steps: 1) a computational fluid dynamics (CFD) analysis of the 3D printed envelope to understand it thermal properties using THERM; 2) an energy simulation of the home to understand the predicted energy consumption and potential savings in monthly utility bills using e QUEST; and 3) the calculation of the simple payback for the initial investment in 3D printed technology. Three options for locating insulation in 3D printed walls will be studies and used as input for the energy simulation. The output will be examined to evaluate the potential meet the Net Zero Energy Building principles. A financial analysis of the payback period will integrate the construction cost based on the site, average annual income, to verify the affordability of the 3D printed home. Based on the results, design guidelines are discussed for future 3D printing building standards. It is expected that the results of this case study will inform the design of 3D printed envelopes towards energy efficient and affordable residential construction.

Thermal Effects of Adding a Balcony and a Window to a Wood Stud Wall Assembly

Mehdi Ghobadi, Travis V. Moore, Michael A. Lacasse
National Research Council Canada, Canada

Improving the thermal performance of buildings is an essential element when addressing issues related to the effects of climate change on the building envelope. Minimizing energy usage of and heat losses from buildings are important measures in achieving these associated goals. It is recognized that the majority of the heating and cooling demand is caused by thermal transmittance through wall assemblies. Hence, characterizing the thermal performance of wall assemblies is a vital part of the design process to help ensure heating and cooling systems have been properly sized. In this context, it is generally recognized that thermal bridging can affect the overall thermal performance of wall assemblies. In this study the thermal bridging effect of a balcony slab edge and window on wood stud wall assemblies were investigated both experimentally and numerically. Two 2.4 m × 2.4 m wood-stud wall assemblies, typical of North American wood-frame construction practice, were fabricated with openings to accommodate a slab edge in one assembly and a window in the other. The openings in the wall assemblies were first filled with EPS and thereafter tested in the guarded hot box; following which, the EPS in the respective wall assemblies, was replaced either with a slab edge or a window. COMSOL Multi-Physics was employed to model the heat transfer across the wall assemblies using a three dimensional simulation configuration of the walls. The use of a three dimensional configuration of the wall assemblies was considered critical to completing the investigation, given that lateral heat transfer is a highly significant component when considering how thermal bridging affects the overall thermal transmittance through the wall. The numerical results were benchmarked against results obtained experimentally from completion of standard guarded hot box tests. The results were used to study the reduction in thermal resistance for each case.

12:00pm - 1:30pm **Lunch**

Rusty's

1:30pm - 3:00pm **Session 23: Moisture and Mold**

Bay Room Session Chair: **Jesper Arfvidsson**, Lund University

Parametric Study of Mold Risk in the Climate Envelope of Timber Buildings Using Hygrothermal Simulations

Oskar Ranefjärd[1], Eva Frühwald Hansson[1], Anders Rosenkilde[1,2]
[1]Department for Building and Environmental Technology, Lund University; [2]TMF- Swedish Federation of Wood and Furniture Industry

With global efforts in reducing energy consumption, house manufacturers are seeking use of new materials and design solutions. However, some believe this will increase the risk of mould. One way to assess the mould risk is to use a hygrothermal software for simulating the climate envelopes' moisture performance. But as with all simulation, the quality of the output can never be better than the quality of the input. In moisture design, some parameters are only based on engineering judgement, which increases the uncertainty. The purpose of this paper is therefore to examine the risks and uncertainties of moisture safety design using WUFI. The parametric study is done by using a factorial design and a mould risk assessment tool, Mould – Resistance Design (MRD), to identify what parameters are most influential in affecting the mould risk. The study includes common mould risks, as rain leakage and small air gaps, but also typical ways in which timber house manufacturers try to improve the moisture resistance. Some of the results were quite expected, e.g. the mould risk increases with water leakage closer to the timber frame. But the methodology also showed that changing the façade insulation to a PIR- insulation increases the mould risk more than the risk is decreased by the increased thermal insulation. The study also proves a point in that a lot of the included factors are just assumptions based on estimates while the real values are unknown, and they still are the most influential. Other parameters that had significant importance are often neglected in moisture design, for instance the coefficient regarding wind driven rain and the temperature of the cladding. This paper further acknowledges that there are many and big obstacles in performing a good moisture safety assessment.

Performance of Models in Predicting Mold Growth on Building Materials

Pernilla Johansson, Lukas Lång, Carl-Magnus Capener
RISE Research Institutes of Sweden, Sweden

Several mould models, aiming to predict the possibility for mould growth on various building materials, have been presented during the last 10-15 years. These are available as postprocessors in hygrothermal calculation programs, as stand-alone programs or are documented as scientific or conference papers. In addition to input of relative humidity (RH) and temperature data, some assumptions need to be made by the end user on, for example, material properties. Previous evaluations of performance have focused on comparisons on theoretical differences in outcome. In this study, RH and temperature measurements from a field study was used as input in different mould models. The results, i.e. if there is a possibility for mould growth or not, were compared to observations of mould growth on test specimens of building materials exposed in the field study where the measurements took place. This study was conducted as a round robin test, part of the Horizon 2020 project RIBuild. Partners chose which model to use and the values of different input parameters. Results show that in extreme cases, very wet or very dry conditions, the models predict accurately. However, when the RH and temperature varied a lot, daily and yearly, the outcome of most models did not agree with the real analysed results; in general they predicted no mould growth when there was extensive growth, with one exception where the model predicted correct in most of the cases. Also, the choices on parameters by different partners influenced the results. One conclusion is that results of the models often

vary depending on end user and the usability may be limited. More knowledge is also needed on how periodic hygrothermal variations should be considered in the models.

Fast, Energy Efficient and Noiseless Wall Drying System

Hartwig Michael Kuenzel
Fraunhofer IBP, Germany

Floods or leaking water pipes have become an increasing problem for building owners and insurers because their frequency and restoration costs are rising. To avoid moisture problems, such as mold growth, the drying process should be fast and effective, usually necessitating special drying devices. These devices either heat the wall, e.g. by infrared panels, or lower the humidity of the ambient air by adsorption or condensation drying systems. Both methods consume a lot of energy which. To reduce the energy consumption without compromising the drying efficiency, a novel drying system has been developed and tested that keeps the applied heat in the wall and lets the moisture out by vapor diffusion. This system consists of a panel with temperature controlled heating wires covered by a mineral fiber slab wrapped in a vapor permeable mesh. To dry a wet wall, the panel is applied with the heated side to the wall. Moisture evaporated from the wall penetrates the insulation layer by diffusion and is released as vapor to the ambient air at the backside of the panel. Compared to conventional wall drying devices, the energy savings by employing the new drying system exceed 80% at the same drying rate. This is mainly achieved by the vapor permeable insulation layer that effectively reduces the heat flux from the wall into the ambient air.

1:30pm - 3:00pm
Palm Room

Session 24: Thermal and Hygrothermal Performance of Walls

Session Chair: **Jasha Kistler**, RWDI USA LLC

Field Study and Analytical Assessment of Two Exterior Walls in a Hot and Humid Climate

Alejandra Nieto[1], Andre Desjarlais[2], William Miller[2]
[1]ROCKWOOL, Canada; [2]Oak Ridge National Lab

A one-year field study was conducted at the Natural Exposure Test (NET) facility on two wall systems exposed to the hot and humid climate of Charleston, SC. Both walls installed on the southern exposure. The first wall is a mass wall (CMU), fully grouted with acrylic stucco finish. The interior of the assembly consists of a layer of vapor permeable rigid insulation and gypsum board finished with latex paint. The second wall is a steel framed wall with semi-rigid batt insulation. The exterior of the assembly consists of clay brick cladding, an air space, vapor permeable semi-rigid insulation and exterior gypsum. The interior of the assembly is gypsum board attached to the steel frame finished with latex paint. Both walls were insulated using vapor permeable mineral wool insulation, applicable to the type of construction. The relative humidity, moisture content and overall heat flux within the assemblies was monitored and analyzed. Field data did not reveal evidence for the potential of moisture condensation in either wall assembly. Although, higher levels of relative humidity were found in both walls during certain times, with the highest values observed during the summer months when the partial pressure gradient from outside to inside would drive moisture into the wall. The relative humidity on the interior side of the gypsum board was found to be highest for the steel framed with clay brick cladding wall, as compared to the mass wall. WUFI ORNL simulations were conducted using the measured indoor and outdoor temperatures and relative humidities as boundary conditions. Simulations showed the clay brick was often wet due to nighttime sky radiation which drops the wall temperature below the dew point temperature of the outdoor air. Moisture content for the layers of mass wall construction show that water diffuses primarily from the exterior toward the interior.

Understanding the Benefit of Ventilation in Stucco Assemblies

Theresa Ann Weston
DuPont, United States of America

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. Stucco use is regional being concentrated in the West (56% in 2015) and South (21%). Despite stucco's popularity over the last 20 years, stucco systems have been associated with several performance questions, including cracking and water intrusion. To respond to the performance questions, proposals requiring ventilation behind the stucco have been proposed to codes and standards in the USA. Additionally, new products have been introduced to facilitate back-ventilation of stucco. Products designed to provide behind cladding ventilation were tested for the amount of airflow under static air pressure difference as measured by ASTM E2925-17 Standard Specification for Manufactured Polymeric Drainage and Ventilation Materials Used to Provide a Rainscreen Function. The experimental data was used in conjunction reported field air pressure differences to inform a parametric modeling study. The goal of the modeling study was to better understand the moisture performance benefits of stucco back-ventilation. The study included the effects of climate, stucco material properties and other assembly characteristics. This paper will present the results of this study against a background of codes and standards development.

Taking the "Perfect Wall" Concept to the Next Level

Hamid Heidarali, John Cheng
HDB, Canada

The concept of "Perfect Wall" is well-known in the industry for its premium performance in cold climates. It consists of a vapour retarding membrane

outboard of the wall structure, complete with all the thermal insulation outboard of that membrane. The vapour retarding membrane serves as vapour

retarder, air barrier, and the last line of defense against rain entry. This wall configuration results in superior condensation resistance, uniform

temperature of the wall structure, reduced thermal bridging, several lines of defense against rain penetration, and a service cavity inboard of the

environmental control layers.

It is acknowledged that the “Perfect Wall”, using a vapour retarding membrane, offers robust performance. That said, would there be room for

improvement? For example, is the vapour retarding characteristic of the membrane still necessary in assemblies that incorporate concrete or mass wood,

both of which already offer reasonable resistance to vapour diffusion? Is it possible to improve the performance of these high moisture storage capacity walls

by switching to a vapour permeable membrane?

This paper provides answers to the above questions using a holistic perspective. Supported by physics and hygrothermal analysis, the paper compares the

performance of exterior insulated concrete and mass wood walls using vapour permeable vs vapour impermeable membranes. Various conditions will be

explored such as normal environmental loads, incidental rain, and construction moisture.

The study suggests that when it comes to exterior insulated concrete and mass wood walls, switching to a vapour permeable membrane would take the

“Perfect Wall” concept to the next level, by improving its year-round performance and drying potential, with the latter being an important consideration

for areas with high precipitation and low sun exposure.

3:00pm - 3:30pm **Break**

3:30pm - 5:30pm
Beach/Gulf Room

Session 25: Window Integration Systems

Session Chair: **Mahabir Bhandari**, Oak Ridge National Laboratory

Impact of Double-Glazed Window Filled with Phase Change Materials on the Energy Performance and Thermal Comfort of an Office Space Located in a Semi-Arid Climate

Daniel Uribe[1,2], Sergio Vera[1,2]

[1]Department of Construction Engineering and Management, School of Engineering, Pontificia Universidad Católica de Chile (PUC Chile), Chile; [2]Center for Sustainable Urban Development (CEDEUS)

Double glazed windows filled with phase change materials (PCM) is a strategy that increases the thermal inertia of the building envelope, which has the potential to improve the occupants’ thermal comfort and decreases the cooling energy consumption of office buildings. EnergyPlus®, a building performance simulation tool, incorporates a heat transfer model of opaque constructions with PCM; however, it is not possible simulating the heat transfer in transparent surfaces filled with PCM to estimate their impact on the building heating and cooling energy consumption and thermal comfort. Therefore, this paper aims to integrate a validated heat transfer model of a PCM glazing, previously developed by the authors, into EnergyPlus, and to evaluate the impact of PCM windows on the thermal and energy performance of an office building located in Santiago of Chile, which is characterized as a semi-arid climate (Bsk according to Köppen-Geiger climate classification). The heat transfer model of the PCM glazing considers conduction, convection, and short and long wave radiation. The latent heat of the PCM is modeled considering the enthalpy variation of the PCM as a function of the temperature. A Prototype Building Model of a medium office building with a high percentage of glazed façade is considered as a study case, while five paraffin waxes of Rubitherm® company are evaluated (RT25, RT25HC, RT28HC, RT31, RT35). Currently, we are finalizing the integration of the PCM glazing heat transfer model into EnergyPlus®, thus no results can be shown in this abstract. However, the full paper will include results how the different PCMs influence the office HVAC energy consumption and thermal comfort (based on Predicted Mean Vote).

Energy Savings from PV-Integrated Window Glazing

Charlie Curcija[1], Jinqing Peng[2], Howdy Goudey[1]

[1]LBNL, United States of America; [2]Hunan Unioversity, China

BIPV windows refer to the integration of electricity-producing PV elements into a window or building façade system, most commonly glazing or spandrel panels. There are several types of BIPV glazing systems available today, ranging from light redirecting layers that direct solar radiation to strategically placed PV cells, to semi-transparent PV coatings (STPV) and traditional opaque PV cells integrated into selected area of laminated glass. Compared to other advanced window technologies, BIPV glazing is distinguished by the ability to transform a portion of the incident solar irradiation into useful electrical power through the photovoltaic effect, while at the same time contributing to the regulation of solar heat gain and daylighting glare by reducing the solar transmittance through the glazing PV. In this paper we present results of measurements of commercial windows incorporating PV-integrated glazing, where crystalline opaque PV cells are cut into strips and integrated into a glass laminate. This glass laminate is incorporated into the insulated glazing unit (IGU), where glass laminate with PV is outdoor-facing to maximize the conversion of solar radiation into electricity. Because the crystalline solar cell area is opaque, transparency of the glazing system is achieved by

appropriately spacing PV strips, so that there is alternating transparent and opaque area. Effects on cooling and heating loads and daylighting potential of windows is evaluated in addition to electricity generation.

The Impact of Different Climates on Energy Efficiency of TiO2@W-VO2 Thermochromic Thin Film for the Application of Energy Efficient Smart Windows

Mohammad Salamati[1], Ghazal Kamyabjou[1], Katayoun Taghizade[2], Elaheh Kowsari[3]
[1]North Carolina State University, United States of America; [2]University of Tehran, Iran; [3]Amirkabir University of Technology, Iran

Windows provide natural light and view of the outdoors in buildings that affect human health, well-being, satisfaction, and productivity. Nonetheless, poor thermal performance of windows is one of the most important factor which has limited architects and designers to take the best advantages of natural light in buildings.

Employing enhanced glazing technologies such as smart and switchable glazing is an effective solution to this problem that can decrease energy consumption in buildings significantly while improving indoor environment quality. Various types of smart glazing have been proposed in this regard, among which thermochromic (TC) glazing due to its high energy saving and passive function with no activation electricity is considered as one of the most promising type of smart glazing. Thermochromic glazing through a reversible phenomenon changes its reflectance rate for solar infrared light in accordance to outdoor temperature. As the result, by reflecting solar heat radiation during summertime and transmitting that during wintertime, thermochromic glazing reduces energy consumption in buildings.

Based on the thermochromic property of vanadium, the authors reported a type of TC coating by sol-gel method. After preparing the chemical solution and coating a quartz in the lab, we carried out SEM test, photocatalytic test, and spectrophotometry test to characterize the fabricated TC glazing.

In this research, we use a series of energy modeling studies to evaluate the performance of the fabricated TC glazing and quantify energy saving achieved by that, in different climates. For these purposes, a simple model of hypothesis room is created in EnergyPlus computer software and the optical and thermal characteristics of the simulated thermochromic glass are obtained from the result of spectrophotometry test.

Local Ventilation Energy Recovery Unit for Windows

Charlie Curcija[1], Jinqing Peng[2], Howdy Goudey[1], Christian Kohler[1], Robert Hart[1]
[1]LBNL, United States of America; [2]Hunan Unioversity, China

Ventilation represents large portion of building cooling and heating loads whether it is from the introduction of outdoor fresh air and the need to condition this air or from electric consumption from large central fans that need to move this air through the building regardless if HVAC system is running. In this paper we describe design and development of autonomously operated local ventilation and energy recovery (LVER) unit that can replace or augment traditional inefficient centralized ventilation designs with a distributed network of efficient localized dedicated outside air systems (DOAS), integrated with windows. These systems provide partially conditioned outside on demand directly to the area where fresh air is required. The window frame integrated LVER unit consists of an energy recovery core and low-power wireless sensors controlled by a “system-on-a-chip” that minimizes energy use and ensures proper air distribution to perimeter zones. LVER units can be distributed along building façades and mesh-networked with the overall HVAC control systems, including carbon dioxide sensors located in the conditioned perimeter spaces. An energy recovery core is incorporated to condition incoming air for both temperature and moisture content, saving energy due to decreased temperature and humidity differentials between the supply and room air. The LVER unit development consists of 1) development of the energy recovery core (membrane heat and moisture exchanger); 2) development of the housing that is integrated with the window framing; 3) sizing and design of air flow pathways, including dampers and their actuators; 4) development of control logic and board, including sensors; 5) battery and PV modules; and 6) testing and energy savings simulation. In combination, the high-performance window and LVER ventilation unit will reduce electricity use by reducing HVAC loads, reduce the size of HVAC equipment and distribution systems, and eliminate the need for perimeter heating and cooling.

3:30pm - 5:30pm
Palm Room

Session 26: Thermal and Hygrothermal Performance of Roofs

Session Chair: **Emishaw Iffa**, British Columbia Institute of Technology

Monitoring of Unvented Roofs with Diffusion Vents and Interior Vapor Control in CZ 5A

Kohta Ueno, Joseph Lstiburek
Building Science Corporation, United States of America

Unvented roof assemblies have been accepted in North American building codes since 2007; code-compliant construction calls for a minimum thickness of “air-impermeable insulation” (based on climate zone) to avoid cold-weather condensation and moisture risks. This is typically implemented with polyurethane spray foam insulation; however, negatives of this material include high first cost and possible adverse environmental impacts. Implementing unvented roofs in a moisture-safe manner with fibrous fill insulations (e.g., fiberglass or cellulose) could potentially reduce the first cost of unvented roof designs, allowing for more widespread use. Building unvented roofs in a cost-effective, airtight, and moisture-safe manner opens up options for high-performance house designers and builders.

This research involved construction of a conditioned test hut in a cold climate (Climate Zone 5A) with multiple side-by-side instrumented roof rafter bays. These test bays compared code-compliant construction (hybrid spray foam/cellulose) with experimental options. Examined variables included the presence or absence of a ridge diffusion vent (vapor-open material at the roof ridge to promote drying), the effect of various interior vapor control membranes (fixed and variable permeance), the effect of interior relative humidity, and the effect

of interstitial airflow (from the interior into the cavity). This research spanned three winters' worth of monitoring, varying interior conditions, roof configurations, and other variables between winters.

At moderate (30-40%) interior RHs, the roofs with variable-perm interior vapor control and a ridge diffusion vent showed acceptable performance; other roofs had less favorable results. At elevated interior RH (50% constant), greater moisture accumulation was seen in all roofs; disassembly revealed mold spotting at the ridges of most roofs. Code-compliant hybrid spray foam/cellulose roofs showed low moisture accumulation and safe performance, compared to the experimental fibrous insulation roofs.

Measured Moisture Performance of Sealed and Insulated Attics with Permeable Insulation in California Homes

Iain Walker, Brennan Less

Lawrence Berkeley National Laboratory, United States of America

This study performed detailed thermal and moisture measurements in two homes in Fresno and Clovis, California with sealed attics insulated with glass fiber insulation to determine if this construction technique is suitable for use in inland California climates. The field monitoring used automated data acquisition to record every minute for more than a year for each home to allow detailed observation of time-varying moisture and thermal conditions. Moisture measurements were taken at multiple locations in each attic and included wood moisture, surface condensation and surface relative humidity. The results showed that there are strong solar-driven diurnal cycles in attic wood and air moisture content and longer-term seasonal and annual variations. These complex moisture dynamics lead to a risk of mold developing even in these sunny dry climates with attics built in compliance with building codes that specifically address sealed and insulated attics with vapor-permeable insulation. We investigated moisture stratification in the attics and found that, although there is stratification under some conditions, they are not those under which wood moisture content, surface humidity or surface condensation are high. Therefore, other moisture transport mechanisms are acting to increase moisture levels near the roof peak. The results also showed that the attic that had the highest moisture levels did not have any mold growth, but mold was visually observed in the attic whose measurements indicted little or no concern, indicating that the state-of-the-art in moisture measurement may be insufficient. Lastly, the results indicate that the effects of attic geometry and solar orientation play a strong role in the susceptibility to potential moisture problems.

Attic Innovations for High Thermal Performance and Durability

Achilles Karagiozis[5], Joseph Lstiburek[2], Neil Freidberg[1], Dean Potter[3], Eric Werling[4], Mikael Salonvaara[6], Anthony Fontanini[5]

[1]Owens Corning, United States of America; [2]Building Science Corporation; [3]K. Hovnanian® Companies, L.L.C.; [4]U.S. Department of Energy; [5]National Renewable Energy Laboratory; [6]Oak Ridge National Laboratory

Innovations in creating a highly insulated durable attic will be presented. The proposed method deploys fundamental principles of thermal performace benefits of unvented attics with a vapor diffusion port at the ridge of the attic and insulation at the floor level of the attic. These attics are sealed, creating no intentional ventilation with the exterior or even interior. This is particularly of value in hot and humid or mixed climate zones where a significant part of the year exist with rather high exterior relative humidities. Current unvented attics reduce the moisture loading during this period but also have sigificant moisture content gradients near the ridge of the attic.

Conventional ventilated attics, are also in risk for condensation when radiant barriers are deployed along with properly sized HVAC systems. Attics are cooling and ducts colder and the moisture drying potential is seriously diminished as the run-time is longer. Condensation around the ducts is present.

To combat this issue an innovative approach championed by the authors is deployed. A diffusion port (allows vapor diffusion but not air flow passage) along the ridge is used to allow vapor to escape from the attic and dry the roof in the cold periods of the year. This vapor diffusion port is a water vapor pressure release valve that creates passive drying from the interior to the exterior of attic.

The presenters will describe the deployment of this innovative approach to create great performing attics (R-50 to R-70) burying the air tight ducts with an air tight attic floor lid. A combined theoretical analysis (advanced hygrothermal modeling analysis) will be presented along with the measurements of 4 real building attics located in Southern hot and humid USA.

Buried Ducts: A Cost-Effective Technical Solution to High Performance Homes

Achilles Karagiozis[1], Mikael Salonvaara[2], Neil Freidberg[3], Kauri Salonvaara[4]

[1]National Renewable Energy Laboratory; [2]Oak Ridge National Laboratory; [3]Owens Corning Science and Technology; [4]Georgia Tech Institute of Technology

Traditionally, attics have been insulated at the flat ceiling with deliberate venting to manage heat and moisture. Having all the duct air distribution system in the occupied space is the best building science approach, however this is not always the preferable solution for builders that like to use the roof space for air distribution. Ducts in attics are exposed to very intense heating and cooling conditions. Not only do we have thermal conduction, convection and radiation exchanges occurring but important duct leakage losses that create significant energy balance losses. In the recent IECC 2018 code, deeply buried ducts systems with minimal air leakage conditions are allowed to be assigned similar performance to those attics that are sealed (non vented). In this presentation we will describe the field/laboratory and modeling effort undertaken by to quantify the performances of attics and duct systems in a number of climate zones. Climate zones 2A and 2B are included in the field testing, include both hot/dry climates and hot and humid climates. What was repeatedly found was the attics that had deeply buried ducts with low air duct leakage had excellent thermal performance and exhibited the best overall durability performance, with performances greater than what codes recognize.

3:30pm - 5:30pm Bay Room	**Session 27: Durability and Risk** Session Chair: **Carsten Rode**, Technical University of Denmark

Protecting Reinforcing Steel From Corrosion: A Comprehensive Analysis of Corrosion Protection Systems Used in Concrete Repair

Wesley Narciso[1,2], **Dr. Fitsum Tariku**[2]
[1]JRS Engineering, BC, Canada; [2]British Columbia Institute of Technology, Canada

The single biggest cause of premature failure in reinforced concrete is the corrosion of steel from chlorides. During repair, it is common to protect the corroded reinforcing steel with a coating or another type of corrosion mitigation system.

The purpose of this study is to qualitatively and quantitatively compare different types of materials and systems of products that are currently in commercial production, as well as in the conceptual research stage.

Reinforcement steel bars were protected with different materials/systems, encased in chloride laden concrete and immersed in salt baths with a small induced current to simulate chloride infiltration and accelerate corrosion. Reference bars were left uncoated to compare as some engineers/designers prefer no corrosion protection system during repairs.

The effects of corrosion were documented and compared via electrochemical testing (half-cell measurements), visual examination (steel, coatings, and galvanic anodes), metallurgical analysis (reduction in effective diameters and cross-sectional areas), and mechanical testing (tensile and bending).

The results were compared and summarized using a weighted rubric with point totals and a ranking system. Additionally, the effects of uncoated sections directly adjacent to coated sections more susceptible to corrosion after repairs are performed (commonly referred to as “hot spots” or “ring halo effect”), which is lacking in research, will be quantified and explored. Similarly, some samples will also be purposefully left uncoated at targeted locations (5% of surface) to simulate improper application.

A comparison of different commercial systems consisting of specific types of coatings and other products (galvanic anodes), as well as tensile testing and metallurgical analysis have not been observed in any other related study or paper. While some specifications and guidelines are available, none provide any real specificity or confidence in corrosion protection – a crucial component in reinforced concrete repair, ultimately creating more durable structures and prolonging service lives

Introducing New Technical Solutions in the Swedish Construction Industry: Interviews with Key Actors

Charlotte Svensson Tengberg[1,2], **Carl-Eric Hagentoft**[1]
[1]Chalmers University of Technology, Department of Architecture and Civil Engineering SE-41296 Gothenburg, Sweden; [2]Skanska Sweden AB, SE-40518 Gothenburg, Sweden

Too often, introduction of new technical solutions in the Swedish construction industry results in functional failure, possibly leading to large-scale damages. In this context, building physics and moisture are topical. This paper, focus on how new technical solutions are currently introduced and verified as to functional requirements regarding building physics, identifying gaps and potentials for improvement. Data was mainly collected by interviews with key actors in the Swedish construction industry.

In this paper, serial failure is defined as multiple cases of failure where a specific technical solution fails to sustain the functional requirements due to reasons in the design or production that could have been predicted by calculations or other assessment in the design phase. Introduction of a new technical solution has two main paths: introduction at a company level, often with routines for evaluation, or introduction at a construction project level, with a varied level of evaluation. The latter path is found to be the predominant. It is mainly the suppliers initiating use of new technical solutions, as well as providing documentation, samples and references. The consequences of failure might be considered smaller when introducing new technical solutions at project level. However projects tend to be used as reference cases even without evaluation, thus the introduction in a single project creates a risk to initiate a serial failure.

The findings of the interviews pinpoints the important role of the supplier and the documentation the supplier provides. A possible way to address the risk of serial failure when introducing new technical solutions could be to develop a methodology to define and strengthen the steps in the evaluation process, to define the use of reference cases and to clarify the requirements on documentation, samples and references cases to be fulfilled by the supplier.

Structural Testing of Screws through Exterior Insulation for Steel-Frame Walls

Lorne Ricketts, **Jun Tatara**
RDH Building Science Inc., United States of America

As the construction industry moves toward more energy-efficient buildings, exterior insulation has been recognized as an effective solution for increasing the thermal performance of wall assemblies. Previous research and in-situ performance has shown that using only screws directly through exterior insulation to provide cladding attachment is a thermally and structurally efficient solution for wood-frame walls. For steel-frame walls, however, there is still skepticism regarding this method of cladding support, and cladding attachment clip solutions are the more common solution.

This study focuses on the impact of density and thickness of insulation materials on the structural performance of screws through exterior insulation as a cladding support system in to a steel stud back-up wall. Previous testing performed on wood-frame walls suggests that the majority of deflection occurs during initial loading; therefore, this study also investigates pre-loaded strapping and pre-compressed insulation as techniques to

minimize initial deflection. In addition to the structural performance, airtightness, water penetration, and constructability considerations of this system are also discussed.

Overall the study aims to provide important information for the industry as to the viability of the screws through exterior insulation cladding attachment approach in steel stud wall applications to facilitate the expanded use of exterior insulation as part of non-combustible wall assembly design.

Thermal Bridging Effects in Steel Stud Wall Assemblies

Medhi Ghobadi, Travis V. Moore, Michael A. Lacasse
National Research Council Canada, Canada

The thermal performance of a building envelope can highly impact the overall performance and energy efficiency of the building. It has been shown that the thermal transmittance (R-value) of a building envelope can be affected by thermal bridging sources. Hence, it is important to accurately determine the R-value of building envelopes with thermal bridging components. Packages that only use one or two dimensional analysis contain significant errors in their calculations, since thermal bridging is a three-dimensional phenomenon. In this project we employed a three dimensional heat transfer module of COMSOL Multi-Physics to evaluate the thermal performance by calculating the thermal resistances of three steel stud wall assemblies. The wall assemblies were drawn in Solidworks and then imported to COMSOL Multi-Physics; the material properties were assigned and corresponding boundary conditions were applied to the assemblies. Finally, based on the calculated heat flow through the walls and average surface temperatures, the thermal resistances of the respective wall assemblies were calculated. The wall assemblies were also fabricated and the thermal properties of the insulation materials were measured using a heat flow meter and thereafter used in COMSOL Multi-Physics. The steel stud wall assemblies were tested in a guarded hot box and the results were used to benchmark the numerical method that was employed. The effects of eliminating the steel stud on the thermal performance of the wall assemblies were studied. A room side temperature analysis was also completed.

6:00pm - 7:30pm **Reception**
Island Ballroom

Date: Thursday, December 12, 2019

7:30am - 8:30am **Breakfast**
Beach/Gulf Room

8:30am - 10:00am **Session 28: Simulation Strategies**
Beach/Gulf Room
Session Chair: **Carl-Eric Hagentoft**, University of Technology

Possibilities with Probabilistic Methods for Dynamic Building Energy Simulations using Stochastic Input Data: Initial Analysis

Tomas Ekström[1,2], Stephen Burke[1,2], Lars-Erik Harderup[1], Jesper Arfvidsson[1]
[1]Lund university, Sweden; [2]NCC, Sweden

As observed in earlier studies, there is evidently a performance gap between the predicted annual energy use from building performance simulations based on traditional deterministic methods compared to the monitored annual energy use of a building. The hypothesis is that using a probabilistic method makes it possible to consider the uncertainties in the input data and determine a probability distribution for the predicted energy performance of a building. Thus, reducing the performance gap between the predicted and monitored energy use. This paper aims to detail the advantages and disadvantages of both the deterministic and the probabilistic methods when determining the energy performance of a building and evaluate the differences based on a qualitative analysis. The differences between the methods are further evaluated based on the results from a case study where the probabilistic method has been implemented in two dynamic building performance simulation software. The conclusion from this study is that both methods have their specific advantages and disadvantages, however the main differentiating point is the scope of application. The deterministic method is a simpler alternative, needing a less amount of data and is performed in less time, thus making it advantageous in early phases when the basic design of a building is decided, and available information still is limited. However, this method must make use of an arbitrary margin of safety when compared to the requirements in the building regulation. The perceived accuracy of the results, since the software reports the result to several decimals, are often misleading since the numerical value says nothing about the probability of fulfilling the requirements. The probabilistic method is more advanced and requires more information, such as a larger quantity of data for each factor, a more complex simulation model, and more advanced knowledge of both energy performance and statistics from the operator. Because of this, it also requires more computational power and is more time consuming. Thus, the method is more advantageous for analysis and determining the risks associated with not fulfilling the building regulations, since the method determines the probability of failure, instead of using an arbitrary margin of safety.

Transient Heat Transfer Calculation Method for Multi-Dimensional Building Envelope Thermal Bridges with Variable Insulation Thicknesses

Farhad Hemmati, Fitsum Tariku
British Columbia Institute of Technology, Canada

Hourly dynamic energy performance study of buildings requires in-depth understanding of dynamic thermal performance of building envelope assemblies. Several studies performed by others have so far confirmed the necessity of considering correct thermal storage behavior of building envelope assemblies in dynamic hourly building energy simulations. Two and three-dimensional building envelope thermal bridges have significant impact on effective heat performance, and once coupled with the effect of heat storage, the dynamic heat

transfer through the assembly can be significantly different from the one obtained from steady-state calculation methods.

In this study, a simplified transient heat transfer model based on frequency response of RC-Network (FR-RCN) is presented that could generate the equivalent model for the same assembly with different continuous insulation thickness simply by systematically modifying the original RC-Network coefficients. In this study, two mass type structures are considered and their dynamic responses in a climate that is characterized with cold winter and hot summer (Toronto climate - climate zone 6) are analyzed using the proposed simplified method. As a validation exercise, the results calculated using equivalent FR-RCN are compared with solutions obtained from finite element analysis using COMSOL, and found to be in good agreement. In addition, the heat flux of the assemblies was calculated based on liner transmittance method and compared with the proposed method, and showed significant difference. In general, the FR-RCN variable insulation thickness method is found to be efficient, fast and flexible calculation method with good accuracy.

Hygrothermal Simulation on High-Performance Computers in the Cloud: Methodology and Use Case

Florian Antretter[1], Matthias Pazold[1], David Pursiano[2], Wolfgang Gentzsch[3], Baris Inaloz[3], Robert Simon[2]

[1]Fraunhofer Institute for Building Physics, Germany; [2]Civil Litigation Law Firm PURSIANO BARRY BRUCE LAVELLE LLP, USA; [3]UberCloud, USA

Hygrothermal simulation is applied to compute the performance of materials, assemblies, systems and whole buildings. Commercially available simulation models require deterministic input for, among others, material properties, climatic boundary conditions, building use and ventilation conditions. The simulations result in a deterministic output, e.g. the time dependent moisture content of a material layer or humidity of interior air. Uncertainties in the input parameters are often not considered or assessed with limited parametric studies.

One way to gain comprehensive insight into sensitivities of input parameters and their impact on uncertainties in the results are large scale parametric simulations. This paper will outline a methodology to run large scale parametric simulations via high-performance cloud computing (HPC Cloud) based on a use case of a twin tower 283-unit residential condominium where extensive expert investigation established, among other issues, exterior plaster failure and high interior humidity levels with apparent biological growth. Competing opinions and the inability to field test the experts' hypotheses resulted in HPC modelling to determine causes for failure of plaster coated exterior walls and high humidity in the condominium living environment.

This study outlines a method for cloud-computing-based hygrothermal simulation and demonstrates that, in general, multi-physics building simulation using HPC Cloud computing is accessible, affordable, and beneficial for private clients. It can be applied for initial design and repair to reduce downstream risk. HPC cloud computing enables the prediction of future performance of buildings by simulation for a broad range of input parameters in a reasonable time due to the performance benefits with HPC cloud computing. Invasive / destructive building forensics can be reduced. Together with the ability to separate design, material, and workmanship deficiencies, the design process, potential forensic investigations, or litigation can draw huge benefits from utilizing HPC cloud computing with hygrothermal building simulation.

8:30am - 10:00am
Palm Room

Session 29: Water Intrusion and Barriers

Session Chair: **Manfred Kehrer**, Wiss Janney Elstner

Water Management in Cladding Systems with Small Drainage Cavities: A Review

Stéphanie Van Linden, Nathan Van Den Bossche

Ghent University, Belgium

In the 60's and 70's face-sealed systems were commonly used in the building envelope to prevent rainwater from penetrating the façade. However, numerous problems with water ingress were reported. As several research studies showed that the presence of a drainage space significantly improved the water management of cladding wall assemblies, wall assemblies have then evolved towards multi-layered systems. The present study provides an overview of past research on the drainage capacity of wall assemblies with small drainage cavities to gain a better understanding of the parameters that affect drainage efficiency and retention in wall assemblies. Furthermore, a numerical runoff model was analysed and compared to preliminary test results. Past research already gave a good overview of measured drainage rates and drainage efficiencies. However, as all these studies adopt different test methods and no detailed information is given on the wetted area, results from different studies cannot be compared. It was found that the drainage cavity width, the drainage media, spreading of water in the wall and the surface roughness and dynamic contact angles had a significant impact on the drainage capacity of wall assemblies. Future research will look more into detail into the impact of these parameters and compare test results with results obtained from simulations with the numerical runoff model.

Adaptive Water-Resistive Barrier for Building Envelopes

Joseph Trentacosta[1], Vivek Kapur[1], Florian Antretter[2], Andre Desjarlais[2], Diana Hun[2], Theresa Weston[3]

[1]EA Membranes LLC, United States of America; [2]Oak Ridge National Laboratory, United States of America; [3]DuPont Performance Building Solutions, United States of America

Excessive moisture transport into building enclosures can lead to elevated moisture levels in wall cavities and associated damage. Such conditions can also produce increased energy consumption. Currently, architects and builders are limited to using static membranes as water-resistive barriers that exhibit a single vapor permeance irrespective of environmental conditions. Membranes with a high permeance may allow moisture

ingression under hot and humid ambient conditions, while membranes with a low permeance may not allow wall cavities to dry out when moisture accumulates within them.

An electrostatically actuated, dual permeance membrane previously demonstrated for protective apparel is under development for use as a water-resistive barrier for building envelopes. When outdoor temperature and relative humidity are high as detected by sensors, the membrane exhibits low permeance (~0.5 perms) to inhibit water vapor ingression into the building enclosure; but when humidity in the wall cavity is high, the membrane exhibits high permeance (~50 perms) to facilitate water vapor egression to the outside. The membrane changes state by electrostatic actuation using a very low current electrical power supply.

In order to quantify the benefits of a dual permeance water-resistive barrier, WUFI® hygrothermal modeling simulations were completed comparing the adaptive membrane to conventional fixed permeance membranes relative to inhibiting mold growth for various US climates and several wall constructions. The WUFI® code was modified to accommodate switching the permeance of the adaptive membrane between low and high permeance states for several humidity setpoint control strategies. The effect of liquid water leakage into the wall cavity was also considered.

This report will summarize the development of prototype dual permeance, electrostatically actuated water-resistive barriers including the challenges of deploying a 'smart' material system within a building enclosure, as well as the results of hygrothermal model simulations of these adaptive structures.

Hygrothermal Modeling of Wall Drying After Water Injection

Charles R Boardman[1], Samuel V Glass[1], Kingston Chow[2], Borjen Yeh[2]
[1]Forest Products Laboratory, Madison, WI, USA; [2]APA - The Engineered Wood Association, Tacoma, WA, USA

Hygrothermal models are commonly used for prediction and evaluation of wall assembly moisture performance. Drying and redistribution of moisture are important to consider because they mitigate the effect of water intrusion during construction and throughout the service life of the building. In this study we compare simulations with measurements for two out of eight different residential wood-frame wall assemblies, in two orientations, with different kinds of insulation outboard of the oriented strand board (OSB) sheathing, in the cold climate of Madison, WI. Over two years we collected weather and moisture content data, challenging the wall systems three different times with water injections to assess drying potential of the different walls. These injections placed 40 mL of water each day, over several days, on a paper towel fixed to the inner surface of the OSB. Water moves into and through the OSB, but also laterally away from the injection site, and evaporates into the wall cavity air raising the relative humidity. This is inherently a three-dimensional process which is challenging for one-dimensional modeling to capture. We introduce a custom moisture source and sink method to allow WUFI Pro to match the experimental data following internal wetting. This technique should be useful for assessment of drying potential during wall design and analysis.

10:00am - 10:30am **Break**

10:30am - 12:00pm
Beach/Gulf Room

Session 30: Simulation and Validation

Session Chair: **Achilles Karagiozis**, National Renewable Energy Laboratory

Contaminant Transport through the Thermal Envelope: Evaluation of Airflows Based on Numerical Modeling and Field Measurements

Fredrik Domhagen, Paula Wahlgren, Carl-Eric Hagentoft
Chalmers University of Technology, Sweden

Contaminants in the indoor air can come from outdoor, be produced within the building or originate from the building envelope. Examples of contaminants from within the building envelope are mold spores from the attic, radon or bad smell from the crawl space, or mineral wool particles from the insulation of ventilation shafts. These contaminants can contribute to poor indoor air quality, and it can be troublesome to determine if the contaminants originate from the building envelope or from elsewhere.

In the current project, the overall aim is to improve the methodology for finding the cause for indoor air problems by providing methods to determine if the contaminant source is within the building envelope. There is an urgent need for this methodology, since many buildings today have unexplained indoor air problems that needs to be better understood before proper measures can be taken.

Measurement methods using tracer gas (from dry ice) and pressure difference measurements have been tested. Also, a numerical model has been developed that considers the influence that climate (wind speed, wind direction and temperature) and ventilation strategies have on the air leakage in a building. The model is compared to measurements of pressure differences, air leakage search and weather data from a case study (a school building with documented indoor air problems). The paper presents guidelines for the different steps that need to be taken to evaluate if the pressure distribution around the building envelope, or climate situation, is such that contaminant transport toward the indoor environment can occur.

Validation and Application of CFD for Condensation Risk Assessment

Fabio Almeida, Patrick Roppel, Ivan Lee
Morrison Hershfield, Canada

Air flow and radiation exchange can have a significant impact on the surface temperatures of glazing systems. Assessment of surface temperatures are essential in evaluating condensation risk with computer simulations. Methodologies, procedures and software already exist for performing general condensation risk assessment. However, these are limited to steady state thermal simulation of the glazing system and there are

circumstances where such general assessments cannot fully account for in-situ conditions. One option to provide a more comprehensive simulation is to incorporate computational fluid dynamics (CFD) to simulate the effects of HVAC systems and model detailed air flow patterns around complex geometry. However, there are questions regarding the feasibility of utilizing complex simulations such as whether the added complexity will lead to better insights, if the extra effort is justified, and what are the necessary procedures to move beyond standard design assumptions.

This paper presents a two part investigation into the use of CFD for condensation risk assessment. The first part includes validation of a room scale CFD model against monitored data in an office building. The second part includes an application of a room scale CFD model with various HVAC systems to perform a diagnostic assessment of condensation risk.

The validation portion investigates key parameters and procedures that are required in an accurate CFD simulation such as the implication of dynamic film coefficients versus static film coefficients that are prescribed in the ASHRAE Handbook of Fundamentals. The diagnostic application involved the assessment of condensation on the interior surfaces of a curtain wall at an outside corner. The inclusion of CFD simulations enabled the thermal model to account for additional factors such as overhead diffusers, hydronic baseboard heaters, in-slab radiation heating, and a structural concrete column obstruction. The modelling confirmed observations made in a previous investigation and validated recommendations for mitigation strategies.

Hygrothermal Performance of Multi-Functional Wood Composite Panel: Comparison of Simulation Results with Field Measurements

Ruolin Wang[1], Hua Ge[1], Mustafa Gul[2]
[1]Concordia University; [2]University of Alberta, Canada

A Multi-Functional Wood Composite Panel (MFP), made of laminated OSB as skin with wood fiber insulation core, has been developed as an innovative wall system for higher energy efficiency and structural performance. To ensure its long-term durability, full-scale field measurements of the hygrothermal performance of prototype wall systems have been carried out in two climatic conditions, i.e. Vancouver and Edmonton. A validated hygrothermal model is needed to evaluate the hygrothermal performance of the proposed MFP with various wall configurations under different climatic conditions than tested.

This paper presents the comparison of simulation results with field measurements for the validation of hygrothermal modeling using a commercially available program WUFI Pro. Two types of MFP were tested: type A having a wood fiber as the insulation core, while type B having the Extruded Polystyrene (XPS) as the insulation core, and a conventional 2x6 wood frame wall was used as the datum wall for comparison. Comparisons show that simulation results predict the general trends well and the differences in moisture content (MC) of OSB between measurements and simulations are within 4.4%. There is no noticeable difference between replica, while distinct different between south and north orientations is observed. No significant difference is observed between type A and type B panels. The WUFI model calibrated with the field measurements can be used to evaluate the hygrothermal performance of the prototype MFP under other application conditions.

10:30am - 12:00pm
Palm Room

Session 31: Dynamic Insulation and Grid Interaction

Session Chair: **Paulo Cesar Tabares Velasco**, Colorado School of Mines

Thermally Anisotropic Composites for Heat Redirection and Thermal Management in Building Envelopes

Kaushik Biswas, Som Shrestha, Diana Hun, Jerald Atchley
Oak Ridge National Laboratory, United States of America

In building envelope systems, thermal management is important from energy conservation and thermal comfort perspectives, and is typically done via insulation, thermal mass, solar control and shading, etc. Thermal anisotropy is commonly utilized in electronics for heat dissipation. This article investigates the feasibility of utilizing thermally anisotropic composites (TACs) to reduce unwanted heat gains and losses through the building envelope by redirecting the heat transfer to or from appropriate heat sinks and sources.

Numerical simulations of building envelope components using COMSOL Multiphysics and whole building simulations using EnergyPlus (E+) were performed to estimate the energy savings potential of TACs used in external walls of residential buildings. Application of TACs was compared with baseline walls cavity insulation as well as with and without exterior continuous insulation (CI). The COMSOL simulations indicated 75% or higher reductions in heat gains when using a TAC coupled with a heat sink compared to an exterior CI case. In terms of energy savings in a hot climate, E+ models estimated cooling energy savings of 19% with "TAC + heat sink" compared to a baseline wall with only cavity insulation. Further, a small-scale test sample with a TAC-heat sink system was built and tested in a multi-transducer heat flow meter (HFM). The heat sink was a copper tube circulating cold water. The experiments verified the re-direction of heat to a sink and significant reduction in heat transfer through the test specimen. The experiments showed that the heat redirection only occurred in the presence of both thermal anisotropy and heat sink (circulating water in this case); if either element was missing, the system behaved like a traditional envelope component.

The Effectiveness of HVAC Demand Response Control on Buildings with Low and High Thermal Insulation

Ehsan Kamel, Alina Iuldasheva
New York Institute of Technology (NYIT), United States of America

Buildings in the U.S. consume about 40% of total energy consumption. A demand response (DR) control in HVAC system can contribute to reducing the loads on the customer and utility sides by adjusting the setpoint temperature or pre-cooling the building. The effectiveness of such control systems to reduce the peak demand and energy use depends on the thermal response of buildings and how fast/slow the internal temperature changes/react to the HVAC activities. Thermal response is influenced by multiple factors such as occupancy, outdoor temperature, solar radiation, and building envelope thermal properties. A DR system does not achieve its maximum potential in terms of reducing the load, energy use, and energy-related costs if it takes too long until the interior temperature adjust itself to the setpoint temperature due to the heat loss through building envelope. Therefore, it is important to study and quantify the impact of building envelope thermal properties on the effectiveness of DR systems.

This paper studies the impact of different building envelope thermal resistance on the effectiveness of DR control system. Five buildings with different overall wall R-value ranging from 10 to 35 BTU/(hr.°F.ft2) are modeled in the 4A/mixed-humid climate region using NREL's BEopt software. Different DR scenarios based on temperature setback and pre-cooling are applied to these buildings and their effectiveness is evaluated by observing three factors including the rate of changes in indoor temperature (oF/hour), energy savings (kBtu/ft2), and cost savings ratios. The results show that the HVAC control system could save about 4.2% and 3.6% on energy use in buildings with low and high wall R-value, respectively. For heating and cooling periods, the rate of changes in indoor air temperature in buildings with low insulation is about 16% and 25% faster, respectively. These findings can help to adopt a proper energy retrofit system and leads to more accurate load prediction, which is an essential part of smart grids to manage the grid-side loads based on the DR system.

Assessment of the Potential of Active Insulation Systems to Reduce Energy Consumption and Enhance Electrical Grid Services

Florian Antretter, Diana Hun, Philip Boudreaux, Borui Cui
Oak Ridge National Laboratory, Oak Ridge, TN, United States of America

Building envelopes today act as passive systems in a dynamic environment. Traditional energy-saving efforts have mainly tried to improve the performance of building envelope systems by increasing thermal resistance to a set value that reduces energy flow. However, changes in weather and indoor conditions often lead to situations in which a low thermal resistance would decrease energy use. The optimization of thermal resistance that is triggered by changes in temperature, solar radiation, or availability of energy from renewable sources is currently not possible.

Controllable active insulation systems (AISs), in which the thermal resistance of the insulation material can be dynamically controlled within a certain range, can expand the capabilities of the building envelope. With AISs the building envelope is no longer only a passive barrier between indoors and outdoors; instead, heat transfer can be controlled. Moreover, when AISs are combined with the thermal mass in the envelope system, these can act as thermal batteries that can be loaded and unloaded on demand.

To quantify the benefits of AISs, a literature study of active insulation and achievable thermal conductivity ranges, thermal simulation models, and control logics was performed. Based on this literature study, a simulation model was developed to control the thermal resistance of insulation materials. A methodology to assess the potential of active insulation systems to reduce energy use and enhance electrical grid services was established and applied to identify ideal implementation scenarios for active insulation systems.