6th Expert Meeting of Annex-79 &

7th International Symposium on Occupant Behavior Research

19th-21st April 2021, Trondheim, Norway

ANNEX 79

NTNU

Research Centre on ZERO EMISSION NEIGHBOURHOODS IN SMART CITIES

PROGRAMME AND ABSTRACTS

EBC
Energy in Buildings and Communities Programme

6th IEA EBC Annex 79 Experts' Meeting Agenda

	Sunday, April 18th, 2021 16.00 – 17:00 Annex 79 Meeting of Subtask Leaders

<table>
<tr><td rowspan="10">Monday, April 19th, 2021</td><td colspan="4">Annex 79 Meeting – Day 1</td></tr>
<tr><td colspan="4">12:45 Registration and log in</td></tr>
<tr><td colspan="4">13:00 Welcome, introduction, roll call & adoption of the agenda</td></tr>
<tr><td colspan="4">13:30 Overview and general information about Annex 79 by Operating Agents, Agenda for breakouts (4 slides from the STLs presented by the OAs)</td></tr>
<tr><td colspan="4">14:00 Group Photo 😊 lunch break</td></tr>
<tr><td colspan="4">14:15 Breakout sessions for presentations, discussions, further work plan, and planning of deliverables</td></tr>
<tr><td>Subtask 1:
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(address of virtual meeting room)</td><td>Subtask 3:
(address of virtual meeting room)</td><td>Subtask 4:
(address of virtual meeting room)</td></tr>
<tr><td colspan="4">16:15 Coffee break</td></tr>
<tr><td colspan="4">16:30 Panel discussion: "What exactly is occupant-centric building design? – Different perspectives but common sense or domain-dependent approaches?"</td></tr>
<tr><td colspan="4">18:00 End of day 1, social time</td></tr>
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<table>
<tr><td rowspan="11">Tuesday, April 20th, 2021</td><td colspan="4">Annex 79 Meeting – Day 2</td></tr>
<tr><td colspan="4">12:45 Registration and log in</td></tr>
<tr><td colspan="4">13:00 Brief agenda for breakouts from STLs for each ST</td></tr>
<tr><td colspan="4">13:10 Breakout sessions (continued)</td></tr>
<tr><td>Subtask 1:
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(address of virtual meeting room)</td><td>Subtask 4:
(address of virtual meeting room)</td></tr>
<tr><td colspan="4">15:10 Lunch break</td></tr>
<tr><td colspan="4">15:30 Plenary session for cross-subtask activities</td></tr>
<tr><td colspan="4">16:30 STs' summary presentations and discussion</td></tr>
<tr><td colspan="4">17:30 Dissemination issues: seminars/workshops at conferences, special issues of journals, website, newsletters, outreach to other organisations</td></tr>
<tr><td colspan="4">17:45 Introduction to next meeting, presented by host
Summary and closing remarks, Andreas Wagner and Liam O'Brien</td></tr>
<tr><td colspan="4">18:00 End of Annex 79 meeting, social time</td></tr>
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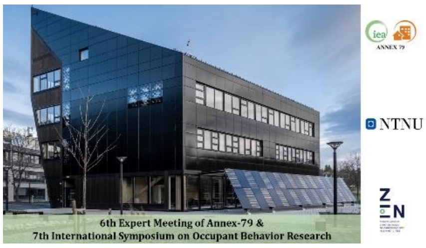
Wednesday, April 21st 2021	**International Symposium on Occupant Behaviour** 13:00 – 18:00

Please note: ALL TIMES ARE IN CEST!

IEA EBC Annex 79 “Occupant behavior-centric building design and operation”
The 7th International Symposium on Occupant Behavior Research



April 21st, 2021, Trondheim, Norway

PROGRAM

Due to the corona pandemic the entire event is arranged online
Schedule is given in CEST time
(7 minutes for presenting and 3 minutes for Q&A)

13.00-14.00 Opening & Topic 1: Personalized Comfort and Building Controls

Session chair: **Vojislav Novakovic**

- 13.00-13.10 Welcome address
  - Operating agents and Hosts
- 13.10-13.20 Presentation of NTNU/SINTEF ZEB Laboratoriet building
  - Recorded virtual tour
- 13.20-13.30 The design process for achievement of an office living laboratory with a ZEB standard
  - Steinar Grynning; Berit Time, Norway
- 13.30-13.40 The ZEB Laboratory - a research tool for climate adapted zero emission buildings
  - Alessandro Nocente; Norway
- 13.40-13.50 T1: Design Specifications for Bidirectional Feedback on Indoor Environmental Quality
  - Angela Sanguinetti, Eli Alston-Stepnitz, Sarah Outcault; USA
- *13.50-14.00 Short break*

14.00-15.00: Topic 1 & Topic 2: Modeling and simulation of occupant behavior based on big data

Session chair: Bing Dong

- 14.00-14.10 T1: SSO User Insight Toolbox – occupant- centric building design to enhance occupant comfort and health
  - Quan Jin, Holger Wallbaum; Sweden
- 14.10-14.20 T1: Three Theories of Occupant Smart-thermostat Override Behaviour
  - Kunind Sharma, Michael Kane; USA
- 14.20-14.30 T1: Shading control strategies based on performance indicators considering occupant comfort and energy consumption
  - Zhang Xinmin, Li Zhengrong, Yu Xuyun, Zhu Han, Li Canjun; China
- 14.30-14.40 T1: They’re smart, but are they usable? An investigation into thermostat usability in Canadian homes
  - Ruth A.F. Tamas, Liam O’Brien, Mario Santana Quintero; Canada
- 14.40-14.50 T2: A Data mining framework for hourly DHW heat use prediction based on occupancy pattern: A case study in Norway
  - Lu Yan, Yuemin Ding, Natasa Nord; Norway
- *14.50-15.00 Short break*

15.00-16.10: Topic 3: Human Building Interactions

Session chair: Liam O'Brien

- 15.00-15.10 T2: Deriving Urban-scale Building Occupant Behavior Patterns through Big Data Analysis
  - Yapan Liu, Bing Dong; USA
- 15.10-15.20 T2: Shape-based clustering and temporal sequential-based forecast of occupancy in public buildings
  - Yuan Jin, Da Yan; China
- 15.20-15.30 T3: Investigating inter-generational factors on behaviour and human building interaction
  - Gregory P. Sewell, Stephanie Gauthier, Patrick A.B. James, Sebastian Stein; UK
- 15.30-15.40 T3: Moving Beyond Thermal Comfort: Capturing Wellness-related Occupant Perceptions Related to Privacy, Movement and Airborne Disease Transmission
  - Clayton Miller; Singapore
- 15.40-15.50 T3: A systemic perspective on human inhabitation
  - Astrid Roetzel, Mark DeKay, Abdul-Manan Sadick, Akari Nakai Kidd; Australia, USA
- *15.50-16.10* *Break*

16.10-17.20: Topic 3 & Topic 4: Integrate occupant modeling into building design process & Topic 5: Occupant-centric building controls

Session chair: Tianzhen Hong

- 16.10-16.20 T3: How can change of the simulation scope from occupants' actions to occupants' reasons, change energy-related occupant behaviour simulations?
  - Jakub Dziedzic, Da Yan, Vojislav Novakovic; Norway, China
- 16.20-16.30 T4: Occupant-centric Key Performance Indicators to Inform Building Design and Operations
  - Han Li, Tianzhen Hong, Zhe Wang; USA
- 16.30-16.40 T4: A Critical Review: Building Performance Co-simulation with Occupant Thermal Comfort Behaviour and Beyond
  - Michael Kane, Maharshi P Pathak, Sugirdhalakshmi Ramaraj, Thomas Stesco; USA
- 16.40-16.50 T4: Incorporating people's behaviour in buildings requires new methods, conceptual frameworks, and Building Performance Simulation tools
  - Germán Molina, Michael Donn, Casimir MacGregor, Micael-Lee Johnstone; New Zealand
- 16.50-17.00 T5: HVAC Energy Savings and IEQ for Occupancy Sensing in Buildings
  - Meng Kong, Bing Dong, Rongpeng Zhang, and Zheng O'Neill; USA
- 17.00-17.10 T5: An ontology on occupants' conscious feedback in building - Zoom into reported Data
  - Ayse Tüzün, Isabel Mino, Romina Rissetto, Andreas Wagner; Germany
- *17.10-17.20* *Short break*

17.20-18.30: Topic 6: Case studies of occupant-centric modelling, design, and operations & Topic 7: Other building occupant-related research

Session chair: Andreas Wagner

- 17.20-17.30 T6: A Proposed Architecture for Longitudinal Studies of Home Thermal Comfort Perception and Behavior
  - Emily Casavant, David Fannon, Michael Kane, Kunind Sharma, Misha Pavel; USA
- 17.30-17.40 T6: Building Operators and their Role in Occupant-centric Building Controls
  - Krissy Govertsen, Ciana Winston, Michael Kane, Alison Brady; USA
- 17.40-17.50 T6: Empirical and computational assessment of lighting conditions in home offices
  - Ceren Sarikaya, Christiane Berger, Ulrich Pont, and Ardeshir Mahdavi; Austria

- 17.50-18.00 T6: Capturing occupant activities of daily living through sensor fusion: framework, modelling and applications
    - Masab K. Annaqeeb, Anooshmita Das, Jakub W. Dziedzic, Jens Hjort Schwee, Mikkel B. Kjærgaard, Vojislav Novakovic; Norway; Denmark
- 18.00-18.10 T7: Exploring cross-modal influences in occupants' perception and evaluation of indoor environments
    - Christiane Berger, Ardeshir Mahdavi; Austria
- 18.10-18.20 T7: Seeking Barriers to Comfort and Energy Efficiency on a University Campus
    - Julia K. Day, Shelby N. Ruiz; USA
- *18.20-18.30* *Closing*

ABSTRACTS FOR THE OB-21 SYMPOSIUM

The ZEB Laboratoriet – a ZEB office living laboratory

The Research Centre on Zero Emission Buildings,
Norwegian University of Science and Technology - NTNU and SINTEF, Norway

Keywords: Zero emission buildings, living laboratory, innovation, testing, demonstration

The Norwegian Zero Emission Building Laboratory (ZEB Laboratory) is a living office laboratory four stories high and 2000 m² located in Trondheim, Norway at the NTNU Gløshaugen campus. It was officially opened in March 2021. The ZEB Laboratory is a full-scale office building where building façades, components and technical systems can be modified and replaced. The elements may furthermore be interconnected in such a way that they form a part of or a complete zero emission building. The building forms a living laboratory, i.e. a laboratory where people using it as an ordinary office building or for educational purposes becomes an experimental parameter giving variations in loads with their use of the premises.

Photo: Nicola Lolli/SINTEF

Investigations and demonstration of new technologies in a full-scale office building is important to reduce risk for the first movers willing and starting to implement zero emission building levels in their building design and construction. The adaptability of the building/laboratory makes it possible to investigate different building configurations and types.
The vision of the ZEB Laboratory is to be an arena where new and innovative components and solutions are developed, investigated, tested and demonstrated.
The ZEB Laboratory shall:

- be a basis for knowledge development at an international level,
- be a basis for international competitive industrial development,
- be an example for new and retrofitted zero emission buildings,
- be a research arena for developing zero emission buildings,
- be an arena for risk reduction when implementing zero emission building technologies,
- be a national resource for all research organisations in the research area.

The design process for achievement of an office living laboratory with a ZEB standard

Steinar Grynning[1*], Berit Time[1*]

[1]SINTEF, Trondheim, Norway,

[*]*Corresponding email: steinar.grynning@sintef.no*

Keywords: Design process, Zero emission, Building, Living laboratory, Partnering contract

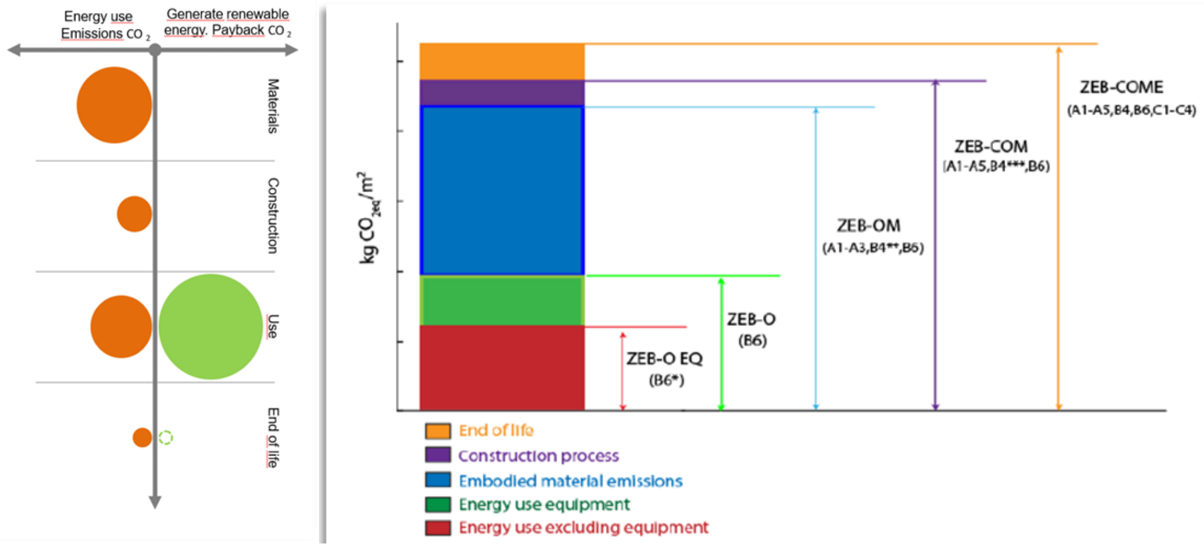


Figure 1. Whole life greenhouse gas emissions, constituted by manufacturing of construction materials and building services, construction process, building operation, and demolition including reuse or recycling of materials (left). The different ambition levels, referring to NS-EN 15978 (right).

The ZEB Laboratory is a full-scale office building with a ZEB-COM ambition, searching a high degree of flexibility and where components and technical systems can be modified for research purposes. The ZEB Laboratory is being built with "tomorrow's" technology. Project delivery of a living laboratory with a ZEB standard is not an easy task and selecting the project's delivery method is an imperative client decision. The delivery method defines the roles and responsibilities of all project participants, how to finance the project, and it sets the framework for the delivery. The ZEB Laboratory is a complex project with ambitions to deliver in areas beyond time, cost and quality, a new type of project delivery method is needed. Three methods; Design-Bid-Build, Design-Build, and a collaborative form of project delivery method were considered.

The implementation of the ZEB method in a partnering contract as a project delivery model has been developed. This paper describes and elaborate the development of the project delivery and design process for ZEB Laboratory seen by the client. The ZEB Laboratory design and procurement process has given valuable insight and experience into the use of partnering and collaborative elements for planning and production of ZEB buildings.

The ZEB Laboratory: a research tool for future climate adapted zero emission buildings

Alessandro Nocente[1]

[1]Sintef Community, Trondheim, Norway
[*]*Corresponding email: alessandro.nocente@sintef.no*

Keywords: Zero emission building, living laboratory, renewable energy, grid integration, BIPV.

The building sector is responsible for approximately 40 % of the energy consumption and carbon emissions worldwide. Buildings of the future will have to comply not only with stricter energy regulations, but they will also have to face changing climate challenges. To increase the level of interdisciplinary knowledge and to develop and test innovative technology with users, new types of adaptive research facilities are needed. The development of the ZEB Laboratory replies to this need. Developing the building as a research tool has made us focus on 1) a flexible laboratory for tomorrow building design research and 2) making the building itself a climate adapted zero emission building. The laboratory building is realised according to the Norwegian ZEB-COM ambition. To find the optimum combination matching the zero emission building's properties with local renewable energy sources and grid, the building laboratory is prepared with BIPV, a twin heat pump system and a heat storage tank based on PCM material. Grid integration makes it possible to implement experiments on the interface between buildings (ZEBs) and the grids, especially smart power grids but also district heating and cooling grids. The building is facilitated to explore ventilation systems together with monitoring of user satisfaction and energy use. The laboratory is constructed with different principles for air handling that can be operated separately and in parallel. Monitoring and control are made available on a common platform.
The ZEB Laboratory gives the possibility for the development and testing of new methods for user centred design of zero emission building technologies and user interfaces of building technologies in general (end users).

Topic 1: Personalized comfort and building controls

1. Design Specifications for Bidirectional Feedback on Indoor Environmental Quality
2. SSO User Insight Toolbox – occupant-centric building design to enhance occupant comfort and health
3. Three Theories of Occupant Smart-thermostat Override Behaviour
4. Shading control strategies based on performance indicators considering occupant comfort and energy consumption
5. They’re smart, but are they usable? An investigation into thermostat usability in Canadian homes

Design Specifications for Bidirectional Feedback on Indoor Environmental Quality

Angela Sanguinetti[1,2,*], Eli Alston-Stepnitz[1,2], Sarah Outcault[1,2]

[1]Consumer Energy Interfaces Lab, University of California, Davis, Davis, CA, USA
[2]Energy & Efficiency Institute, University of California, Davis, Davis, CA, USA

[*]*Corresponding email: asanguinetti@ucdavis.edu*

Keywords: Indoor environmental quality, Air quality feedback, Air quality monitor, User interface design, Usability

Recent technological developments in air sensors have enabled a proliferation of indoor air and environmental quality monitoring tools. The COVID-19 pandemic has raised awareness of the importance of indoor air quality and motivated an interest in such tools. The researchers were brought on as consultants to help with the development of an air quality monitoring system for commercial buildings that collects and visualizes data on a variety of parameters, including temperature, humidity, light, CO2, PM2.5, and VOCs. The data are displayed to facilities staff through a website that enables a more proactive approach to maintaining comfortable and healthy indoor environmental quality (IEQ) for occupants. Building occupants can access some of this information through a web app, which also allows them to report IEQ problems to facilities staff and provides suggestions for how to adapt to indoor conditions they find uncomfortable but are within acceptable standards.

This research, which informed the design of the occupant web app, sought to identify best practices for the user interface design of tools that provide commercial building occupants with air quality feedback. To this end, the researchers reviewed and analysed available IEQ monitoring and feedback products and subjective IEQ assessment tools (i.e., surveys), focusing on those developed for commercial buildings. Best practices were inferred from a combination of common practices and insights obtained by applying the Eco-feedback Design-behavior (EFDB) framework to IEQ feedback interfaces. The EFDB framework is based on behavioural theories and a large body of empirical research on eco-feedback. Best practices articulated pertain to IEQ data visualizations (e.g., message framing, use of colors, graphics, imagery, etc.), as well as question prompts and response options for crowdsourcing occupant feedback and collecting complaints regarding perceived IEQ. This presentation will summarize our methodology and results, focusing on identified best practices for commercial IEQ feedback products.

SSO User Insight Toolbox – occupant-centric building design to enhance occupant comfort and health

Quan Jin[1,*], Holger Wallbaum[1]

[1]Department of Architecture and Civil Engineering, Chalmers University of Technology, Sweden

[*]*Corresponding email: quna.jin@chalmers.se*

Keywords: Indoor Environmental Quality, Office building, Comfort, Behaviour, Survey tool

Users have significant impacts on building energy consumption and can interact with indoor environments. Identifying user needs, behaviour and preference are crucial for the design of both new and the renovation of existing buildings. Offices are important since people spend on average one-third of their life at work that is often taking place in offices. Offices are also responsible for a significant share of the energy use and the floor area occupation of non-residential buildings in Europe. Moreover, more ambitious regulations and the increasing application of voluntary building certification schemes require the construction of more energy-efficient buildings, but in reality, a 'performance gap' is often observed. Therefore, deep insights into user perceptions and experiences can provide the knowledge basis for developing a new generation of office buildings that provide a healthier and more productive indoor environment guided by a user-centric approach. In this article, we will introduce the web-based application of the Questionnaire and Diary Apps and a Virtual Reality (VR) design tool developed to support the interactive co-creation session with users and designers. A case study of an office building which is certified as Miljöbyggnad Silver by Swedish Green Building Council, will demonstrate the tools and explore the gaps between the building design and the real building performance perceived by the occupants. The deep insights reflect the conformity and discrepancy of energy-efficient building design and occupant comfort, for instance, window shading and occupant satisfaction for the daylight, and thermal comfort and VAV ventilation. In summary, by utilizing the smart and sustainable office (SSO) user insight toolbox, occupant responses are collected in a holistic manner and on aspects like satisfaction, stress and preferences. Furthermore, occupant behaviour, perceived health, and self-reported work performance is also gathered. The SSO user insight toolbox could enhance efficient communications among various building stakeholders and the interactions between the building and its users to to enable beneficial occupant comfort and health.

Three Theories of Occupant Smart-thermostat Override Behaviour

Kunind Sharma[1], Michael Kane[1*]

[1]Department of Civil and Environment Engineering, Northeastern University, Boston, MA, US
[*]*Corresponding email: mi.kane@northeastern.edu*

Keywords: Thermal comfort; Occupant behaviour; Occupant centric controls; Data-driven modelling; Residential

Heating and cooling systems in residential buildings consume a significant portion of the total energy use of developed countries. Decades of technology advancements and social change have focused on reducing the energy consumption of this sector. However, a greater change is on the horizon: flexible loads to balance uncontrollable renewable resources on the electric grid. Since occupant behaviours are a leading source of variation in building energy consumption, advancements in occupant thermal comfort behaviour models could serve as a critical tool to reliably manage electricity demand through internet-connected thermostats while maintaining occupant comfort and avoiding, or at least predicting, occupant overrides.

This study adapts and introduces three theories of occupant thermostat override behaviours: delay theory, comfort zone theory, and thermal frustration theory. Delay theory follows the practice of many current demand response programs that turn-off HVAC systems for a fixed duration for all participants. Comfort zone theory follows industry standard comfort models that assume a certain percent of occupants will be dissatisfied for a given temperature. The novel thermal frustration theory presented herein explicitly acknowledges the dynamics of occupant behaviour (humans do not respond instantaneously to stimulation such as temperature changes) and the dynamics of buildings (indoor temperatures do not change instantaneously with setpoint changes). Specifically, delay theory, comfort zone theory, and thermal frustration theory—respectively—predict an override after a fixed time-period, when the temperature deviation from a nominal value exceeds a threshold, and when the integral of the deviation exceeds a threshold. These three theories are tested on a dataset of tens of thousands of occupant thermostat setpoint changes and are compared in their trade-offs between accuracy and reliability.

Shading control strategies based on performance indicators considering occupant comfort and energy consumption

Zhang Xinmin, Li Zhengrong, Yu Xuyun, Zhu Han, Li Canjun

School of Mechanical Engineering, Tongji University, Shanghai, China

Keywords: Shading control strategy; performance indicators, Visual and thermal comfort, Energy consumption

Most of the existing studies about automatic control of shading use physical environmental parameters as the input and evaluation indicators of control strategies, such as illuminance and irradiance. However, these parameters cannot accurately describe occupants' sense. Hence the effect of the control strategies based on the physical environmental parameters always deviate from the real requirement and preferences of occupants, which leads to the dissatisfaction with the environment and the failure to decrease the load. In the past research, scholars proposed kinds of performance indicators to the visual and thermal comfort of occupants, such as DGP, PMV. With the development of chip technology, it is possible to calculate such complex performance indicators in real time. In this study, a shading control logic based on the selected key performance indicators is proposed. The control strategy generated by this logic can well meet the requirement and preferences of occupants. It is proved by simulation that the proposed control strategies with the objective of combining the energy saving and comfort demands reduce the solar radiation heat gain by 60% in the cooling season under the condition of ensuring the visual and thermal comfort of occupants, and it almost do not lead to the increase of lighting energy consumption compared with no shading.

They're smart, but are they usable? An investigation into thermostat usability in Canadian homes

Ruth A.F. Tamas[1*], Liam O'Brien[1], Mario Santana Quintero[1]
[1]Department of Civil and Environmental Engineering, Carleton University, Canada
**Corresponding email:* ruthtamas@cmail.carleton.ca

Keywords: Human-centred design, thermostat, usability, existing buildings, residential

Thermostats were originally very simple devices. Energy saving practices, such as nighttime setbacks, required diligent user adjustment. Programmable thermostats emerged in the 1990s, allowing schedules to be set, reducing the need for user interaction. However, later studies showed that programmable devices did not achieve expected savings due to lack of interface usability. New, 'smart' thermostats promise to address these downfalls while offering increasingly complex features. This has the potential to be highly desirable, as thermostat upgrade represents one of the least invasive and inexpensive measures for improving building performance. While thermostat usability is not a new subject, the literature is limited due to a lack of in-situ testing, few interfaces tested, a lack of interdisciplinary methods/approaches and small participant samples. This study examines the relationship between thermostat usability and interface characteristics in Ottawa, Canada, with a focus on devices currently installed in homes. To compare interfaces, human computer interaction methods, including participant interviews and think-aloud analysis, were employed. A sample of 51 participants were interviewed in their homes and attempted six usability tasks on their thermostat interface(s). Interviews were recorded and each thermostat type (manual, programmable and smart) was evaluated based on the time to complete, buttons pressed and qualitative observations for each task. The interviews provided insight into various aspects of thermostat usability, addressing common misconceptions, user mental models and what occupants like/dislike about their device(s).

In general, smart thermostats were found to be significantly more usable than their programmable counterparts. Figure 1 presents data from participants ranking the usability of their thermostat interface(s). Results are relatively consistent with other quantitative findings. When asked about thermostat features, participants expressed a desire for more real-time energy use feedback and half (51%) of all participants noted they either wanted or enjoyed thermostat control through a smartphone application. In general, smart thermostats were found to be significantly more usable than their programmable counterparts. Figure 1 presents data from participants ranking the usability of their thermostat interface(s). Results are relatively consistent with other quantitative findings. When asked about thermostat features, participants expressed a desire for more real-time energy use feedback and half (51%) of all participants noted they either wanted or enjoyed thermostat control through a smartphone application.

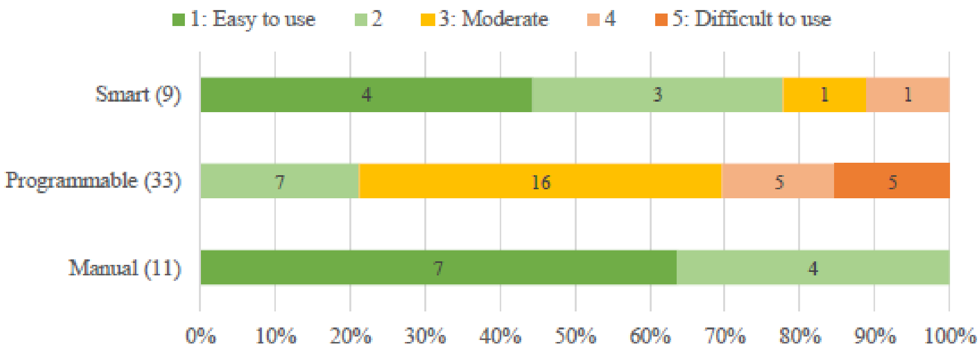


Figure 1: Usability ranking as prescribed by study participants

Topic 2: Modeling and simulation of occupant behavior based on big data

1. A Data mining framework for hourly DHW heat use prediction based on occupancy pattern: A case study in Norway
2. Deriving Urban-scale Building Occupant Behavior Patterns through Big Data Analysis
3. Shape-based clustering and temporal sequential-based forecast of occupancy in public buildings

A Data mining framework for hourly DHW heat use prediction based on occupancy pattern: A case study in Norway

Lu Yan[1,2,*], Yuemin Ding[1], Natasa Nord[1]

[1]Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
[2]School of Civil Engineering, Chongqing University, Chongqing, China

[*]*Corresponding email: luya@ntnu.no*
yanlu2029@126.com

Keywords: DHW heat use; Data mining; Occupancy pattern; Clustering; Prediction

Domestic hot water (DHW) heat use prediction model is a critical reference for demand side management. DHW usage pattern is significantly different among different building types. However, currently, there is limited research on predicting the DHW heat demand in non-residential buildings. More related research in non-residential buildings was focused on hotel rather than office buildings. The objective of this research was to propose a data mining framework for the DHW heat use prediction in office buildings based on the occupancy pattern and investigate the effects of spatial resolution of occupancy patterns input on predictive performance. An office building in Norway was taken as a case study. In the first step, a data mining framework was proposed. Firstly, hourly occupancy rate based on zone-level and building-level in this building was both calculated. Secondly, fuzzy c-means clustering method was applied to obtain typical occupancy patterns. Thirdly, decision tree was applied to predict the daily occupancy pattern taking the month of the day and the day of the week as the inputs. Finally, after obtaining typical occupancy patterns and its predictive model, the hourly occupancy rate in each typical occupancy pattern was applied to predict the hourly DHW heat use. XGBoost algorithm was used as the prediction method and cross-validated grid-search was used to search for best hyper parameters of prediction model. Data from January to April 2019 was used as the training data set, and data from May to June 2019 was used as the testing data set. In the second step, zone-level occupancy data and building-level occupancy data was applied into this prediction data mining framework. It was found that the zone-level occupancy inputs could achieve better predictive performance, with its CV-RMSE and R^2 at 23% and 0.81, respectively, comparing with the building-level occupancy data (CV-RMSE and R^2 at 50% and 0.12, respectively). The results showed that the CV-RMSE could be reduced from 50% to 23% by using the zone-level occupancy inputs instead of the building-level occupancy inputs. In addition, the performance of the proposed data mining framework for the hourly DHW use prediction was also within the recommended values by ASHRAE of 30% for CV-RMSE. The most important results of this study are related to the occupancy pattern definition for the office building.

Deriving Urban-scale Building Occupant Behavior Patterns through Big Data Analysis

Yapan Liu[1] *, Bing Dong[1]
[1]Department of Mechanical & Aerospace Engineering, Syracuse University, Syracuse, NY, United States
**Corresponding email: yliu88@syr.edu*

Keywords: Urban-scale Occupant Behavior; Big Data Analysis; Building Occupancy.

In the United States, the buildings sector accounts for about 76% of electricity use and 40% of all primary energy use and associated greenhouse gas emissions. Occupant behavior has been identified as one of the factors which impact building energy consumption. Many researchers have studied building occupant behavior at a single building scale, and a very limited number of studies have been conducted at community scale or urban-scale. It remains a challenge to study and model occupant behavior at urban-scale. Recently, with the development of information technologies, such as mobile technology, urban sensing, and IoT, big data was generated by those technologies which provide opportunities to better understand occupant behavior at urban-scale. Recent studies have demonstrated the feasibility to model occupant behavior at urban-scale utilizing Global Position System data. Based on the newly derived occupant behavior model, urban-scale building energy simulations were conducted, and show significant savings of up to 50%.

The objective of this study is to investigate and model occupant behavior in New York City. The authors have obtained one year's (10/1/2016 – 9/30/2017) anonymous GPS data of mobile device users collected by the Cuebiq company. After initial data cleaning, this study extracts stay points from GPS raw data based on the thresholds of stay duration (10 minutes) and travel distance (300 meters). Each stay point indicates that the user has been staying in that location for at least 10 minutes without traveling more than 300 meters. Based on the stay points of different users, a preliminary study was conducted to derive building occupancy profiles. Case study buildings in New York City Manhattan area were chosen, each building was given a centroid based on its footprints and a radius of 300 meters to capture users' stay points. Finally, building occupancy profiles were derived from the proposed approach. Results of this study can be further integrated into urban-scale building energy modeling, building-to-grid integration study, urban planning, etc.

Shape-based clustering and temporal sequential-based forecast of occupancy in public buildings

Yuan Jin[1], Da Yan[1*]

[1]School of Architecture, Tsinghua University, Beijing, China

[*]*Corresponding email: yanda@tsinghua.edu.cn*

Keywords: Occupancy, Shape-based clustering, Forecast, Public building

Occupancy in buildings is the basis of building energy simulation and management. With the increasing requirement for energy conservation and occupant-centric service of building energy system, the occupancy clustering method and forecast for future horizon become more and more essential, and are potential to optimize the usage of renewable energy sources. This research aims to conduct shape-based clustering and profile analysis on occupancy data in public buildings, which would contribute to the building design phase. From the characteristic analysis, occupancy in buildings possess the temporal sequential nature and seasonal feature (as shown in Figures), which could be combined with the current models. Therefore, an occupancy forecast framework based on temporal sequential analysis, named “TS-based-NN” model has been proposed. The analysis is conducted based on the occupancy data from different public buildings, including train station, airport, commercial complex, and hospital. The proposed analysis is promising to promote the occupancy-oriented building design, and occupancy forecast-based operation strategy.

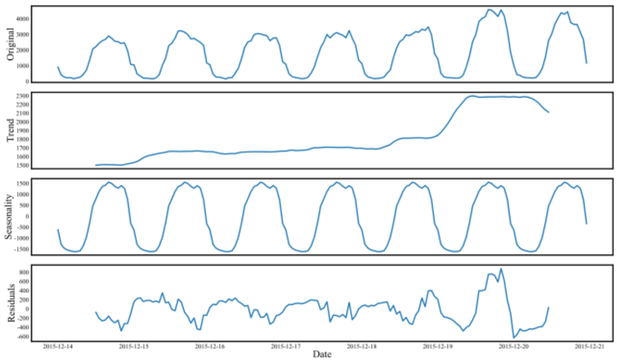
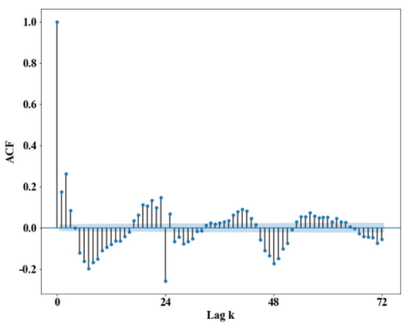
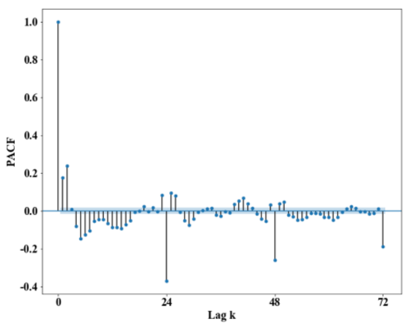


Figure 1 Seasonal decomposition of occupancy in a commercial complex



(a) ACF



(b) PACF

Figure 2 ACF and PACF analysis of occupancy in a commercial complex

Topic 3: Human Building Interactions

1. Investigating inter-generational factors on behaviour and human building interaction
2. Moving Beyond Thermal Comfort: Capturing Wellness-related Occupant Perceptions Related to Privacy, Movement and Airborne Disease Transmission
3. A systemic perspective on human inhabitation
4. How can change of the simulation scope from occupants' actions to occupants' reasons, change energy-related occupant behaviour simulations?

Investigating inter-generational factors on behaviour and human building interaction

Gregory P. Sewell[1*], Stephanie Gauthier[1], Patrick A.B. James[1], Sebastian Stein[2]

[1]Sustainable Energy Research Group, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton SO17 1BJ, UK
[2]Electronics and Computer Science, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton SO17 1BJ, UK

[*]*Corresponding email: G.P.Sewell@soton.ac.uk*

Keywords: Occupant behaviour; Residential buildings; Building interactions; Inter-generational influences

Residential buildings in the UK represent twice the energy consumption when compared to all industry and services. Moreover, this is consistently increasing despite national and international policies. Within the home, space heating is responsible for over 60% of this total, thus representing the greatest potential for change. Many factors influence the occupant's behaviour towards heating usage; some outside the occupier's control such as weather, building fabric and energy cost, but occupier thermal comfort is the obvious driver towards heating usage. However, a user's energy literacy and personality type may also influence occupants' heating behaviour. These traits, along with perceived thermal comfort, can significantly vary with differing cultures and demographics. Demographics such as age (both younger and older than the main occupant) have seen little research into their respective influences on the main occupant's behaviour, but may be considerable factors in the overall use of domestic heating usage. These factors could include sub-conscious health concerns for older relatives or pressure from the ever-increasing environmental awareness of children. It raises the question; do other generations affect occupants' heating behaviour, in particular the frequency and type of interaction with the heating system in the home? To address this question, a survey engaged a pool of 26,000 dwellings in the UK. The survey also gathered information on the occupier's energy literacy levels, personal traits, social demographics and general dwelling information. Analysis initially divided the participants' homes between those with a younger generation, older generation or those with both. A second contrast was drawn between those homes that saw an increase or a decrease in heating usage within these groups. The survey results were analysed with reference to these contrasting groups. Then the analysis provided evidence describing if and how inter-generational factors influence occupants' heating behaviour and human building interactions. These results helped to identify potential pathways for future research; leveraging these inter-generational influences to reduce household energy consumption. Moreover, these results could be used to improve the future engagement of public health and national energy reduction policies to aid sustainable development.

Moving Beyond Thermal Comfort: Capturing Wellness-related Occupant Perceptions Related to Privacy, Movement and Airborne Disease Transmission

Clayton Miller[1,*]

[1]Building and Urban Data Science (BUDS) Lab, National University of Singapore (NUS)

[*]*Corresponding email: clayton@nus.edu.sg*

Keywords: Micro-ecological momentary assessment, Smart watches, Privacy, Movement, Wellness

Evaluation of thermal comfort in the built environment has dominated much of the research in occupant-centric design and operations for decades. While important, keeping people thermally comfortable is only one of many objectives of the built environment. Other often overlooked occupant experience aspects include the feeling of privacy (sound and visual), building features that encourage occupants to be more active, and design decisions that impact the perception of infectious disease risk. These attributes can have a similar or greater impact on productivity, satisfaction, fitness, and safety as compared to thermal comfort alone. In this presentation, a platform will be presented that collects crowdsourced data from people in urban settings using a smartwatch and indoor and outdoor localization and ambient environmental sensors. This discussion includes a description of the deployment of an existing micro-ecological momentary assessment (micro-ema) with three question sets related to Covid-19 mitigation, privacy in an office context, and the movement behavior of occupants. This platform, known as Project Cozie, has already been developed and tested (for Fitbit: https://cozie.app/ and Apple Watch: https://cozie-apple.app) on the indoor thermal comfort context and this work focuses on extending its use to collect information regarding user's perception of these new applications. Ten research participants were deployed using smartwatch devices along with a few smartphone applications to collect subjective data from participants across a subsection of a large university campus. These participants were asked to give feedback about their experience in the buildings using the micro-ema platform. These data were then converged with IoT data sensors from the buildings through matching using indoor localization technologies. The resultant data of these proof-of-concept experiments were then used to characterize the preferences of the occupants and the spaces they inhabit. *Cozie is open-source and is intended to be a tool that anyone can use to design and conduct experiments using smart watches in the built environment. Guidance on how to get started with the platform will be provided.*

A systemic perspective on human inhabitation

Astrid Roetzel[1], Mark DeKay[2], Abdul-Manan Sadick[1], Akari Nakai Kidd[1]

[1]School of Architecture and Built Environment, Deakin University, Geelong, Australia
[2]College of Architecture + Design, University of Tennessee, Knoxville, TN, USA
[*]*corresponding email: roetzel.astrid@gmail.com*

Keywords: Human building interaction; Integral Methodological Pluralism; Systems thinking; Occupant Behaviour; Building design and operation

The International Energy Agency Annex 66 project "Definition and Simulation of Occupant behaviour in Buildings" differentiated between behaviours, movement and actions of occupants in a space, while also acknowledging other contextual parameters as influential. These contextual factors were described as the building itself, the energy context (usage and cost), comfort, culture and economic context, as well as physiological and psychological influences.

This paper integrates these different contexts in which individual occupants are embedded and aims to describe human building interaction from a systemic perspective. The theoretical framework for the systems approach is Integral Methodological Pluralism (Wilber 2007), which is an expansion of previous work by the authors using an Integral Research Approach (DeKay et al (2018), Roetzel et al (2019), Sadick et al (2020)) based on Integral Sustainable Design (DeKay 2011).
Aims of this work are:

- to differentiate the internal and external perspectives on the four fundamental subjective and objective quadrants representing individual experiences, behaviours, cultures and systems.
- To holistically map the system of human inhabitation
- To discuss the potentials and limitations of this systemic perspective on human inhabitation for building design and operation
- To illustrate possibilities how this approach can serve as a framework for interdisciplinary research collaboration on the topic.

How can change of the simulation scope from occupants' actions to occupants' reasons, change energy-related occupant behaviour simulations?

Jakub Dziedzic[1,3*], Da Yan[2], and Vojislav Novakovic[1]
[1]Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
[2]Tsinghua University, School of Architecture, 100084 Beijing, China
[3]PICTEC, Polanki 12, 80-308 Gdansk, Poland

*Corresponding email: jakub.w.dziedzic@ntnu.no

Keywords: Agent-Based Modelling, occupants' actions, occupants' reasons

The energy-related occupant behaviour (OB) gains a growing interest in building and energy disciplines. It is caused by efforts to optimise energy use in the buildings sector. The occupants' needs and activities are the main reasons for indoor energy use. Therefore, understanding occupants' actions and their interactions with indoor appliances plays a crucial role in energy optimisation. There are a few OB numerical models supporting analysis in both design and operation stage. In both stages, the models' main task is to translate the research findings related to human thermal comfort into proper response of HVAC, hydronic or electrical systems. Reaching such a target requires a time-demanding numerical model setup, that must be conducted separately for design and operation stage. This is influenced by the simulation scope, which is, by default, a simulation of occupant actions. An event of occupant interaction with indoor appliances is considered as an action. The observed event can be repetitive and triggered by indoor conditions. With change of the simulation scope towards occupants' reasons, each occupant would behave following its own "personal" rules. Thus, there would be no need for setting up models into the simulation solver. It would require loading up a database of occupants' "personal" rules into the main solver. An example of such approach was not found in the literature. To address the issue, the Building Occupant Transient Agent-Based Model (BOT-ABM) was introduced [1].

Instead of observing and analysing the phenomena affected by OB, it proposed gathering information about the occupants' actions and causality. Change of analysis scope allows formulating the fundamental blocks of occupants' actions and activities (sequenced actions). Generated blocks can be analysed from the perspective of a person to draw its personal profile. Once a significant amount of data would be collected, it would allow formulating personality archetype that could be implemented in building simulation software. The benefit of the proposed approach is the consistency of the investigation subject. It enables interchangeable functionalities of the OB model between design and operation stage. Additionally, with a proper monitoring system, the proposed BOT-ABM has the potential to forecast the energy-related occupants' actions. Therefore, it would lower the respond latency of building control systems and increase energy efficiency. To demonstrate BOT-ABM performance, a sample simulation is presented with an analysis of output information and its useability for building simulation applications.

[1] Dziedzic, Jakub Wladyslaw, et al. "Building occupant transient agent-based model–Movement module." Applied Energy 261 (2020): 114417

Topic 4: Integrate occupant modeling into building design process

1. Occupant-centric Key Performance Indicators to Inform Building Design and Operations
2. A Critical Review: Building Performance Co-simulation with Occupant Thermal Comfort Behaviour and Beyond
3. Incorporating people's behaviour in buildings requires new methods, conceptual frameworks, and Building Performance Simulation tools

Occupant-centric Key Performance Indicators to Inform Building Design and Operations

Han Li[1], Tianzhen Hong[1,*], Zhe Wang[1]
[1]Building Technology and Urban Systems Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA
[*]*Corresponding email: thong@lbl.gov*

Keywords: Building performance; KPIs; Indoor environmental quality; Occupant behavior

Building performance indicators are widely used to guide building design and track and benchmark operational performance. Traditional building performance indicators mostly focus on the energy efficiency perspective. Yet, the increasing penetration of renewable energy resources, distributed energy technologies, and frequent extreme weather events impose a need to quantify building energy flexibility and resilience to support research and development of grid-interactive efficient buildings (GEBs). One key factor to consider in the GEB context is occupant comfort and well-being, since occupants are the primary building service recipients in residential and most commercial buildings. This study first identified significant attributes of occupant-centric key performance indicators (KPIs) and analysed the diverse factors that should be considered in formulating an occupant-centric KPI. Then a suite of occupant-centric KPIs were synthesized from the review and enhancement of existing occupant-related performance metrics. The proposed occupant KPIs represent the occupant lens on three integrative aspects of building performance: resource use (including energy and water), indoor environmental quality, and human–building interactions. A simulation-based case study was conducted to demonstrate how occupant-centric KPIs can be used to quantify the impacts of building operation changes from the occupants' point of view.

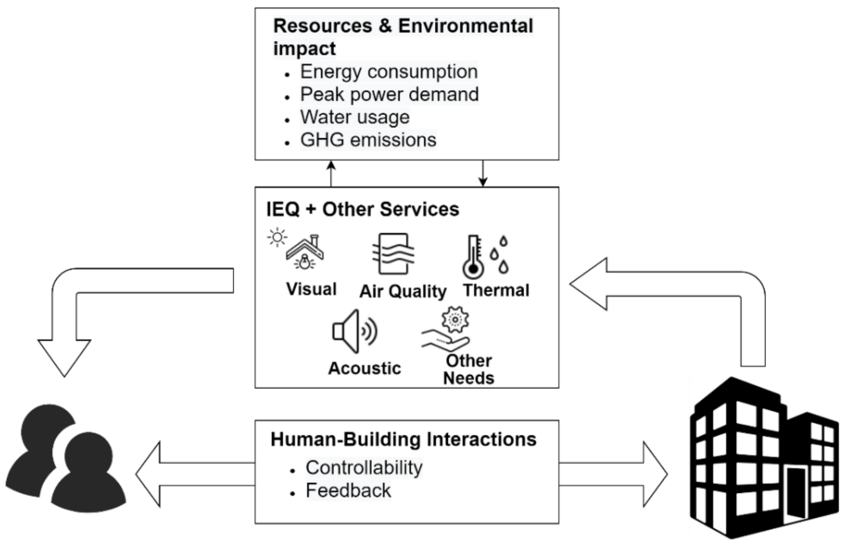


Figure 1. Occupant-centric building performance aspects

A Critical Review: Building Performance Co-simulation with Occupant Thermal Comfort Behaviour and Beyond

Michael Kane[1*], Maharshi P Pathak[1], Sugirdhalakshmi Ramaraj[2], Thomas Stesco[3]

[1]Department of Civil and Environmental Engineering, Northeastern University, Boston, MA, USA
[2]National Renewable Energy Laboratory, Golden, CO, USA
[3]Ecobee Inc, Ontario, Canada

[*]*Corresponding email: mi.kane@northeastern.edu*

Keywords: Grid-interactive efficient buildings, Building performance co-simulation, Occupant comfort modelling, Demand response, Heat pumps

Building performance simulations are increasingly used in research and industry outside their original primary purpose of comparing lifetime energy use of different design choices. For example, new equipment such as variable speed heat pumps and EV chargers, new applications such as real-time digital twins of building stocks and hardware-in-the-loop simulation, and new objectives such as modelling grid-interactivity and occupant behavior are pushing standalone building energy simulation software to their limits. To meet these new demands, various methods and tools have been proposed and developed for simultaneously simulating—that is co-simulating—the bulk of a building in these software with a component of interest in another software.

This presentation provides a critical review and survey of building performance co-simulation tools and methods to meet the demands listed above, especially modeling comfort, occupancy, and occupant behavior. Specifically, this will cover common core software such as EnergyPlus, Spawn, and TRNSYS; the use of functional mock-up interfaces and application programming interfaces for co-simulation with other component models; application-specific environments for developing such component models; and wrappers to facilitate parametric studies and sensitivity analyses. The review will discuss compatibility of methods and tools with other software and versions; extensibility and constraints; learning curves; and model fidelity limitations. The goal of this work is to provide a shared understanding of available tools, their capabilities and limitations, and opportunities for future developments in this space.

Incorporating people's behaviour in buildings requires new methods, conceptual frameworks, and Building Performance Simulation tools

Germán Molina[1*], Michael Donn[1], Casimir MacGregor[2], Micael-Lee Johnstone[3]

[1]School of Architecture, Victoria University of Wellington, Wellington, New Zealand
[2]Building Research Association New Zealand (BRANZ), Porirua, New Zealand
[3]School of Marketing & International Business, Victoria University of Wellington, Wellington, New Zealand

[*]*Corresponding email: german.molinalarrain@vuw.ac.nz*

Keywords: Building performance simulation, Comfort,

People's interactions with buildings are often triggered by a desire of feeling more comfortable, thus modelling said actions requires a good understanding of what people mean by "comfort". Nonetheless, based on a qualitative study in which participants from Chile and New Zealand described "Comfortable homes", this research identified a considerable mismatch between our (researchers' and practitioners') view of Comfort and that of those individuals whose comfort we are meant to predict and improve.

An example of this mismatch is that, while researchers and practitioners seem to explain comfort almost exclusively through perceptions (e.g., glare) that can be estimated from the *here and now* environmental conditions (e.g., contrast), respondents expressed a constant awareness of the future. That is to say, if they *know they can* fix potentially uncomfortable situations, they seem to feel more comfortable (explaining the well-known beneficial effect of Personal Control). This also affects behaviour as, we suggest, people choose whether to act or not based on what they *think* will happen if they take an action. This and other differences between people's and researchers' points of view suggest that new conceptual frameworks, methods, and simulation tools are required for appropriately understanding and modelling people's feeling of comfort and behaviour in buildings.

To bridge this gap, this research produced a new qualitative model of the Feeling of Comfort. This model can serve as a conceptual framework for driving Comfort research and practice. For instance, we used this framework to propose a set of equations that can represent people's Comfort in quantitative terms and also to inform the development of (a prototype of) a new Building Performance Simulation tool. This tool is meant to more appropriately incorporate people's feeling of comfort and behaviour in buildings. These developments evidence that it is possible to transition to new methods and conceptual frameworks.

Topic 5: Occupant-centric building controls

1. HVAC Energy Savings and IEQ for Occupancy Sensing in Buildings
2. An ontology on occupants' conscious feedback in building - Zoom into reported data

HVAC Energy Savings and IEQ for Occupancy Sensing in Buildings

Meng Kong[1,2,*], Bing Dong[1], Rongpeng Zhang[2], and Zheng O'Neill[3]

[1]Department of Mechanical and Aerospace Engineering, Syracuse University, Syracuse, USA
[2]Well Living Lab, Delos Living LLC, Rochester, USA
[3]Mechanical Engineering, Texas A&M University, College Station, USA

[*]*Corresponding email: meng.kong@delos.com*

Keywords: Occupancy-based control; occupancy sensing; energy saving; indoor environmental quality

The performance of the occupancy-based HVAC control was tested in this study using side-by-side rooms configured as typical open-plan offices. One room was set as the baseline case with the fixed schedule control, while the other room was controlled by occupancy counting sensors. Three sensors of different technologies were tested individually in this study. The complete occupancy-based control (OBC), both temperature and ventilation rate were controlled based on the occupancy, OBC temperature control, and OBC ventilation control were tested. The supply and return air temperature, outdoor air temperature, and fan speed and power were monitored and recorded for calculating the heating and cooling load and total energy consumption. The accuracy of the occupancy sensors was compared against the ground truth and correlated with the energy-saving potential by OBC. The occupant's feedback on the IEQ by OBC was surveyed to demonstrate the comfort-maintaining capability of OBC.

The accuracy of the occupancy sensors varied between 5% and 100% compared with the ground truth. By using two side-by-side energy-balanced rooms, the real energy savings by OBC were quantified. The results have shown that with occupancy sensors of different levels of accuracy, the daily energy-saving by the OBC varied from 0% to 35% depending on the weather and sensor accuracy. The OBC temperature control gave minimal energy saving compared with the ventilation control. A correlation between the daily energy-saving and system accuracy as well as the outdoor temperature was found in this study, which could be represented using a two-layer neural network model. The relationship could be interpreted as the higher the outdoor temperature was, the less accuracy the system could bear with for energy-savings. The thermal comfort level and perceived indoor air quality both far achieved the 80% comfort criteria under the OBC. No significant discomfort was observed during the initial start-up stage in the morning.

An ontology on occupants' conscious feedback in building - Zoom into reported data

Ayse Tüzün*, Isabel Mino, Romina Rissetto, Andreas Wagner

Karlsruhe Institute of Technology, Buildings Science Group, Germany

*Corresponding email: ayse.tuezuen@alumni.kit.edu

Keywords: Occupant behaviour, self-reported data, memory model, survey

Understanding occupant behaviour plays a crucial role in improving the indoor environment while reducing energy use at a low cost. Over the past years, significant research explored human behaviour and interaction with building technologies. The lack of consistent and systematic data collection and sharing has led to an increased interest in the development of comprehensive energy-related occupant behaviour frameworks. Together with monitoring techniques, surveys and interviews are the most common methods to capture occupant behaviour. However, surveys and interviews are diverse and vary among studies, which may lead to difficulties regarding the interpretation and comparison of the results. In addition to the multiple efforts to standardise energy-related occupant behaviour data, this study seeks to provide a framework to describe occupants' conscious feedback regarding perceptions and behaviors within the indoor environment. This work proposes a bottom-up approach to integrate self-reported data from occupants in buildings into an occupant behavior ontology for conscious feedback. About 900 unique questions from 42 questionnaires corresponding to 19 experimental studies carried out in the indoor climate test facility LOBSTER in Karlsruhe, Germany were categorized and structured into the proposed ontology. Each question was tagged with multiple keywords, which were later clustered in two levels; the focus on the question object resulted in a differentiation between attitude and attribute questions, while the focus on the participant's perspective resulted in the working memory and long-term memory categorization (Figure 1). This framework aims to support the research community by providing a structured and systematic way of collecting and representing occupant-related feedback of indoor environments.

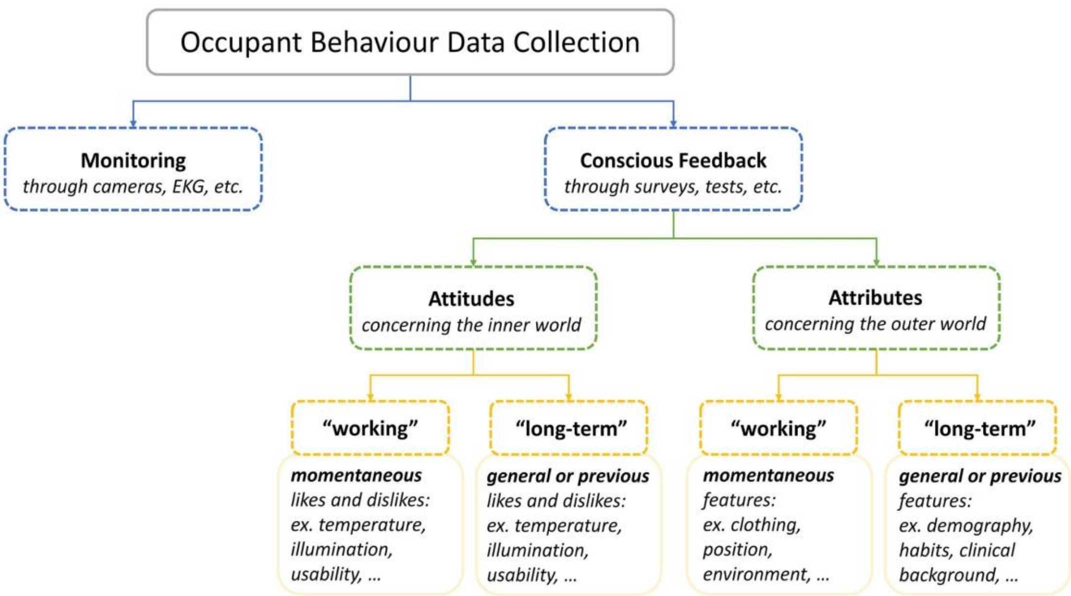


Figure 1: Occupant behavior framework for conscious feedback

Topic 6: Case studies of occupant-centric modelling, design, and operations

1. A Proposed Architecture for Longitudinal Studies of Home Thermal Comfort Perception and Behavior
2. Building Operators and their Role in Occupant-centric Building Controls
3. Empirical and computational assessment of lighting conditions in home offices
4. Capturing occupant activities of daily living through sensor fusion: framework, modelling and applications

A Proposed Architecture for Longitudinal Studies of Home Thermal Comfort Perception and Behavior

Emily Casavant[1], David Fannon[1,2], Michael Kane[1*], Kunind Sharma[1], Misha Pavel[3,4]

[1]Department of Civil and Environmental Engineering, Northeastern University, Boston, MA, USA
[2]School of Architecture, Northeastern University, Boston, MA, USA
[3]Bouve College of Health Sciences, Northeastern University, Boston, MA, USA
[4]Khoury College of Computer Sciences, Northeastern University, Boston, MA, USA

[*]*Corresponding email: mi.kane@northeastern.edu*

Keywords: energy-demand flexibility, occupant behavior, thermostat control

Electrifying heating and cooling systems in homes and transitioning to renewable energy sources is essential to reduce greenhouse gas emissions. Grid-interactive efficient buildings (GEBs) have the potential to increase energy-demand flexibility. However, traditional demand response (DR) programs aiming to shed peak electric loads do not explicitly incorporate human-building interactions. Specifically, they do not model occupants' ability to override thermostat controls, nor how the timing and magnitude of overrides is affected by the rate-of-change and magnitude of indoor temperature variations. Recent work into such human-building interactions have been enabled by large datasets of temperature and override dynamics—or—large datasets of occupant thermal comfort perception and behavior in fixed environments. The lack of a dataset that combines building thermal dynamics with the dynamics of perception and behavior is hindering the development of robust and generalizable models of such behavior.

This presentation highlights the challenges and opportunities of psychophysiological occupant-centric building models and describes the scalable methods of a study underway to create such a dataset. Smart thermostats and a smart-home hub will be used to monitor 30 homes in three different regions of the United States over two years. Their occupants will be monitored with just-in-time ecological momentary assessments (EMAs) administered via smart watches. Additionally, structured interviews and home surveys will be conducted to gain an understanding of individual environmental attitudes and future orientations, the role of economics in comfort and behavior, perceptions of risk, and thermostat-use mental models. The first phase of the study will passively collect building data as well as psychophysiological data from the occupants, while the second year of the study will continue such data collection during a simulated DR program. At the completion of the study, these data will be disseminated to the community to accelerate the development of occupant-centric models, controls, and interventions.

Building Operators and their Role in Occupant-centric Building Controls

Krissy Govertsen[1], Ciana Winston[1], Michael Kane[1], Alison Brady[1]

[1]Department of Civil and Environmental Engineering, Northeastern University, Boston, Massachusetts

**Corresponding email: mi.kane@northeastern.edu*

Keywords: Occupant-centric Control, Building Operation, Sensing technologies, Network Analysis

Building operators are tasked with the day-to-day monitoring, management, and maintenance of building HVAC systems in mid- and large-sized commercial buildings. Due to the complexity of these buildings, occupants and owners are typically unable to understand and effectively control the system themselves, thus relying on the expertise of building operators. Thus, operators play a critical role in occupant-centric buildings to reduce occupant-related building energy consumption and to improve individual occupant comfort. To better understand this role, an activity within the IEA EBC Annex 79 conducted 70 interviews with building operators across seven countries and four climates zones.

This presentations summarizes the findings of the large-scale international study of building operators. The intent of the study was to survey occupant-centric control technologies; operators skills, trust, drivers, needs, and opinions; and their relationship with occupants and other personnel. The analyses of these interviews revealed a network of (1) occupants, (2) operators, (3) sensors and interfaces, and (4) heating, ventilating, and air conditioning (HVAC) equipment. This study aims to qualitatively understand this network and its role regarding occupant-centric building design and operation. We first define each of the four nodes, then we describe the relationship between them. We then discuss both the limitations of these relationships as well as how these relationships can be strengthened to improve occupant-centric building controls.

Empirical and computational assessment of lighting conditions in home offices

Ceren Sarikaya, Christiane Berger*, Ulrich Pont, and Ardeshir Mahdavi

Department of Building Physics and Building Ecology, TU Wien, Austria
**Corresponding email: christiane.berger@tuwien.ac.at*

Keywords: Visual performance, home offices, illuminance, uniformity, glare

The design and installation of lighting systems in conventional office buildings typically benefits from expertise of domain specialists. However, this is typically not the case, when lighting settings in home offices are concerned. As such, the arrangement of lighting settings in home offices often results from ad hoc decisions and do-it-yourself activities. This can have undesirable consequences, when issues related to occupants' health, comfort, and productivity are considered. The related challenges have gained further significance, given the recent global trends and circumstances that led to major increase in the number of people who work partially or entirely at home offices. In this context, our presentation reports on a recent detailed cased study and its results. This study pertains to lighting conditions in nine home offices (located in the city of Izmir, Turkey). These home offices are used by diverse set of professionals. The existing visual conditions in these home offices were examined using measurements under both daylight and electrical light conditions. Values of common indicators of lighting performance (prevailing illuminance availability and uniformity, luminance and glare) were obtained and compared with applicable code-based benchmarks (Figure 1 below illustrates one such comparison). In addition, lighting simulations were conducted to explore the possibilities for the improvement of lighting conditions. The results of the case study reveal a rather uneven level of performance across the selected cases. Some instances of excessive illuminance notwithstanding, the visual conditions were generally better under daylighting conditions. However, visual conditions under electrical lighting were found to be in multiple instances unsatisfactory. This was mainly due to unsuitable luminaires as well as shortcomings in their positioning. Simulation-based optimization studies suggest that it is possible to improve the visual conditions in the home offices via measures including via relatively simple measures involving exchanging and repositioning the light sources.

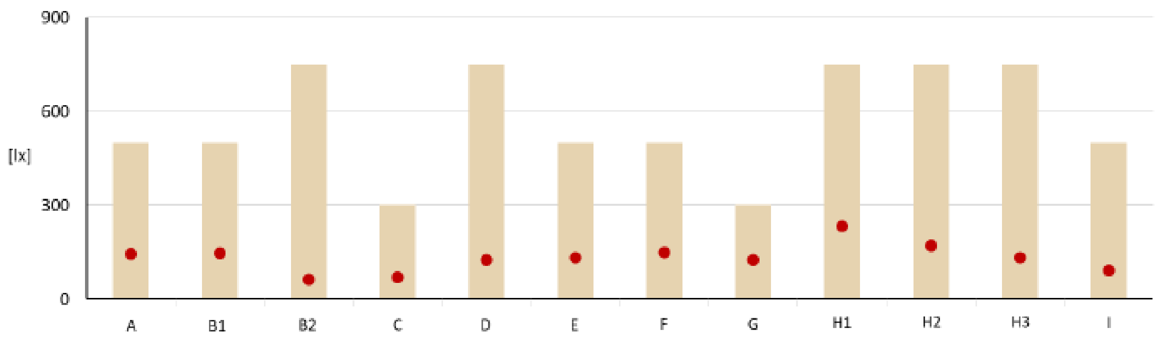


Figure 1. Comparison of the measured mean task illuminance levels in various home offices due to electrical light (red dots) with the applicable minimum recommendations (bars).

Capturing occupant activities of daily living through sensor fusion: framework, modelling and applications

Masab K. Annaqeeb[1*], Anooshmita Das[2], Jakub W. Dziedzic[1, 3], Jens Hjort Schwee[2], Mikkel B. Kjærgaard[2], Vojislav Novakovic[1]

[1]Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
[2]The Maersk Mc-Kinney Moller Institute, University of Southern Denmark, Odense 5230 M, Denmark
[3]PICTEC, Polanki 12, 80-308 Gdansk, Poland

[*]*Corresponding email: masab.k.annaqeeb@ntnu.no*

Keywords: Activity Recognition, Occupant Behaviour, Smart Living Lab, Data Fusion

With the emergence of smart homes from a niche to the mainstream, Human Activity Recognition (HAR) has become a vital component for enhancing building performance. The routine tasks conducted frequently by the occupants are termed as Activities of Daily Living (ADL). Recognition of these activities is a complex task, due to the complications involved in active monitoring such as making informed decisions and inferences about a human activity. Furthermore, modelling complexities arise from interclass resemblance, interclass variance, subject variability, and privacy concerns, among others. Generated datasets and models also need to have adaptability, to be applied independently by other researchers.

This study uses depth registration and sensor fusion to capture the activities of daily living. The experiment is conducted in a smart living lab in Norway, an initiative taken under the Net Zero Energy Buildings (nZEB) project. The objective was to collect an empirical dataset, wherein three participants performed several continuous activity sequences in a no-restriction environment, mimicking the real-world setting. The data, captured with the use of three depth registration cameras, was used to develop an activity recognition framework for generating deep learning models. The different models used were unidirectional, bi-directional, and cascaded variants of Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU). The results from the HAR analysis showed higher accuracies and boost in performance compared to others available in the literature. In addition, the models were also applied to publicly available datasets for validation. The developed framework and models can be beneficial to a number of occupant-centric fields, such as elderly assistance, safety monitoring, occupant analytics etc. The study also discusses the privacy concerns of such surveillance and proposes a privacy risk modelling to mitigate them.

Topic 7: Other building occupant-related research

1. Exploring cross-modal influences in occupants' perception and evaluation of indoor environments
2. Seeking Barriers to Comfort and Energy Efficiency on a University Campus

Exploring cross-modal influences in occupants' perception and evaluation of indoor environments

Christiane Berger* and Ardeshir Mahdavi

Department of Building Physics and Building Ecology, TU Wien, Austria

*Corresponding email: christiane.berger@tuwien.ac.at

Keywords: multi-domain indoor-environmental exposure, thermal, visual, auditory

Building occupants are typically exposed to a multitude of indoor-environmental conditions that include a variety of different thermal, auditory, visual, and air quality factors. However, the majority of related research efforts and almost all codes and standards on this subject deal with indoor-environmental stimuli in isolation. Recently, the interest in cross-modal influences in occupants' multi-perceptual indoor environment assessment has increased. Recent reviews in this area have underlined the need for more research. In this context, we present the results of an original study of cross-modal influences in occupants' perception and evaluation of indoor environments. Within the framework of this empirical (laboratory-based) study, participants evaluated thermal, visual, and auditory conditions under different combinations of relevant indoor-environmental conditions. To this end, a laboratory space including two adjacent identical mock-up office rooms was used to conduct parametric studies with human participants. The thermal conditions can be controlled in these rooms. Moreover, both lighting settings in and the acoustic landscape outside these units can be changed. Specifically, traffic noise can be emulated in the larger laboratory space that houses the office units. In the course of the conducted experimental study, different thermal, visual, and auditory conditions were maintained in the aforementioned office rooms. Participants were exposed, on a short-term basis, to different combinations of thermal, visual, and auditory conditions. The objective was to explore if participants' evaluation of one aspect of the indoor environment (e.g., the thermal conditions) was affected by the influence of other aspects (e.g., glare-inducing visual exposure and/or traffic noise exposure). We present the detailed statistical analysis of the collected data and summarize the main findings

Seeking Barriers to Comfort and Energy Efficiency on a University Campus

Julia K. Day[1*], Shelby N. Ruiz[1]

[1]School of Design + Construction, Integrated Design + Construction Laboratory, Washington State University, Pullman, WA. United States

[*]*Corresponding email: julia_day@wsu.edu*

Keywords: Occupant behaviors, energy efficiency, thermal comfort, tenant engagement, survey method

The primary goal of this research project was to gather data from building occupants to help inform, design, and eventually, implement a tenant engagement campaign to help save our University Campus up to $1 million in annual energy costs. Our team gathered data through a large-scale University survey and interviews to support energy-use reduction goals for the Washington State University (WSU), Pullman Campus. In total, over 65 interviews and 2800 survey responses were collected. Several important findings illustrate surprising ways in which occupant behaviors or perceptions significantly impacted energy use, perceived comfort, and overall satisfaction in buildings. Reported interactions between occupants and their buildings were a significant challenge, as automated controls and lack of comfort-seeking interfaces have led to significant thermal discomfort and complaints. Overall, most people agreed they cared about the energy they consumed, and they generally knew how to save energy. However, many participants expressed interest in automated energy saving devices, such as smart power strips or requested reminders in their workspaces to raise awareness of energy efficiency initiatives. They also mentioned that they could save more energy if they knew how much energy they were using in the first place. These stories support the notion that many code requirements, comfort settings through building management systems and assumptions do not truly reflect the reality of occupant behaviors, their experience, and building use. These data provide insight into human interactions with buildings in ways that may help inform and better define building codes. Ultimately, findings from study have guided tenant engagement strategies, which are currently under development through the Fall of 2021. Outcomes of this project will help our team encourage a culture of energy efficiency and sustainability for our campus building occupants in ways that will positively affect the WSU community.