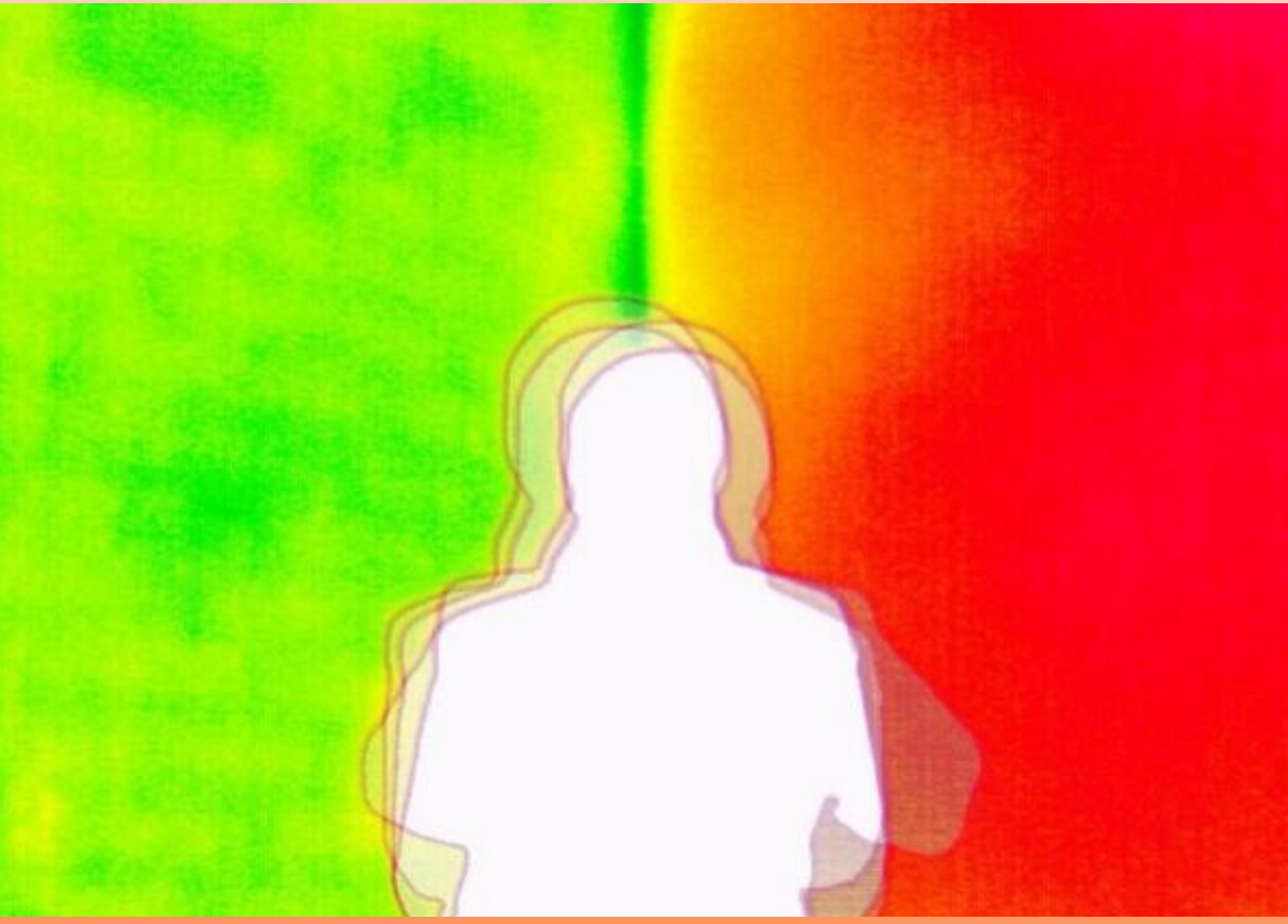
5th International Symposium on Occupant Behaviour

Annex 79

Southampton
20 - 23 April 2020



Symposium Programme

Including Contributed Paper Abstracts

Organised by the
Energy and Climate Change Division
www.energy.soton.ac.uk
www.iea-annex.org

UNIVERSITY OF Southampton

Welcome

Message from the Chairs

Occupant Behaviour 2020 (OB-20) is the 5th International Symposium focusing on designing and operating buildings that have occupants focus, including the underlying comfort and wellbeing, behaviour, and energy considerations. OB-20 aims to stimulate discussions and debate and to encourage contributions to IEA EBC Annex 79 “Occupant behaviour-centric building design and operation”. Presenters from broad backgrounds have submitted abstracts to address relevant issues covering the following themes:

- Personalised Comfort and Building Controls.
- Occupant-Centric Building Controls.
- Modelling and Simulation.
- Case Studies of Occupant-Centric Modelling, Design and Operations.
- Other Building Occupant Related Research.

The devised programme, which is based on the submitted abstracts, will have sessions covering presentations of various time slots as well as provisions for discussion. Each session will have three long presentations (8 minutes with 2 minutes for questions) and four short presentations (3 minutes) followed by 25 minutes for discussion and debate.

In light of the current coronavirus pandemic, the meeting will now take place remotely using a digital meeting platform (see below). This gives more flexibility to better accommodate the time differences for participants, by allowing the symposium to be run over two-days (Monday 20th and Tuesday 21st April), starting later in the day at 11:45 hours and finishing at 16:30 hours (London, UK). Please note the OB-20 will be followed by a two-day Annex 79 meeting (Apr 22nd and Apr 23rd).

Prof AbuBakr S. Bahaj ICEC 2020 Chair | Head, Energy & Climate Change Division, University of Southampton
Dr Stephanie Gauthier ICEC 2020 Co-chair | Lecturer in Energy and Buildings, University of Southampton

Programme at a Glance

Day 1 Monday 20 April 2020	Day 2 Tuesday 21 April 2020
11:30 — 11:45 Registration and log-in	11:30 — 11:45 Registration and log-in
11:45 — 12:00 Welcome and introduction	11:45 — 12:00 Welcome and introduction
12:00 — 13:10 Personalised Comfort and Building Controls	12:00 — 13:10 Modelling and Simulation, Session 2
13:25 — 14:35 Occupant-Centric Building Controls	13:25 — 14:35 Other Building Occupant-Related Research
14:50 — 16:00 Modelling and Simulation, Session 1	14:50 — 16:00 Case Studies of Occupant-Centric Modelling
16:00 — 16:10 Closing Remarks	16:00 — 16:15 Closing Remarks and Invitation to Expert Meeting

General Information

The IEA Secretariat have given notice that all face-to-face meetings before June are to be changed to an online format, due to the perceived risks of coronavirus. The University of Southampton has also decided to host all events virtually allowing the symposium and expert meeting to proceed as planned.

The Occupant Behaviour Symposium will be conducted using Zoom video and web conferencing platform (https://www.zoom.us) using the Zoom webinar functionality hosted by the University of Southampton. This provides functionality with which to actively control and change presentations for each session and manage questions using the 'Q&A' and 'raise hand' features. Two moderators will be on hand throughout the event to provide support and assistance during the webinars.

Registration

Online registration and login will be between 11:30 and 11:45 on both days with multiple moderators online to assist where necessary. All participants will be required to provide their full name with institution in brackets. Attendees will be encouraged to share their camera; however, those that do not wish may use a profile picture instead.

Use of Zoom

Zoom can be used on a PC, Mac, tablet or mobile, where presenters and attendees will be able to communicate using the device microphone with text options available. If you have not used Zoom before, we will provide you with a link in an email. The meeting ID for each session will also be emailed to attendees prior to the meeting.

To ensure full functionality, it is recommended that participants download the Zoom app or plug-in where possible (www.zoom.us/download). For those unable to download any plugins or software there is a zoom web client allowing one to join from browser. The web client functions best on google chrome however has limited features. You can enter the meeting at any time to test your connection, and this will allow you to download the plug-in in advance of the symposium. If you are unable to attend, the meeting will be recorded and those that logged-in post meeting will be automatically directed to a recording of the meeting.

Panellists

For those presenting we will be hosting a two-hour drop-in training session on the Friday afternoon before the event to test connection and the functionality of the software for the attendees. Presenters are asked to send their presentations a week beforehand to Symposium organisers, to be held locally. During the meeting, presenters will need to share their presentation on their screen. In case there is a problem, the host will use the local versions of the presentation for the meeting.

Please note the programme is structured to deliver the presentations within the allocated time slots. Please make sure that you do not go beyond your allotted time and allow time for questions where required. The moderators will be strict with the programme timing.

Attendees

Attendees will be muted upon joining the webinar and will be able to raise questions either through the 'Q&A' or 'raise hand' function of the platform. The Q&A board will be moderated during the proceedings with answers given where appropriate. The 'raise hand' system will be used to take questions from the room where upon being selected the attendee will be granted permission to use their microphone to ask their question. All those that join the meeting will initially join as an attendee and those presenting will be temporarily given presenter (panellist) permissions where they will be able to unmute and share their screen. These permissions will be altered between sessions by the moderators.

Internet connection

In the event that one participant has a poor connection, that is causing issues a moderator will privately message the individual offering possible solutions. Where necessary moderators will also have the ability to restrict access and move to the next presentation.

Contact

In case of issues during the conference, please either call or text +44 772 435 1399 to speak to one of the conference organisers or email *info@energyandcities.org*. In addition, multiple moderators will be online who will be happy to address your questions.

Day 1

Monday, 20 April 2020

11:30	**Registration and log-in**
11:45	**Welcome to Southampton** — AbuBakr Bahaj & Stephanie Gautheir, *Chairs*
11:50	**Introducing Annex 79** — Liam O'Brien & Andreas Wagner, *Operating Agents of Annex 79*

Personalised Comfort and Building Controls (Chair: AbuBakr Bahaj)

12:00	**Exploring Thermal Comfort in Immersive Virtual Environment** — Yimin Zhu, *Louisiana State University, USA*
12:10	**Extending the Fanger PMV Model to Include the Effect of Non-Thermal IEQ Conditions on Occupant's Thermal Comfort** — Sarah Crosby, *University of British Columbia, Canada*
12:20	**Are Comfortable Temperature Ranges Healthy?** — Simona D'Oca, *Huygen Engineers and Consultants, Netherlands*
12:30	**Energy Flexibility of Buildings: Understanding how Thermal Acceptability can Enable Demand-Response Strategies** — Matteo Favero, *Norwegian University of Science and Technology, Norway*
12:34	**Occupant-Centric Control with Personalized and Contextual Thermal Comfort Behaviour Dynamics Prediction** — Michael Kane, *Northeastern University, USA*
12:38	**Leveraging Differences in Building Characteristics to Improve Indoor Climate Perception and Energy Efficiency** — Kasper Furu Nielsen, *Copenhagen Centre on Energy Efficiency, Denmark*
12:42	**On Multidimensional Comfort: Multi-Parametric Experimental Experiment Within a BIM Designed Virtual Environment** — Anna Laura Pisello, *University of Perugia, Italy*
12:45	**Open Discussion**
13:10	**Refreshment Break**

Occupant-Centric Building Controls (Chair: Ben Anderson)

13:25	**Implementation of Occupancy-Based Predictive Controls for Outdoor Air Intake Dampers: Lessons Learned** — Brodie Hobson, *Carleton University, Canada*
13:35	**What do Occupants Want? Let's Ask Them Using Smart Watches and Cozie** — Clayton Miller, *National University of Singapore, Singapore*
13:45	**A Human-Centered Approach to Residential Buildings** — Philip Agee, *Virginia Tech, USA*

13:55	**Optimization of Solar Shading Control Strategies in Terms of User Behaviour, Energy Performance, Visual and Thermal Comfort** — Ghadeer Derbas, *Wuppertal University, Germany*
13:59	**A Reinforcement Learning for Occupant Centric Thermostat Control** — June Young Park, *University of Texas, USA*
14:03	**Monitoring Occupant Window Opening Behaviour in Buildings and Relevant Influential Parameters: A Critical Review** — Shen Wei, *University College London, UK*
14:07	**Preliminary Insights into Interviews with Building Energy Mangers Regarding Occupant Centric Control** — Michael Kane, *Northeastern University, USA*
14:10	**Open Discussion**
14:35	**Refreshment Break**

Modelling and Simulation, Session 1 (Chair: Victoria Aragon)

14:50	**Occupant Behaviour Profile Development based on Smart Meter Data** — Miklós Horváth, *Budapest University of Technology and Economics, Hungary*
15:00	**Analysing Smart Thermostat Data and Unregulated Loads to Support the Canadian Net Zero Energy Ready Code** — Mohamed Ouf, *Concordia University, Canada*
15:10	**Agent-Based Modelling of Building Occupants: Promise and Challenges** — Ardeshir Mahdavi, *Tu Wien, Austria*
15:20	**Inserting Occupant Behaviour Models Within the Workflow of Practitioners: A Practice -Based Perspective** — Clarice Bleil de Souza, *Welsh School of Architecture, Wales*
15:24	**Is a Zero-Net-Energy (ZNE) Home Really ZNE?** — Tianzhen Hong, *Lawrence Berkeley National Laboratory, USA*
15:28	**Demand Response Events in Residential Buildings: Not Noticeable at All?** — Marika Vellei, *La Rochelle Université, France*
15:32	**Occupant Behaviour and SAP: Integration of Stochastic Occupancy Modelling into Compliance Tools** — Benjamin Halls, *Loughborough University, UK*
15:35	**Open Discussion**
16:00	**Closing Remarks** — AbuBakr Bahaj & Stephanie Gautheir, *Chairs*
16:10	**End of day**

Day 2

Tuesday, 21 April 2020

11:30	**Registration and log-in**
11:45	**Welcome** — AbuBakr Bahaj & Stephanie Gauthier, *Chairs*

Modelling and Simulation, Session 2 (Chair: Patrick James)

12:00	**Generic vs. Occupant Specific Behaviour Modelling in Building Simulation and Building Automation** — Clara-Larissa Lorenz, *RWTH Aachen University, Germany*
12:10	**What Does a Zero Energy and Zero Carbon Tenant Look Like?** — Julia Day, *Washington State University, USA*
12:20	**Effectiveness of Feedforward Information System on Occupant's Behaviour** — Isabel Mino-Rodriguez, *Karlsruhe Institute of Technology, Germany*
12:30	**Quantifying the Impact of Occupant Presence on Building Energy Simulation with Real and Synthetic Data** — Adrian Chong, *National University of Singapore, Singapore*
12:34	**Prediction of Indoor Clothing Insulation Levels: A Comparison of Different Machine Learning Approaches** — Anooshmita Das, *University of Southern Denmark, Denmark*
12:38	**Analysis of Occupants Presence in Homes** — Alasdair Mann, *University of Southampton, UK*
12:42	**The Impact of Occupants' Distribution on Energy and Comfort in a Case study Office Building** — Tareq Abuimara, *Carleton University, Canada*
12:45	**Open Discussion**
13:10	**Refreshment Break**

Other Building Occupant-Related Research (Chair: Massimilianno Manfren)

13:25	**Does Teleworking Save Energy? A Critical Review of Quantitative Studies and their Research Methods** — Liam O'Brien, *Carleton University, Canada*
13:35	**A Systematic Approach to Preserve Privacy in Smart Buildings** — Alan Wang, *University of Virginia, USA*
13:45	**Understanding New Technology and their Impacts on Occupants** — Victoria Aragon, *University of Southampton, UK*

13:55	**Towards Low-Energy Housing in the Canadian North from an Occupant-Centric Perspective** — Louis Gosselin, *Université Laval, Canada*
13:59	**User Behaviour in Low-Environmental Impact Buildings in Tropical Climates** — Maareva Payet, *University of La Réunion, France*
14:03	**N-Gage: Sensing in-class Multidimensional Learning Engagement in the Wild** — Nan Gao, *Royal Melbourne Institute of Technology University, Australia*
14:07	**Energy Consumption and Nudges to Influence Behaviour** — Tom Rushby, *University of Southampton, UK*
14:10	**Open Discussion**
14:35	**Refreshment Break**

Case Studies of Occupant-Centric Modelling, Design and Operations
(Chair: Stephanie Gauthier)

14:50	**Introduction to PhD Thesis: Subjective Data-Streams for Indoor Climate Assessment in Buildings** — Niels Lassen, *Norwegian University of Science and Technology, Norway*
15:00	**Evaluating Acoustic Comfort in Multi-Unit Residential Buildings** — Marianne Touchie, *University of Toronto, Canada*
15:10	**Learning to Live in Low-Energy Dwellings: A Mixed-Methods Case Study** — Lucile Sarran, *Technical University of Denmark, Denmark*
15:20	**Capturing Real-Time Motivations Behind Human-Building Interactions: The OBdrive App** — Verena Barthelmes, *Ecole Polytechnique Fédérale de Lausanne, Switzerland*
15:24	**Evaluating Varying Comfort** — Gary Raw, *GRPS, UK*
15:28	**Case Study: Reasons of Office Occupant's Dissatisfaction with an Automated Lighting Control System** — Sarah Weiner, *Fraunhofer Institute, Germany*
15:32	**Impact of Visual and Auditory Factors on Perceived Thermal Comfort: A Case Study** — Ardeshir Mahdavi, *Tu Wien, Austria*
15:35	**Open Discussion**
16:00	**Invitation to IEA Annex 79 Expert Meeting** — Liam O'Brien & Andreas Wagner, Operating Agents of Annex 79
16:10	**Closing Remarks** — AbuBakr Bahaj & Stephanie Gauthier, Chairs
16:15	**End of day**

Oral Presentation Abstracts

Abuimara, Tareq

Carleton University, Canada

Session 4

Day 2, 12:42

The Impact of Occupants' Distribution on Energy and Comfort in a Case study Office Building
T. Abuimara

Observing the current occupant modelling approaches during simulation-aided building design reveals that energy modellers and designers assume that occupants are evenly distributed within areas of a given type (e.g. office space). Designers typically assume uniform occupant density (i.e. number of people/m2) to perform design tasks which is usually specified by building codes and standards. However, this assumption does not necessarily reflect reality, as occupants are often distributed heterogeneously in buildings due to several factors such as inter-tenant diversity in office buildings. To this end, this study examines the impact of occupants' distribution on energy and comfort performance of an office building model located in Toronto, Canada. A 15-zone model was simulated using EnergyPlus simulation tool under 33 different randomly generated occupants' distribution scenarios. The energy performance was assessed based on the energy use intensity (EUI) while a metric called discomfort occupant hours (DOH) was developed to assess comfort levels. DOH is calculated by summing the multiplication of the discomfort hours (i.e. indoor temperature not within acceptable range) by the number of people present at that hour in the zone. In addition, the traditional ASHRAE Standard 90.1 unmet hours, where the building is considered to have an unmet hour when a single zone of the building has an unmet hour, were reported. The results of the study indicate that occupant distribution scenarios can have significant impact on occupants' comfort as overpopulated zones had a significantly higher DOH compared to the DOH of standard distribution used in typical design processes. On the other hand, the change in occupants' distribution had moderate impact on energy performance as the highest difference in EUI was observed to be 9 kWh/m2 given that model HVAC were hard sized for all simulations.

Agee, Philip

Virginia Tech, USA

Session 2

Day 1, 13:45

A Human-Centered Approach to Residential Buildings
P. Agee

Traditionally, the Architecture, Engineering, and Construction (AEC) industry has employed a linear design and delivery approach. As residential buildings race to zero energy performance, the AEC industry must adapt. To maximize human well-being and the operational performance of zero energy buildings, an iterative, human-centered approach must be employed. The omission of human factors in the design and delivery of residential building systems risks misalignment between occupant-user needs and the AEC industry's perception of occupant-user needs. This research proposes a human-centered approach to housing. The study employed a multiphased, mixed-methods research design. Data were collected from 309 high performance housing units in the United States. Longitudinal energy use data (simulated and measured), occupant surveys, and semi-structured interviews are the primary data inputs. Affinity diagramming was leveraged to categorize the qualitative data. The output of the affinity diagramming analysis led to the development of data-driven Personas that communicate user needs. While this data was gathered in the United States, researchers, practitioners, and policy makers can leverage the human-centered approach beyond residential buildings toward the design of a human-centered built environment.

Barthelmes, Verena

EPFL, Switzerland

Session 6

Day 2, 15:20

Capturing Real-Time Motivations Behind Human-Building Interactions: The OBdrive App
V. Barthelmes

Despite significant advances in the field of energy-related behavioural research in buildings, gaining a more comprehensive and "multi-dimensional" understanding of drivers and perceived motivations behind human-building interactions remains an open challenge. Increasing effort is put on understanding how the combined effect of IEQ factors affects user perception and behaviour in real buildings. Oftentimes, the motivations behind actions are

Barthelmes, Verena

EPFL, Switzerland

Session 6

Day 2, 15:20

deducted solely from physical measurements of the environment, which might not always reflect the real triggers behind occupants' actions. On the other hand, certain combinations of perceived motivations related to different dimensions of comfort (e.g. thermal comfort and indoor air quality) might be stronger linked than others. In the context of the eCOMBINE project ("Interaction between energy use, COMfort, Behaviour, and INdoor Environment in office buildings"), we developed an ad-hoc designed mobile application aimed at gathering feedback from the occupants each time they interact with windows, window blinds, and lights. In that way, perceived motivations can be compared to results from the environmental monitoring campaign. Further, the compact design of the app allows for gaining basic information on group dynamics and social interactions before interacting with controls. This contribution is aimed at presenting the OBdrive mobile application and provide first insights into the analysis of perceived motivations behind the interactions with windows and blinds, and their link to physical measurements of the global indoor environment. The study was carried out in Swiss open space offices over two-weeks monitoring campaigns during the Fall and Winter season.

Bleil de Souza, Clarice & **Tucker**, Simon

Welsh School of Architecture, UK & Liverpool School of Art and Design, Liverpool John Moores University, UK

Session 3

Day 1, 15:20

Inserting Occupant Behaviour Models Within the Workflow of Practitioners: A Practice-Based Perspective

C. Bleil de Souza, S. Tucker

We invite the building performance simulation community to discuss how occupant behaviour models can be inserted or integrated within the workflow of practitioners. We propose a practice–based perspective, where the workflow of practitioners is rationalized from high level, considering how they make decisions, down to its lower level, when decisions are implemented in practice aided by simulation tools. This practice-based perspective was developed in previous work sponsored by EPSRC/UK, grounded on a mixed methods approach which included, Interaction Design, Participatory Action Research, a survey, interviews and discussions with practitioners. It explored the workflow of decision-making behind ill-defined problems, in which designers make decisions in a non-systematic way based on reflection in action as a result of 'what if' experiments. This is one of the most challenging types of decision making processes to be rationalised as building designers need information and ideas in order to understand better what is significant to the design challenge at hand and to inform design decisions based on evidence. Increasing the uptake of occupancy modelling by designers will require that inherently complex information is presented to practitioners in ways that support their design process. Therefore, this presentation is supposed to: 1. Briefly show the overarching framework of decision-making for ill-defined problems, providing an overview on how practitioners make decisions, including worked examples validated in practice. 2. Discuss how the framework can be translated into simulation workflows within the logic of object oriented programming, likewise commonly used in digital design tools. 3. Open a discussion on how catalogues of decisions, grounded on the identification of the different 'dimensions' of occupant modelling which are relevant to the design process, can be developed to insert and recall different types of occupant behaviour models within the decision-making workflow of practitioners.

Chong, Adrian

National University of Singapore, Singapore

Session 4

Day 2, 12:30

Quantifying the Impact of Occupant Presence on Building Energy Simulation with Real and Synthetic Data

A. Chong

Occupants have been recognized as a source of uncertainty with a significant impact on building energy simulation. To date, occupant behavior related inputs have typically been treated as an uncertain parameter to be calibrated. With advancements in occupant sensing, occupant information is becoming increasingly available and more easily accessible, providing an opportunity to model occupant information as an observed model input instead of a calibration parameter. This research aims to answer the question, "what is the lowest spatial resolution of occupant count needed for reducing the gap between

Oral Presentation Abstracts

Chong, Adrian

National University of Singapore, Singapore

Session 4

Day 2, 12:30

simulated and measured energy use in buildings given an adequate calibration procedure." Thirteen case studies were defined to evaluate the impact of different levels of occupant presence on the calibration efficacy of building energy simulation. Different levels of spatial resolutions (building, level, and zone) were investigated. Of the thirteen, seven were derived from synthetic data using the DOE commercial large office reference building and an agent-based occupancy simulator. The remaining six case studies were derived from a real mixed-use building located at the National University of Singapore in Singapore, using WIFI data as a proxy for occupancy count. Synthetic data are useful because we know the true values of the calibration parameters that can be used for a quantitative evaluation of the effect of occupant presence. The real dataset is then used to verify the results and test the hypothesis using energy models of actual buildings, under real-life operating conditions.

Crosby, Sarah

University of British Columbia, Canada

Session 1

Day 1, 12:10

Extending the Fanger PMV Model to Include the Effect of Non-Thermal IEQ Conditions on Occupant's Thermal Comfort

S. Crosby

The judgment of thermal comfort is a cognitive process influenced by occupant's well-being and overall satisfaction. The potential implications of occupants' thermal dissatisfaction and its effect on overall satisfaction with the indoor environment have been the focus of many recent studies in the literature. Taking advantage of the emerging awareness of the interdependencies between perceived thermal comfort and overall IEQ, we have developed a novel methodology that considers the effect of non-thermal building environmental design conditions, such as indoor air quality and noise levels, on perceived thermal comfort. The methodology involves the use of Bayesian inference to relate occupant's thermal satisfaction not only to thermal conditions (i.e., parameters of the original Fanger model) but also to measurable non-thermal, "well-being"-type, metrics. In the first phase of this study, field data are drawn from a prior field study of about 800 offices throughout Canada and the US conducted by the National Research Council of Canada in early 2000s. The Bayesian inference analysis reveals that there exist statistically significant independent correlations between some non-thermal metrics of IEQ and thermal comfort, as perceived by occupants of open-plan offices. The most significant finding is that a modest increase in measured indoor CO2 concentrations, from 500ppm to 900ppm, is found to be correlated with a decrease in perceived thermal satisfaction by 30%. Such observable correlations have revealed the need for developing an updated version of the data collected. A large IEQ field study of 150 offices carried out at the University of British Columbia across 2019/2020 is presented. This study seeks to update the recent findings while addressing the most prevailing research gap vis-à-vis thermal comfort models by proposing an extension to the Fanger model which consists of a more holistic evaluation method.

Das, Anooshmita

University of Southern Denmark, Denmark

Session 4

Day 2, 12:34

Prediction of Indoor Clothing Insulation Levels: A Comparison of Different Machine Learning Approaches

A. Das

Accurate prediction of clothing insulation levels is imperative for reducing building energy consumption. Clothing insulation is a critical parameter in the prediction of occupant thermal comfort. Lack of this information may result in miscalculations in the comfort conditions required, which may result in poorly sized heating, ventilation, and air conditioning (HVAC) systems. Predicting thermal comfort via clothing insulation levels of occupants in indoor settings using machine learning (ML) is a hot research topic. The advances in ML opens new opportunities for occupant thermal comfort prediction to mitigate the challenges encountered by existing models. Diverse algorithms and data preprocessing methods get applied to predict thermal comfort indices in heterogeneous contexts. But limited studies have systematically analyzed how different algorithms and data processing methods can have repercussions on the prediction accuracy. We experimentally study the perspectives of predicted

Das, Anooshmita

University of Southern Denmark, Denmark

Session 4

Day 2, 12:34

comfort indices, algorithms implemented, different input features, data sources, sample-size, training and test set proportion, and predicting accuracy. For the data collection, a Microsoft Kinect camera is deployed and created a database with different clothing patterns, see Figure 1 (a). Ground-truth labels were collected with a second camera to validate the data annotations on clothing patterns for the classification task. We have applied four ML algorithms (K-Nearest Neighbor, Catboost, Gradient Boosting, XGBoost) for the Clo-value estimation. We also investigated the clothing patterns in natural and dark light settings. The relationship between clothing and gender was also meticulously analyzed and came up with interesting conclusions. The results in Figure 1 (b) highlight that the KNN has the best performance among the tested algorithms with an accuracy of 84.50% in dark light setting and 91.68% or the natural light setting.

What Does a Zero Energy and Zero Carbon Tenant Look Like?

J. Day, A. Schwabe, S. Ruiz

Day, Julia, **Schwabe**, Alison & **Ruiz**, Shelby,

Washington State University & McKinstry PowerEd, USA

Session 4

Day 2, 12:10

Occupancy patterns are necessary to estimate energy demand and evaluate thermal comfort in households. Because of this, many European countries are developing representative domestic schedules to replace outdated criteria. This paper evaluates the state of knowledge of UK domestic occupancy patterns and develops new domestic occupancy profiles for England. The presented research (1) characterizes methods for collecting occupancy data and inferring patterns; (2) identifies and assesses the quality of categories of occupancy patterns used in building simulation; and (3) develops updated occupancy profiles. A systematic scoping review identified social and monitoring surveys as the most deployed data-collection methods. A systematic literature review also established that the occupancy categories most frequently used in UK building simulation are (a) a family with dependent children where the parents work full time; and (b) a retired elderly couple who spend most of their time indoors. The interview sample from the English Housing Survey 2014–15 was used to map household typologies. Results show that categories (a) and (b) combined amount to only 19% of England's households, which suggest models are over-reliant on these groups. Considering this result, the paper develops occupancy patterns for England derived from 2015 UK Time Use Survey diaries for each household typology previously identified.

Optimization of Solar Shading Control Strategies in Terms of User Behaviour, Energy Performance, Visual and Thermal Comfort

G. Debras

Derbas, Ghadeer

Wuppertal University, Germany

Session 2

Day 1, 13:55

Automated shading systems represent a promising solution for improving the indoor environment and saving energy, particularly in highly glazed office buildings. Recent research reported that these systems are either deactivated or overrode by the occupants. For instance, some studies found conflicts between the commonly used metrics of automated shading and what occupants accepted. Moreover, the current study proposed that the accuracy of the shading control sensors could affect the user acceptance of the established metrics. Further research was needed to investigate the sensors' accuracy and user-shade interactions to find the optimal metrics of shade control with limited overrule actions. In this contribution, the current study presented an experimental field study on human interactions with automated shading systems in a full-scale test laboratory. The experiment was designed to (a) examine the accuracy of shade control sensors by testing two commercial devices and (b) investigate user interactions under three shade control strategies, then evaluate their satisfaction concerning thermal and visual comfort. Two simple strategies were used solar irradiance as triggering threshold, and an optimized control strategy was developed based on a combination of three control criteria: incident irradiance, indoor temperature and vertical illuminance. Shade deployments, indoor and outdoor physical parameters were recorded as well as a self-reported questionnaire. The current study found that the measurements of shading control sensors were statistically approved to be inaccurate with a high degree of

Oral Presentation Abstracts

Derbas, Ghadeer

Wuppertal University, Germany

error. Mean shade occlusion under the different control strategies was slightly different, whereas the optimized control strategy showed a significant impact on decreasing user shade lowering actions. Furthermore, glare and brightness were found to have more influence on shade adjustment than indoor thermal conditions. The current study was further expanded to simulate space design impact on shade control optimization in terms of energy performance, occupant behaviour and comfort.

D'Oca, Simon

Huygen Engineers and Consultants, Netherlands

Session 1

Day 1, 12:20

Are Comfortable Temperature Ranges Healthy?
S. D'Oca

Building occupants have often limited knowledge about the quality of the indoor climate they are working or living in. There is an overall lack of awareness of the influence of adaptive behaviors and indoor climate on overall building's performance, and even less on personal health. Experimental studies showed regular exposure to mild cold environment can increase energy expenditure in terms of human energy metabolism, resilience to thermal discomfort due to acclimation, and resistance to cardiovascular disease and insulin sensitivity. In the MOBISTYLE project, we are aiming to prove gradually cooler environment in winter and warmer in summer can lead to higher acceptance of comfort ranges in office settings. Dynamic temperature training can furthermore have a great effect on the productivity and well-being of the occupants, therefore optimizing operating (labor) costs of the building. Not only, significant reduction of final energy consumption (up to 16%) can be prompted by dynamic thermal environment, as well as reduction of CO2 emissions. Dynamic open-office settings have been deployed in the Huygen offices (Netherlands) combining dynamic temperature profiles for improving health, comfort and saving energy, with dynamic lighting for increasing alertness and improving sleep-wake rhythm. Under these living-lab dynamic settings, the Office App is coupling the office BMS data, with data from wearables gathering information on workers well-being and physical health, as well feedback on perceived comfort and productivity.

Favero, Matteo & **Carlucci**, Salvatore

Norwegian University of Science and Technology, Norway

Session 1

Day 1, 12:30

Energy Flexibility of Buildings: Understanding how Thermal Acceptability can Enable Demand-Response Strategies
M. Favero, S. Carlucci

Current research in building science aims at implementing strategies to exploit the energy flexibility of buildings. This consists in shifting energy use for given energy services in order to adapt the hour-by-hour energy consumption to what is optimal for the energy system. Energy uses for space heating and cooling are important terms of a building's energy balance and can be displaced by some hours, utilising building's thermal mass, without significantly affecting the thermal comfort of the occupants. However, this is an assumption that needs to be verified. Thus, to what extent it is possible to exploit building's energy flexibility without compromising thermal comfort experienced by their occupants remains an open research question. A dedicated experiment, executed in the ZEB Test Cell Lab in the NTNU premises, aims at understanding occupant's thermal acceptability in dynamic indoor conditions and how it compares with the ASHRAE 55-2017 limits on temperature cycles, ramps, and drifts. In this study, participants were asked to spend full or half days in the facility, furnished like a typical cellular office, and to evaluate the indoor environment through questionnaires while carrying out their everyday work activity. During the experiment, the air temperature was modified according to predefined thermal ramps (Fig. 1) while other environmental parameters, such as air velocity, relative humidity, CO2 concentration, and illuminance on the work surface were also recorded. Furthermore, the participants were asked to press a button as soon as they felt uncomfortable, where uncomfortable was defined as "take an action to restore a comfort condition" (e.g., if too warm environment, then regulate the thermostat or open the window). In this way, it will be possible, after the analysis of collected data, to understand the limits of the human thermal acceptability under different temperature variations, before voluntary adaptation mechanisms or actions are undertaken.

Gao, Nan

Royal Melbourne Institute of Technology University, Australia

Session 5

Day 2, 14:03

N-Gage: Sensing in-class Multidimensional Learning Engagement in the Wild

N. Gao

The study of student engagement has attracted growing interests to address problems such as low academic performance, disaffection and high dropout rates. Existing approaches to measuring student engagement typically rely on survey-based instruments. While effective, those approaches are time-consuming and labour-intensive. Meanwhile, both the response rate and quality of the survey are usually poor. As an alternative, in this paper, we investigate whether we can infer and predict engagement at multiple dimensions just using sensors. We hypothesize that student multidimensional engagement level can be translated into physiological responses and activity changes during the class, and also be affected by the environmental changes. Therefore, we aim to explore the following questions: Can we measure the multiple dimensions of student's learning engagement including emotional, behavioural and cognitive engagement in high school classrooms with sensing data in the wild? Can we derive the activity, physiological, and environmental factors contributing to the different dimensions of student learning engagement? If yes, which sensors are the most useful in differentiating each dimension of the learning engagement? Then, we conduct an in-situ study in a high school from 23 students and 6 teachers in 144 classes over 11 courses for 4 weeks. We present the n-Gage, a student engagement sensing system using a combination of sensors from wearables and environments to automatically detect student in-class multidimensional learning engagement. Extensive experiment results show that n-Gage can accurately predict student multidimensional engagement in real-world scenarios with an average mean absolute error (MAE) of 0.794 and root mean square error (RMSE) of 0.977 using all the sensors. We also show a set of interesting findings of how different factors (e.g., combinations of sensors, school subjects, CO2 level) affect each dimension of the student learning engagement in high school.

Gosselin, Louis & **Rouleau**, Jean

Université Laval, Canada

Session 5

Day 2, 13:55

Towards Low-Energy Housing in the Canadian North from an Occupant-Centric Perspective

L. Gosselin, J. Rouleau

Nunavik is the northern region of the Province of Québec (Canada). It has a population of around 14,000, most of which being Inuit (90%). They live in 14 villages along the coast. Due to their remoteness, these communities are off-grid. A diesel power plant in each village provides electricity, while space heating is obtained from fuel oil. Due to the cold climate, the typical heating need exceeds 300 kWh/m2. The environmental footprint of fossil fuels and their cost are among serious issues in that region. Additionally, the lack of dwellings and their unfitness to meet local needs have been recurrent problems related to housing in the North. Historically, Inuit were nomadic; they gradually transitioned to sedentary only in the 1950s. At that time, the government provided matchbox houses, which proved to be unfit for their needs. Today, stakeholders are aiming in the direction of designing, building and operating highly energy-efficient dwellings that are also culturally and socially adapted. With this target in mind, an occupant-centric perspective appears to be crucial. The analysis of building operational data, the development of models, and interviews and co-design with Inuit can help to better understand how occupants use energy in Nunavik's houses, what can be done to reduce that consumption and increase comfort, and what solutions are adapted to the people. During the talk, we will present current research projects on that topic and share some preliminary results.

Oral Presentation Abstracts

Halls, Benjamin

Loughborough University, UK

Session 3

Day 1, 15:32

Occupant Behaviour and SAP: Integration of Stochastic Occupancy Modelling into Compliance Tools

B. Halls

This study will address the topic of 'Integrate occupant modelling into building design process'. Occupant behaviour has a significant impact on the energy demand of buildings. However, representation of occupant behaviour within building simulation tools and building regulations is often simplified, leading to discrepancies between predicted and actual energy demand of buildings. The UK standard assessment procedure (SAP) is used to measure the energy performance of buildings for compliance and regulation. SAP is used to produce Energy performance certificates (EPCs), rating buildings on their energy efficiency. However, SAP uses standard assumptions for occupant behaviour, resulting in large variances between predicted and actual energy demand of buildings. A better representation of occupant behaviour in SAP and compliance tools will aid in low energy building design.

This study aims to integrate occupant behaviour into compliance such as SAP, to investigate the potential benefit, applications and impact of including stochastic occupant behaviour within energy demand predictions for domestic buildings. The integration of occupant behaviour will provide a better representation of how and when occupants use energy in UK dwellings, by including the variation in energy demand across households within the SAP calculations. Integration of heating, lighting, appliance use, and occupancy presence distributions will be examined in SAP.

A literature review which outlines the research gap and highlights the potential for improvement has been developed along with an initial Markov model. Further work will consider alternative modelling techniques such as agent-based modelling and logistic regression to test the performance of more detailed modelling approaches in SAP for domestic buildings. Time use survey datasets such as Energy follow up survey, household electricity survey and UK time use survey will be used for the development of the models.

Hobson, Brodie

Carleton University, Canada

Session 2

Day 1, 13:25

Implementation of Occupancy-Based Predictive Controls for Outdoor Air Intake Dampers: Lessons Learned

B. Hobson

As modern workplaces begin to transition towards flexible work hours, commercial and institutional buildings are hosting a fraction of their maximum occupancy on typical workdays. Despite this, most HVAC systems operate on static pre-set schedules that assume the building is almost fully occupied during working hours, resulting in chronic overventilation. As conditioning outdoor air requires significant energy in heating dominated climates, there is a growing oppourtunity to reduce energy use and greenhouse gas emissions by providing HVAC services at an appropriate level for the actual occupancy of the building, without significantly impacting occupant comfort. However, reactive controls based on occupant-count estimates alone are insufficient for optimal operation of system-level equipment, such as air handling units. This is due to the transient nature of buildings' thermal and air quality conditions. Instead, forecasting occupancy levels can facilitate proactive and informed decisions about air handler operations. An occupancy-based predictive control program was implemented in a building automation system to control the outdoor air intake dampers of two air handling units. Clustering and motif identification were used to create a rules-based approach for occupancy forecasting by leveraging readily available electrical load data and historic Wi-Fi device count data. Three-parameter univariate changepoint models show that the program reduced building cooling and heating energy use by 10.3% and 38.4%, respectively, during a 24-week implementation period. The program had a negligible impact on indoor CO2 concentrations and caused a 5.8% reduction in hours spent within ± 1°C of temperature setpoints. Challenges and relevant anecdotes from the implementation are also examined and discussed. This study highlights how occupancy data can improve building operational efficiency without the need for additional sensing or controls infrastructure.

Hong, Tianzhen

Lawrence Berkeley National Laboratory, USA

Session 3

Day 1, 15:24

Is a Zero-Net-Energy (ZNE) Home Really ZNE?
T. Hong

California, as a U.S. state, requires new residential buildings to be zero-net energy (ZNE) starting 2020 by its building energy efficiency standards, aka Title 24. The zero-net energy metric is on an annual basis, i.e., a residential building (either single or multi-family) produces enough energy on-site to meet its energy demand during a whole-year period. ZNE homes are designed with a package of technologies based on the optimized cost balancing energy efficiency measures and on-site renewable energy generation (e.g., from PV). However, the actual operating performance of ZNE homes would vary significantly due to actual weather conditions and more importantly, the energy use behaviours of the occupants in those ZNE homes. In the energy modelling and analysis that derives the ZNE home design, typical meteorological year (TMY) weather data in 16 Californian climate zones and static and homogeneous occupant profiles are used. There lacks quantification of the variability of performance of ZNE homes. This presentation introduces research and energy modelling conducted to characterize and quantify the influence of weather and occupant behaviour on the performance of ZNE homes, which helps address the question – when does a ZNE home become energy positive or negative, and by how much? The findings suggest scenarios of weather data and occupant behaviours should be developed and considered in the energy modelling process that supports the Title 24 development so that variations of ZNE home performance are quantified and ZNE home technologies can be optimized to ensure robust ZNE target.

Horváth, Miklós
Czetany, Laszio &
Vámos, Viktória

Budapest University of Technology and Economics, Hungary

Session 3

Day 1, 14:50

Occupant Behaviour Profile Development based on Smart Meter Data
M. Horváth, L. Czetany, V. Vámos

This presentation will cover the objectives and first results of the research project entitled “Large Scale Smart Meter Data Assessment for Energy Benchmarking and Occupant Behaviour Profile Development of Building Clusters,” conducted based on data from Hungary. The project seeks to utilize a new and unique opportunity for accessing and processing an enormous dataset collected by smart meters. Recently in Hungary, nearly 10 000 buildings have been equipped with smart meters within the "Central Smart Grid Pilot Project". By means of advanced data analysis techniques, consumption trends and motivations of building users are being investigated. The aims are to help building designers and engineers design more energy efficient buildings at lower investment costs by avoiding system oversizing and to obtain better knowledge about hourly, daily and monthly energy consumption trends. Furthermore, standard net demand values for normative energy calculations are being updated and specified more precisely since consumption habits change with time and depend on the region. In the first phase of the project, questionnaire surveys were conducted in public buildings both equipped and not equipped with smart meters. Attitude, knowledge and behavioural patterns of occupants were measured and then compared to smart meter datasets. Currently, the energy consumption profiles are being developed using different kind of clustering techniques. First, the classic K-Means and Fuzzy K-Means clustering methods are used but the research is going to be extended to the Hierarchical clustering method as well and the results will be compared. It was also investigated whether the commonly used data analysis techniques in electricity-based datasets can also be used for heat and natural gas consumption datasets of buildings.

Kane, Michael

Northeastern University, USA

Occupant-Centric Control with Personalized and Contextual Thermal Comfort Behaviour Dynamics Prediction
M. Kane

Demand response (DR) as a gear in the energy sector, works to curtail peak electricity demand to maintain high grid reliability and reduce costly transmission capacity. Conventional DR programs use emails, texts, and phone calls, with the latest automatic DR using direct load control. These methods lack fidelity to provide accurate load curtailment. Even with the advent of adoption smart devices, the same settings are implemented for all participants, irrespective of

Oral Presentation Abstracts

Kane, Michael

Northeastern University, USA

Session 1

Day 1, 12:34

each person's thermal comfort zone, leading to reduced quality of service. Eventually, frustration tends to mount up and the result is an increase in occupant overrides, over 30% of 8-hour DR events in one study. The consumers as a result of this frustration lose trust, which further impacts demand response programs and utilities in the form of millions of dollars in penalties nationwide. This motivates the need to personalize thermal comfort and architect DR controls that consider contextual and personal factors. The goal the work to be presented is to develop personalized predictive models of manual thermostat overrides. Machine learning methods like decision trees and artificial neural network applied to the ecobee Donate Your Data dataset with ~1259 users and ~285 events per user. Based on these methods, the resulting personalized models are compared in terms of their accuracy, computational complexity, and outlier management. Interactions with ecobee thermostats were also analyzed to predict the impact of such personalized DR on overrides, energy curtailment magnitude, and reliability.

Kane, Michael

Northeastern University, USA

Session 2

Day 1, 14:07

Preliminary Insights into Interviews with Building Energy Mangers Regarding Occupant Centric Control

M. Kane

The presentation will provide an overview and preliminary results of the activity in Annex 79 – Subtask 4 on an "International survey on occupant sensing technologies and their usage". The goal of the project is to identify common occupant sensing technologies for energy management, determine how these technologies are used and supplemented with operator expertise, and define white-space for future R&D. The planned approach includes interviewing facility managers, energy managers, and building operators from across the world in multiple languages. This presentation covers preliminary insights into the initial surveys conducted in North America.

Lassen, Niels

Norwegian University of Science and Technology, Norway

Session 6

Day 2, 14:50

Introduction to PhD Thesis: Subjective Data-Streams for Indoor Climate Assessment in Buildings

N. Lassen

A general presentation of background, research questions, experimental activities and preliminary findings in an ongoing PhD thesis. The aim of the thesis has been to understand the potential, functioning and validity of methods for continuous subjective occupant feedback for indoor climate in buildings and answer the question «Can continuous, non-intrusive collection of subjective data from occupants outperform traditional deterministic comfort models and POE's and can they bring added value to building benchmarking, tuning, control and design?». The research activities range from literature studies, development of a framework for classifying subjective information sources, and field experiments of occupants in 6 separate office spaces in Norway and Berkeley, USA. Field tests have focused on the validation of information gathered through a public smiley face poling station placed in the office environment, as well as occupants' use of personal heaters. Collected field data has been compared to results from occupant surveys and measurements of the physical climate during normal operation and during temperature interventions. All field tests have been performed on un-informed subjects performing regular office activities. Preliminary results indicate that real-time non-intrusive occupant feedback can outperform traditional predicting models and was able to capture occupant dissatisfaction in cases where physical measurements and comfort models were proven incapable.

Lorenz, Clara-Larissa & **Syndicus**, Marc

Generic vs. Occupant Specific Behaviour Modelling in Building Simulation and Building Automation

C. Lorenz, M. Syndicus

Machine Learning and Deep Learning are promising methods to model occupant behaviour (OB). OB models are particularly meaningful for 1) building simulation, to accurately simulate building energy consumption, and 2) building automation, where control strategies can be optimised based on predicted occupant

Lorenz, Clara-Larissa & **Syndicus**, Marc

RWTH Aachen University, Germany

Session 4

Day 2, 12:00

interactions with the building. The requirements to OB models may however differ between use-cases. In the case of window-opening models, reliable results have so far only been obtained for use in building simulation. For example, Markovic et al. (2018) reliably predicted current window states via a generic model. As the model generalises occupancy types, the method points to difficulty when trying to predict and adjust to a specific occupants' future behaviour in building automation. It is further unknown how interfering in the current state changes the trajectory of a future prediction (e.g. when reducing output power for heating and ventilation based on a predicted upcoming window-opening event, the event may be delayed or not occur anymore). Hence, prognosis-based system adjustments in building automation require counterfactual reasoning and analysis, i.e. if change had been imposed (in system control), would OB patterns have remained the same and could energy savings have been achieved? We critically discuss these and other topics arising from implementations of Machine-and Deep Learning-based OB models. Specifically, we structure the discussion such, that we address the question as to what underlies the high accuracy of OB models for building simulation. We further inquire about the requirements that need to be met so that this success can similarly be acquired in building automation. With this work, we hope to provide clarity on the topic and help realise the innate potential of Machine- and Deep Learning methods in building automation.

Mahdavi, Ardeshir & **Berger**, Christiane

TU Wien, Austria

Agent-Based Modelling of Building Occupants: Promise and Challenges
A. Mahdavi, C. Berger

Session 3

Day 1, 15:10

Building design, construction, and operation can benefit from utilization of digital technologies. In this context, Building Information Modeling (BIM) represents a well-known class of digital media geared toward supporting the building delivery process. More recently, efforts are made to extend BIM beyond static representation of buildings' constituent components: Utilizing numeric simulation, BIM could provide high-resolution dynamic representations and thus support a wide range of performance assessment services. Thereby, it is increasingly recognized that digital models of building must include representations of occupants. This is not only because occupants are the main recipients of the services buildings provide, but also because they influence buildings' performance. In this context, agent-based modelling (ABM) has been viewed as a promising instrument toward computational representation of processes associated with occupants' patterns of presence and behavior in buildings. In this context, the present contribution provides a general assessment of the state of the art regarding ABM deployment in the context of buildings' energy and indoor-environmental performance (e.g., energy demand, adaptive thermal comfort, visual comfort, acoustic comfort, indoor air quality, HVAC system design and operation). The investigation entailed in the present contribution suggests that the ABM-based incorporation of occupant behavior in simulation applications can increase their effectiveness. However, the contribution also reveals a number of shortcomings concerning the state of the art in this area. Thereby, a central drawback is the paucity of comprehensive empirical information concerning processes related to occupants' perception, evaluation, and behavior. ABM developments and platforms, no matter how elaborate they may be technically, must be supplied with detailed and reliable domain knowledge on human perception and behavior. Otherwise, they would fall short of providing useful insights toward building design and operation support.

Mahdavi, Ardeshir & **Berger**, Christiane

TU Wien, Austria

Impact of Visual and Auditory Factors on Perceived Thermal Comfort: A Case Study
A. Mahdavi, C. Berger

The present contribution reports on a case study of multi-aspect indoor-environmental exposure situations. As with a number of similar efforts, this research is motivated by the circumstance that most available human comfort models (as well as related standards and guidelines) focus on one indoor-environmental independent variable at a time. In other words, thermal, visual,

Oral Presentation Abstracts

Mahdavi, Ardeshir & **Berger**, Christiane

TU Wien, Austria

Session 6

Day 2, 15:32

auditory, and olfactory aspects are typically addressed in isolation. Whereas past research has – to some extent – explored multi-domain exposure situations, there is a need for continued research in this area. In this context, the present contribution describes an empirical research study that was conducted under controlled conditions in two small office-like units in a laboratory. The thermal conditions can be controlled in these units. Moreover, the lighting settings in the units can be arranged in different ways. In addition, outdoor soundscape (for example, traffic noise) can be emulated in the larger laboratory space that houses the office units. Small groups of participants experienced – on a short-term occupancy basis – similar thermal conditions in the two units, but different visual or acoustical conditions. Using customized evaluation scales, the participants provided feedback regarding their perception of thermal, visual, and acoustical conditions. The results of the experiments were analyzed to determine if and to which extent evaluations of similar thermal conditions were influenced by differences in other (i.e., visual or auditory) variables.

Mann, Alasdair

University of Southampton, UK

Session 4

Day 2, 12:38

Analysis of Occupants Presence in Homes
A. Mann, S. Gauthier

Forecasting occupant behaviour will enable people in need of social care to intelligently manage their informal and formal care network, reducing the individual burden on carers. Creating these forecasts can be difficult since the occupant's schedule can change unexpectedly. Furthermore, the same methods might not be repeatable since occupants each have their own lifestyle. This means that models are prone to overfitting. This study explores how different amounts of features, lag times, and training instances affect the performance of traditional supervised machine learning regressors in forecasting occupants' presence (frequency and length of time within one hour). A key finding is that there is a threshold of around 72 hours for the number of useful lag times and training instances. After this threshold, depending on the occupant, the model's performance would plateau or decrease. Minor exceptions can be observed in some occupants with a weekly schedule where a model will suddenly improve if fed a week of lag times. This means that feature selection should be done carefully for predicting occupant behaviour.

Miller, Clayton

National University of Singapore, Singapore

Session 2

Day 1, 13:35

What do Occupants Want? Let's Ask Them Using Smart Watches and Cozie
C. Miller

A large amount of focus is placed on the passive detection and characterization of occupancy using sensors and machine learning. These techniques have made significant progress in certain aspects of performance improvement, namely in energy conservation (turning things off when no one is there). However, when it comes to the thermal, aural, or visual preferences of the occupants, sometimes observation is not enough - we need to ask them what they like. This presentation will a set of experiments using wearables devices and an open-source platform called Cozie. The methodology showcased is Ecological Momentary Assessment (EMA), an ad-hoc method of collecting information from experimental participants in the field in a longitudinally-intensive way. We show the initial deployment of Cozie in several scenarios in Singapore and request collaboration for deployment in other research projects around the world. Issues are covered related to survey fatigue, sampling rate, and subtle integration into tools designed for uses other than feedback.

Mino-Rodriguez, Isabel

Karlsruhe Institute of Technology, Germany

Effectiveness of Feedforward Information System on Occupant's Behaviour
I. Mino-Rodriguez

Feedforward is the strategic flow of information that forecasts patterns in anticipation of changing environmental conditions, intended to activate and direct coping responses of occupants in reaction to their perceived conditions. The scope of a feedforward information system is transferring energy-related data which enable occupants to learn, understand, and engage in and with buildings

Mino-Rodriguez, Isabel

Karlsruhe Institute of Technology, Germany

Session 4

Day 2, 12:20

to achieve their desired outcomes such as comfort and energy targets. The effectiveness of feedforward information relies on the quality of communication between system and occupant and the level of persuasion among other factors. Thus, an appropriate design of a feedforward interface as a tool to convey energy information to occupants aiming to direct or modify attitudes or behaviour is of utmost importance. This study aims on understanding the key components to be considered in the design of feedforward interfaces and the potential effect of a well-structured feedback on modifying or redirecting occupant's behaviour. The study provides a review on four of the main basic components in feedforward processes that are (a) what is communicated, (b) when is the information revealed, (c) how is the information presented and, (d) where is the information shown. The study explores the feedback collected from 76 participants in a naturalistic office environment after interacting with a visual interface of an occupant assistance system. The analysis explores positive and negative feedback on two alternative interfaces that provide the predicted course of comfort levels on energy consumption of four cooling strategies (removing a piece of clothing, opening the window, switching on the ceiling fan, or switching on the air-conditioning). In addition, the analysis focuses on the relationship between (positive and negative) interface feedback and the effectivity of the feedforward interface in modifying occupant's behaviour. The study will draw conclusions on key elements to be considered for effective feedforward design.

Nielsen, Kasper & **Slott**, Babette

Copenhagen Centre on Energy Efficiency, Denmark

Session 1

Day 1, 12:38

Leveraging Differences in Building Characteristics to Improve Indoor Climate Perception and Energy Efficiency

K. F. Nielsen, B. P. Slott

According to the well-known PPD-index (P.O. Fanger), the optimal thermal indoor climate still results in 6% dissatisfied occupants. At the same time, it is a recurring challenge to ensure uniform indoor climate in buildings. The Danish research project Dynamic Office Environments on the Users Terms is aiming to merge the two challenges into one solution. The ambition is to create energy efficient indoor climate with extraordinary occupant satisfaction.
The project demonstrates how modern offices can be efficiently utilized, thereby reducing energy consumption while simultaneously increasing occupant satisfaction. The purpose is to take advantage of the inherent characteristics of the building to meet the occupants' requirements.
The indoor climate and workstations are monitored and visualized to the occupants by leveraging IoT solutions. This gives occupants the opportunity to decide a location which accommodates preferred indoor climate and facilities required for the task at hand – e.g. silent zones or collaboration zones.
Based on the mapping of behavior, machine learning can ensure the best possible correlation between operation and use of the premises. This ensures energy efficient control and greater knowledge of how office environments can be better utilized in practice. The results will be relevant in a wide spectrum of buildings ranging from low to high technical complexity.

The project applies an interdisciplinary perspective consisting of both anthropology and civil engineering. This methodology makes it possible to obtain a wider understanding of the building and how it is used in three different levels: The interaction between facility manager and building, the interaction between end users and building and finally the interaction between facility manager and end users. The building and the user behaviour are directly connected to achieve optimal building performance in practice.

O'Brien, Liam

Carleton University, Canada

Does Teleworking Save Energy? A Critical Review of Quantitative Studies and their Research Methods

L. O'Brien

Teleworking has been widely perceived as a more sustainable mode of working for office workers compared to the status quo because of its reduced dependency on transportation and centralized office space. However, the

Oral Presentation Abstracts

O'Brien, Liam

Carleton University, Canada

Session 5

Day 2, 13:25

situation is far more complex than would appear on the surface, when the scope is expanded to include home office energy use, the Internet, long-term consumer choices, and other so-called rebound effects are considered. Though telecommuting has been researched for the past four decades, few studies have quantified home, office, transportation, and communications energy or GHG emissions implications of telecommuting simultaneously. Moreover, the lack of data about workers' behaviors and purchasing decisions has led to researchers making simplistic assumptions. To make progress in answering the question of whether telecommuting results in less energy use than conventional centralized office working, this paper reviews research methods and results of primarily quantitative studies of any and all four domains that consider operating energy and/or greenhouse gas emissions. The results ultimately show that this problem is much more complex than most of the literature would suggest and indicate that current datasets and methods are inadequate for fully answering the research question.

Ouf, Mohamed

Concordia University, Canada

Session 3

Day 1, 15:00

Analysing Smart Thermostat Data and Unregulated Loads to Support the Canadian Net Zero Energy Ready Code

M. Ouf

Increasing efficiency requirements in energy codes typically focuses on adding more stringent provisions for HVAC and building envelope systems to decrease heating/cooling loads and associated energy use. However, reducing heating/ cooling loads can increase the contribution of occupants to overall building energy consumption. Although previous studies demonstrated this effect, occupant-related assumptions, which are represented by schedules used in building simulations, remain treated with standard simplistic assumptions that do not match data from existing buildings. Since simulations are a principal mechanism for developing new code provisions, inappropriate input assumptions may lead to provisions with sub-optimal performance in practice. To this end, we re-evaluate occupant-related assumptions in the Canadian energy code using data from existing buildings. The research scope focuses on code provisions for unregulated loads (i.e., plug loads) and thermostat setpoint settings. To address unregulated load assumptions, published data on plug loads' usage in residential, commercial office and school buildings was analyzed. Two different approaches, namely scenario-based analysis and Monte-Carlo simulations were used to derive schedule inputs for building simulations and quantify the effect of plug load assumptions on energy use in 5 building archetypes across 5 Canadian climate zones. Results also compared the impact of unregulated load assumptions across 3 different versions of the Canadian energy code to demonstrate their relative effect. To address thermostat setpoint assumptions, anonymized, voluntarily shared smart thermostat data from 14,000 households across Canada were analyzed. This analysis identified unique setpoint profiles and investigated the effect of several factors such as house/household characteristics, seasonal variations and outdoor temperature. Using this dataset, novel approaches were also explored to characterize buildings' thermal properties using indoor and outdoor temperature measurements to identify the effect of changes in energy code requirements on the thermal behaviour of different homes.

Park, June

University of Texas, USA

Session 2

Day 1, 13:59

A Reinforcement Learning for Occupant Centric Thermostat Control

J. Park

Building systems need to control the indoor environment with the comfort range. With the rapid development of information and communication technology, building controllers have been developed with the goal of overall energy savings. However, conventional building control strategies typically use fixed threshold values and set-points for operation without considering the preference of the occupants. Therefore, we need an automatic adaptation to occupant comfort. In this paper, we propose a reinforcement learning (RL) based occupant centric controller (OCC) for learning the optimal thermostat set-points. The RL-OCC agent acquires data on the physical, indoor environment, which is interpreted as

Park, June

University of Texas, USA

Session 2

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states for RL controller. Besides, data on the interaction between the occupant and the building systems, which is indicative of the comfort or, more often, the discomfort of the occupant, is also collected as rewards for RL controller. With this data, the agent can adapt to unique occupant behaviors and indoor environments over time and calculate the optimal control actions. We demonstrate our controller on an existing BAS system with facility managers in the loop. The case study is an academic office space and located on the campus of The University of Texas at Austin. Currently, this building is equipped with an active chilled beam system for heating and cooling, and the occupants have individual thermostats. We develop a low-cost hardware device (HVACLearn), which monitors indoor environmental quality as well as the feedback of the occupants. HVACLearn then calculates the optimal & personalized control actions, e.g., thermostat set-points, to balance between occupant comfort and energy efficiency. The optimized control action is updated with the facility manger's confirmation to avoid malfunctions of the current system. We present system hardware, control algorithm, and the experimental results of 19 office spaces.

Payet, Maareva

University of La Réunion, France

Session 5

Day 2, 13:59

User Behaviour in Low-Environmental Impact Buildings in Tropical Climates

M. Payet

Efforts are currently made to reduce the impact of the building sector. However, studies have shown that the impact of user behaviour on energy consumption is poorly estimated by designers. As a result, there are discrepancies between the energy performance predicted by simulation software and the actual one. Tropical climate characteristics allow the development of bioclimatic buildings, which use passive solutions, and where air handling uses are different from current temperate climates. These include the use of natural ventilation, sometimes combined with the use of fans, and the addition of air conditioning during the hottest periods, currently the main source of energy in the building sector. Except some recent post occupancy evaluation, which showed different behavioural patterns between air-conditioned and naturally ventilated environments, there is little feedback on user behaviour in naturally ventilated buildings in tropical climates. The aim of our research work is to analyse when users will switch from natural ventilation, by acting on windows, to the use of fans and air conditioning, and thus better predict consumptions. Data collection is in progress on 2 tertiary buildings in Reunion Island. We measure simultaneously the environmental parameters (indoor and outdoor weather), and the action parameters through the real time consumption monitored by end-use (air-cooling, fans) and by the level of opening of the windows. A statistical regression is applied to the first data, to detect which factors influence actions. The next step will be to use probabilistic models to model behaviours, preliminary step to the integration in simulation software. The originality of this study is its tropical character which determines particular uses of natural ventilation and air treatment. This issue could concern more geographic areas in the coming years that will be confronted with summer problems due to global warming.

Pisello, Anna, **Vitorj,** Filippo & **Pigliautile,** Ilaria

University of Perugia, Italy

On Multidimensional Comfort: Multi-Parametric Experimental Experiment Within a BIM Designed Virtual Environment

A. Pisello, F. Vitori, I. Pigliautile

Architecture, Engineering, and Construction industry professionals, together with building physics scientists, agree about the key role played by building occupants in determining final energy needs imputable to their energy-related behaviors. Occupant behavior represents indeed a major variable affecting buildings' energy performance, but its impact is difficult to predict since the early design stage. That is the reason why this study proposes a new analysis framework and field test method aimed at better comprehending and monitoring people feelings and attitudes, while stimulated by means of virtual design stage variables and building energy efficiency parameters, assumed to produce non-

Oral Presentation Abstracts

Pisello, Anna, **Vitorj,** Filippo & **Pigliautile,** Ilaria

University of Perugia, Italy

Session 1

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negligible effect on people perception and related actions. Nevertheless, the same selection and construction of a proper test bench represents a key issue within this research framework, together with the selection of the affecting variables, for better predicting occupants' perception versus the indoor environmental quality. This work proposes to face this challenge by means of Virtual Reality (VR) strategies included in a workflow where immersive environments are modeled in a parametric platform, able to change the geometry and every necessary peculiarity of the future spaces, after verifying the immersive quality of the virtual context. The investigated methodology integrates Building Information Model (BIM) and VR in order to simulate the human factor in the built environment. A preliminary validation test is submitted to 50 people, with a result of 76% of tested subjects declaring a satisfactory sense of presence inside the virtual environment, showing promising possible development in the field of multidimensional comfort studies.

Raw, Gary

GRPS, UK

Session 6

Day 2, 15:24

Evaluating Varying Comfort

G. Raw

Understanding behaviour entails understanding the environmental perceptions that underlie behaviour. In the case of thermal comfort, numerical scales for measuring human response have emerged largely in the context of environmental conditions and respondents' activities that vary little over time – for example in climate chambers or conditioned offices. In this context, asking "how do you feel" makes sense and lends itself to understanding how comfort is determined at a point in time. But many people live or work in conditions that vary markedly over time, and where their physical activity varies too – even within seasons or within a day. It is questionable how people in these circumstances would give a single scale rating. We have therefore tested an alternative approach. In a pilot study in a UK primary school, we asked staff to report the percentage of the time when it is (a) too cold and (b) too warm. They were asked to report separately for summer and winter and within a single day. Students also separately indicated whether they had felt too hot or too cold during the day. Both staff and students were able to report without difficulty and could state, for example, that the same room was sometimes too cold and sometimes too warm, even within one day. Furthermore, the findings show a logical relationship with other subjective variables and with objectively measured conditions in different parts of the school. Further research should serve to refine this approach and set benchmarks, thus allowing the performance of an indoor or outdoor space to be evaluated in a way that better matches how people experience that space.

Sarran, Lucile

Technical University of Denmark, Denmark

Session 6

Day 2, 15:10

Learning to Live in Low-Energy Dwellings: A Mixed-Methods Case Study

L. Sarran

Occupants' routines and practices around the use of the building services in their home may lead to energy performance gaps and indoor environmental issues, in particular when the building services are unknown. This work aims at documenting the successes and difficulties encountered by occupants while getting acquainted with new building services (heating and mechanical ventilation systems) after moving in a low-energy dwelling. Explanatory mixed methods were adopted. A questionnaire survey was first carried out in a social housing complex of 2007 recently retrofitted and non-retrofitted single-family houses in Denmark. The questionnaire investigated occupants' satisfaction with the indoor environment in their homes as well as their experience with using the building services. In a second phase, semi-structured interviews were carried out. The interviews set to ask the "why" questions and elucidate occupants' use and understanding of the building services. 23 interviews were carried out in the same social housing complex followed by 14 supplementary interviews in three newly built multi-family residential buildings. The questionnaire was answered by 344 residents (response rate: 17.1%). Occupants were in majority able to achieve a satisfactory indoor environment in their homes. In particular, stable temperature and pleasant air quality were largely appreciated. The usability of

Sarran, Lucile

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building services was however more of a concern, with occupants expressing difficulties to understand and operate them. Reasons for these issues were dysfunctional systems, lack of information and knowledge, and lack of personal control. Automation was mainly perceived as detrimental to comfort and user satisfaction when the building services were not functioning as intended. In order to avoid frustration and discomfort among occupants, the increasing complexity and automation in residential building services must go hand in hand with an increased product quality and a better exchange of information with the residents.

Touchie, Marianne

University of Toronto, Canada

Session 6

Day 2, 15:00

Evaluating Acoustic Comfort in Multi-Unit Residential Buildings
M. Touchie

Acoustic comfort is a growing concern in today's society because of the increasing noise levels in urban environments and the subsequent effects on people. Indoor acoustic conditions can significantly affect people's productivity and physical and psychological well-being. Noise exposure in high-density MURBs is particularly an issue because residents are likely to be exposed to more indoor and outdoor noise sources resulting in a much higher total noise exposure and limited mitigation options compared to single-family housing. Many residents express dissatisfaction with indoor acoustic conditions despite existing building acoustic standards. Reasons for this include lack of proper characterization of acoustic comfort in MURBs and lack of comprehensive and stringent standards and regulations which give developers little incentive to improve building acoustic performance. The current work aims to 1) identify the main factors that impact MURB acoustic comfort/performance, 2) study the various effects noise exposure has on MURB residents, and 3) identify noise level limits and acoustical performance criteria to improve acoustic comfort in MURBs. This presentation will cover an overview of the methodology, including a survey and field monitoring campaign, and present the findings of the initial survey including 213 responses from over 30 MURBs in Toronto. The results show that both indoor and outdoor noise sources are important causes of noise annoyance. 79% of respondents are annoyed with one or more outdoor noise sources (e.g., traffic and construction) and 70% of respondents are annoyed with one or more sources of indoor noise (e.g., noise from HVAC and neighbors). In addition to annoyance, effects on sleep quality, work performance, communication, and reported mental health are identified as important impacts of noise exposure in MURB. Actions residents take to mitigate noise were identified to have secondary consequences on energy consumption and indoor air quality.

Vellei, Marika

La Rochelle Université, France

Session 3

Day 1, 15:28

Demand Response Events in Residential Buildings: Not Noticeable at All?
M. Vellei

Demand Response (DR)-activated smart thermostats can be used to exploit the flexibility of residential electric heating and/or cooling systems. Their acceptance depends on how occupants' thermal comfort is affected by the dynamic thermal conditions induced during DR events. In residential settings, occupants can engage in activities other than sedentary ones and, thus, their thermal conditions can be dynamic due to the time-varying metabolic rates. If the dynamic thermal comfort conditions induced by changes in metabolic rates are comparable with the dynamic conditions induced during DR events, these events could remain unnoticed to the occupants, who are already accustomed to behaviourally adjust, e.g. by adapting their clothing, to such transient thermal conditions. To evaluate the impact of DR events, we therefore compare differently induced dynamic conditions by simulating both occupants' stochastic activity levels and DR events in two case study buildings, which represent typical archetypes of old and new single-family houses in France. The dynamic thermal simulations are carried out within the simulation platform DIMOSIM (DIstrict MOdeller and SIMulator), which use a R7C4 mono-zone building model. Occupants' activity levels and, thus, the time-varying metabolic rates are simulated with a stochastic activity model, while for evaluating the transient thermal conditions we adopt a

Oral Presentation Abstracts

Vellei, Marika

La Rochelle Université, France

novel dynamic thermal comfort model. This comprises a thermo-physiological model able to predict the body core and mean skin temperatures and a dynamic thermal perception model, which uses the simulated temperatures to predict thermal sensation and thermal comfort. The used thermo-physiological model is an updated version of the classical Gagge's two-node model, while the dynamic thermal perception model is elaborated from Fiala's Dynamic Thermal Sensation (DTS) model and Fanger's Predicted Percentage of Dissatisfied (PPD) indices.

Wang, Alan &
Heydarian, Arsaian

University of Virginia, USA

Session 5

Day 2, 13:35

A Systematic Approach to Preserve Privacy in Smart Buildings
A. Wang, A. Heydarian

Longitudinal studies for naturalistic occupant behavior implicitly carry privacy risks. Longer duration studies divulge more information about trends that might not have been easily visible in shorter studies. Furthermore, discovering the long term patterns in occupant behavior can lead to improved building energy efficiency, occupant well-being, and work productivity. However, increasing the modalities of data collected exposes users to contextual privacy concerns. In this work, we propose a framework to track and adopt longitudinally to users' privacy settings and increase their perceived trust in the system. In our system, at first, we define data access between a device and a user. Making each user a subscriber to the device groups allows for effective ontological management of scenarios common in a research setting. For example, in the case of environmental sensors (e.g. temperature and humidity sensor) in an open office setting, one device normally covers more than one occupant. We then define the data access relation between two users based on their hierarchical relationship (e.g., employee and supervisor). Users with any vertical hierarchical relationship above (e.g. supervisor) that of another user (employee) are defined by default to never have access to the lower user's data unless the user opts-in. Lastly, since actuating one device to one user relationships are trivial, we describe the behavior for actuating the privacy-related settings between multiple users. By default, the system utilizes the principle of least privilege. For example, when controlling the frame rate of a camera resource that might cover two users, the user with the smallest frame rate is what the camera would collect. For our future work, we look towards adopting real-time edge computing paradigms that reduce the risk of user exposure, allowing the system to pre-process the data and remove sensitive information before pushing it onto the database.

Wei, Shen

University College London, UK

Session 2

Day 1, 14:03

Monitoring Occupant Window Opening Behaviour in Buildings and Relevant Influential Parameters: a Critical Review
S. Wei

This paper introduces existing methods that have been used to measure/monitor occupant window opening behaviour in buildings, due to its significant impact on the building energy consumption. The review has identified five existing methods that have been used to monitor window usage (i.e. self-recording, electronic recording, observing by surveyors, self-estimating and camera images), and each method has its advantages and disadvantages in terms of feasible sample size, monitoring interval and duration, recognition of window states/opening angle, and the relative dynamic nature of behaviour. The aim has been to provide researchers with systematic criteria for selecting a suitable monitoring method for their specific research objectives. Additionally, the paper also demonstrates the need for a standard method for monitoring relevant influential factors, as these varied considerably between existing studies with respect to the accuracy, interval and location. Such variation clearly has the potential to influence the ability to perform cross-study comparisons.

Weiner, Sarah

Fraunhofer Institute, Germany

Session 6

Day 2, 15:28

Case Study: Reasons of Office Occupant's Dissatisfaction with an Automated Lighting Control System

S. Weiner

In order to reduce the energy demand of buildings, building automation systems are being used more and more frequently, especially in office buildings. For instance, the presence and brightness in an office room are measured in order to control the lighting based on this data. Such automated lighting control system focus primarily on energy efficiency rather than on the comfort of occupants. Potentially leading to the often reported higher dissatisfied of occupants with automated systems than with a manual controlled systems. This contribution presents data on the current spread of automated lighting control systems in German office buildings, based on survey data from 2018/19. The results confirm an increased dissatisfaction among the occupants with automated control systems. In order to investigate the background to this tendency in more detail, a further survey was carried out in an exemplary office building, together with the evaluation of the building automation data. In this building an automated lighting system, which adjusts the level of illumination depending on the brightness in the room once it has been activated and automatically switches off after an hour of inactivity in the office, is used. The results of this study characterize several sources of discomfort in the context of the building under investigation and highlight differences in the occupant behavior based on the distinct levels of satisfaction with the lighting control system. The presented findings contribute to a better understanding of the reasons for dissatisfaction and adaptive occupant behavior regarding automated office lighting control systems.

Zhu, Yimin &
Hong, Tianzhen

Louisiana State University, USA and Lawrence Berkeley National Laboratory, USA

Session 1

Day 1, 12:00

Exploring Thermal Comfort in Immersive Virtual Environment

Y. Zhu, T.Hong

Immersive virtual environment (IVE) has been increasingly applied to building design. Most applications utilize the strength of the technology to support visual and spatial modeling. However, such capability is not enough, because IVE alone cannot effectively provide thermal stimuli for thermal comfort-related studies. The project team examined the potential of augmented IVE, i.e., IVE plus a climate-controlled environment, to support thermal comfort-related studies. To this end, experiments were conducted comparing the thermal experience of participants (such as thermal sensation, thermal comfort, and thermal acceptability) between IVE and in-situ settings. Each experiment had a heating and a cooling sequence in both in-situ and IVE settings. The heating and cooling sequences were controlled at 65°F/18°C, 75°F/24°C, and 85°F/29°C with the relative humidity set at 55%. Thirty participants completed all experiment sessions. Thermal state votes, physiological responses (e.g., skin temperature and hear rate), and other demographic data were collected, cleaned, and processed for analysis. Statistical analysis was applied to testing the hypothesis that the thermal experience of participants was not significantly different between IVE and in-situ. The experience was measured using three parameters, the control temperature distribution over the thermal state scale, the thermal state vote distribution at a temperature step, and the physiological response. The sample-wide analysis suggests that participants' experience is not significantly different between IVE and in-situ settings, when experiment conditions are well-controlled.

Notes

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