OB-17 Symposium on Occupant Behaviour and Adaptive Thermal Comfort

Joint symposium between

IEA EBC Annex 66

and

IEA EBC Annex 69

Technical University of Denmark

May 17, 2017

EBC
Energy in Buildings and Communities Programme

DTU

Agenda

09:00	Welcome note
09:10	Measuring the environment, occupant behaviour and its triggers: physical and physiological – 5 presentations. Chair: Richard de Dear
10:50	Coffee break
11:20	Measuring the environment, occupant behaviour and its triggers: social and psychological – 4 presentations. Chair: David Shipworth
12:40	Lunch
13:40	Group Photo
14:00	Modelling occupant behaviour at the building and population scales: integration into building models and standards – 5 presentations. Chair: Marcel Schweiker
15:40	coffee break
16:10	Learning from case study buildings: lessons from occupant behaviour in exemplar buildings- 5 presentations. Chair: Liam O'Brien
17:50	Closing remarks
18:00	Reception
19:00	End of program

Venue: Glass Hall, building 101, Technical University of Denmark – See full map on last page

Welcome to the Technical University of Denmark

It is a great pleasure to host you at the Technical University of Denmark for the OB-17 symposium on occupant behaviour and adaptive thermal comfort. OB-17 is a joint symposium between IEA EBC Annex 66 and IEA EBC Annex 69. It is the third international symposium focusing on monitoring, modelling, and manipulating occupant behaviour and the energy and comfort consequences of these behaviours. The aim is to bring researchers from Annex 69 and Annex 66 together to share recent research, technological developments and best practices on the understanding and influence of adaptive thermal comfort and occupant behaviour in buildings. The breadth and depth of the abstracts submitted to OB-17 is very encouraging and the high-quality research efforts from so many countries and intuitions are very inspiring.

It is a great honour to host many of the world's leading experts on thermal comfort and occupant behaviour at The International Centre for Indoor Environment and Energy at The Technical University of Denmark.

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And

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List of Participants

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Clinton Andrews	Rutgers University
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Vojislav Novakovic	University
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Yingxin Zhu	Tsinghua Universiity
Zi Wang	Tongji university
Zsofia Belafi	Budapest University of Technology and Economics

Posters

Wednesday May 17 OB 17-Occupant Behaviour and Adaptive Thermal Comfort – Posters

Measuring the environment, occupant behaviour and its triggers: physical and physiological

1. **Performance comparison of occupancy count estimation and prediction with common versus dedicated sensors for building model predictive control**
   Mikkel Baun Kjærgaard

   Model predictive control is a promising approach to optimize the operation of building systems and provide demand-response functionalities without compromising indoor comfort. The performance of model predictive control relies among other things on the quality of weather forecasts and building occupancy predictions. While weather forecast models already provide input with a sufficient accuracy for model predictive control, building occupancy modeling remains the Achilles' heel of building energy simulation due to the unpredictable nature of occupant behavior. The present study compares the accuracy and computational demand of two occupancy estimation and prediction approaches suitable for building model predictive control: 1) count prediction based on indoor climate modeling and parameter estimation, 2) count prediction based on data from 3D stereovision camera. The performance of the two approaches was tested in two rooms of a case study building. The results show that the method with dedicated sensors outperforms common sensors. However, if a building is not equipped with dedicated sensors, the present study shows that the common sensor method can be a satisfactory alternative to be used in model predictive control.

Measuring the environment, occupant behaviour and its triggers: social and psychological

2. **Immersive virtual environment for occupant energy behavior:**
   A look at Psychological Theories of Human Behavior
   Tracey Rizzuto, Yimin Zhu, Sanaz Saeidi, Robert Kooima, and Astrid Roetzel

   Occupant energy behavior is a major factor affecting the energy performance of buildings, but its impact is difficult to predict during design. Although a significant amount of research has been done based on empirical and lab experiments, the performance gap of buildings still exists. Immersive virtual environment (IVE) offers a unique opportunity and alternative for studying occupant energy behavior because of its proven potential to provide realistic virtual experience to participants that elicit and record their behavioral responses. The objective of this study is to perform a comprehensive literature review to understand the status of IVE applications to occupant energy behavior studies. The review covers research in both occupant energy behavior and IVE applications. By comparing IVE capabilities with factors of the Driver Need Action System (DNAs) framework and occupant energy behavior studies, the authors found that applications vary depending on IVE's technical maturity to handle DNAs factors; and that they are more centered on validating (rather than predicting) occupant behaviors. Future research is needed to enhance behavior and sensation modeling in IVE in order to improve strategies for data generation, behavior modeling prediction and validation, and the creation of virtual experiences with multiple sensory inputs and social presence.

Modelling occupant behaviour at the building and population scales: integration into building models and standards

3. Occupant behaviour modeling and building typologies for the rehabilitation of the architectures for education

Marilisa Cellurale

The study that we intend to present investigates the correlation between the innovative learning behavioural models, the thermal comfort of the learning environments and the building typologies that characterized the existing architectures for education in Italy.
The innovative educational guidelines expressed by the European institutions, imply the adoption of adaptive models for the definition of environmental comfort levels.
Besides, occupant's behavioural pattern represents a relevant factor in building performance simulation itself. The probabilistic approach used for the behavioural modeling complies with the real variable operating conditions.
Main contributions of this study consist in:
- Defining a dynamic classification of school building typologies, both morphological and constructive, using the Building Information Modeling (BIM) methodology;
- Defining the behavioral models defined by the innovative pedagogical guidelines, in terms of internal thermal loads and spatial requirements;
- Defining a methodology of data mining and normalization of the results and an operative framework of energy-related data.
The reliability of the adopted approach will be demonstrated through a case study that refers to a typological model identified in the previous phases. The results of the research constitute a qualitative models framework, able to drive and evaluate the transformative processes of a strategic public building section.

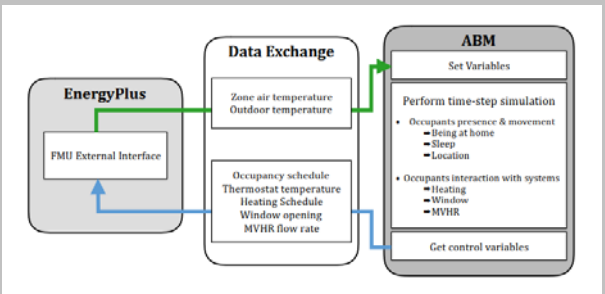
4. Critical analysis of the application of the adaptive thermal comfort models proposed by standards

L. Bai, S.Carlucci, L. Yang

Abstract: In the recent years, adaptive thermal comfort models were integrated into several standards. Although the theoretical background of the adaptive comfort models is quite mature, still some ambiguities exist for their application.
The objective of this study is to identify the main sources of uncertainty to the application of adaptive comfort models and to analyze quantitatively the difference between the adaptive comfort models proposed by the standards when applied in cities located in different climates. This paper analyzes the adaptive comfort models proposed by the ASHRAE standard 55, the European EN 15251, the Dutch ISSO 74 and the Chinese GB 50785. Furthermore, the degree-day method is used to assess the deviations of such adaptive comfort models with respect to the Fanger comfort model as proposed by the international standard ISO 7730 for a typical summer office-like condition. Next, for each standard, the major variations or sources of uncertainty are investigated: (i) for ASHRAE 55, the length of the calculation period of the prevailing mean of outdoor temperature, (ii) for EN 15251 and the newer prEN 16798, the α-value used in the running mean external temperature and the differences between the models proposed in EN 15251 and prEN16798, which is assessed through the degree-day method, and (iii) for ISSO 74, the differences between the two adaptive comfort models proposed in 2006 and 2014, which is assessed through the degree-day method.
This study shows that, although standards are a major carrier for spreading the adoption of adaptive comfort models among practitioners and designers, they still are affected by a few uncertainties in the application that prevent their full exploitation. In particular, this paper contributes in a tentative fine-tuning of some of the adaptive comfort models. However, the issue of their application in hybrid or mixed-mode buildings has to be solved, and a new approach should be identified to set a rule to identify univocally the period when the adaptive comfort models can be applied, because of their intermittence compliance to the current rules during the transition seasons and in the hottest days of the year.

5. **Towards Better Buildings Performance Estimations?**
A Framework for Integrating Dynamic Occupants Behaviours in Dynamic Buildings Simulation Tools.
Alaa Alfakara

This paper presents the development of a co-simulation system of an Agent-Based Model (ABM) that simulates dynamic occupant behaviour in buildings, which is coupled to a Dynamic building simulation model (DBSM). As a first step to realising the impact of dynamic occupant behaviour in DBSM, the implementation of ABM in a DBSM was developed. This ABM implementation does not yet contain many of the requisite features for a fully-fledged ABM behavioural model, but does provide a robust framework for building up to a complete feature-set. The ABM, builtin REPAST (Java) was developed to model adaptive thermal behaviour of occupant for different family types. Range of behaviours included heating system, window opening and the use of mechanical ventilation. The ABM was linked to the widely used Energy Plus Building simulation model using the Functional Mock-up Interface standard (FMI). This novel linkage allowed co-simulation of the occupants-building systems, and a real-time exchange of inputs/outputs at short time intervals, between the two dynamic models as shown in Figure 1.



The co-simulation was performed using a case-study of a dwelling in an existing residential block, for four different family types under two scenarios: 1) A comfort-scenario where agents (occupants) maintained their thermal comfort and 2) A conserving scenario where agents tolerated slight thermal discomfort to save energy. The results of the co-simulation system were compared to a conventional EnergyPlus simulation of the same dwelling, which showed considerable variations in results. The results at a finer level of detail also presented different patterns of using the systems between the four family types considered. The co-simulation system brought changes to the estimation of DBSM, and highlights the importance of detailed, realistic and dynamic occupants behaviours in DBSM. Moreover, the co-simulation system provides the potential of additional information that could help us understand occupants' interactions with buildings, thus, improving buildings design and performance.

6. **Review of the methodology and challenge in the modelling of occupant behavior of home appliance use**
Selin Yilmaz

This presentation presents a review of the methodologies for modelling the operation of home appliances as an important component of models of residential electricity demand. There have been several bottom-up models in which electricity consumption of home appliances is stochastically simulated. The review especially focused on the occurrence of switch-on events of appliance use developed in these bottom-up models. The authors categorises four types of modelling methodology for appliance use in which one develops a model based on empirical data of appliance operation, whereas the other three use time use data. The authors briefly explain the features of the methodologies and address five issues that have a significant impact on the model performance. These issues are summarized as the lack of Consideration of the intra-variation, of consideration of influence of socio-economic and demographic conditions, time resolution of the data, conversion factor from activity to appliance switch-on event and applicability to a variety of context. Evidence from empirical showed that more research is needed to address these issues. The presentation finally discusses the design of future monitoring studies (including monitoring strategies and sample sizes) and the design of future research studies (including statistical analysis, probabilistic modelling and validation approaches) to further improve our understanding of and ability to predict the behaviours of occupants within buildings.

Learning from case study buildings: lessons from occupant behaviour in exemplar buildings

7. Analysis of the occupant behaviour influences on the energy consumption of an office building with low-cost sensor-based techniques

A. van der Aa, D. van Deijzen, B. Giskes

The impact of occupant behaviour in office buildings on the total energy consumption is one of the aspects that is not clearly defined and understood. Within the framework of the IEA Annex 66 research project and the Dutch research project Treco-Office measurements, in combination with energy simulations, have been conducted to discriminate the occupant related influences from other factors (building and installation characteristics and climate conditions). The aim of the research approach is to come up with practical applicable tools that can be easily implemented and installed in existing office buildings as a means to implement energy performance contracting. Therefor the focus has been on the application of easy to install low-cost sensor-based techniques. This has been done by implementing a software based building automation system in combination with camera based sensor techniques for occupant detection and tracking and gas meter reading. Furthermore, smart meters in combination with plug-load meters are used for tracking and reading the total end- use electricity consumption and the end-use consumption of four workspaces.

A low cost camera is used in order to be able to monitor the behaviour of the occupants throughout the day. Motion of each of the occupants is detected and tracked throughout the space. Data is logged to a text file once certain tracked paths of interest are completed by the occupants.

The gas meter consists out of an analogue readout. A camera captures a photo every ten minutes which is streamed to a server. Via its API (Application Programming Interface) a direct translation is achieved and logged to a text file throughout the day in order to monitor the gas consumption.

The monitored data have been analysed and compared to the simulated data. Based on the measurements simplified algorithms have been developed to describe the relation of the occupant related actions and the energy use in this building. Implementations of these algorithms into the simulation models show a fairly accurate prediction of the total energy consumption of the office building.

8. Evaluation of user's interactions with internal blinds in office buildings in Florianópolis – Brazil

Mateus Vinícius Bavaresco, Enedir Ghisi

Occupants' behaviour has significant impact on the energy performance of buildings. Thus, the objective of this work is to evaluate the users' interactions with internal blinds in office buildings. Questionnaires were applied to users of shared spaces in an office building located in Florianópolis, southern Brazil. The results of 164 questionnaires were analysed to evaluate the users' interactions with the internal blinds of their workspaces. The distance between workstations and windows was identified as an important factor to occupants' interactions with internal blinds. Therefore, the nearest the users are to the window, the more they will adjust the internal blinds. Time dependency and reasons for opening and closing the internal blinds were assessed; differences between both actions were noticed. Most users, 63.4%, open the internal blinds upon arrival at the workplace in the morning, mainly due to the comfort provided by daylight. Most users (77.0%) stated that the main reason for closing the internal blinds is excessive solar radiation on the work surface. Thus, it was concluded that these interactions are due to space orientation. This information was confirmed by obtaining the moment the main internal blinds are closed. In south-oriented spaces, the internal blinds are kept open most of the time over the year since south orientation has the lowest direct solar radiation in Florianópolis. Three representative occupants' interactions patterns were observed; two of them were classified as passive and the other one as active. The first passive behaviour consists of maintaining internal blinds always open throughout the year. The second group of passive occupants maintain the internal blinds always closed. The active users tend to open the internal blinds upon arrival at the workplace in the morning and close them when excessive solar radiation is detected on the work surface.

Detailed agenda

Wednesday May 17 OB 17-Occupant Behaviour and Adaptive Thermal Comfort

09:00 - Welcome note by Rune Korsholm Andersen

09:10 Chair: Richard de Dear

Measuring the environment, occupant behaviour and its triggers: physical and physiological

1. **Long-term adaptation and short-term effects on thermal comfort under warm and humid conditions**
   Michael Kleber, Andreas Wagner

   This study examines influences of elevated air humidity at temperatures above the comfort range on occupants' comfort. During summer 2016 a total of 136 participants have been exposed to warm and humid conditions in a field laboratory. Each participant experienced one out of nine combinations of operative temperature (26, 28, 30°C) with relative humidity (50, 65, 80%) for one hour, followed by another of those combinations for another hour. The subjects were wearing summer clothing and sitting at a desk. Comfort parameters (concerning thermal, humidity and air quality aspects) were questioned after 0, 15, 30 and 60 minutes of each time span. Participants' heart rate as well as skin moisture and temperatures have been recorded.
   Analysis focuses on influences by short-term effects (caused by step changes from first to second condition) as well as the possible impact of long-term adaptation (outdoor climate) on the participants' votes and physiological responses.
   Votes at the beginning of the second time span are strongly influenced through the condition experienced by the participant during the hour before. This influence decreases with time and seems negligible after 60 minutes of exposure with most parameters. However, temperature and humidity of the first condition (represented through a combined index like enthalpy) have an impact on the humidity votes after 60 minutes in the second condition.
   Concerning long-term effects it can be observed that the linear model for predicting thermal sensation votes (TSV) after 60 minutes by operative temperature and humidity ratio significantly improves (ANOVA: $p=0.0001$), if a 4-week-average of the outdoor temperature is included. A model for predicting humidity sensation votes (HSV) based on the enthalpy of indoor air is also significantly improved (ANOVA: $p=0.0005$), if a 4-week-average of the outdoor enthalpy is taken into account. Results on percentage of thermal acceptance (TAC) are presented and compared to data from other climate regions.

2. **Indoor Temperature Modulations: A New Way to Save Cooling Energy and Maintain Alliesthesia-Based Comfort**
   Caleb Traylor, Dr. Weihuan Zhao, and Dr. Yong Tao

   Energy efficiency in the operation of buildings is becoming increasingly important with a growing emphasis on sustainability and reducing environmental impacts of irresponsible energy usage. Improvements have been made both on the technology side of energy efficiency and on the human behavior side. It is critical to find energy conservation measures that will maintain comfort for occupants. It is common knowledge that increases in temperature setpoint in cooling season and decreases in heating season can save energy. However, limits are placed on the setpoint bounds based on the human thermal comfort range. The possibility of saving energy by using modulating-temperature setpoint schedules instead of altering the temperature by a constant value was investigated for this study based on the concept of alliesthesia, which states that pleasure is observed in transient states. If this increase in pleasure from change is greater than any unpleasantries experienced due to the wider range of temperatures, an opportunity is presented to increase thermal pleasure indoors. This presentation covers results from a series of thermal comfort experiments conducted at the Zero Energy Lab at University of North Texas. These experiments showed that temperature modulations can cause occupants to experience more pleasure than if the temperature remained constant in a cooled space, whereas modulating temperatures had a negative impact on comfort relative to the constant temperature in the heated space. This is in line with previous research relating to alliesthesia, but the application to building energy is new. EnergyPlus simulations were used to show that in cooling applications, this type of scheduling can produce energy savings up to 5-10%. However, energy savings are not predicted for heating applications. Nonetheless, this presents evidence for an ideal opportunity for cooling applications by implementing modulating-temperature setpoint schedules: an increase in thermal pleasure, accompanied by a decrease in cooling energy.

3. **Residential adaptive comfort in a humid subtropical climate – Sydney Australia**
Richard de Dear, Jungsoo Kim, Thomas Parkinson and Christhina Candido

The aim of this study was to apply new technological survey capabilities to a field setting that is underrepresented in the thermal comfort research literature, namely the residential setting. Indoor temperature readings from autonomous datalogging devices (iButtons) were combined with simultaneous and contiguous subjective thermal comfort assessments via personal smartphones. Householders' spatio-temporal patterns of A/C usage, indoor and outdoor thermal environmental parameters, right-here-right-now thermal comfort perceptions and adaptive comfort behaviours were recorded. The longitudinal research design included a sample of 42 homes who were polled intermittently across a two-year monitoring period in which a total of 4,867 A/C usage events and 2,105 online comfort questionnaires were logged.
The study derives statistical models to enable predicting of the percentage of adaptive strategies (e.g. operation of air-conditioners, heaters, fans and windows) in use, as a function of temperature. The analysis on our Sydney sample indicated that an outdoor temperature of 25°C was the most favourable condition, maximising the use of natural ventilation and simultaneously minimising the householders' dependence on their home air-conditioning system.
Based on the right-here-right-now thermal sensation votes, the householder samples' neutral residential temperature was estimated to be about two degrees lower than that predicted by the ASHRAE 55's adaptive model for office occupancies. Despite the lower-than-expected neutrality, comfort zone widths for 80% acceptability were found to be 9K in the Sydney residential setting, which is 2K wider than prescribed in the adaptive model for office occupants. These findings suggest that people in their homes are more adaptive and tolerant of significantly wider temperature variations than their counterparts in office settings. An adaptive model that can be used for the assessment of residential thermal comfort is proposed.

4. **Monitoring building occupancy to build data-driven models: how long is enough**
Liam O'Brien

In the interest of continually improving the quality of occupant modelling for building simulation applications, a fundamental question of great interest to the occupant research community is: how long should occupants be monitored in-sit in order to build reliable models? The answer to this question depends on occupants' consistency of the data that describe actions and presence over time. To this end, this presentation will summarize the development and testing of a methodology to quantify the necessary monitoring duration to achieve reliable and repeatable occupant models. The methodology is applied to a set of 42 occupants in private offices. The presentation will conclude with some general discussion on necessary monitoring periods for other occupant behaviour domains.

5. **Method for measurement of the Dynamic Clothing Factor (D-CLO) for better OB modelling**
Jakub Dziedzic

Clothing, providing thermal insulation of the human body, is one of the major influencing factors with regard to thermal comfort. Unfortunately, measurement or estimation of clothing thermal resistances in thermal comfort studies are often subject to misconception or over estimation of the CLO factor. Without going into the details concerning contact zones between the fabric and the human skin or regarding humidity transfer through layers, estimation of the CLO-factor is already a challenge. Lack of the concrete information on layers of worn clothing or on skin coverage prevents development of this topic. Current state of development allows only a general description of typical clothing and its thermal resistance. For some cases this is enough, e.g. where there is a dress code regime like in some corporation office buildings. However, for the most situations it is an overgeneralization or oversimplification. An additional obstacle is measurement difficulty. Estimation of basic information on occupant clothing requires daily surveys or video recording. In both cases, evaluation of gathered data would be difficult, and it may violate ethical rules for monitoring occupant behaviors. To by-pass this challenge, it is proposed to use Microsoft Kinect to develop a dynamic clothing coverage model (D-CLO-C model). Monitoring performed by this device bounds the observed human with its "skeleton model", which can be treated as moving body points for color analyses. Small samples of a picture can recreate pattern of clothing coverage. This is done automatically by use of machine learning technique. An occupants change of the wears, by dressing up or undressing, can be treated as an added or a taken off layer of clothing. Long term measurements will make it possible to generate a model for estimation of clothing patterns and habits of occupants.

10:50
coffee break

11:20 Chair: David Shipworth

Measuring the environment, occupant behaviour and its triggers: social and psychological

6. Clusters of comfort and behaviour: their characteristics and relationships
Marcel Schweiker and Andreas Wagner

Researchers in the fields of thermal comfort and occupant behaviour recognized limitations in the application of averaged models for advanced building energy concepts. At the same time, looking at the individual level is also beyond practical application considering the huge variety of individual comfort requirements and behavioural patterns. In order to show and model the diversity in both aspects, previous studies presented simplified and partly artificial classifications (e.g. active/passive occupants) or data-driven distributions of behavioural patterns.

In line with the latter this work proposes the application of a clustering method to the results of mixed-effect regression analyses. In order to show the potential and limitations of such method for simulation and control purposes, data from two studies with human subjects working in a realistic office setting with controlled indoor environments and connection to the outdoors are taken (Nsubjects = 53). First, mixed-effect regression models including random effects of subjects' identifiers for intercept and slope were fitted individually for the dependent variables: thermal satisfaction (Nvotes = 872), visual satisfaction (Nvotes = 496), window opening, heating, and lighting behaviour (Nhours = 1038). Second, individual slope and intercept terms were extracted from these models and used for clustering. Consequently, each subject was assigned to five clusters (one related to each dependent variable). Third, the characteristics for each cluster, their relationships, and the influence of psychological factors (e.g. preference) on the likelihood of membership in a specific cluster were analysed.

Results show a) the advantage of this method in creating independent and distinct patterns related to thermal comfort, visual comfort, and occupant behaviour, b) that the relationship between clusters e.g. between clusters of thermal and visual comfort or between thermal comfort and heating behaviour is not significant, and c) that psychological factors show a significant influence on the membership to a cluster.

7. Indoor Thermal Comfort: Are We Missing the Diversity Factor
Dolaana Khovalyg, Bjarne W. Olesen

The built environment nowadays is undergoing the transformation towards human-centered design. Moreover, our society is experiencing significant changes related to gender equality, increased migration and social mobility – our society and working space are becoming more and more diverse, and families are becoming multi-racial. Can we consider in such society the diversity factor when designing buildings and building service systems?

Various international standards on thermal comfort (e.g. ASHRAE 55, ISO 7730) account for four basic environmental (tair, tmrt , φ, and u air) and two personal parameters (metabolic rate and clothing) when thermal sensation is evaluated. However, human beings exist in social context, and social and psychological factors can be equally influential. Although published standards do not take directly into account difference in thermal perceptions due to the gender, age, origin, ethnicity, physical state, cultural identity, income, and expectations, it does not mean that research on these topics is not available.

This work overviews available published literature on laboratory and field experiments examining the indoor conditions preferences by various social groups of people, and attempts to synthesize an available pool of knowledge and to define any missing diversity factor.

8. **Investigating cross-country energy-related occupant behaviors in office buildings through an interdisciplinary approach**
Simona D'Oca

This work presents an interdisciplinary approach for investigating occupant behavior in office buildings through a cross country survey in four continents (Europe, America, Asia and Australia). A questionnaire survey is exploring building characteristics, control options, social-psychological and demographic factors based on a motivational framework explaining energy-related behaviors (D'Oca et al. 2016), the Social Cognitive Theory (Bandura 1986) and the Theory of Planned behavior (Ajzen 1991). A review of state-of-the-art transversal occupant behavior surveys conducted in the energy field highlighted a still limited knowledge on key motivational and psychological drivers, as well as a lack of focus on group behaviors and contextual factors leading to the decision-making process behind the choice of diverse adaptive actions in individual and shared working spaces. Expecially in the workplaces, occupant behavior is influenced by multiple factors including perceived behavioral control, injunctive or descriptive norms, as well as energy saving attitudes, beyond the building technology (Chen and Knight, 2014). By combining energy and social science research approaches, this survey has the objective to (1) improve understanding of occupants' environmental, cognitive and behavioral motivational drivers leading occupants to interact with the control systems in socially dynamic environments such as office settings; (2) investigate how subjective norms, as well as group negotiation and workspace dynamics influence the group interaction with control systems – such as opening/closing windows, blinds and shades, adjusting thermostats, and artificial lights, and (3) understand how the actual exercised control (frequency of interaction, order of adaptive actions) during the heating and cooling seasons is influenced by perceived behavioral control, and correlated to perceived comfort, satisfaction and productivity. This study attempts to take one step further to fill the gap between engineering and social science in occupant behavior research, including limitations of behavioral model usability in building energy simulations.

9. **A Preliminary Investigation on Human-Brain-Interface to Improve Productivity of Office Workers**
Bing Dong

Understanding how indoor environments affect office worker's performance and developing methods to predict human performance in changing indoor environment have become highly important research topic that bears significant economic and sociological impact. Past research studies have presented the effect of indoor environment such as temperature and air quality causing sick building syndrome (SBS) in office workers. While past research groups have attempted to find predictors for performance, they do not provide satisfactory prediction ability. We conduct in this paper a study of predicting human performance during simulated office-work tasks using human brain signals collected by electroencephalography (EEG) under different indoor room temperatures (220C and 300C). Seven participants were recruited to participate in this study whose age ranged between 18-25 years. Apart from EEG signals, skin temperature and heart rate were also recorded along with a thermal survey questionnaire. Analysis was carried out to investigate effectiveness of using EEG signals as predictors of office work performance under varying indoor temperatures and a sparse regressor that combines EEG brain power spectral densities (PSD) from multiple brain regions. We found that this predictor using EEG PSDs provides higher R2 than regressors using skin temperature or heart rate by approximately over 5 folds. Finally, we show that our regression model using PSD is more robust than the regressors using skin temperature or heart rate. Our work demonstrates the potential of accurately predicting office worker's performance using EEG signals.

12:40
Lunch

13:40
Group Photo

14:00 Chair: Marcel Schweiker

Modelling occupant behaviour at the building and population scales: integration into building models and standards

10. Persistent misconceptions regarding occupancy-related models in building performance simulation
Ardeshir Mahdavi, Farhang Tahmasebi

There has been arguably significant progress in the building performance simulation field in the last decades concerning methods and practices for specification of building geometry, material properties, and external (weather) conditions. However, modelling practices pertaining to people's presence and behaviour in buildings are still in need of substantial improvement. In a number of previous contributions, we have pointed to a number of critical misconceptions with regard to the representation of occupants' presence and behaviour in building performance simulation models. These included, for instance, the conflation of simulation with prediction, the unwarranted use of the term "deterministic" while referring to standard diversity profiles, and unsubstantiated claims regarding the superiority of specific modelling techniques. Despite efforts geared at reasoned arguments and conceptual clarification, such misconceptions still appear to persist in current discourse of occupancy-related models in building performance simulation. It thus is necessary to further address the nature and implications of such misconceptions. Toward this end, we consider in the present contribution a number of archetypal building performance simulation deployment scenarios. The appraisal of these scenarios provides a logical framework to shed light on the sources of the aforementioned misconceptions. For instance, whereas some scenarios may imply, as the objective, specific predictions of future processes, others may be geared toward comparative analysis and benchmarking. Likewise, the significance of addressing uncertainty in occupancy-related model input assumption may be dependent on the utility of specific deployment scenarios. We expect that the discussion of such differentiations can effectively contribute to the improvement of the quality of discourse in occupancy-related modelling efforts.

11. A Hidden Markov-switching Occupancy Model with Autocorrelated Observations
Sebastian Wolf

Heating and ventilation strategies in buildings can be improved significantly if information about the current presence and activity status of the occupants is taken into account. Therefore, there is a high demand for inexpensive sensor-based methods to detect the occupancy status. This study suggests a new occupancy model based on the use of CO2 trajectories, trained on measurements in class rooms of two schools in Denmark. A Hidden Markov-switching Model with autoregressive observations using normal state dependent distribution was employed to identify the occupancy states. This modelling approach is a generalization both of Hidden Markov Models and Autoregressive models. In contrast to ordinary Hidden Markov Models, the suggested method takes into account that the current CO2 level is not only dependent on the occupancy status but also heavily dependent on its own past values. This is done by an additional autoregressive part which models the persistence of the CO2 concentration by relating the current value to its past lags. The analysis of residuals shows that this method inherits the dynamics of the CO2 curves much better than an ordinary Hidden Markov Model, and can therefore be considered as a promising candidate for occupancy models. Noise levels and occupancy schedules of the class rooms can be used to validate the model. Furthermore, the model can also be used for simulations of the occupancy status and the accompanying CO2 levels.

12. Verification of occupants' behaviour models in residential buildings
Rune Korsholm Andersen, Valentina Fabi and Stefano Corgnati

Occupants' interactions with the building envelope and building systems can have a large impact on the indoor environment and on the energy consumption in a building. As a consequence, any realistic forecasts of building performance must include realistic models of the occupants' interactions with the building controls (windows, thermostats, solar shading etc.).
During the last decade, stochastic models of occupants' behaviour in relation to control of the indoor environment have been published. Often the overall aim of these models is to enable more reliable predictions of building performance using building energy performance simulations (BEPS). However, the validity of these models has only been sparsely tested.
In this paper, stochastic models of occupants' behaviour from literature were tested against measurements from five apartments. In a monitoring campaign, measurements of indoor temperature, relative humidity and CO2 concentration was measured in the living room and bedroom at five minute intervals in five apartments with similar layout in a building located in Copenhagen. Outdoor temperature, relative humidity, wind speed and solar radiation was obtained from a weather station close by.
Stochastic models of window opening and heating set-point adjustments were implemented in the BEPS tool IDA ICE. Two apartments from the monitoring campaign were simulated using the implemented models and the measured weather data. The results were compared to measurements from the monitoring campaign to get an estimate of the forecast's realism.
The simulations resulted in realistic predictions in a sense that the measured values were within or close to the range of the simulated values. The variation in the simulated variables between apartments and over time was similar to that of the measurements. However, comparisons of the average stochastic predictions with the measured temperatures, relative humidity and CO2 concentrations revealed that the models did not predict the actual indoor environmental conditions well.

13. **The Impact of Window Opening and Other Occupant Behavior on Simulated Energy Performance in Residence Halls**
Holly Wasilowski Samuelson, Jose Guillermo Cedeno Laurent, Yujiao Chen

Based on measurements taken in 76 dormitory rooms, we developed a model for predicting occupant window-usage based on environmental conditions, including indoor and outdoor temperatures and time of day. We tested the performance of this model, derived from measurements in a pre-renovated building and two similar buildings, in predicting window-operation in 15 dormitory rooms in the post-renovated building. We compared the predictive capabilities of our model with other window-operation models proposed in past literature. We then implemented each window-operation model in a calibrated EnergyPlus building performance simulation, comparing the results of each simulation to metered hourly steam consumption.

Our model demonstrated the highest capability of predicting window state (accuracy=85.8%) and steam use (0.2% error; Hourly NMBE=0.3%, Hourly cvRMSE=17.2%) among the compared models. The impact of the different window operation models on simulated heating energy use was significant (annual error ranging from 0.2-10%) despite the fact that these models only applied to a portion of the building (only the dormitory rooms, not the common rooms). However, some previously published window-operation models also produced satisfactory performance, implying that models may be generalizable to some extent. A model derived from a different building type (office) but similar climate (Switzerland) performed better in our test case than a model from an air-conditioned dormitory in a hotter climate (Tokyo).

In addition, we present a method estimating air exchange rate and window operation from a combination of indoor/outdoor temperatures and CO2 concentration decay. We also derived occupancy and lighting schedules (from a combination of physical metering, surveys, and wearable activity monitors) for use in building performance simulation and compared these schedules to published (building code/software default) schedules. The college students in our study both slept less and spent more time at home, which resulted in a 41% increase in predicted lighting energy use. The variations in occupant behavior identified here, for both window-operation models and lighting schedules, have meaningful implications for estimating saving from energy conservation measures such as heating and lighting upgrades.

14. **WinProGen: A windows status profile generator based on Markov chains and field test data**
Davide Calì, Mark Wesseling, Dirk Müller

Natural ventilation strongly affects the energy consumption of buildings. However, window opening cycles are often omitted when simulating buildings' energy performance (air change rate is normally approximated by constant values), since difficulties arises in selecting a proper occupant behaviour model. Several occupant behaviour models related to the opening/closing of windows and based on general linear models are available in the literature. However, the use of such models presupposes a knowledge of occupants' presence within the building, which is not always given, especially for residential buildings. When detailed knowledge about occupants' presence in buildings (real or artificially generated) is not available, such models cannot be realistically used.

In this work we present and validate a stochastic windows' state profile generator (WinProGen) based on the Markov chain technique. Within the Markov chain process, WinProGen uses transition probability matrices obtained from measured data from two field tests including 60 retrofitted apartments and over 40 offices. WinProGen offers three different models. A first model generates windows state profiles (WSP) depending on time of day and daily average outdoor temperature. A second model generates WSP depending on time of day, daily average outdoor temperature and day of week (week, weekend day). A third model generates WSP depending on time of day, daily average outdoor temperature of the actual and the previous day.

We validate WinProGen through the Markov chain Monte Carlo technique and demonstrate the robustness of the implemented models. Furthermore, we use the generated windows state profiles (WSP) to simulate the energy performance of two residential buildings. We compared the simulation results to the real energy consumption of the buildings: the use of WSP generated by WinProGen leads to much more realistic results.

15:40
coffee break

16:10 Chair: Liam O'Brien

Learning from case study buildings: lessons from occupant behaviour in exemplar buildings

15. Two adjusted adaptive comfort models of elderly in elderly facilities in shanghai
Wang Zi, Yu Hang, Jiao Yu

With the rapid growth of aged population in recent years, the thermal feelings and demands of these people to living environments have become a hot topic and attracted more and more attentions.Field surveys had been conducted in elderly facilities of shanghai from January 2013 to November 2016.Totally 909 people aged 70 or above from 18 buildings were invited to evaluate their instantaneous feelings to on-site thermal environments. Indoor thermal parameters were measured, and meteorological data were obtained from the nearest station of each building.
Based on the field surveys, two adjusted adaptive thermal comfort models were developed separately to describe the relationship between the neutral temperature and the outdoor climate following the principles of ASHRAE and EN models. Although the correlations of thermal sensation and operative temperature reached significant levels (P-value less than 0.05) in only 4 buildings, the function of neutral temperature with 7-day running mean outdoor temperature was established under the guidance of ASHRAE. A new Griffiths constant (0.13) derived from our field surveys was used to establish a European standard adaptive model. Comparing with ASHRAE and EN models, both the slopes of our two adaptive comfort models were steeper. And the indoor neutral temperatures of elderly were always lower than the values as ASHRAE and EN models suggested, under the same outdoor temperatures. Clothing insulation level of each individual in winter, summer and mid-season was obtained, and correlations of clothing insulation against indoor operative temperature and outdoor temperature were also found.

16. Approaches to the evaluation of the predictive performance of occupant behavior models
Farhang Tahmasebi, Milica Dukic, Ardeshir Mahdavi

Given the impact of occupants' control actions on indoor environment and the complex nature of such interactions, sophisticated occupant behavior models are increasingly deployed to enhance the reliability of building performance simulations. However, use of these models in building simulation efforts and their predictive performance in different contexts involves potentially detrimental uncertainties. While a number of recent studies have dealt with the validity of existing occupant behavior models, there is still a need for development of procedures and metrics for identification of fitting models for different building performance simulation scenarios. In this context, occupant behavior models pose a specific challenge for evaluative procedures: These models conventionally use indoor environmental parameters as independent variables, which themselves can be influenced by predicted states of building control devices. There is unlikely that for any sequence of predicted user actions matching monitored data can be obtained. Empirically calibrated building performance models could be of course used to obtain the indoor environmental parameters resulting from the predicted occupants’ actions. But in this case, the uncertainties associated with the accuracy of such calibrated simulation models could represent a problem. In this context, the current study explores a variety of possibilities to analyze the predictive performance of occupant behavior models without relying on building performance models. Specifically, empirical occupant behavior data obtained from an office area is used to evaluate the performance of shading use models in terms of the following parameters: i) Predicted states of the shades in discontinuous and continuous model runs, ii) Predicted action probabilities, and iii) Frequency and seasonal variations of predicted actions. Thus, the study provides a basis to address the challenges in evaluation of occupant behavior models.

17. **First results of case studies on thermal comfort and occupant behavior in office buildings in Amman/ Jordan'**
Farah Al-Atrash

The objective of this research is to investigate whether the Adaptive Thermal Comfort Models which are included in the ASHRAE 55 or EN 15251 standards, can be applied to an office workplace context under Jordan's climate conditions. Furthermore, this study aims to increase understanding of adaptive opportunities and perceived control at office workplaces.

In order to suit the objectives of the study, longitudinal field surveys have been conducted in three office buildings during four seasons. The survey periods were selected according to the mean monthly external temperatures in Amman: Spring 2016 (20°C in April), Summer 2016 (27.6 °C in August), Autumn 2016 (22 °C in October) and Winter 2017 (8 °C in January and February).

For the surveys three office buildings were chosen as case studies, of which two buildings have been awarded LEED Gold Certificates. The third building presents a naturally ventilated and passively cooled traditional building. All buildings provide different adaptive opportunities to investigate the thermal comfort model and understand the effect on occupants' adaptive actions to reach thermal comfort.
During the surveys the physical thermal comfort parameters, air quality and acoustic parameters were measured.

The occupants completed questionnaires two times a week and over 2 to 3 weeks in each season. The questionnaires included questions about recent occupancy, thermal sensation, thermal comfort, acceptability, and preference; recent behavioral opportunities and actions, and perceived control.

The first results are: 1. The range of temperatures which occupants tolerate during the four seasons differ from the current Adaptive Thermal Comfort Model. 2. Occupants prefer having some control options at their work places e.g. operable windows and thermostat to increase their satisfaction, even they didn't use them. 3. A prevalent reasons for not using the given 'options to control indoor climate' was given by the occupants: 'I was comfortable and adjusting would not have helped'.

18. **Roadmap and Goals of an Office Occupant Moving Study**
Zsófia Bélafi

The behaviour of office occupants is one of the most important contributors to the building energy performance. Significant effort has been made recently to investigate and model office workers' everyday activities that have an influence on the energy consumption of a building (such as window opening, shading, lighting, pludload use). Often the limitation of these studies is that one sample of office workers show one kind of behavioural pattern in one specific space but we do not have data about their behaviour in a different setting. Therefore, researchers have a hard time on determining the exact performance, validity and generalizability of the models and patterns created on such datasets. In this project, this vicious cycle can be solved in case of a Hungarian office building population. 60 office workers of a construction-industry firm have been recently moved to a new office location in August 2016. The old office was a naturally ventilated, low-performing historical building with many environmental control options. The new office of the company is located in a modern, green, automatd office building built in 2009. Only half of the workers have access to operable windows. As part of this study, cross-sectional surveys are carried out both before and 1 year after moving in, in the summer season about the use of environmental controls. For the new office, indoor envirnomental quality and energy consumption submetering (electricity and heat for FCs) data is going to be available. Measurement and survey data are used to discover the differences in the very same office workers' environmental perception and behaviour in the different office settings. The aim of the study is to find out whether the behaviour of the same population changes in a different office setting. Another important question is whether an education program on environmental controls was successful and to what extent.

19. On occupants' thermal/visual comfort and air-quality perception may be improved thanks to non-physical drivers in a working place

Anna Laura Pisello, Veronica Lucia Castaldo, Ilaria Pigliautile

Thermal and visual perception by occupants has been demonstrated to be affected by a variety of parameters, stimuli and other boundaries which play a dynamic role in building human perception about their living environment. In this view, adaptive thermal comfort theories take into account the dynamics of environmental boundary conditions influencing humans' opinion about their acceptability and adaptability ranges during the course of the year. Starting from this deep acknowledgement, the present work is aimed at investigating the environmental multiphysics performance of a mixed industry-office work place in central Italy with about one thousands permanent employees. The company policy aims at building the most comfortable environment and at establishing high quality of life standard in food, in working time-tables, in the outdoor pleasant surrounding providing fitness facilities, open-air accessible parks, local organic restaurant and general view of the peaceful very well maintained environment they are investing on. In this view, the works consists of a i. microclimate assessment of several working positions in different seasons, ii. Questionary development for investigating workers' perception about thermal and visual acceptance and satisfaction, iii. Medical analysis of people health conditions at work. Such threefold analysis allows to investigate how people perception may be depending on physical parameters, adaptive capability and outdoor dynamics, health conditions and pathology influence, but also to identify the further benefits perceived by occupants thanks to these non-physical actions such as the possibility to enjoy the outdoor environment with green facilities and good food quality, together with the company policy not to stress employees for a better quality of working life. To this aim, different data collections are compared and the gaps between people opinions and physical analysis are evaluated by identifying their better perceptions due to these non-quantifiable factors such as social and psychological drivers triggering their satisfaction, adaptability readiness and, potentially, productivity rates.

17:50
Closing remarks
Rune Korsholm Andersen

18:00
Reception

19:00
End of program

Notes


DTU
Legend
Departments
Oticon Hall
Administration
Campus Service
Residential halls and guest houses
Scion DTU
Instructional buildings
Bus stops
Canteens
DTU Library
DTU Meeting Centre
N
Busstop from Copenhagen
OB-17 meeting room
Annex 66 and annex 69 meeting rooms - access through Entrance A
International Centre for Indoor Environment and Energy
Convenient store
Lundtofte
Helsingør
Jægersborg Dyrehave
Nordvej
Brovej
Bygnings-torvet
Lundtoftegårdsvej
Rævehøjvej
Kolonnevej
Henrik Dams Allé
Knuth-Winterfeldts Allé
Sankts Plads
Lundtoftevej
Kemikalievej
Kemitorvet
DTU Library
Oticon Hall
Canteen
Glass Hall
S-huset
Hall 1 Sportshal
Hall 2
DTU Meeting Center
Anker Engelunds Vej
Villum Kann Rasmussen Residence Hall
Brede
Virum
Matematik-tårnet
Fysikvej
Elektrovej
Richard Petersens plads
Vagn Aa. Jeppesens Vej
Kollegiebakken
Kampsax Residence Hall
Daycare center
Housing cooperatives
Helsingørmotorvejen - freeway
E47
E55
Vandtårne
Centrifugevej
Akustik-vej
Ørsteds Plads
Asmussens Allé
Nils Koppels Allé
Produktions-torvet
Akademivej
Ole Nørgaards Have
Villum Demant Residence Hall
Diplomvej
Guest houses
Til kgs. Lyngby st.
Lyngbygårdsvej
Klampenborgvej
Klampenborg/ Strandvejen
Lyngby
København
15
LUNDTOFTE HJORTEKÆR
16
KGS. LYNGBY C KLAMPENBORG
0
100
200
300
400
500 meter