WINDSOR

Rethinking Comfort

Book *of* Abstracts

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Rethinking Comfort

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16:00	REGISTRATION
18:00	WELCOME RECEPTION IN THE DRAWING ROOM
19:00	DINNER

After Dinner Talk - Chair: Fergus Nicol 20:30 – 22:00

20:30

Low-tech Comfort: Heating People not Buildings

Kris de Decker

Thermal comfort in winter is typically provided by heating the entire volume of air in a room or building, and in summer by cooling it. In earlier times, our forebear's concept of heating was more localized: heating people, not places. They used radiant heat sources that warmed only certain parts of a room, creating micro-climates of comfort, and countering the resulting large temperature differences with insulating furniture, such as hooded chairs and folding screens. They also used additional, personal heating sources that warmed specific body parts. The understanding better the three types of (sensible) heat transfer: convection (the heating of air), conduction (heating through physical contact), and radiation (heating through electromagnetic waves) gives building designers effective tools with which to create buildings that run to a far greater extend on natural energy. In this talk it is argued that it would make a lot of sense to restore this old way of warming, especially since modern technology has made it so much more practical, safe and efficient to do so.

FRIDAY 13TH APRIL 2018

SESSION 1: Rethinking Thermal Comfort 09:00 - 11:00

Invited Chairs: Edward Ng and Luisa Brotas

09:00

Puzzles and paradoxes in adaptive comfort

Michael A Humphreys and J Fergus Nicol

The welcome and widespread recognition that comfort is best seen as an interactive adaptive process has resulted in a proliferation of field study research. The analysis of the data from these studies, and attempts to formulate their results into guidelines and standards, has produced a number of puzzles that verge on the paradoxical: 1. Estimation of people's sensitivity to temperature-change by regression analysis appears to be logical, but often gives a misleading result; 2. The Griffiths method to obtain comfort-temperatures is sometimes necessary, yet its use entails apparently arbitrary choices; 3. The adaptive approach must be written into standards and codes, yet the concept of adaptation prohibits the stipulation of fixed values; 4. Is there a single worldwide relation between climate and comfort-temperature, or do we need numerous locally-derived relations? 5. Standard scales of subjective warmth help international comparisons, yet they often fail to translate across language and culture; 6. Humidity affects comfort, yet statistical analysis rarely captures its effect. The paper illustrates and examines several such puzzles.

09:15

Thermal adaptation and seasonal alliesthesia: Two conflicting concepts?

Marcel Schweiker, Susanne Becker and Karin Schakib-Ekbatan

Leaving the static view on thermal comfort, two concepts are presented in the literature: adaptation and alliesthesia. So far, there was no comparison between the consequences of these two concepts. However, their basic hypothesis related to preferred conditions in different seasons are antithetic – while adaptation suggests warmer conditions in summer being closer to neutrality – often set synonymous with comfort – alliesthesia suggests cooler conditions in summer leading to a higher level of pleasure – also set synonymous with comfort. The objectives of this paper are to compare both concepts and the resulting views on "optimal" thermal conditions by means of an experimental study. The experimental study consisted of a between-subject design with two groups (winter (N=32) and summer (N=31)) experiencing the same three thermal conditions (classified as cool, neutral, warm) each for 50 minutes in a balanced order in a field laboratory with windows to the outdoors. Subjects voted their thermal sensation and thermal pleasure at the end of each session. Indoor environmental parameters and subjects' skin temperature were recorded. Analyses showed that thermal sensation assessed by the ASHRAE scale followed the assumptions of the adaptive approach: subjects perceived the warm conditions slightly less warm in summer. Thermal pleasure had its maximum at slightly cool conditions in summer and at slightly warm conditions in winter. Skin temperature variations did not explain such seasonal difference in the perception. Yet, it is hypothesized that a new mode of alliesthesia can explain such effects: seasonal (or long term) alliesthesia. In conclusion, adaptation and alliesthesia focus on different dimensions of thermal perception and lead to distinctive results concerning the optimum thermal conditions. The consequences for the operation of buildings is a challenging discussion to be continued with future research work.

09:30

Performance of medium-rise, thermally lightweight apartment buildings during a heat wave

Ella S. Quigley ES and Kevin J. Lomas

There is growing evidence that medium rise, thermally lightweight, well-insulated, naturally ventilated, single apartment blocks are at risk of overheating especially when sited in the SE of England. This paper reports the thermal comfort and heat stress conditions recorded in 15 apartments located in North London on the outer fringes of the urban heat island. The apartments were built using off site, light gauge steel prefabrication methods. Bedrooms on floors one and two and on floors seven to eleven were monitored for 22 days during July and August 2013, a period that included a heat wave, which precipitated a level 3 heat wave alert. The risk of overheating was assessed using the static criteria in CIBSE Guide A and the three CIBSE TM52 adaptive thermal comfort criteria. Heat stress levels in one room were assessed using the Humidex and Heat Index metrics. The bedrooms on floors one and two did not overheat whereas all the apartments on the upper floors failed both the static and the adaptive criteria producing conditions that would lead to heat stress. The results strongly suggest that the design, ventilation and servicing strategy, combined with the inherent fragility of thermally lightweight and well insulated construction, is inappropriate in some areas of the UK and may even be dangerous in hot summers. The findings have significance for construction companies, landlords and social housing providers and those concerned with construction guidelines and the building regulations.

09:45

Percentage of commercial buildings showing at least 80% occupant satisfied with their thermal comfort

Caroline Karmann, Stefano Schiavon, Edward Arens

Most thermal comfort standards prescribe that buildings must provide satisfactory thermal comfort to at least 80% of their occupants. To assess how many buildings meet this criterion, we analysed temperature satisfaction votes from 52,980 occupants in 351 office buildings, obtained via a web-based seven-point satisfaction survey over 10 years, mainly in North America. 43% of the occupants are thermally dissatisfied, 19% neutral and 38% satisfied. The percentage of buildings meeting 80% satisfied occupants was only 2% if one considers votes from +1 to +3 ('slightly satisfied to very satisfied') as representing satisfaction, 8% if one includes votes from 0 to +3 ('neutral to very satisfied'), and 33% if one includes votes from -1 to +3 ('slightly dissatisfied to very satisfied' – a seemingly generous criterion suggested in ASHRAE Standard 55). These results are concerning because they suggest that buildings are far from creating thermal environments that their occupants consider satisfactory. This might be due to inability of the large majority of HVAC systems to provide adequately personalized conditioning or control. This paper also discusses the relevance of the 'satisfaction' metric used for long-term building evaluations.

10:00 **Revisiting overheating indoors**

Runa T. Hellwig

In recent years, an increasing amount of overheating issues in buildings has been reported. Despite available knowledge and recognition of the problem by research, in practice little attention has been paid to the problem. The aim of the paper is to identify contradictions, missing interconnections, communication deficits or barriers. Terminologies used, and time and dynamics in the context of overheating and heatwaves will be discussed. Planning pathways and their consequences on preparedness for overheating or heatwaves will be discussed subsequently. In the context of overheating as well for heatwaves, informing people about the human ability to acclimatise to seasonal changes and addressing acceptable healthy temperature ranges instead of comfort ranges could be supportive in relaxing people's expectations towards indoor climate. Three areas should become a focus of future activities: a) enhancing adaptability in humans b) managing human expectation towards the indoor environment and c) enhancing adaptability of buildings. Time and dynamics in building performance, adaptation processes and mortality predictions are interrelated and will require more attention in future studies.

10:15 **Changing Thermal Comfort Expectations: Studies in Darwin, Australia**

Terence Williamson and Lyrian Daniel

This paper presents an examination of the thermal expectations of occupants in naturally ventilated dwellings from two studies in Darwin, Australia, conducted some 25 years apart (1988/89 and 2013/14). The 25 years between the two studies have witnessed dramatic changes in Darwin, that include a doubling of the population, considerable differences in dwelling styles offered in the market, technological developments making the installation of air-conditioning more available, relative changes in incomes, and energy prices making air-conditioning more affordable. The 1988/89 study employed Comfort Vote Logger devices to record a total of 3800 comfort votes in 16 un-air-conditioned houses during the build-up and wet seasons. The 2013/14 study involved 20 mainly free-running houses in which thermal conditions were recorded on purpose built logging instruments while the occupants recorded 2535 comfort votes over a ten-month period. Analysis presented in the paper gives a detailed comparison of the results from the two studies covering four criteria central to the adaptive comfort concept - external versus indoor temperatures, thermal acceptability, thermal sensitivity and thermal neutrality. The paper concludes with a discussion of the findings and implications of these findings for the adaptive approach to thermal comfort.

10:30	**Light exposure effects on the perception of the thermal environment** **Marije te Kulve, Luc Schlangen and Wouter van Marken Lichtenbelt** A wider range for acceptable indoor temperatures can reduce building energy consumption and may be beneficial for health. In the current study, we investigated the influence of the intensity and spectrum of white light exposure on thermal comfort and sensation. In two well-controlled laboratory studies with 35 healthy young adult females, we tested the effect of the correlated colour temperature of light (2700K and 6500K, both 55lx) and the intensity of light (5lx and 1200lx, both 4000K) on thermal comfort and sensation. The light exposures were provided during cool, neutral and warm thermal conditions. Core and skin temperatures were measured. Thermal comfort and thermal sensation were not significantly affected by the light intensity or relative correlated colour temperature. The preferred lighting conditions differed between individuals. Interestingly a significant positive correlation was found between visual comfort and thermal comfort. This result implies that visually comfortable conditions may improve thermal comfort, but individual preferences should be taken into account. The main conclusion therefore is that thermal discomfort can partly be alleviated by lighting conditions that result in a higher perceived visual comfort. Field studies are required to demonstrate the practical relevance of the interaction between light exposure and ambient temperature.
10:45	DISCUSSION
11:00	COFFEE BREAK

SESSION 2: New approaches to heating and cooling people 11:30 - 13:00
Invited Chairs: Richard de Dear and Atze Boerstra

11:30

The Effect of the Visual Cue of Mist Cooling on Perceived Thermal Comfort

Craig Farnham, Yuki Okazaki, Kazuo Emura, Miki Kubota, Jihui Yuan, and Md Alam Ashraful

On hot summer days, the cooling effect of fine water mist has been well-received. Although fine mists typically only yield an air temperature reduction of 1 – 3K, the comfort votes of those experiencing the mist are far better than expected by the PMV (Predicted Mean Vote). The transient effect of a sudden reduction in temperature may account for much of this over-evaluation of mist cooling. Yet, subjects may also be affected by an expectation that mist should feel cool and vote accordingly. In these experiments, subjects are exposed to a misting fan and a non-misting fan and asked which fan feels cooler. Unknown to the subjects, a heater increased the temperature of the misting fan air flow, producing an airflow up to 1.7K warmer than the fan without mist. Tests of over 300 subjects while varying this misted air temperature showed that on average the misting fan was perceived as cooler than the non-misting fan, even when the misting fan airflow was up to about 0.5K-0.7K warmer than the non-misting fan. It is likely that the expectation of cooling by mist significantly influences the perception of comfort. This effect should be considered in thermal comfort evaluations of mist cooling.

11:45

Study on Thermal Indices under Mist Spray Condition through Thermal Sensation and Comfort

Wonseok Oh, Ryozo Ooka, Junta Nakano, Hideki Kikumoto, Osamu Ogawa

Recently, a cooling system using water evaporation has been widely utilized as an alternative for relieving human thermal stress. The mist spray system is known to be able to lower the air temperature by 1–3 °C in the outdoor environment and increase the thermal sensation. However, the existing mist spray system tends to raise the humidity too high around the human or fail to deliver cooled air properly according to the wind effect. To overcome the problems of the conventional systems, a mist spray with an air-blowing system was proposed. As a result, this mist spray system led to an increase in convection and evaporation effects. In addition, the effectiveness of the system was confirmed by the field experiment. The survey by subjects and the measurement of environmental factors were performed simultaneously in the summer. The surveys were conducted using a seven-point modified thermal sensation vote (mTSV) scale from very cold (-3) to very hot (+3) and the comfort sensation vote (CSV) scale from very uncomfortable (-3) to very comfortable (+3). The results of the survey showed that the mean mTSV value dropped from 2.3 to 0.2, decreasing the degree of feeling hot, and the mean CSV value increased from -1.3 to 1.4, improving the comfort feeling. To confirm the thermal effectiveness of the mist spray system, environmental factors were measured in two different locations where it was and was not influenced by the mist spray, respectively. The factors were air temperature, humidity, wind speed, globe temperature, and solar radiation. Since the inside of the mist is wetted by the influence of the water droplet and cannot be measured with a conventional sensor, a cyclone type of measurement for the dry bulb temperature and density of water vapor were used. To predict the human's thermal state in an outdoor environment and the mist spraying condition, the feasibility of Gagge's two-node model was verified with the field experiment. The results showed that the gap of in the mean skin temperature between the predicted model and field experiment was 0.2–0.3 °C. In addition, this study proposes an environmental index that can predict the mTSV in an outdoor environment and the mist spray condition by a two-node model.

11:50 **Evaluation of Radiant Ceiling Heating Systems for Renovated Buildings based on Thermal Comfort Criteria**

M. Reza Safizadeh and Andreas Wagner

This study aims to evaluate the potential application of low-temperature radiant ceiling heating systems in new and energy-renovated buildings having a low space heating load, based on thermal comfort criteria. Towards the goal, subjective experiments (within-subjects) with 14 participants were performed in an indoor climate test facility. Local and overall thermal sensation and comfort responses in connection to four different scenarios (combinations of ceiling temperatures of 28 and 35°C and distances of 1 and 3 m to the window) were collected using questionnaires. During the experiments, room air temperature, humidity, velocity and globe temperature, as well as skin temperature at eight body-points were measured. Findings of this research prove that the radiant ceiling heating system operating at even low temperatures (28-35 °C) can provide fairly neutral thermal sensation and satisfactory comfort at the majority body-parts, if the building envelope satisfies advanced building energy-efficiency regulations. The overall thermal sensation and comfort closely follow the local votes at the upper-body limbs. Beyond the expectation, the head is perceived as the most comfortable body part, despite it is a sensitive extremity to warm conditions. Furthermore, the results show that unlike the local comfort votes, the local sensation votes are strongly related to the local skin temperatures.

11:55 **Comparing occupant thermal perception of air conditioning and ceiling-mounted radiant cooling panels coupled to a roof pond**

Eduardo Krüger, Leandro Fernandes, Wolfgang Mutsafi-Haller, Evyatar Erell

An experimental study compared the thermal response of subjects in two test rooms, one of which was cooled by a roof pond coupled to radiant cooling panels and the second by a conventional split AC unit. Measurements of the surface temperatures indicated that structural cooling and thermal stabilization were obtained in the roof pond room, whereas in the air-conditioned room thermal control was achieved only within the short period of the session through air temperature changes. For similar air temperature, there was a slight preference for the roof pond room, which had a lower Mean Radiant Temperature. The roof pond room was found to be more effective in ensuring comfort conditions continuously and without occupant intervention

12:10 **Reliability of characterising buildings as *HVAC* or *NV* for making assumptions and estimations in case studies**

Rick Kramer, Henk Schellen, Jos van Schijndel, Wim Zeiler

Buildings are often categorised into HVAC-buildings and naturally ventilated (NV) buildings. This study explores the extent to which a fully air-conditioned museum adheres to the typology of being an HVAC-building regarding (i) the acceptable indoor temperature range and variation, (ii) the clothing variation, (iii) the validity of the PMV model. Estimations of these aspects and of the PMV model's inputs are based on data from the literature that differentiates between HVAC and NV buildings. Then, the estimated aspects are compared with experimental data based on a large-scale measurement and survey study (n=1250) at the Hermitage Amsterdam museum. Conclusions: (i) More seasonal temperature variation is accepted in the museum than expected for an HVAC-building; (ii) The permissible temperature range exactly matches that of HVAC-buildings, i.e. neutral ±1.2°C; (iii) Clothing behaviour in the museum corresponds to NV-buildings; (iv) Metabolic rate was found to be 22% higher than estimated; (vi) PMV model increasingly underestimates mean thermal sensation towards cold and warm sides of thermal spectrum; (vii) Outdoor temperature significantly influences thermal sensation indoors. Hence, categorising a building solely based on the criteria of perceived control into HVAC-building or NV-building yields unreliable estimations of clothing behaviour, acceptable temperature range, and validity of the PMV-model

12:25 **Dynamic Evaluation Method for Indoor Thermal Environmental Acceptability Using P-R Chart**

Masanari Ukai and Tatsuo Nobe

This study was conducted to characterise thermal environmental acceptability for various airconditioning systems. The authors developed a new thermal comfort index called a P-R chart using the concepts of "provided temperature" and "required temperature" for use in evaluating uniform, high-quality indoor thermal environments and non-uniform, unsteady thermal environments. In this study, first, the authors surveyed the required temperature distribution of workers. Then they surveyed indoor thermal environmental stabilities in the four offices during the summer with different air-conditioning systems to calculate provided temperature distribution. Finally, the indoor thermal acceptability in offices was evaluated using the P-R chart. The results showed that the convective air-conditioning systems caused wide temporal and spatial variations in the thermal environment. Therefore, in buildings with convective air-conditioning systems, even if the planar average thermal environment is categorised as comfortable, it is presumed that workers sensitive to cold or heat will complain of discomfort more frequently than those in buildings with radiant air-conditioning systems and floor-supply displacement HVAC systems, because the probability of workers sitting in cold- or hot-spot areas is higher in the former case.

12:40	**How does Passive Chilled Beam system rate from an indoor thermal comfort perspective when compared to Variable Air Volume and Under Floor Air Distribution HVAC systems?** **Ashak Nathwani** This study evaluates how Passive Chilled Beam (PCB) system rates in terms of indoor thermal comfort and energy efficiency when compared to Variable Air Volume (VAV) and Under Floor Air Distribution (UFAD) HVAC systems. A human shaped skin-temperature controlled thermal manikin is utilized to directly measure equivalent temperatures (t_{eq}) in a set of adjacent climate chambers that incorporate these three types of HVAC systems. Clothing data was obtained by exposing the manikin to uniform thermal environments. The manikin was moved between chambers subjecting it to non-uniform conditions created by the different HVAC systems, each of which maintained 22.5 +/- 0.5^{o}C. The overall outcome is that UFAD and VAV displayed similar vertical profiles (for a 'clo' value of 0.36) with cooler feet (t_{eq} = 20.9^{0}C & 21.6^{0}C, respectively) and warmer head (t_{eq} = 22.4^{0}C & 22.7^{0}C, respectively). PCB demonstrated relatively warmer feet (t_{eq} = 22.4^{0}C) and cooler head (t_{eq} = 22.1^{0}C). PCB air conditioning system, hence, highlights the adage that cooler head and warmer feet offers better comfort. These are compared with outcomes from similar experiments with human subjects. Energy efficiency values, in the form of energy intensities obtained using thermal modelling analysis, are also presented for the three types of systems with Chilled Beams achieving a 10% advantage.
12:45	**Effects of ceiling fans on the thermal comfort of students in learning environments of Bayero University, Kano, Nigeria** **Sani M. Ali, Brett D. Martinson, Sura Al-Maiyah, and Mark Gaterell** It is well known that thermal comfort is influenced by major physical parameters; air and radiant temperatures, humidity, and air speed in combination with personal attributes; clothing insulation and activity level. Although temperature is conventionally considered in adaptive thermal comfort model, as the most important physical parameter where cooling is involved, moderate air speed can enhance thermal comfort during higher temperatures. Through convective and evaporative cooling, ceiling fans cool people by causing sweat from the occupant's body to evaporate. The northern part of Nigeria, being in the tropics, is known for higher temperature regimes for most part of the year. The use of air conditioning to achieve thermal comfort is not sustainable, for economic reasons and the lack of stable electrical energy. Therefore, a majority of naturally ventilated spaces could be kept thermally comfortable with the control of ceiling fans and operable windows. As part of a research work on learning environments in a Northern Nigerian university, this study reports on the effects of ceiling fans on the thermal comfort perception of the students in two lecture theatres. Air speed, air and radiant temperatures, relative humidity were measured, concurrently comfort surveys were undertaken in the spaces, from which activity levels and clothing insulations were obtained. Adaptive thermal comfort standards, ASHRAE 55 and EN 15251, state that thermal comfort can be maintained as air temperature rises with the use of ceiling fans operating at moderate speed. The results show that reductions of 31% and 22% in overheating from the two lecture theatres were realised, as a result of ceiling fans usage, measured by the degree hour's exceedance indicator. These results were further corroborated by the students' acceptance of thermal conditions of the lecture theatres at temperatures above T_{max}.
12:50	DISCUSSION
13:00	LUNCH

SESSION 3: Personal Control, Perception and Adaptive Behaviours 14:00 - 16:00
Invited Chairs: Michael Humphreys and Madhavi Indraganti

14:00

Personal control: windows, fans, and occupant satisfaction

Margaret Pigman, Gail Brager, Hui Zhang

The availability of personal control is one of several explanations underlying adaptive comfort theory. This work distinguishes between four main aspects of personal control: access, satisfaction, perception, and usage. In this paper, we look at three case study mixed-mode office buildings using an expanded version of the indoor environmental quality (IEQ) survey from the Center for the Built Environment. Results reveal interesting patterns about behavior and responses to operable windows and ceiling fans, and both access to and perception of controls. For example, although the occupants were satisfied with their operable windows and fans, having access to these controls did not significantly influence their satisfaction with the indoor environment. IEQ satisfaction was most strongly correlated with perception, as measured by satisfaction with the ability to control IEQ and confidence that adjusting windows would have the desired effect.

14:15

Rethinking user behaviour comfort patterns in the south of Spain - What users do

Samuel Domínguez Amarillo, Jesica Fernández-Agüera and Juan José Sendra

Any investment made in refurbishing buildings in order to limit their energy demand can generally be classified as being of strategic interest. However, we have found that, although the application of current energy analysis techniques can imply significant potential energy savings when retrofitting housing stock, it is often the case that significant deviations from the envisaged energy performance can come about, in particular in southern Europe. A monitoring process has been carried out in occupied dwellings over a long, continuous period of time, in order to obtain values of over one year of duration of multiple environmental variables, most notably the indoor air temperature readings, relative humidity and HVAC operation. This monitoring has been completed with a series of surveys on the behavioural habits of tenants, in order to obtain correlations between energy consumption and their behaviour comfort patterns. This work has demonstrated that there is generally no direct relation between official and real user comfort patterns in social housing in southern Spain. Indeed, energy consumption tends to be lower than expected, due mainly to the fact that inhabitants spend long periods in unsuitable living and health conditions. This information has been used to generate a real comfort behaviour pattern.

14:30

What do households do to keep cool?

Gary Raw

With climate change in mind, we need effective strategies to avoid overheating in homes – strategies built on an understanding of what households currently do to keep cool and why they do it. This paper reports findings from a survey of 2,313 households, supported by literature review and qualitative research. Only 9% of respondents say that it would not get too warm on a typical summer day. The actions taken to avoid overheating are often successful but there remain 27% who do not always keep cool enough on a typical summer day. Even in winter, a majority need to avoid overheating, and households that report always feeling warm enough in winter are more likely to overheat in winter. This suggests potential both to improve comfort and to reduce energy use. Households avoid overheating partly by controlling room temperature but a majority also use methods targeted at themselves: reducing clothing/bedding, cooling the body, or changing location. Behaviour varies with characteristics of both the dwelling and the household, and reflects needs beyond thermal comfort. A majority of households do open windows but also report barriers to doing this (e.g. security or noise). Reducing barriers should facilitate cooling without air conditioning.

14:45

Developing user profiles for mixed-mode office buildings operation based on occupant behaviour evaluation

Leticia de Oliveira Neves, Eduardo Rodrigues Quesada, Camila Anchieta and Karin Soares Chvatal

User profiles can generate discrepancies between the measured and simulated data, when building performance simulation tools provide the latter. Nevertheless, specialized literature observed the inadequacy of using current thermal comfort models to describe occupant comfort in mixed-mode buildings and no specific guidelines are provided in current standards. This paper addresses occupant behaviour within mixed-mode office buildings controlled by occupants, located in a Brazilian humid subtropical climate, with the objective to develop user profiles of operation to be used as input data in computer simulation analyses. Three office rooms operating in a concurrent mixed-mode configuration were investigated in a field research. Indoor climatic measurements monitored the environmental variables (dry bulb temperature, radiant temperature, air velocity and relative humidity) and user control variables (manual operation of the air-conditioning and natural ventilation systems) in situ. Field surveys were simultaneously conducted with the offices' occupants. As a result, occupant behaviour regarding the building's controls is analysed and compared to the static and adaptive thermal comfort models from ASHRAE Standard 55-2013. In conclusion, a user profile to be used as input data for computer simulations is developed, aiming to support more accurate investigations about the thermal and energy performances of mixed-mode office buildings.

14:50

Managing comfort in low energy housing – the role of gardens, balconies, allotments and greenhouses

Sonja Oliveira, Elena Marco, Bill Gething and Martin Green

This paper examines management of thermal comfort in a low energy housing development in England drawing on residents', designers' and housing managers' views. Thermal comfort studies have tended to mainly focus on measurement techniques and comfort criteria. There has been little attention devoted to how designers as well as residents account for thermal comfort in the design and management of indoor and or outdoor space. Findings suggest designers and housing managers play a critical role in the conception of interstitial spaces between an individual home, street, garden and collective community landscaping. It was found that whilst equipped with advanced technologies to heat and cool their homes, residents' adaptation strategies to manage discomfort evolved primarily around escaping to a range of individual, ad hoc collective and dedicated community spaces. The importance of outdoor spaces as traditional regimes of cooling is well researched, however an extended understanding of an outdoor environment's spatial and social role for designers and residents in planning and managing comfort is largely unexamined. The analysis also provides a novel method in the studies of thermal comfort – a timely contribution in light of recent questioning of the nature of human interaction with thermal comfort (Nicol and Roaf 2017).

15:05

Seeing is Believing, or is it? An assessment of the influence of interior finish characteristics on thermal comfort perception at a University campus in a temperate climate

Jansen Foo and Anna Mavrogianni

Being a 'condition of mind', thermal comfort can be considered to be both a physiological and psychological response. Research shows that other than the physiological factors which are well established in prevailing thermal comfort standards, behavioural and psychological factors equally affect how humans adapt to the thermal conditions of their environment. Human response to thermal conditions is often based on predispositions associated with their perception and expectations of the physical environment. This paper examined the impact of interior finish characteristics on thermal comfort perception in learning spaces by analysing thermal comfort perceptions of students across 48 lecture theatres surveyed during the winter and spring season between 2012 and 2015 in University College London. A taxonomy of interior finish characteristics was first developed to guide the classification of the lecture theatres into different groups for statistical analysis. Results from hypothesis testing found small yet statistically significant differences in thermal comfort as a function of the colour hues ($\Delta = 0.1$) as well as the perceived naturalness ($\Delta = 0.06$) of interior finish characteristics. The findings of this study may have potential implications for the interior design of low carbon and healthy buildings that aim to minimize energy used for space heating whilst maintaining high indoor thermal comfort.

15:10

Personal control over indoor climate in office buildings in a Mediterranean climate - Amman, Jordan

Farah Al-Atrash, Runa T. Hellwig, Andreas Wagner

The objective of this study is to increase understanding of personal control in office workplaces by: 1) analysing the adaptive opportunities available to the occupants, how they perceive these adaptive opportunities, as well as their desire to have these opportunities. Statistical analyses were conducted to find out the impact of available control on perceived control, and interrelations between perceived availability and desired control; 2) mapping of how often these controls were used (exercised control); 3) analysing the reasons for not exercising available adaptive opportunities; 4) analysing the effect of office types and seasons on perceived control; and 5) determining the impact of perceived control on thermal comfort perception and air quality. For this, data from longitudinal surveys which have been conducted during four seasons in three office buildings in the Mediterranean climate of Amman, Jordan were analysed. Operable windows and adjustable thermostats are the most desired adaptive opportunities. The most stated reason for not exercising available adaptive opportunities was 'No need to change'. The study found significant correlations between office types and perceived control. On the other hand, no significant correlation was found between seasons and perceived control. Perceived control correlates positively with occupants' thermal comfort perception.

15:15

Using feature selection techniques to determine best feature subset in prediction of window behavior

Hailun Xie, Shen Wei, Li Zhang, Bobo Ng, Song Pan

Previous studies have demonstrated diverse effects of different factors on occupant window behaviours. It is necessary to choose appropriate subsets of different behavioural window opening features, and to eliminate irrelevant and redundant features so as to avoid overfitting, noise and random fluctuations being learned by the model, and improve the accuracy of predictive models of window opening. The choice of protocols for the selection of features has been widely accepted as one of the most important steps in developing machine learning prediction algorithms. This study employed the use of both a recursive and a non-recursive feature selection method designed to consider all influencing factors simultaneously to explore the confounding effects inherent in various factors pertaining to the prediction of window opening behaviour. Two machine learning algorithms were applied as estimators in a recursive selection process, namely support vector classification (SVC), logistic regression (LR), and one in a non-recursive process, namely random forest (RF). Additionally, two processing schemes in the recursive method analysis were tried to determine the optimal feature subset based on corresponding algorithms, namely recursive feature elimination (RFE) and recursive feature elimination with cross validation (RFECV). Seven factors were considered in the feature selection process based on collected data, including: indoor temperature, outdoor temperature, relative humidity, concentrations of PM2.5, air quality index (AQI), wind speed and wind direction respectively. The results showed that different feature subsets can generate different prediction accuracy within the recursive method. RFECV can determine the most appropriate feature subset effectively with the consideration of the correlation among various factors. Both LR and SVC were proved to be effective as estimators embedded in RFECV, however SVC is more computationally expensive and LR shows a larger variance within the feature subset space. RF, as a non-recursive method, demonstrated real advantages in eliminating redundant features compared to the recursive feature selection process.

15:30	**Adaptation by coexistence: A comparative study of thermal comfort in individual and shared office spaces in Chile** **Laura Marín-Restrepo, Maureen Trebilcock and Jaime Soto-Muñoz** In shared spaces, adaptive actions can be limited by a coexistence factor, which has an impact on thermal expectations. This study aims to compare the perception of thermal comfort, comfort temperature and adaptive actions in individual and shared offices. Fieldwork was carried out in 9 office buildings in Concepción (36°S) and 8 in Santiago (33°S), Chile. In each building, the indoor environment was measured and thermal comfort surveys were administered at 3 different times during a winter day. The comfort temperature calculated showed variations from 0.3 to 1K between individual and shared spaces. In most cases, occupants of individual offices showed a greater preference for thermal variation than occupants of shared ones. Slightly more acceptability was found in individual spaces. Participants performed more adaptive actions in individual versus shared spaces, although this does not imply thermal discomfort. These findings suggest that the occupants of shared spaces have "adapted", since even when their comfort temperature is not equal to the indoor temperature, they declare that they accept the indoor environment and prefer no changes in it. This shows that thermal comfort varies according to the type of space and social constraints, which should be considered in design phase calculations.
15:45	DISCUSSION
16:00	TEA BREAK

WORKSHOP 1: Usage and Interpretation of Comfort Scales **16:30 - 18:00**
Invited Chairs: Marcel Schweiker and Giorgia Chinazzo **Hodgson Room**

16:30

A field study investigation on the influence of light level on subjective thermal perception in different seasons

Giorgia Chinazzo, Luisa Pastore, Jan Wienold and Marilyne Andersen

This paper evaluates the influence of light levels (i.e., illuminance) on subjective thermal perception of people, distinguishing between thermal sensation and thermal evaluation. The goal is to investigate whether reported effects found by other studies in controlled environments can be observed in real-life contexts and to understand if results are influenced by the season. By means of a post-occupancy evaluation conducted in four buildings in Switzerland, instantaneous air temperature and illuminance measurements were collected together with occupant's thermal perception votes during daytime in both summer and winter. Findings show that illuminance has a significant effect on the thermal perception of people, but only in terms of thermal evaluation and not of thermal sensation. In particular, results indicate that, at high temperature (above 25 °C), a less satisfying thermal evaluation is reported by people exposed to dim light (lower than 300 lux) compared to people exposed to brighter environments. We assume that this finding can be explained by *thermal expectations induced by light intensity*. The evaluation of data across summer and winter indicates that results are independent of the season (no interactions between illuminance, temperature and time of the year) and that the illuminance effect is accentuated depending on the season, which tends to highlight the psychological nature of thermal evaluation.

16:45

Collective understanding of ASHRAE thermal sensation phrases among Arab students

Hanan Al-Khatri and Mohamed B. Gadi

Despite their widely spread application, thermal scales' behaviour is not always well understood, especially between non-native English subjects. Examining some translations implemented in recent Arabic studies revealed differences from the international Arabic version. This version, itself, is questioned as its formation and the dialect it considers are not obvious. Moreover, positive impressions were possibly associated with phrases outside the widely accepted range of comfort in the investigated translations. In this regard, two short questionnaires were distributed among Omani high school students to explore their collective understanding of ASHRAE thermal sensation phrases. In the first, the students were requested to translate the phrases into Arabic, order them, and identify (thermal comfort). The second was a multiple-choice questionnaire which questions were derived from the answers of the first. Analysing results revealed a variety in the translated phrases that ranged from 7 to 44, which may be related to the Arabic language features. Besides, there was a weak agreement between the students' translations and the internationally accepted version. Phrases like (slightly cool) and (slightly warm) were not clear for most students. Further research is recommended to explore the impact of using phrases like (cool and not acceptable) and (warm and not acceptable).

17:00	**What do people associate with "cold" or "hot"? - Qualitative analyses of the ASHRAE-scales' labels** **Karin Schakib-Ekbatan, Susanne Becker, Antonina Cannistraro and Marcel Schweiker** The ASHRAE-scale is often applied in the field of thermal comfort in order to evaluate occupants' perception of the built environment. Participants' ratings on the scale are considered as being comparable, based on the assumption that participants have similar associations with the labels of the scale. Because of the complexity of perception, this assumption can be questioned and it is worthwhile to scrutinize the usage of the scale. As qualitative component of an interdisciplinary experimental study the think-aloud-method was used to gather qualitative data regarding the associations with the verbal anchors of the scale: People were asked to mention whatever comes to their mind. A specific context, e.g. in terms of thinking of outdoor or indoor conditions, was not given in the instruction. 61 participants (32 females, 29 males) participated in interviews. Qualitative analyses show that most associations were linked to perception, seasons (winter, summer) as well as to inside/outside. The label 'neither cold nor warm' was mostly linked to indoor contexts such as private rooms and was considered as being difficult to describe. The results indicate that neglecting the variation of peoples' associations with verbal anchors of a scale might bear the risk of drawing wrong conclusions regarding the generalizability of the understanding of a scale.
17:15	DISCUSSION

WORKSHOP 2: Overheating 16:30 - 18:00
Invited Chairs: Runa Hellwig and Wouter van Marken Lichtenbelt Sandby Room

16:30

Variance of future UK heat wave incidents with geographic implications on mitigation

Asif Din and Luisa Brotas

The effect of heat waves on human comfort is an area of research that needs to be further investigated. Many of the parameters to deal with heat wave events are similar mitigation strategies to those used for overheating. This study examines weather files from 8 UK cities to identify heat wave periods which are used to quantify the effectiveness of shading and thermal mass in a simulated prototype. Both heat wave and cooling season results are compared to highlight the differences in their characteristics. Based on a previously used prototype model, EnergyPlus software is used to quantify the effect of thermal mass and fixed shading in the building. Results show that the number of heat wave days has no correlation with the city's population, a possible proxy for the heat island effect. A combination of thermal mass and shading can be 90% effective in reducing the impact of a heat wave event. The next best solution is thermal mass, then shading alone, which reduces heat wave impact by up to 50%. These roughly follow the results obtained for the cooling season but the proportions of overheating criterion given in TM52 for the cooling season and heat wave events show little relationship and require further investigation.

16:45

Overheating in UK homes: Adaptive opportunities, actions and barriers

Daniel L Wright, Victoria J Haines and Kevin J Lomas

New-build homes and bungalows are particularly at risk of overheating during hot UK summers. Bungalows are a dwelling type favoured by the elderly who are more vulnerable to the negative health impacts of overheating. Whilst modelling studies have identified overheating risk, monitored data is lacking and limited information about the adaptive opportunities available to households (e.g. ventilation and shading). Even less is known about the adaptive actions taken during hot spells or about the physical, physiological or psychological barriers to acting. A mixed-method survey tool (OAST) was developed for this study and used to assess overheating occurrence, adaptive opportunities, actions taken and barriers to action. The tool was deployed with a cohort of new-build (n = 4) and bungalow homes (n = 4) in Loughborough, central England. The survey highlighted potential indicators of overheating risk, including post-occupancy retrofit such as extensions and loft conversions. Occupants' reports provided context and were a key strength of the OAST. Expressed barriers to adaptive action included concerns about security, but there was an inherent lack of concern about overheating and the associated health risks. Recommendations are made for the further development of the OAST as a method of assessing overheating risk in households

17:00 DISCUSSION

WORKSHOP 3: Personal Comfort Models **16:30 - 18:00**
Invited Chairs: Stefano Schiavon and Christoph van Treeck **Flitcroft Room**

16:30 **Personal comfort models – new paradigm in thermal comfort for occupant-centric environmental control**

Joyce Kim, Stefano Schiavon, and Gail Brager

A personal comfort model is a new approach to thermal comfort modeling that predicts an individual's thermal comfort response, instead of the average response of a large population. It leverages the Internet of Things and machine learning to learn individuals' comfort requirements directly from the data collected in their everyday environment. Its results could be aggregated to predict comfort of a population. To provide guidance on future efforts in this emerging research area, this paper presents a unified framework for personal comfort models. We first define the problem by providing a brief discussion of existing thermal comfort models and their limitations for real-world applications, and then review the current state of research on personal comfort models including a summary of key advances and gaps. We then describe a modeling framework to establish fundamental concepts and methodologies for developing and evaluating personal comfort models, followed by a discussion of how such models can be integrated into indoor environmental controls. Lastly, we discuss the challenges and opportunities for applications of personal comfort models for building design, control, standards, and future research.

16:45 **Personal thermal comfort models based on physiological parameters measured by wearable sensors**

Shichao Liu, Ming Jin, Hari Prasanna Das, Costas J. Spanos, Stefano Schiavon

Existing HVAC systems involve little feedback from indoor occupants, resulting in unnecessary cooling/heating waste and high percentage of discomfort. In addition, large thermal preference variance amongst people requires the development of personal thermal comfort models, rather than group-based methodologies such as predicted mean vote (PMV). This study focuses on assessing wearable solutions with the aim to predict personal thermal preference. We collected physiological signals (e.g., skin temperature, heart rate) of 14 subjects (6 female and 8 male adults) and environmental parameters (e.g., air temperature, wind speed, solar radiation, precipitation) for two weeks (at least 20 hr/d) to infer personal real-time thermal preference. The subjects reported their real-time thermal sensation and preference using cell-phones approximately every hour. We trained a Random Forest algorithm using data collected from individuals to develop a personal comfort model with the objective to predict thermal preference. The results show that subjects expressed needs for "warmer" or "cooler" conditions at about 30% (from 21% to 88%) of their daily time on average, implying the strong demand for a personalized indoor thermal comfort. In addition, the personal comfort model using Random Forest can infer individual thermal preference with a mean accuracy of 75% (53 - 93%) using physiological and environmental parameters, demonstrating the strengths of the proposed data-driven method.

17:00

Developing Personal Thermal Comfort Models for the Control of HVAC in Cars Using Field Data

Umberto Fugiglando, Daniele Santucci, Iva Bojic, Paolo Santi, Toby Chin To Cheung, Stefano Schiavon and Carlo Ratti

Personal comfort models predict an individual's thermal comfort instead of the average response for a large population. We attempted to develop personal comfort models for car drivers using data collected from 10 cars while driving for approximately 2,000 hr. We measured conditions collected by the CAN-bus (Controller Area Network), a data acquisition system that is present in most of the modern cars. Data includes information about the in-vehicle thermal conditions, the surrounding environment, the status of the Heating, Ventilation, and Air Conditioning (HVAC) system, and the behavior of the occupant. The objective of the study is to assess the feasibility of inferring occupant's thermal preference from the data available already available in most cars. By selecting and filtering all the available signals that are relevant for comfort, in this study we map the user actions of turning on/off their seat heating and correlate them to the vehicle indoor and outdoor conditions. The presented study provides the basis for using a machine learning automated process for thermal self-regulating HVAC system with the aim to improve comfort conditions and safety.

17:15

Equivalent Contact Temperature (ECT) for personal comfort assessment as extension for ISO 14505-2

Carolin Schmidt, Daniel Wölki, Henning Metzmacher and Christoph van Treeck

This paper introduces a new calculation method for the determination of the so-called equivalent contact temperature (ECT). It completes the missing contact area related thermal comfort information that is currently neglected in (ISO 14505-2, 2016), but which is inevitable for the evaluation of the local and overall thermal comfort of passengers in vehicles. There is strong evidence that currently used central HVAC units, which are based on convective heating and cooling of entire vehicle cabins will be replaced by various combinations of much more energy efficient decentralized systems that locally act on the human body in the future. However, such concepts must be able to provide the same level of thermal comfort to the passengers as currently existing HVAC systems to guarantee their acceptance. For this reason, the work at hand introduces an appropriate evaluation scheme, which holds for summer and winter test settings. Introduced experimental results provide the fundamental correlations between ECTs and corresponding thermal comfort votes for two distinct summer settings. The latter are made compatible to the existing evaluation schemes of (ISO 14505-2, 2016).

17:30	**Thermal comfort-driven feedback control for electric vehicles based on thermal image recognition, passenger tracking and thermophysiological modelling** **Daniel Wölki, Henning Metzmacher, Carolin Schmidt and Christoph van Treeck** This work introduces an innovative approach for the assessment of individual-specific thermal comfort as a part of the so-called human centred closed loop control (HCCLC) platform. The entire system targets on the control of a passenger's thermal comfort instead of the conventionally used air temperatures and solar irradiation of a vehicle cabin. Local thermal comfort of a passenger is evaluated on the basis of equivalent temperatures. The latter are calculated on the basis of body part specific temperature information that are simulated in real-time with the numerical human model MORPHEUS and measured with an infrared (IR) camera. The introduced approach allows to calculate thermal comfort driven dynamic and transient energy requirements of individual body parts at transient, uniform and non-uniform ambient conditions. Corresponding system outputs serve as control signals for decentralized HVAC systems. A robust tracking system for the face region is introduced that is based on an active appearance model (AAM). A central data exchange platform is described, which manages the data exchange between the applied sensor hardware, numerical models and local actuators. It is based on a loose-coupling approach that guarantees the highest possible flexibility with respect to system modularity. In order to be compliant with industrial applications, the system implements a CAN-interface.
17:45	DISCUSSION
18:00	END OF WORKSHOPS (workshop 3 is expected to end later)
19:00	DINNER

After Dinner talk 20:30 - 21:30

Invited Chairs: Susan Roaf and Peter Foldbjerg

20:30

Economic, social and culture experiences of thermal comfort from field studies in Brazil

Roberto Lamberts

This talk will outline the current socio-economic realities of life in Brazil and their implications on thermal comfort research and understanding. The development of a huge country with a wide range of diverse but mild climates from coastal to continental and high levels of social inequality brings challenges to regulating construction. A special focus of the talk will be on occupant's expectations across the housing and commercial building sectors, which are changing with the proliferation of air-conditioning. The historic lack of building regulations and the new developments for building energy labeling raises a key question: should Brazil follow international standards?

To support a discussion based on this scenario, field studies on thermal comfort from the Brazilian population will be presented together with the new standard being approved. However, there is still a long way to go for residential buildings, where little information has been documented all over the world about adaptation, preferences related to thermal histories, and occupant behaviors. The development of building regulations has to take thermal comfort preferences, habits and cultural experiences into account across all buildings typologies in order to prepare the Brazilian building stock for future climates within the constraints of often challenging economic conditions.

SATURDAY 14TH APRIL 2018

SESSION 4: Surveys in Hot Climates 09:00 - 11:00

Invited Chairs: Terence Williamson and Ryozo Ooka

09:00

Mixed-mode building with moderately cool temperature and responses of humans

Hitoshi Nagatsugu and Pawel Wargocki

To achieve energy saving and efficient business continuity planning (BCP), the number of mixed-mode buildings is increasing. A laboratory experiment was performed to examine human responses in mixed-mode buildings with both natural ventilation and air-conditioning. The aim was to examine whether the mode of operation affects the responses when the physical environment, in particular thermal conditions, were maintained when natural ventilation or air-conditioning were used. The operation modes were simulated in a classroom. Eight subjects participated, each time for 2 hours. They rated environments, their responses and performed tasks selected to simulate office work. In the results, subjects in natural ventilation mode felt air velocity higher than them in air-conditioning mode although it was the same. It was suggested that psychological effects which were caused by the difference of operation of ventilation made votes of thermal sensation, comfort, satisfaction and acceptability in natural ventilation worse than in air-conditioning.

09:15

Defining Thermal Comfort in Desert (Hot-Arid) Climates: A Thermal Comfort Field Survey in Baghdad, Iraq

Saif Rashid, Oliver Kornadt and Conrad Voelker

Indoor air measurements were conducted in 6 housing units in Baghdad between 2014 and 2016. A deeper look at the measured data showed that air temperatures during spring and autumn complied with the adaptive comfort model. On the other hand, a big variation within the same season was found during winter and summer periods. To verify whether comfort models apply for the climate in Baghdad, a field survey was conducted to define comfort conditions during critical winter and summer periods. The winter survey was conducted in two identical classrooms at the University of Baghdad in December 2016 and January 2017 with 233 responses. The survey was repeated 11 times under 5 different air temperature settings. The survey in summer was a longitudinal survey with 149 responses to evaluate. It was conducted in August 2017; it was repeated 14 times to test the responses under 7 different indoor environmental conditions. The results of the field surveys showed a variation in thermal sensation when compared with the predicted mean vote.

09:20

Upper limits for thermal comfort in a passively cooled office environment across two cooling seasons

Kit Elsworth, Rod Bates, Ryan Welch, and Billie Faircloth

During two summers in a hot humid climate, an architecture firm conducted a thermal comfort study in a passively cooled office to better the understand the limits of thermal comfort. The office, located in a renovated industrial building in Philadelphia, relied upon natural ventilation, elevated air movement, and desiccant dehumidification for cooling. Thermal comfort surveys were sent to the staff and matched to corresponding ambient temperature and humidity measurements, totalling almost 10,000 survey responses across a 11.5 °C range of indoor temperatures. The overall findings suggest that 80% of the population was satisfied at 28.5 °C and 90% at 27.5 °C. Regression models predict thermal comfort based on indoor temperature and indicate that humidity and clothing did not significantly impact comfort. Occupant clothing insulation (clo) value decreased with temperature from 21 -27 °C, resulting in a minimum clo value of 0.50, including chair insulation, for temperatures above 27 °C. The results show strong agreement with the rate of adaptation in the adaptive thermal comfort model and supports the increase in the comfort threshold given 1.0 m/s of elevated air movement. The findings from the continuous observations of an occupant population across two summers allow for validation of the adaptive thermal comfort model and support design strategies that can maintain comfort over a large range of indoor thermal conditions.

09:35

Effects of environmental perception on thermal sensation in sub-tropical and high-density cities: a case study of Hong Kong

Mona Sum Ching Chung and Kevin Ka Lun Lau

Outdoor thermal comfort is crucial in sub-tropical regions where summer heat stress impede outdoor space usage. Research on the effects of environmental perception on thermal comfort has increased in recent years as a result of intensified urban development and it has been found that urban geometry design can modify the relationship between climate and thermal comfort. Despite this, there is a lack of holistic studies focusing on the effects of qualities of urban space on thermal adaptation and comfort. This study investigates the relationship between environmental perception and outdoor thermal comfort under typical summer conditions in streets and parks in Hong Kong by conducting questionnaire survey on thermal sensation and environmental perception in terms of convenience, visual and acoustic comfort, air quality and safety. Simultaneous micrometeorological measurements were also conducted to obtained objective conditions of thermal comfort in designated urban spaces. A total of 1921 responses were collected between June 2017 and September 2017 in 12 locations. Overall, we found that environmental perceptions, particularly the perceived air quality, acoustic comfort and visual comfort, significantly affect thermal sensation and comfort. Improved perception of each investigated environmental parameter could lead to a substantial increase in the percentage of people feeling thermally comfortable.

09:40

Thermal Environments and Comfort Perception in Shophouse Dwellings of Ho Chi Minh City

Hung Thanh Dang and Adrian Pitts

This paper reports on a long-term investigation into the thermal environment and perceptions of comfort in dwellings located in Ho Chi Minh City. Of particular interest is the so-called 'shophouse' dwelling types prevalent in Vietnam and other SE Asian countries. Shophouses are narrow urban buildings used for business as well as living accommodation. A review of shophouses across the city determined three main types (traditional/new/row house) and four subgroups. Automated data recording systems were set up for longitudinal investigations (long-term recording of air temperature/humidity/movement) in four dwellings coupled with occupant questionnaires/interviews and shorter cross-sectional studies in additional buildings. The paper explains the techniques utilized to derive optimum data collection and some of the difficulties encountered. Summaries of the extensive data are presented noting for the warm season, typical indoor temperatures ranged from 29-35°C though the neutral temperature was 28.5°C (upper limit to the comfort range =31.5°C). The results are compared to previous comfort research findings. Due to the nature of the dwellings, an important environmental factor was considered to be air movement. Though there was a correlation between internal/external airspeed, indoor air movement rarely exceeded 0.2ms^{-1}. Design guidelines/suggestions for optimising comfort are made based on shophouse type.

09:55

Developing the adaptive model of thermal comfort for offices in the GCC region

Madhavi Indraganti and Djamel Boussaa

Escalating building energy expenditure encourages rethinking on thermal comfort delivery in the Gulf Cooperation Council (GCC) countries, in warm desert climate. The GCC states do not have an adaptive comfort standard, or its precursor long term field surveys. Therefore, we carried out thermal comfort field studies in Qatar for thirteen months. In ten typical air-conditioned office buildings, 1174 voluntary subjects completed 3742 questionnaires, while their thermal environments were simultaneously being measured. We found the mean Griffiths comfort temperature to be 24.0 °C. It varied with indoor temperature and seasons. Indoor Griffiths comfort temperature adaptively related with the outdoor temperature. This relationship can be used in buildings of similar nature in the GCC region. The subjects mostly felt cooler sensations. Thermal acceptance was high (82.7 %). The offices had low indoor air movement (median air speed 0.02 m/s), while 80% recorded less than 0.05 m/s. This is below the average air speed of 0.28 m/s, American Society of Heating, Refrigerating and Air-conditioning Engineers permitted. Increased air movement can effectually facilitate an elevated thermal regime, more in sync with outdoor conditions. Adopting variable comfort standards may be advantageous to achieve the building sustainability goals of the GCC nations.

10:10 **Thermal comfort in office buildings during the summer season: Findings from a field study in Kuwait**

Rasha AlNajjar, Adil Al-Mumin and Madhavi Indraganti

A thermal comfort field study was conducted in four office buildings in Kuwait for four months in the summer of 2016. All the four environmental and two personal variables were measured. Through a paper based survey, a total of 611 responses were collected from 284 different thermal environments. The mean comfort temperature was found to be 22.5 °C. This finding shows that people are very much accustomed to overcooled building environments that lack provisions for thermal adaptation. The subjects adapted mainly through clothing and very little environmental controls which were available to them. The mean clo values of nonwestern clothing was found to be higher than that of the insulation of the western clothing. In 86.6% of the cases, the air speed was below 0.2 m/s. The predicted mean vote significantly overestimated the actual sensation always. An adaptive model specific to Kuwait's climate must be developed and this research is a stepping stone to address this issue. This study calls for elaborate field studies in offices in Kuwait for the development of custom made adaptive comfort standards and a verified thermal comfort scale in Arabic to be uniformly used in surveys in the Middle Eastern Region.

10:15 **Temperature analysis and the effect of urban development on the outdoor thermal comfort and intensification of the Urban Heat Island phenomenon in the United Arab Emirates**

Evangelia Topriska, Hassam Nasarullah Chaudhry, Mehdi Nazarinia

This paper presents the temperature distribution and identification of Urban Heat Island intensity and outdoor thermal comfort conditions in a residential cluster in Dubai, UAE. Temperature and humidity data are collected during peak summer period and thermal imaging is further used as additional tool. From the analysis it is reported that the maximum temperature recorded in the cluster is 55 °C and the minimum is 22.9 ° C. The hottest day has an average temperature of 40.5 °C and the coolest day an average temperature of 36.1 °C. The highest temperatures during each day occur between 10am and 3pm and relative humidity peaks to 100% during night hours. The outdoor comfort is evaluated as a combination of the high temperatures and the relative humidity, and extreme discomfort is identified. Further analysis in the residential cluster, identified "hot spots" in specific areas where the spacing between the buildings is minimized. The temperature difference between these spots and other locations in the residential cluster can reach a maximum of about 12%. The temperature patterns in the cluster are also analysed with the use of CFD modelling and the results highlight the relation between the ventilation paths and the increased temperatures.

10:30	**Development of a Mexican Standard of Thermal Comfort for Naturally Ventilated Buildings** **N. Morgan and G. Gomez-Azpeitia** This paper presents results of the first stage of the project Development of a Mexican Standard of Thermal Comfort for Naturally Ventilated Buildings (MSTC-NVB). The project is based on the adaptive thermal comfort approach. The aim of such standard is to determine internal thermal conditions appropriate to climates of Mexico as well as their inhabitants´ lifestyles. Thus, this standard could serve as a useful tool supporting buildings' design in order to decrease their need of air conditioning; which increases day by day as a consequence of global warming. In the last ten years, a large number of thermal comfort field studies have been conducted in different climate regions of Mexico (temperate and hot zones, both dry and humid); from these a database consisting of 8,018 surveys was created, comprising 38 field studies conducted, in accordance with ISO 10551, ASHRAE 55 and ISO 7726, at different times in 13 different cities. Raw data was analyzed, standardized, debugged and integrated. For the meta-analysis the neutral temperatures were estimated by the Griffiths method, whose regression coefficient was determined from the quotient of the standard deviation (SD) of the votes of thermal sensation and the standard deviation of the registered internal temperatures.
10:35	DISCUSSION
11:00	COFFEE BREAK

SESSION 5: Schools and Homes 11:30 - 13:00
Invited Chairs: Azadeh Montazami and Gary Raw

11:30

Adaptive Behaviours and Occupancy Patterns in UK Primary Schools: Impacts on Comfort and Indoor Quality

Sepideh Sadat Korsavi, Azadeh Montazami

To improve the quality of school environment and reach state of comfort, it's important that teachers and students take appropriate personal and environmental adaptive behaviours. Studies on adaptive behaviours are mainly focused on adults, especially in residential and office buildings while children's adaptive behaviours at schools are not largely studied. This paper has investigated adaptive behaviours, influential factors and their impact on comfort and indoor quality by doing field studies in 4 primary schools and 15 classrooms in Coventry, UK during July, September, October and November 2017 through observations, subjective and objective measurements. The results are derived from observations on around 400 students aged 9-11 and from more than 600 surveys. Results illustrate that students usually take personal adaptive behaviours after or before breaks, and the number of these behaviours increases during warmer seasons and in afternoon sessions. Students' decisions over appropriate clothing level is related to time of year, however, 27% of students could improve their thermal vote by taking off or taking on jumpers/cardigans. Some environmental adaptive behaviours like door operation are less related to climatic factors, however, window operation is correlated to indoor temperature (R^2=0.29) and outdoor temperature (R^2=0.35). Observations show that around 80% of all environmental adaptive behaviours are done by teachers, teacher assistants or on their request, which can provide conditions that are not comfortable for children. Therefore, it is important to facilitate adaptive behaviour of children to improve their comfort level.

11:35

Thermal Comfort in the UK Higher Educational Buildings: The Influence of Thermal History on Students' Thermal Comfort

Mina Jowkar and Azadeh Montazami

Statistics regarding the number of international students in the UK higher educational buildings show an upward trend in the recent years. These students coming from different cultural and climatic backgrounds have various thermal perceptions inside the classrooms. According to the significant influence of thermal quality of learning environments on students' productivity and wellbeing, it is essential to develop specific environmental guidelines for the UK higher educational buildings based on the students' backgrounds. Developed standards not only can provide occupants' thermal comfort in such multicultural spaces, but also can minimize energy consumption and running costs within the higher educational buildings in this country. This study evaluated the students' thermal perception in three different types of learning environments including fifteen Naturally Ventilated lecture rooms, studios and PC Labs from three different buildings of Coventry University. Indoor air temperature, humidity level, air velocity and mean radiant temperature were monitored in different times of a day. A questionnaire survey was conducted on approximately 1000 undergraduate and postgraduate students at the same time of recording operative temperature. This study is completed based on thermal comfort votes of 650 students. Results reveal the influence of short and long-term thermal history including climatic background, thermal condition of current accommodation and thermal adaptation to the UK weather on students' thermal comfort perception inside a classroom. The outcome of this study can be applied to develop the reliable and practical guidelines for the multicultural higher educational buildings within the UK.

11:40

Thermal comfort study in naturally ventilated lecture room based on questionnaire survey

Marta Laska and Edyta Dudkiewicz

The internal building conditions strongly influence our well-being therefore it is crucial to create healthy indoor environment. The literature offers a range of models describing the satisfactory indoor conditions, however due to complex nature of the subject the outcomes from these models may differ significantly from the individual sensations of building occupants. The paper presents the results of survey on thermal sensation votes among students in naturally ventilated lecture room dedicated for 300 students at Wroclaw University of Science and Technology, Poland. The investigation took place during lecture hours between March and May of 2016 and 2017. The respondents answered the questions about their thermal comfort sensations, expectations and discomfort when attending the lecture. The outcomes of the survey present the level of students satisfaction from the indoor environment and its influence on their comfort and feelings like headaches, eye or throat irritation, dry or itching skin, difficulty in concentration, somnolence and overall fatigue. At the same time thermal comfort variables were measured, namely: indoor temperature, humidity and CO_2 level. The paper presents individual thermal comfort sensations trends among students and discusses discrepancies in individual sensations and expectations in comparison with measured parameters and simplified literature models.

11:45

Thermal comfort in Classrooms: A critical review

Manoj Kumar Singh, Ryozo Ooka, Hom B Rijal

Classrooms play an important role in every student's life as the quality of thermal environments also influences a student's performance and well-being. It is well known that at each educational stage, curricula demand different learning approaches and types of systematic thinking, requiring increasing levels of concentration. The absence of any standard or reference document relating to the design of appropriate classrooms based on educational stages is worsening the situation. Total 81 research articles selected from the Scopus database were considered for this study. It was found that at each education level in the studied schools, students were highly dissatisfied with the prevailing indoor thermal environments. Primary school students were least sensitive to outdoor temperature changes. There are relatively few published articles published on thermal comfort in classrooms. Based on the reported findings, no consistent temperature change was found necessary to record a shift of one thermal sensation vote by students in classrooms. This study proposed different adaptive comfort equations for use in the estimation of indoor comfort temperature in classrooms at different educational stage. Moreover, the study provides robust evidence that there is a need for a separate set of different guidelines or standards for students of different ages in different stages of their education.

12:00

Thermal comfort in classrooms in Mexico´s hot and humid climate

Maella González Cetz, Gabriel Gómez Azpeitia

There are no design standards which consider the climatic diversity of Mexico regarding the design of school buildings. At present, there are no thermal comfort studies in classroom environments of hot and humid climates in the country. A field study was conducted following the ASHRAE 55 methodology and adaptive comfort approach in three classrooms with natural ventilation (NV) and 2 with air conditioning (AC) in a scholar building from Merida, Yucatan. A total of 3,369 data sets from 255 students were collected for a six month period. The neutral temperatures obtained by linear regression were of 28.03°C in NV and 27.28°C in AC. A logistic regression analysis revealed preferred temperatures of 24.21°C in NV and 24.70°C in AC. The acceptable ranges obtained by thermal sensation analysis suggested ranges of 25.43°C to 30.62°C in NV and 23.01°C to 31.55°C in AC. It is necessary to conduct more thermal comfort surveys in schools in Mexico which address the association between thermal comfort and users' performance and health.

12:15

Thermal comfort and heat stress in cross-laminated timber (CLT) school buildings during occupied and unoccupied periods in summer

Timothy O. Adekunle

This study investigates thermal comfort and heat stress in CLT school buildings during occupied and unoccupied periods in summer by evaluating Wet Bulb Globe Temperature Heat (WBGT) index and Universal Thermal Climate Index (UTCI). As structural timber is increasingly used for the construction of various buildings and such buildings are susceptible to summertime overheating as discussed in existing studies, the study aims to understand the heat stress index and temperatures at which the vulnerable occupants will be subject to heat stress in CLT school buildings. The case study is an educational building located in the Northeast region, USA. The survey was conducted from June-August 2017. The environmental parameters (temperature, RH, dew-point temperature-DPT) were measured at 15-minute intervals but measurements taken at every 60 minutes were considered in this study. The WBGT and UTCI were also calculated for comparison. The external temperature was collected from a nearby weather station. The building was occupied from 08:00-17:00 and unoccupied from 18:00-07:00. The results showed the average temperature in the main hall on the lower floor (a double-volume space) was 21.2°C. The average temperature in the classroom on the upper floor level was 24.1°C. The average WBGT varied from 18.8-20.0°C while the average UTCI varied from 21.9-24.0°C. The findings showed the vulnerability of the occupants to summertime temperatures in the spaces on the upper floor especially when the building is naturally ventilated. Applying the WBGT index and UTCI heat index to determine the heat stress thresholds, the study recommends the WBGT of 19.3°C (occupied) and 20.0°C (unoccupied); the UTCI of 23.4°C and 24.0°C for occupied and unoccupied periods respectively. Overall, the study highlights WBGT of 19.8°C and UTCI of 23.9°C as possible heat stress indicators for the vulnerable occupants in CLT school buildings. The investigation revealed a higher UTCI heat stress index than the WBGT index for occupants because higher wind speeds at warm temperatures do not have a significant impact on WBGT.

12:20	**The impact of the quality of homes on indoor climate and health: an analysis of data from the EU-SILC database** **Ashok John, Andreas Hermelink, Nicolas Galiotto, Peter Foldbjerg, Katrine Bjerre Milling Eriksen and Jens Christoffersen** Today one out of six Europeans (84 million Europeans, or the equivalent of Germany's population), report deficiencies regarding the building status. In some countries, that number is as high as one out of three. This puts these buildings in the 'Unhealthy Buildings' category, which is defined as buildings that have damp (leaking roof or damp floor, walls or foundation), a lack of daylight, inadequate heating during the winter or overheating problems. 10% of Europeans report having poor perceived general health. And the probability that a person reports poor health increase up to 70% if that person also lives in an unhealthy building vs. a healthy one. The results of this study show a correlation between poor health and the specific unhealthy building factors: • 1.7 times report poor health in a damp building; • 1.5 times report poor health when living in a building with insufficient daylight; • 1.3 times report poor health when perceiving overheating; • 1.7 times report poor health when living in uncomfortably cold temperatures. The paper is based on an analysis of the correlation between health and buildings in 27 EU member states using the Eurostat database EU-SILC (Survey on Income and Living Conditions). The presented research is based on EU-SILC raw data. For the purpose of the study, Eurostat approved the research proposal behind the analysis and gave access to the data to Ecofys Germany GmbH.
12:35	**What the Indoor Air Temperatures in Houses in Three Australian Cities Tell Us** **Dong Chen, Zhengen Ren, Melissa James** This study analysed over 1.8 million measurements of air conditioner power consumption and indoor/outdoor air temperatures in 129 houses in Adelaide, Brisbane and Melbourne from 2012 to 2014. It was found that the preferred indoor air temperature range, at which occupants are most unlikely to operate air conditioners, increases for warmer local climates. In each city, the air conditioner switch on and off indoor temperatures, and the indoor temperatures when air conditioner is in operation can be grouped into three prevailing outdoor temperature ranges: the low range, the shoulder range and the high range. Occupants are not very tolerant at the low and high temperature ranges, while they are more adaptive with the shoulder temperature range. This finding supports the simplified static thermostat setting approach used in the *AccuRate* software for house energy rating, though the existing thermostat settings should be adjusted with more research in understanding thermal comfort and air conditioner operation behaviours in residential houses.
12:50	DISCUSSION
13:00	LUNCH

SESSION 6: Comfort in Different Conditions 14:00 - 15:30
Invited Chairs: Eduardo Krüger and Cao Bin

14:00

Adaptive Mechanisms for Thermal Comfort in Japanese Dwellings

H.B. Rijal, M.A. Humphreys and J.F. Nicol

In order to quantify the seasonal differences in the comfort temperature and to develop a domestic adaptive model for Japanese dwellings, thermal measurements, a thermal comfort survey, and an occupant behaviour survey were conducted for 4 years in the living and bedrooms of dwellings in the Kanto region of Japan. We have collected 36,114 thermal comfort votes from 244 residents of 120 dwellings. The results show that the residents are highly satisfied with the thermal environment of their dwellings. People are highly adapted in the thermal condition of the dwellings, and thus the comfort temperature has large seasonal differences. An adaptive model for housing was derived from the data to relate the indoor comfort temperature to the prevailing outdoor temperature. Such models are useful for the control of indoor temperatures. The adaptive model of thermal comfort is highly supported by the various adaptive mechanisms.

14:15

Thermal Comfort for Occupants of Nursing Homes: A Field Study

Federico Tartarini, Paul Cooper and Richard Fleming

The primary aim of this research was to assess the quality of the thermal environment of six Australian nursing homes, and to understand and quantify the impacts of the indoor thermal environment on the perceptions and comfort of staff, residents and other occupants. The impact of the thermal environment on perceptions and comfort of building occupants of six nursing homes was determined through: 1) a long-term building evaluation survey (staff members only); and 2) a point-in-time thermal comfort study, involving 322 residents and 187 non-residents. In addition, a combination of spot-measurements and long-term monitoring of indoor air temperatures was used to assess the overall quality of the thermal environment in the nursing homes. Results showed that some facilities did not provide a thermally comfortable environment for occupants through both summer and winter seasons, while results from the point-in-time study showed that residents preferred warmer temperatures (0.9°C) and generally wore more clothes than non-residents. The article also presents a discussion of the applicability of adaptive thermal comfort approaches to assessment of the indoor environment in nursing homes and differences between the perceptions/preferences of residents versus staff.

14:30

The influence of outdoor transient conditions on the dynamic response of pedestrian thermal comfort in high-density cities

Kevin Ka-Lun Lau, Yuan Shi, Edward Yan-Yung Ng

In high-density cities, the highly variable environmental conditions within short walking distances result in a considerable influence on pedestrians' thermal comfort when they travel within the urban environment. Conventional studies adopted the "static" approach which is insufficient to consider the transient nature, and hence requires a new approach to incorporate the dynamic response of human thermal comfort to inform urban geometry design. This study aims to investigate how people's thermal sensation and pleasure respond to the changing environmental conditions. Subjects were asked to perform two walking routes with thermal sensation vote (TSV) and thermal pleasure vote (TPV) asked at designated points. Meteorological parameters were measured for the calculation of physiological equivalent temperature. Parameters of urban geometry were also acquired from field measurements and geographical information system. Results showed that TSV and TPV showed remarkable differences under partially cloudy and clear sky conditions. Their relationship also showed the possible effect of thermal alliesthesia due to the higher magnitude of response of TPV. Results of the autocorrelation analysis implied the existence of potential thresholds for the level of tolerance to unfavourable thermal conditions. Further work includes the design of walking routes to define such thresholds and the development of practical design recommendations.

14:35

From indoors to outdoors and in-transition; thermal comfort across different operation contexts

Marialena Nikolopoulou, Alkis Kotopouleas and Spyridon Lykoudis

This paper focuses on the investigation of thermal comfort conditions in three very different operational contexts using meta-analysis of different studies within a similar climatic context in the UK. This includes extensive surveys indoors from offices, outdoors from urban areas, as well as indoors from airport terminals. Recent research in airport terminal buildings has highlighted that there are very different user groups, with diverse requirements for thermal comfort in such facilities. The paper investigates the hypothesis that staff working in the different areas have needs more similar to those of staff working in offices, while passengers use the building as a transition area with very different requirements and hence closer to the outdoor environment. Analysing and comparing the thermal comfort conditions from the different contexts, it explores the role of adaptation for thermal comfort attainment and satisfaction with the environment and the similarities of very different operational contexts in terms of their thermal comfort characteristics. Finally, the paper highlighted techniques for the potential transformation of thermal comfort scales, which can enable comparison between different types of surveys and inform the wider thermal comfort debate.

14:50

Thermal comfort in dwellings in the subtropical highlands – Case study in the Ecuadorian Andes

Isabel Mino-Rodriguez, Ivan Korolija and Hector Altamirano

Thermal comfort in dwellings located in different weather conditions have been largely studied. The indoor environmental criteria have been well defined for mechanically conditioned buildings in mid-latitudes and naturally ventilated spaces in the subtropics. The subtropics are known for being hot-humid environments at low altitude. However, the highlands in the tropics have a subtropical-highland climate characterised by narrow annual temperature oscillation, noticeable diurnal temperature variation and high levels of solar radiation and precipitation due to its latitude and altitude. Field thermal comfort studies in housing in the Highlands reveals up to a 90% of user's satisfaction to temperature below 18°C. Indoor temperatures in dwellings in the Andes highlands can be even lower than 18°C as buildings are uninsulated and operate under free-running conditions throughout the year. This study seeks to identify the thermal comfort range and the difference in residents' perception of inhabitants living between 2300 m and 3100 m above sea level, in the Andes highlands. 195 thermal comfort votes were collected during the dry season. Results show that people living in the high-altitude are more sensitive to draught and prefer lower temperatures (16°C – 24°C), while inhabitants living in the low-altitude find temperatures above 26°C pleasant and prefer higher air movement.

15:05

The courtyard pattern's thermal efficiency: Limits and significance of impact

Omar Al-Hafith, Satish B K, Simon Bradbury and Pieter de Wilde

The courtyard pattern has been advocated as a thermally efficient design for hot regions. Many studies have been yielded the suggestion of re-introducing this building pattern for its thermal efficiency. However, it has not been widely investigated to which extent courtyards actually provide thermal comfort for people. By examining the thermal behaviour of 360 courtyards, this paper investigates the impact of courtyards' geometry and orientation on its thermal conditions and occupants' thermal sensation. Baghdad was used as a case study due to its hot climate and traditional use of courtyards. A comfortable temperature for hot climate defined by a previous study was used to judge the tested courtyards. Calibrated Envi-met simulation models have been used to determine courtyards' thermal conditions. The results show that the most effective design parameter on courtyards' thermal efficiency is the courtyard's Width/Height and the most effective climatic factor is the Mean Radiant Temperature. The thermal efficiency increases by having deep and small courtyards. If properly designed, courtyards can provide 4-7 ºC less Globe Temperature than the outdoor temperature, while improperly designed ones can be 20ºC higher than the outdoor temperature. In all cases, courtyard spaces cannot provide thermal comfort if the outdoor Globe Temperature exceeded 38ºC.

15:10	**Impact of physical characteristics on comfort and well-being in selected neighborhoods of metropolitan Lagos, Nigeria** **Mokolade B. Johnson, Anthony C.O. Iweka and Michael Adebamowo** People and their surroundings are principal factors that impact comfort and well-being in urban environments. Past research asserts that approximately half of the world's population presently reside in urban areas. However, due to rural-urban influx, pressure on existing basic infrastructure and amenities are on the rise, a situation which further compounds problems of residential inadequacy, urban heat island, crowding, environmental pollution, and other underlying societal challenges with direct effects on urbanite's well-being. Notwithstanding these glitches, there is paucity of information on how physical characteristics impinge on urban comfort which is critical for well-being. This paper explores the impact of 'physico-urban' characteristics on comfort and well-being and its implication on city planning. The study employed a multi-layered methodology through historical exploration and quantitative survey technique with questionnaire to residents of two (2) purposively selected municipals of Metropolitan Lagos. Findings show that in the Ikeja and Lagos Island localities, inadequate car parks constitute the main open spaces, there is a general lack of purpose built, people oriented, and accessible open neighborhood spaces designed for citizen's comfort and well-being benefits. A reformation of existing conditions can positively influence comfort, health and physical well-being of susceptible urban dwellers in a sustainable manner.
15:15	DISCUSSION
15:30	SPECIAL SESSION on the ASHRAE data base Chaired by Richard de Dear
16:00	TEA BREAK

WORKSHOP 4: The Diversity Factors **16:30 - 18:00**
Invited Chairs: Dolaana Khovalyg and Fergus Nicol **Hodgson Room**

16:30

Responses of German subjects to warm-humid indoor conditions

Michael Kleber and Andreas Wagner

In summer of 2016 and 2017 experiments with a total of 300 participants have been conducted in a German test facility. Each participant experienced two out of nine different combinations of operative temperature (26°C, 28°C, 30°C) and relative humidity (50%, 65%, 80%) in order to examine an elevated humidity ratio between 10 and 21 g/kg. Questionnaires were filled out in specific intervals and certain physiological parameters have been measured continuously. The subjects wore their own summer clothing (average clo = 0.50, SD 0.09) and were recruited from male and female persons in two age groups: 18 to 32 years and 50 to 80 years. Results indicate that responses are dependent on both temperature and humidity as well as on other factors like thermal history. A linear regression model using operative temperature and humidity ratio is presented to describe the percentage of acceptability and is used to derive an extended comfort zone for seated activity in summer conditions (met = 1.1 and clo = 0.5). Different responses are compared to ones of other studies. Thermal acceptability for example proves to be significantly lower with the German subjects than with participants who are adapted to a hot-humid climate. PMV shows overestimation of thermal sensation at the lower temperatures and underestimation at the higher ones.

16:45

Comfort, climatic background and adaptation time: first insights from a post-occupancy evaluation in multicultural workplaces

Luisa Pastore and Marilyne Andersen

One of the effects of globalization and work mobility is the increasing multiculturalism in the workplace. While contemporary design policies for energy efficiency and comfort regulations are moving towards the adoption of models customized for local communities, consideration on the co-existence of people with different origins is underestimated in the current comfort debate. The aim of this study is to show whether building occupants' comfort rating can be affected by their climatic background as well as their duration of living in the current country of residence. A post-occupancy evaluation (POE) was carried out in two office buildings located in Switzerland accounting for a high rate of international employees. Questionnaires were distributed among the building occupants with the aim to investigate, among other things, their satisfaction with temperature, air quality, lighting, noise, view to the outside and privacy. With regard to thermal comfort and air quality, the results show that indeed people's rating varied significantly according to their climate of origin as well as with the time span spent in the country. However, no statistically significant differences were found in terms of their satisfaction level with the other above-mentioned comfort factors. Overall, the study provides new insights on the relationship between comfort perception, cultural background and people's adaptive behavior, raising questions about the appropriateness of current comfort models and design strategies to achieve adequate environmental conditions in workplaces.

17:00 DISCUSSION

WORKSHOP 5: Measuring comfort in the real world **16:30 - 18:00**
Invited Chairs: Atze Boerstra and Adrian Pitts **Sandby Room**

16:30

Data collection methods for accurate spatial use within rooms

Nick Van Loy, Ann Bosserez, Griet Verbeeck, Elke Knapen

Dwellings in Belgium are comparatively larger than residences in other countries and the occupancy rate of the living spaces is rather low. Both occupant presence and behaviour have a large impact on the actual energy consumption. Rooms are generally fully acclimatized while only part of them is used effectively which impacts the energy consumption of the dwelling. This paper discusses spatial use within rooms and a methodology to monitor the effective spatial use of dwellings. Better insights in the effective spatial use can be used to increase the space and energy efficiency, e.g. by adapting the design of the house as well as the systems for heating and ventilation to the actual spatial use. In an in-depth case study, the spatial use patterns within three single family houses are monitored during 9 consecutive days in each season. During the monitoring period, a low cost, highly accurate, ultra-wideband, indoor localisation system was used to monitor the exact location of the residents within the dwelling. In addition, the temperature, relative humidity and light intensity in each room was recorded. Each hour, the residents were asked to fill in a survey on thermal comfort, activity and operation of windows or heating systems.

16:45

Thermal Comfort Assessment Based on Measurement and Questionnaire Surveys in a Large Mechanically Ventilated Space

Ali Alzaid, Maria Kolokotroni, Hazim Awbi

This paper presents a thermal comfort study in a large occupied office (floor-to-ceiling height >5m) ventilated by a simple mixing ventilation system. The evaluation was conducted during the summer seasons of 2016 and 2017 using three different tools; (a) long term monitoring, (b) short term detailed measurements and (c) occupant questionnaire. Long term monitoring included air temperature and relative humidity at several locations and heights within the space with external conditions retrieved form a weather station on the roof of the building. The short term spot measurements included air temperature, relative humidity and air speed each at three vertical occupancy heights and the inlet diffusers. The surveys involved collection data using questionnaires developed based on ISO 10551. Analysis of long term data using temperature clouds indicate that the building can be approximated to be free running. A comparison between the measurement (analysed using PMV/PPD and adaptive thermal comfort) and the questionnaire surveys' results show good agreement between predictions and occupant evaluation. The existing ventilation system was able to meet the requirement for thermal comfort in this large enclosure. However, with regards to the air movement, it did not achieve the recommended levels and this has affected occupant responses.

17:00 DISCUSSION

WORKSHOP 6: Domestic Comfort and Health at Low temperatures 16:30 - 18:00
Invited Chairs: Lyrian Daniel and Dennis Loveday Flitcroft Room

16:30 **Residential wintertime comfort in a temperate Australian climate**

Lyrian Daniel, Emma Baker and Terence Williamson

There is a growing realisation among policy-makers and researchers that Australia has a vastly under-recognised cold housing phenomenon. Overshadowed by the dominance of concern for summer heatwaves and cooling, to date little Australian work has been undertaken on winter housing conditions. In responding to this research and evidence gap, this paper presents the findings from a wintertime thermal comfort field study in metropolitan Adelaide, South Australia between July and October 2017. Participant households were selected from a larger random sample of 4,500 Australian households in the Australian Housing Conditions Dataset (AHCD). Data for this field study was collected from 19 households in the AHCD who self-identified as unable to keep warm in cold weather in their homes. On average, internal temperatures in the sample dwellings were well below standard thermal comfort levels. Interestingly, findings also indicate that residents reported being comfortable at temperatures much lower than accepted norms. Overall however, they reported very low satisfaction with their indoor thermal environment. Several hypotheses are put forward as possible explanations of these findings but will need to be subject to further research. Nevertheless, the findings from this paper position indoor cold as a forefront concern for Australian housing research and policy development.

16:45 **Energy and thermal performance of apartment buildings in Albania: the case of a post-communist country**

Jonida Murataj, Rajat Gupta, Fergus Nicol

This paper undertakes a comparative evaluation of the energy and thermal performance of apartment buildings in Albania built both Pre-90 and Post-91 (a year that marks the change of the political system from communism to democracy in Albania). Building surveys, occupant surveys and continuous monitoring of outdoor and indoor environmental conditions during the summer and winter to allow for seasonal variations, were conducted in 29 case study flats randomly selected to represent both periods. Electricity bills were also provided for a full year. It was found that electricity consumption has been 22% lower in flats built Pre-90 and that the average temperature in living rooms were found to be very close to 29°C in summer and 16°C in winter in both Pre-90 and Post-91. Notwithstanding that measured average temperatures were similar in the two building cohorts, higher range and variance on mean indoor temperature has been found in summer in the flats built Pre-90, which has affected the thermal sensation votes of occupants living in them. It was found that over 60% of residents living in apartment buildings built Pre-90 were feeling cold in winter and hot in summer, compared to 30-40% of residents living in apartment buildings built Post-91, who felt cold in winter and hot in summer respectively. Although the findings cannot be treated as statistical generalization, the analysis provides an in-depth contextual insight into environmental, thermal and energy performances of flats in Albania, which would help inform future energy retrofitting programmes.

17:00 DISCUSSION

18:00 END OF WORKSHOPS

19:00	DINNER

After Dinner Event **20:30 - 21:30**
Hosts: Atze Boerstra, Wouter van Marken Lichtenbelt and Craig Farnham

20:30	QUIZ NIGHT

SUNDAY 15TH APRIL 2018

WORKSHOP 7: Health Physiology and Comfort: Real Life impacts 09:00 - 10:30
Invited Chairs: Wouter van Marken Lichtenbelt and Yingxin Zhu Flitcroft Room

09:00

Creating comfort and cultivating good health: The links between indoor temperature, thermal comfort and health

Rachel Bills

There is a growing body of evidence that suggests human thermal requirements change as with age. This study aims to determine the conditions which will provide both a comfortable and healthy environment for the increasing number of older people in Australia. A longitudinal study of thermal comfort and its relationship to health in 18 older households was undertaken in Adelaide, South Australia during 2015 and 2016. The comfort vote survey included measures of thermal comfort as well as a checklist of symptoms experienced in the last 24 hours. These surveys were matched to environmental measurements from the homes. Results show two important relationships between thermal conditions and health: 1. A quadratic relationship exists between reported symptoms and minimum and maximum indoor temperatures in the 24 hours proceeding the reported symptoms. These data indicate that both low and high indoor temperatures may be related to the health of the occupants; 2. A quadratic relationship also exists between the thermal sensation vote and the reporting of symptoms. This research presents evidence that even with Adelaide's relatively mild winters, cold temperatures can have an impact on health, as well as the more extreme summer temperatures. This has implications for healthy housing design for an ageing population.

09:15

Health Responses of Acclimatized Construction Workers in Summer Season with high ambient temperature: A case study in Chongqing, China

Sadia Yasmeen, Hong Liu, Chen Lu and He Jiaze

Heat stress and labor health are two most concerning matters in the construction field. The objectives of our research were to observe physiological responses of construction workers during hot summer and identify the worker heat tolerance level. Environmental parameters together with workers (10 subjects) physical responses (i.e. heart rate, skin temperature) were collected. Labors avoided work during the hottest period of a day (appx. 10:30 A.M. to 3:30 P.M.). Therefore, they worked continuously without felt fatigue though in some cases WBGT was higher than the normal limit and with a high workload. Workers heat tolerance level was found to be good because all of them were local people and acclimatized with the hot weather for at least 7 years. The workers resting time heart rate ranged from 58-87bpm. Natural wind and artificial wind (fan) were used as cooling methods at the end of each day work for 15 minutes' rest time (on-site shaded place). Under artificial wind, skin temperature gradually decreased on average 1°C but in natural ventilation, the result fluctuated. Heart rate in both conditions decreased around 15-20 bpm within 2-3 minutes and then remained almost steady. Our study suggests that a labor-friendly work schedule may reduce labor heat stress.

09:30	**Can regular exposure to elevated indoor temperature positively affect metabolism in overweight elderly men?** **Hannah Pallubinsky, Bas Dautzenberg, Esther Phielix, Marleen A. van Baak, Patrick Schrauwen and Wouter D. van Marken Lichtenbelt** Thermoneutrality of indoor environments is suspected to be involved in the current 'diabesity epidemic'. Regular exposure to elevated temperature might have positive implications for metabolic and cardiovascular health. This study investigated the effect of prolonged exposure to elevated ambient temperature (passive mild heat acclimation, PMHA) on fasting plasma glucose (FPG) and insulin (FPI) values, thermophysiology and thermal perception in an overweight population. 11 overweight elderly men (65.7±4.9y, BMI 30.4±3.2kg/m^2, HOMA-IR 4.3±2.4) underwent PMHA (10d, 34.4±0.2˚C, 4-6h/d). Pre- and post-PMHA, FPG and FPI samples were taken. A temperature-ramp-protocol was conducted to assess adaptation of thermophysiological parameters pre-/post-PMHA. Thermal sensation (TS) and thermal comfort (TC) were evaluated during PMHA, at 1-hour intervals. FPG, FPI, HOMA-IR and Tcore decreased significantly after PMHA (ΔFPG:-0.27mmol/L, P=.036; ΔFPI:-12.69pmol/L, P=.026; ΔHOMA-IR:-0.7, P=.012; ΔTcore:-0.17±0.19˚C, P=0.017). Insulin sensitivity, Tskin and sweating did not change. MAP decreased (Δ-2.91±2.67 mmHg, P=0.007); heart rate tended to decrease (Δ-2.98±3.50bpm, P=0.065) post PMHA. TS increased while TC decreased during the day, but both remained unchanged post-PMHA. This study is the first to show that PMHA induces significant thermophysiological and cardiovascular changes and may affect glucose metabolism in overweight elderly men.
09:45	DISCUSSION

WORKSHOP 8: Personal Comfort Systems **09:00 - 10:30**

Invited Chairs: Sally Shahzad and Gail Brager **Hodgson Room**

09:00

Self-Learning Framework for Personalised Thermal Comfort Model

Yiqiang Zhao, Kate Carter, Fan Wang, Ola Uduku and Dave Murray-Rust

This paper presents a novel self-learning framework for building personalised thermal comfort model. The framework is built with the understanding that each occupant has a unique thermal comfort preference. Current thermal comfort models focus on analysing average data for groups of people in different types of building, rather than considering individual thermal preference. We argue that building a personal level comfort model using learning algorithms may provide the basis to represent personalised dynamic thermal demands. By bringing more personal interest and data, the ground-up personalised model may help us better understand the internal links of personal factors from psychology, physiology and behavioural aspects. Furthermore, we developed an Smart Thermal Comfort (STC) environment sensors and mobile application to efficiently collect distributed personal data and make it open-sourced for other researchers to use. The aim of this paper is to rethink current comfort studies to standardize the methods in modelling personalised thermal comfort. By summarising the past five years' papers on personal thermal comfort model, this paper critically evaluates the methods used for personal data collection and learning algorithms. Finally, we conclude an Personal Thermal Comfort (PTC) framework including distributed personal measurement tools and machine learning algorithm for personalised thermal comfort study.

09:15

Dynamic Decision and Thermal Comfort: CFD and Field Test Analysis of a Personalised Thermal Chair

Sally Shahzad, John Kaiser Calautit, Ben Richard Hughes

The dynamic aspect of thermal comfort is overlooked in research, resulting in the aim to provide a steady thermal environment to satisfy the occupants. In this study, the thermal decision (combination of thermal sensation and preference) of the occupants were measured before and after providing localised personal control of a thermal chair in the workplace. Field test studies of thermal comfort (environmental measurements and survey questionnaires) were followed by a numerical modelling of the thermal performance of the thermal chair with heated seat and backrest using the commercial Computational Fluid Dynamics (CFD) tool FLUENT17. The 3D steady Reynolds-averaged Navier–Stokes equations were solved in combination with the k-ε turbulence model. The effect of varying the seat and back rest temperature settings (low, medium and high) on Predicted Mean Vote (PMV) at different locations were investigated. Overall, the results indicated that thermal decision of the occupants is dynamic and it is subject to change. This study suggests the application of localised personal control of the thermal environment in order to provide thermal comfort. In this way, the occupant can find their own comfort at any given time according to their immediate and dynamic requirements. The implication of this finding needs to be considered as part of the environmental design of a building.

09:30	**'Intelligent furniture': the potential for heated armchairs to deliver thermal comfort with energy savings in the UK residential context** **Shiyu Pan, Ziqiao Li, Dennis Loveday and Peter Demian** Personal heating (or cooling) has long been considered a means for reducing energy demand and providing thermal comfort, most commonly in the form of heated seats. In this paper, findings are reported of what may be the first investigation of the potential for heated furniture to maintain occupant thermal comfort in the UK residential context. In a thermally-controlled environmental room, a thermal manikin was seated in a living-room armchair equipped with an electrically-heated blanket. Results suggested that the manikin total heat flux recorded for the PMV range -0.5 to +0.5 without heated blanket could be achieved in a room 0.7^{o}C cooler but with the blanket operating as compensation. Chest/back radiant asymmetry across the body, and surface contact temperatures of the blanket, were both found to be well-within acceptable limits. The implication for residential energy usage was analytically simulated using an apartment ('flat') as a case study. This showed that energy-saving potential was dependant on the building's thermal performance, the building's dimensions and occupant behaviours. When extrapolated to the UK housing stock it was found that around 5.6 TWh of energy might be saved by using heated armchairs in the UK instead of whole house heating systems. 'Intelligent furniture', in the form of heated armchairs, can potentially contribute to energy saving in the UK residential context, and further investigation is warranted.
09:45	DISCUSSION

WORKSHOP 9: Using Statistics for Thermal Comfort Data **09:00 - 10:30**

Invited Chairs: Jane Galbraith and Rex Galbraith **Sandby Room**

09:00

Moving beyond averages: variations in reported thermal comfort

Stephanie Gauthier and DespoinaTeli

Thermal comfort research characterises group thermal perception using averages. This approach overlooks the value of analysing variation as a dependent variable characterising groups' state of comfort. In this paper, we reviewed the results of 219 surveys carried out in five schools in the UK and in Sweden between 2011 and 2016. Results show that pupils' thermal sensation and preference votes varied more at moderate indoor operative temperature. This result suggests that pupils may have a greater range of adaptive opportunities, including clothing, in moderate environments. Substantively, reviewing the spread of the thermal comfort is critical to unpick behavioural, psychosocial and physiological mechanisms. Furthermore, results are significantly different while analysing the central tendency or spread of comfort votes. For example, there is no difference in comfort votes' central tendency between surveys carried out during the heating seasons and the non-heating seasons but there is a significant difference in the spread, indicating the need for multilevel analysis. Methodologically, reviewing the spread of thermal comfort is also critical to establish the data analysis method. With recent advances in surveys' tools allowing larger datasets to be gathered at individual and group levels, it is essential to review the range of analysis methods.

09:15

Introducing thermal comfort attitudes, psychological, social and contextual drivers in occupant behaviour modelling with Bayesian Networks

Verena M. Barthelmes, Rune K. Andersen, Yeonsook Heo, Henrik Knudsen, Valentina Fabi, and Stefano P. Corgnati

The acknowledgment of occupant behaviour as a key driver of uncertainty in building energy analysis is today well established. Existing literature highlights the need of carefully addressing human-related interactions with the building envelope and systems. In response to this need, researchers have proposed a number of stochastic models that aim at reflecting occupant behaviour patterns in building energy simulation to bridge the gap between simulated and real energy consumptions in buildings. However, most proposed approaches for modelling occupant behaviour consider time-related factors and physical parameters such as indoor or outdoor environmental variables while less attention is paid to other influential factors such as psychological, social and contextual drivers or individual thermal comfort attitudes and preferences of the occupants. To understand occupant behaviour in a comprehensive manner, these factors should be carefully addressed in upcoming occupant behaviour models. The Bayesian Network framework presents a promising environment for hierarchically and flexibly structuring a large number of explanatory variables that drive the occupant to perform a certain action. This paper describes the development of a theoretical model of occupant's window control behaviour with an extensive set of drivers and highlights the capability and usability of Bayesian Networks to develop such models based on field measurements and information collected through surveys compiled by the building occupants.

09:30	**Regression Dilution, Bayesian Analysis and Adaptive Thermal Comfort** **Harry R. Kennard, David Shipworth, Gesche Huebner, J. Fergus Nicol** The adaptive approach, as realised in adaptive thermal comfort standards, is an empirically based estimation of the gradient of an ordinary least squares (OLS) linear regression model of operative temperature at neutral comfort vote (the neutral temperature), and external temperature. The neutral temperature itself may be determined by an OLS regression of comfort votes against operative temperature. Thus the strength of the adaptive model's relationship rests on the estimation of two regression gradients. Correct estimation of these gradients is therefore essential in correct implementation of adaptive standards. Should these independent variables be measured with error, the gradient of the regression will be systematically underestimated, in a phenomenon known as regression dilution. This paper uses a Bayesian method which is not effected by regression dilution to reanalyse SCATs data for thermal comfort in free-running UK offices. Following a discussion of the probable uncertainties present in the variables that underpin adaptive thermal comfort standard EN15251, the broader implications of regression dilution are outlined. Application of this approach serves to highlight the importance of conceptual clarity and specification of the measureands of operative temperature and external temperature on which the gradient of the regression slope of the adaptive relationship is critically dependent.
09:45	DISCUSSION
10:30	COFFEE BREAK

SESSION 7: Sleep, IEQ and Energy 11:00 - 13:00
Invited Chairs: Susan Roaf and Kevin Lomas

11:00

Room temperature during sleep

Fergus Nicol and Michael Humphreys

There is pressure in the UK to limit the temperatures in bedrooms to below 26^{o}C to avoid overheating. This short paper looks at the temperatures in bedrooms and uses data from comfort surveys combined with models which link comfort to the thermal environment. Evidence is given that people sleep comfortably at temperatures of 29 - 31^{o}C in their personal space within the bed and they use bedclothes to allow them to attain these temperatures. The effect of the use of a mattress and the adaptive opportunities afforded by the bedclothes and sleepwear are briefly explored as are methods used in hot climates to offset high bedroom temperatures.

11:15

A research on the effects of indoor environment on sleep quality

Nan Zhang, Bin Cao and Yingxin Zhu

Sleep is an important behaviour for humans to maintain good physical and psychological status after a day's work. Indoor environment, along with many other factors such as emotion and body condition, can disturb our daily sleep. To explore the effects of indoor environment on sleep quality quantitatively, a field study was conducted in university dormitories. The field study included the measurement of environmental parameters (ambient temperature, relative humidity, black globe temperature, airflow velocity, noise level, illumination intensity, concentration of CO_2 and $PM_{2.5}$), measurement of physiological parameters (heart rate and wrist skin temperature), and subjective questionnaire (before and after sleep). Environmental and physiological parameters during nocturnal sleep are different with those during non-sleep time. The satisfaction range of different environmental parameters for occupants' to fall asleep were analysed. Subjects feel more neutral and less sensitive to thermal environment during sleep. Multiple-factor analyses were applied to figure out the impacts of different environmental factors on sleeping environment satisfaction. This study indicates that several environmental factors, which may disturb sleep, are interrelated and need more transactional analysis and research.

11:20

The assessment of the environmental quality directly perceived and experienced by the employees of 69 European offices

A. Marchenko, S. Carlucci, L. Pagliano, M. Pietrobon, T. Karlessi, M. Santamouris, N. Delaere

A number of scientific studies have shown that the performance capacity and employees' satisfaction, enjoyment and health are directly affected by how building occupants perceive the environmental conditions that characterize their working environment. The physical well-being and comfort perception of employees directly impacts their productivity and satisfaction. However, several researchers have shown that, in numerous office environments, indoor environmental conditions are far from being perceived as comfortable. Often the main causes are faultily commissioned and operated building management systems, the lack of appropriate and coherent quality management procedures and errors in design or construction of the building systems. In order to identify critical conditions and provide a set of improvement measures, a data collection and analysis tool has been developed. It is called *Comfortmeter* and is used, in this paper, to analyze 69 office environments distributed throughout Europe. The tool enables the evaluation of the performance of a building as directly experienced by its occupants. The evaluation covers the themes of thermal, visual and acoustic comfort, indoor air quality, individual control possibilities and the quality of the office environment. It provides detailed outcome and practical advice to create a healthier working environment for employees. In order to use the tool, it is required, first, to administrate an online survey among the employees. Then, the employees' responses are gathered and stored in a database. Next, the stored data are statistically analyzed to objectify the occupants' subjective comfort experience. Finally, a report is generated and presents (i) a comparative analysis of the building performance, (ii) a structured and easy-to-understand overview of the current comfort satisfaction as perceived by occupants, (iii) an indication of possible areas of improvement as well as (iv) a suggestion of the measures necessary to raise the comfort level and, eventually, the occupants' satisfaction and productivity.

11:35

A real-world empirical investigation of indoor environment and workplace productivity in a naturally-ventilated office environment

Rajat Gupta and Alastair Howard

Most studies on indoor environments and productivity in buildings have been conducted in controlled, static conditions often not representative of the real world, and have used self-reported assessments of productivity. This paper uses a case study-based, real-world approach to empirically investigate the relationship between the indoor environment and workplace productivity in a naturally-ventilated office environment in central London. A range of environmental parameters (indoor temperature, relative humidity (RH) and CO_2) were monitored continuously, alongside outdoor temperatures and RHs for six months covering both heating and non-heating periods. Transverse (BUS survey) and longitudinal surveys (Online survey) recorded occupant perceptions of their working environments, thermal comfort and *self-reported* productivity, while *performance tasks* were designed to *objectively* measure productivity over time in various environmental conditions. Statistical analysis of the data shows that mean indoor temperatures were more strongly correlated with mean outdoor temperatures in the non-heating season (May-July) when compared to the heating season (Feb-Apr), probably due to opening of windows. Indoor RH was found to be low (<30%) while CO_2 levels were high in the heating season (peaks >2500ppm, higher diurnal ranges, higher daily averages). Results from online surveys showed that productivity was reported to decrease when there was an increase in mean indoor temperature and CO_2 levels. Negative but weak correlations were found between the

performance task scores and CO_2 levels. Insights from the study can be used to optimise indoor office environments to improve staff productivity.

11:50 **Thermal comfort and air quality: one-year measurement, analysis and feed back to users of an educational building**

Sébastien Thomas, Samuel Hennaut and Philippe André

Whereas thermal comfort and air quality in buildings are often measured locally and over a short-term period, the complaints of user may occur everywhere in the building regardless the time of the day or the season. The dynamic nature of indoor environments make it hard to closely assess and compare the comfort conditions in the day-to-day life within all the spaces of a building over time. In this study, thermal comfort and air quality have been measured in four teaching rooms in a university building located in Belgium. The analysis gives a letter (A-B-C or D) for the comfort and the air quality for each room. The computed level of thermal comfort and air-quality is shown to users on a yearly and monthly basis via the TV screen located in the building. The vulgarisation, or sharing of the results with the building occupants makes the users aware of their own impact on comfort conditions and the options available for them to improve them through their own actions. The whole year gathered data illustrates the various occupancy patterns and highlights the opportunities to improve comfort:. On the one hand, the results shown a low air quality, the CO_2 thresholds have been modified. On the other hand, the summer comfort, was found to be poor in two rooms. This argues with the landlord to do something to improve the comfort especially in these rooms.

12:05 **The influence of building envelope design on the thermal comfort of high-rise residential buildings in Hong Kong**

Yu Ting Kwok, Kevin Ka-Lun Lau, Edward Yan Yung Ng

Combined effects of climate change and rapid urbanisation make buildings in high-density cities vulnerable to overheating, and thus induce high cooling energy demand, especially during the more frequently occurring near-extreme conditions in summer. It is necessary to minimise building energy consumption without compromising the comfort of occupants by adopting climate-adaptive building envelope designs. By employing the summer reference year weather data for building simulations, this study examines how the indoor thermal comfort of free-running high-rise buildings in subtropical Hong Kong may be affected by modifications of the wall U-value, the depth of window overhang shading, and the window-to-wall ratio (WWR). Results show that better insulated flats experience less extreme thermal conditions but maintain a warmer-than-comfortable indoor environment, while flats with appropriate shading enjoy a net improvement in thermal comfort, especially for eastward and westward facing flats. When considering the WWR, thermal comfort can be maximised by placing windows strategically to facilitate cross-ventilation. Nevertheless, none of the models are able to achieve comfortable conditions for over 40% of the summertime. Further work is required to explore the potential of combined passive strategies or mixed-mode ventilation in optimising building performance and providing thermal comfort for occupants under future climate change.

12:20	**An Exergetic Investigation on the Effect of Long-term Thermo-physical Exposure on Thermal Perception** **Masanori Shukuya, Rinto Nagai and Hom B. Rijal** People are exposed to ever-changing thermal environment. In due course they subconsciously develop their respective perception and cognition. With such general fact in mind, we designed a two-stage subjective experiment focusing on hot and humid summer weather in Yokohama, Japan, and analysed the experimental results from the exergetic viewpoint. At the first stage experiment, thirty-eight subjects were asked to carry grey-coloured globe-temperature sensors and others for one week. At the follow-up second stage experiment, we asked them to visit and stay for a while in three rooms of different thermal conditions, and to answer their thermal preference and cognitive temperature. The subjects were divided into two groups according to their thermal history. Their perception and thermal history were then investigated in terms of human-body exergy consumption rate and also thermal radiant exergy, to which they were exposed in naturally ventilated and mechanically conditioned rooms. The relationship between the human-body exergy consumption rate and the preference votes made by the two groups were not different much, but there was a distinctive difference with respect to thermal radiant exergy input rate. The result suggests that the thermo-physical exposure becomes the memory of thermal history and it affects their respective thermal perception.
12:25	DISCUSSIONS AND ROUND-UP
13:00	LUNCH
	END OF THE CONFERENCE

PAPERS appearing in the proceedings but authors unable to present

Effect of Operational energy variations on life cycle energy: An evaluation in residential apartments

Akshay Kumar Bishnoi, Soumya R., Dr. Rajasekar Elangovan

This paper deals with characterization of operational energy in a group of apartment buildings and its impact on the life cycle energy (LCE) predictions. Field investigations covered eight apartment buildings with 656 residential units representing three spatial types located in a hot-humid climatic zone of India. The residences were predominantly naturally ventilated, but used air-conditioners during peak summer. Data collected include monthly electrical energy consumption for four-year duration and primary field surveys focused on the characteristics of connected appliance loads, operational patterns, type of air-conditioning system and their operating conditions. The overall average energy performance index (EPI) of the residential units is 32.4 kWh/m^2/year. Comfort conditioning had a major contribution in operational energy use which is evident from a strong correlation (r^2=0.85) between monthly energy consumption and monthly mean outdoor temperature ($T_{out-\mu}$). The magnitude of variation in energy consumption among residential types is found to be lesser during winter than summer attributed to the diversities in air conditioner usage during this season. Factors such as orientation, height at which the residence is located, mutual shading by adjacent buildings and operational patterns had a statistically significant impact on the operational energy consumption. However, the impact of subjective preferences and operational characteristics had a much stronger impact on the energy use. Statistical cluster analysis of the data indicated the presence of three distinct clusters representing low, mid and high consumption residences. The residential units were found to be distributed in these clusters irrespective of their spatial typology. Life cycle energy per residential unit is 1688.4 $x10^3$ MJ out of which EE contributes 627.7$x10^3$ MJ (37%) and operational energy contributes 1060.7 $x10^3$ MJ (63%) for a 50-year life span. Mean LCE of low, medium and high consumption clusters are 1424.9 $x10^3$ MJ/home, 1931.1$x10^3$ MJ/home and 2386.3$x10^3$ MJ/home respectively. The results indicate a strong influence of subjective variations in building operations on the life cycle energy.

Method to determine Indoors Thermal Comfort Range for Mexico's climates

Luis Armando Canul-Euán, Luis Gabriel Gómez-Azpeitia and Gonzalo Bojórquez-Morales

The research sought to establish a method to define a thermal comfort range standard correlating the thermal comfort range of different studies with adaptive approach carried out in interior spaces with the external thermal oscillation. The value of the coefficient of determination (R^2) was the validation parameter. The sample size was 38 studies conducted in Mexico, with 6,744 surveys. The methodology is based on a proposal made by Humphreys, Nicol and Roaf: for each day survey, subtract from the operating temperature (Top) its mean value to form the variable (δTop) and from the thermal sensation (ts) its mean value to form the variable δts. Next, a polynomial regression analysis of δts in δTop was performed to obtain an adjusted regression coefficient. The thermal comfort range per study was obtained from the inverse of the regression coefficient. Additionally, two alternative values of the regression coefficient were calculated: through the quotient of the standard deviations of the δtf and δTop, and of the quotient of the δts and δTop ranges. The results indicate a greater correlation between the OSC_δDBText and the comfort range of the inverse of the standard deviations. The value of R^2 was 0.4408.

A study on seasonal indoor thermal environment in condominiums under the use of HEMS system

Rajan KC, H.B. Rijal, M. Shukuya, K. Yoshida

Energy management in an effective way is important in building sectors including residential buildings. So, the uses of smart devices and energy management system have dragged the attention of developers and buyers in housing industries. The use of Home Energy Management System (HEMS) is increasing. The Japanese government also aims to set up HEMS to all of the new dwelling by 2030. Thermal comfort is associated with the trend of energy use in a building. In order to find out the thermal environment of the occupants living in smart houses, we conducted a measurement survey in a condominium equipped with HEMS. Indoor air temperature and relative humidity was measured for one year. The result showed a large variation in indoor air temperature and relative humidity during the study period. The occupants behaved differently according to flats, floor and seasons. The indoor air temperature in summer was observed higher as recommended in Japan. Due to high insulating materials used in the building, the indoor air temperature was not low even in winter. The result indicates that the occupants behaved differently to adjust the indoor thermal environment even during the use of HEMS.

Thermal environment ranges providing good sleep quality in bedrooms during summer – Analysis of university students in Osaka

Noriko Umemiya, Hirona Bessho, Tomohiro Kobayashi, Yoshiki Tachibana and Yusuke Nakayama

A questionnaire survey and bedroom thermal environment measurements were conducted for 24 university students for 581 nights in the peak of summer for three years to clarify subjective ranges of thermal comfort and good sleep quality. Results revealed the following. 1) Thermal comfort decreased as the standard effective temperature (SET*) increased when SET* was more than 21°C. 2) The SET* range at which more than 80% voted in three central categories of seven-point thermal sensation scale was 19.3–22.7°C, 'thermally acceptable' temperatures were 17.7–28.0°C. The good side of the sound sleep evaluation scale was 20.1–23.7°C. 3) Subjective sleep quality decreased gradually when SET* exceeded 22°C. However, sleep quality related to Drowsiness and Fatigue recovery increased when SET* exceeded 26°C. 5) The ratio of 'thermal comfort' for air conditioner (AC) non-use nights peaked when SET* was 20°C, although it peaked at 25°C for AC use nights. 6) Subjective sleep quality decreased as SET* increased for AC non-use nights, although it peaked at 25°C for AC use nights.

Defining Thermal Comfort in Desert (Hot-Arid) Climates: A Thermal Comfort Field Survey in Baghdad, Iraq

Saif Rashid, Oliver Kornadt and Conrad Voelker

Indoor air measurements were conducted in 6 housing units in Baghdad between 2014 and 2016. A deeper look at the measured data showed that air temperatures during spring and autumn complied with the adaptive comfort model. On the other hand, a big variation within the same season was found during winter and summer periods. To verify whether comfort models apply for the climate in Baghdad, a field survey was conducted to define comfort conditions during critical winter and summer periods. The winter survey was conducted in two identical classrooms at the University of Baghdad in December 2016 and January 2017 with 233 responses. The survey was repeated 11 times under 5 different air temperature settings. The survey in summer was a longitudinal survey with 149 responses to evaluate. It was conducted in August 2017; it was repeated 14 times to test the responses under 7 different indoor environmental conditions. The results of the field surveys showed a variation in thermal sensation when compared with the predicted mean vote.

Methodological framework for evaluating liveability of urban spaces through a human centred approach

Daniele Santucci, Umberto Fugiglando, Xiaojiang Li, Thomas Auer and Carlo Ratti

The quality of urban spaces is fundamental to the liveability of cities. In past decades, many studies at different scales have developed methodologies to evaluate comfort conditions in public spaces, as this aspect is essential for making cities more *walkable*. In this context, the present study develops a methodology for evaluating quality of cities through a dataset that collects millions of anonymous pedestrian trajectories through smartphone applications. This data, which includes about 1 million trips in the Boston area of over 60,000 anonymous users from May 2014 - May 2015, estimates human walking activities. Presence is used as an indicator for walkability by relating it to additional layers to provide an accurate model of the urban morphology. The aim of this paper is to present a case study on how human walking activities can be sensed, quantified and applied to determine the impact of the urban morphology and its effects on climate at a micro-scale. This study also reveals how people flows react to highly fluctuating microclimatic conditions and how pedestrians respond to the variability of the urban environment. Together, these approaches will affect multiple aspects of human life including health and wellness, infrastructure and quality of life in cities to create liveable and healthier cities.

Assessment of transient thermal comfort characteristics in an underground metro station

Kapil Sinha and E. Rajasekar

This paper presents the results of a thermal comfort evaluation of an underground metro station located in a composite climate zone of India (New Delhi). The evaluation comprised real-time monitoring of indoor thermal comfort during winter and summer seasons accompanied by subjective thermal comfort surveys. This study extends the existing field study protocols to transport buildings, which are characterised by dynamic passenger flow. Parameters such as dry bulb temperature (Ti), globe temperature (Tg), relative humidity (RH) and air velocity (Va) were measured using a thermal comfort monitoring system. In addition, spatial variation of Ti, Tg and RH were monitored using lab-assembled Arduino kits. Subjective surveys comprised of transverse responses collected from 360 users and 360 sequential thermal experience responses collected form 60 users. The subjective responses were collected separately for boarding and alighting sequences using an android-based application developed by the team. Transient thermal comfort was estimated using Relative Warmth Index (RWI). A comparative analysis of mean RWI indicates a gradual and uniform change along the alighting sequence of passenger flow. However, the variation of mean RWI is non-uniform and undulated along the boarding sequence. RWI varied from 0.26 at platform to 0.45 at the walkway along the alighting sequence. It varied from 0.3 at concourse to 0.51 at the ticket lobby along the boarding sequence. The neutral temperature (Ti) obtained through thermal sensation vote (TSV) is 30.3°C. The variation in TSV between alighting and boarding passengers were found to be statistically significant at platform, concourse and walkway. A strong positive correlation was obtained between $TSV_{alighting}$ and RWI (R^2=0.52) as well as $TSV_{boarding}$ and RWI (R^2=0.53). An RWI value of 0.14 corresponded with mean neutral TSV for the alighting sequence while it was 0.33 for the boarding sequence. The passengers exhibited higher level of tolerance to heat discomfort than that predicted by RWI. Acceptable thermal limits along the alighting and boarding sequence of the metro station are presented.

Evaluation of Seasonal Thermal Environment of Temporary Shelters Built in Nepal after Massive Earthquake 2015

Rita Thapa[1], Hom Bahadur Rijal[2], Masanori Shukuya

Two major earthquakes struck in Nepal on 25th April and 12th May 2015. Especially, who lost their permanent house in this hardest hit has been living under makeshift tents. In Nepal, there is no such research has conducted yet based on different materials used as insulations in temporary shelters. Thus, this paper investigated to evaluate the seasonal indoor environment of temporary shelters where using various local materials used as insulations. Thermal measurements were conducted for 26 days in winter for seven shelters (S1-S7) and 24 days in summer for three shelters (S1-S3) located in Lalitpur district. The indoor air temperatures for all shelters are highly dependent on outdoor air temperature in winter and summer. The fluctuations of indoor air temperature of shelter S3 and S7 is higher than other shelters in both seasons. The result might be due to low thermal insulations in these shelters. The mean indoor air temperature during the sleeping time is 5.4°C in S7 and 10.1°C in S1 in winter. The mean indoor air temperatures are considerably low in winter and high in summer where people are compromising these harsh indoor environments by adapting their clothing behaviours.

Evaluation of subjective occupant thermal comfort in the selected buildings in upper east region of Ghana

Frederick W. Manu, Christian Koranteng and Leonard K. Amekudzi

International thermal comfort standards such as the American National Standards Institute/ American Society of Heating Refrigeration and Air-conditioning Engineers (ANSI/ASHRAE) standard 55-2013, European Norn (EN) standard 15251-2007 and International Standards Organization (ISO) standard 7730-2005 have not been found to be true reflection of the response to thermal environments of people in the tropics. This has been reported by researchers such as Bouden and Ghrab (2005), and Dhaka et al. (2015). This has left a gap in understanding of thermal comfort in tropical regions such as Ghana in a real life situation. The goal of this study is to assess the subjective occupant thermal comfort in 12 selected buildings in urban and peri-urban areas of Bolgatanga, Upper East Region of Ghana. Furthermore, the specific objectives of the study are to assess prevailing environmental parameters, thermal comfort voting and distribution, and deduce a comfort temperature. The study area was carried out in the Savannah climatic zone of Ghana in the 6 warmest months of 2015. A longitudinal thermal sensation survey method was adapted with the intention of deriving long term data from relatively small number of respondents. The sample size of the survey was 144 occupants with 2 respondents for a month from each household. A thermal sensation questionnaire formulated comprised biodata, ASHRAE seven-point thermal sensation scale with a pictograph, and the McIntyre thermal preference scale. From the analysis, it was found out that 88% of the respondents found their thermal indoor conditions acceptable with a neutral temperature of 30.3°C derived through linear regression.

END OF ABSTRACTS

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