Rethinking Comfort

Overview from the Windsor conference 2018

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Introduction

Research on thermal comfort has been carried out for a long time. The PMV model was developed already about 50 years ago, but still has a major influence in the field. The adaptive comfort approach recognized that thermal comfort is not a fixed phenomenon but is influenced by physiological, psychological and behavioural adaptations. This allows for a larger variation in indoor temperature, along with the variation of the outdoor temperature, thereby enabling reduction of building energy use. Still building energy consumption, global warming, health implications and individual thermal discomfort give rise to new developments in research and design of indoor thermal environments of a variety of building types.

The 10th Windsor conference, hosted by prof. Fergus Nicol (NCEUB) and prof. Sue Roaf, was themed "Rethinking Thermal Comfort", giving the attendees the opportunity to share and discuss ideas on new approaches in providing comfort in a changing world. This resulted in a conference program with sessions on new approaches for heating and cooling, personal control and user behaviour, comfort in different types of building, comfort during sleep and thermal comfort in hot climates. Keynotes addressed the debate on the development in the direction of low-tech versus high tech buildings and the impact of social, economic and cultural experience on thermal comfort. Lastly, workshops facilitated discussions on comfort models, overheating of buildings, research methodologies and health implications of the indoor environment. In this article we highlight a selection of the studies related to the topics that were presented during the conference (impression in Figure 1).

Figure 1. Discussions and presentations during the conference

Prediction of thermal comfort

Thermal comfort standards prescribe indoor environments in buildings that should satisfy 80% of the building occupants. A study of Karmann et al. investigated if this matches the votes from occupants in real world buildings. Investigation of 351 office building in North-America revealed that 43% of all occupants were in general thermally dissatisfied, 19% were neutral and 38% were satisfied (N=52980). The percentage of buildings with 80% or more satisfied occupants was only 2% (8% when including the neutral votes) (Figure 2). These concerning results were hypothesized to be attributed to the inability of the large majority of HVAC systems in providing personalized conditioning or opportunities for personalised control. The results imply that many buildings do not create an indoor environment that occupants consider satisfactory [1]. The study addresses the deviation of real world thermal satisfaction from prediction, thereby indicating the influence of individual thermal preference.

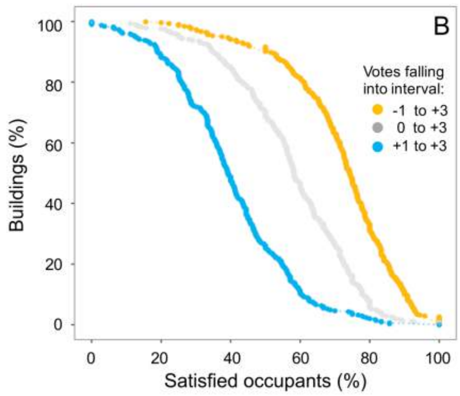

Figure 2. Line graph showing the percentage of buildings meeting given percentage of occupants satisfied with temperature. The analyses are conducted for 3 satisfaction criteria ("-1 slightly dissatisfied to +3 very dissatisfied"; "0 neutral to +3 very dissatisfied"; "+1 slightly satisfied to +3 very dissatisfied"). Figure obtained from Karmann et al. 2018.

Personal control and preference

Several studies presented at the conference aimed to improve individual thermal satisfaction by applying personal control opportunities and personal thermal comfort models in the indoor environment. In a field study by Pigman et al. the responses to windows and fans in three buildings were investigated to study the effect of personal control on overall satisfaction with the indoor environment. The surveys revealed that occupants appreciate the operable windows and fans. Satisfaction with the environment was however not significantly related to just having access to personal control, but with perceived control and the ability to control the indoor environment parameters. These results are line with previous findings of Boerstra (2016) and emphasise the need of providing effective control opportunities, and to educate people in how to use them [2].

To predict and anticipate on individual thermal comfort response, the study of Kim et al. provided a framework for personal comfort models and how these can be integrated in indoor environmental controls. Using the internet of things and machine learning, individuals' comfort requirements can be obtained. Challenges and opportunities for the application of personal comfort models include collection of data feedback, generalisation to larger populations and different thermal preferences in shared spaces. Monitoring of thermal behaviour, analyses on repeatable patterns between different individuals in large samples and personal comfort systems are relevant aspects in resolving these issues [3]. Additionally, a self-learning framework was proposed by Zhao et al. and focussed on personalised thermal comfort considering that each occupant has a unique thermal preference. Learning algorithms to build a personal level comfort model may provide the basis of personalised dynamic thermal demands. The model may also help to give a better understanding between the internal links between psychology, physiology and behavioural aspects [4]. All imply that personalized components to the workplace are required to improve satisfaction with the indoor environment. Self-learning algorithms and data collection using IOT can assist in providing individually tuned workplace environments and to increase knowledge on the influence and interaction between psychological, physiological and behavioural aspects.

Interactions between different indoor environmental parameters

According to Foo and Mavogianni, thermal perception is associated with expectations of the physical environment. Therefore, they investigated the effect of interior finish characteristics on thermal comfort in learning spaces. Thermal comfort was evaluated ant a systematic characterisation of the interior finish was developed. Small but significant effects of the naturalness of the materials and the colour tones were found: thermal comfort was higher in lecture rooms with natural materials and when warm colour tones were used [7]. The latter confirms the hue-heat hypothesis, which states that a room that is illuminated by light towards the warm end of the spectrum is perceived as warmer compared to light dominant in the cool part of the spectrum. A study of te Kulve et al, also investigated the effect of visual perception on thermal comfort and/or thermal sensation. In a laboratory study the effect of the correlated colour temperature and illuminance of light on thermal perception was tested. There was however no significant effect of correlated colour temperature or the intensity of light on thermal sensation or thermal comfort in this study. Interestingly, the change in visual comfort between light sessions was related to the change in thermal comfort for the same ambient temperature. This implies that visually comfortable conditions may improve thermal comfort, but individual preferences should be considered [5]. Chinazza et al. evaluated the influence of light levels on thermal perception in a real-world environment during the summer and winter. Their results show that in both seasons thermal satisfaction was higher at illuminances >300 lux (illustrated in Figure 3). Especially in summer when indoor temperature was >25°C thermal satisfaction was clearly lower when exposed to low light levels (<300 lux) compared to exposure to brighter light. The results were assumed to be explained by the thermal expectations indicated by the light intensity e.g. a higher light intensity results in a higher expectation of the temperature [6]. These three studies indicate that thermal satisfaction and thermal comfort is affected by visual perception of the environment. Expectations raised from and appraisal of the visual environment may interact with thermal evaluation.

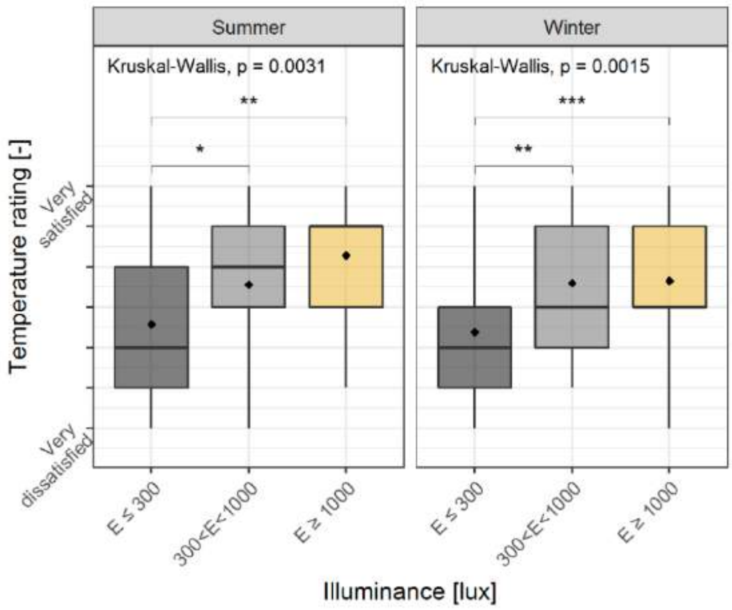

Figure 3. Thermal evaluation responses according to the two seasons and the

Comfort and health implications of the indoor environment in different building types

Different buildings types have different requirement for the design of a healthy and comfortable indoor environment. In predicting thermal satisfaction in HVAC buildings, in this case a fully air-conditioned museum, a study of Kramer et al. showed that this building does not adheres its typology of being a HVAC building in terms of thermal comfort. The acceptability of seasonal variation was larger, clothing behaviour corresponded that of naturally ventilated (NV) buildings, mean thermal sensation was under estimated towards the cold and warm end of the thermal spectrum and the outdoor temperature significantly influenced thermal sensation indoors. Though the indoor temperature range matched that of HVAC buildings. So, the categorisation of buildings solely based on HVAC or NV is not sufficient for predicting thermal sensation in museums [8].

The paper of Nikolopoulos analysed thermal comfort in different contexts; in offices, outdoor urban spaces and airport terminals. Airports have very different user groups with different requirements for thermal comfort. The study tested if the needs of staff are more like offices workers and if passengers' requirements, who use the building a transition area, are closer to the outdoor environment. Indeed, the results show that employees and office workers are more acclimated to the working thermal environment and comfort temperatures are closer to the mean operative temperature. Passengers on the other hand, demonstrate a wider adaptation capacity, like in urban spaces [9]. Differences in expectation probably partly explain this observed dissimilarity.

Classrooms function quite different from other building types. A review of Kumar Singh et al. about thermal comfort in school buildings found that in each education level (primary school, secondary school and university), students were highly dissatisfied with the indoor thermal environment. This while the quality of the thermal environment influences school performance and wellbeing of the students. Specific guidelines for the design of the indoor environment in school is therefore desirable. The comfort temperatures in schools obtained in the selected studies will be used to develop an adaptive comfort equation for primary, secondary and university classrooms [10]. Another type of buildings with specific demands are nursing homes. In six Australian nursing homes, the thermal environment was measured and the impact on the perception and comfort of staff, residents and other occupants was investigated by Tartarini et al. The results of their study show that nursing homes do not provide thermally comfortable conditions for occupants during both summer and winter. Residents prefer a higher temperature (0.9°C) and wear more clothes compared to non-residents. Further research is required to support the development of best practice guidelines [11].

These studies all indicate that thermal satisfaction in buildings largely depend on the function of a building and differs between users group within a building.

Dwellings

In European residential buildings the indoor environment problem is more related to negative health effects. Analyses of the EU-SILC database by John et al. showed that one out of six homes in Europe can be categorised as “unhealthy”. In this case, “unhealthy” is defined as buildings that have damp, a lack of daylight, inadequate heating during winter or overheating problems. The probability that a person reports poor health increases with 70% when living in an “unhealthy building”. Although there are of course many other factors influencing a persons’ perceived health, individual and societal health would benefit from indoor environmental improvements in buildings and specifically in homes [12].

Performance of renovated buildings in winter and different heating systems
New and renovated buildings need to be well insulated to reduce the required energy for heating and cooling. Low temperature radiation systems are often applied in these buildings. Therefore, the study of Safizadeh and Wagner investigated thermal comfort for four different scenarios of low temperature heating. These consisted of combinations of a heated ceiling with a temperature of 28 and 35°C and a distance from the window of 1 and 3 meters. The study results show that during a 60 minutes exposure; i) it is possible to achieve mostly neutral thermal sensation votes using low temperature heating, even close to the window (if regulation of energy efficient buildings are used); ii) overall thermal sensation followed the local votes at the upper-body parts, iii) surprisingly, the head was perceived as the most comfortable body part; iv) lower body limbs and hand

were the least comfortable limbs; v) for the different scenarios, thermal comfort votes had a wide range at the lower limbs and hand; vi) unlike local comfort votes, the local sensation was strongly related to the local skin temperatures. Further studies will be carried out to be able to develop a comfort model for asymmetric condition as created by radiant systems [13].

Climatic adaptions to temperatures and its effect on preferred temperature and health

Globalisation leads to a working environment where people with different comfort and climatic background work. Hence it was investigated whether building occupants' comfort rating are affected by climatic background. A post-occupancy evaluation was carried out by Pastore and Andersen in two office buildings located in Switzerland (high rate of international employees). The result of the surveys indeed revealed that thermal comfort and air quality ratings were affected by the climate of origin and the time spent in the country (as shown in Figure 4) [14].

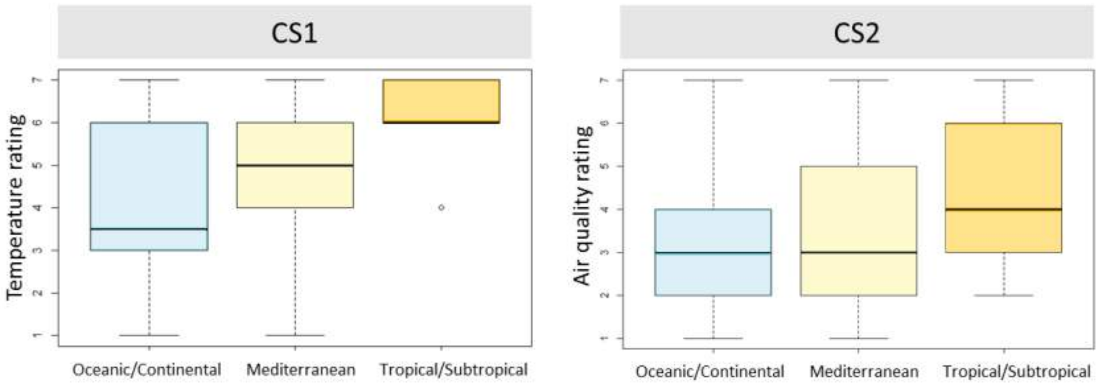

Figure 4. Rating distributions for temperature in Case Study 1 (CS1) (left) and air quality in building CS2 (right) based on climate of origin (1 corresponds to "Very dissatisfied" and 7 to "Very satisfied"). Figure obtained from Pastore and Andersen, 2018.

The effect of climate on preferred indoor temperature was also shown by a study by Mino-Roderiguez et al., who investigated the preferred temperature in houses in the subtropics. The differences in temperature preference of people living at a high and a low altitude was of interest. The highlands in the tropics are characterised by a narrow annual temperature oscillation and a noticeable diurnal temperature variation combined with high levels of solar radiation. At low altitude, the tropics are hot and humid. The study revealed that the acceptable indoor temperature range in the highlands was lower, between 16°C-24°C compared to 26°C at the low-altitude. People at high-altitude were more sensitive to draft, whereas people at the low altitude prefer higher air movement [15]. These results also indicate that people get used to a certain range of ambient temperatures, thereby affecting their preferred temperature.

Adaptation to ambient temperatures may not only affect preferred temperature, but also impact health. Regular exposure to temperature outside the thermal neutral zone might have positive implications for metabolic and cardiovascular health. Pallubinsky et al. studied the effect of acclimation to mild heat (34°C) in overweight elderly men. After 10 days of acclimation, fasting plasma glucose levels, fasting plasma insulin values and HOMA-IR were significantly decreased, which implies effect of passive mild heat acclimation on glucose metabolism. Additionally, core body temperature and mean arterial pressure were lower during thermoneutrality and warmth. The results indicate positive health effects for this study group as cardiovascular diseases are common in overweight and elderly people [16]. The studies show that the human body and its thermal perception is not fixed but can adapt to higher or lower temperatures. Exposure to elevated temperatures may even be beneficial for health.

Thermal comfort to enhance sleep and next-day productivity

Thermal comfort studies are carried out to improve satisfaction with the thermal environment. The importance of providing thermally comfortable environments is strengthened when looking at the impact of the ambient temperature on sleep quality and on next-day productivity. The paper of Nicol and Humphreys provides starting points for a model on the effect of bedroom temperature on comfort and sleep quality. For a sleeping person, the desired temperature around the body is 29-32°C. Sleepwear and bedclothes allow for adaptation to the indoor temperature and a well-insulated matrass lowers the comfortable room temperature. Maximum bedroom temperatures should avoid discomfort and sleep loss [17]. In a field study in university dormitories by Zhang et al., the effects of indoor environmental parameters, including room temperature, on sleep quality were investigated. The study results indicate that people felt more neutral and less sensitive to the thermal environment during sleep (as subjectively evaluated just after waking-up) compared to being awake. In this study, the indoor temperature that resulted in the highest temperature satisfaction during sleep was 24,2 °C. Different indoor environmental factors were interrelated and therefore more research is needed to address the individual effects [18]. This is highly relevant because improving sleep quality can enhance next day performance.

Thermal environment and productivity

The daytime indoor environment can also improve performance during the day. Gupta et al., studied the relationship between the indoor environment and workplace productivity in a naturally ventilated office. The results show that self-reported productivity decreased when the indoor temperature and CO_2-concentrations increased [19]. These three studies emphasise that studies on desirable indoor environmental conditions should not only focus on comfort but should also evaluate how it affects the activities carried out in the room e.g. sleeping or performing office tasks.

Concluding remarks

This overview of current research topics related to thermal comfort show that:

- Prediction of thermal comfort solely based on the designed physical environment does not match real comfort op building occupants.
- Attention should be paid to the wide range of factors influencing thermal perception (building type, function, user groups, overall experience and expectations).
- Technology can be used to make systems more efficient, self-learning and personalised, thereby enhancing individual comfort.
- Design and research on thermal environments should not only focus on comfort but should also incorporate effects on health and productivity, thereby increasing its social relevance.

In conclusion, research on thermal comfort and development of new heating and cooling strategies are highly relevant to be able to anticipate on current developments such as global warming and the need the reduce building energy consumption.

Figure 5. Group picture in front of the Cumberland Lodge at Windsor Great Park.

Acknowledgements

The organising committee of the 10th International Windsor Conference is greatly acknowledged for hosting the interesting meeting at the Cumberland Lodge, Windsor Great Park, UK 12th-15th April 2018.

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The book of abstract and all conference papers can be downloaded from the conference website: http://windsorconference.com/