Windsor 2018: Workshops Overview

There were nine workshops held during the 10th Windsor Conference on Thermal Comfort in April 2018 (www.windsorconference.com). Their subjects and Chairs are listed below:

No.	Chairs		Subject
1	Marcel	Schweiker	**Usage and Interpretation of Comfort Scales**
	Giorgia	Chinazzo	
2	Runa	Hellwig	**Overheating of People and Buildings**
	Wouter	V M Lichtenbelt	
3	Stephano	Schiavon	**Personal Comfort Models**
	Christoph	van Treeck	
4	Dolaana	Khovalyg	**Indoor Thermal Comfort: Are We Missing the Diversity Factor?**
	Fergus	Nicol	
5	Atze	Boerstra	**Measuring Comfort in the Real World**
	Adrian	Pitts	
6	Lyrian	Daniels	**Domestic Comfort and Health at Low Temperatures**
	Dennis	Loveday	
7	Wouter	V M Lichtenbelt	**Physiology, Health and Comfort: Implications for Real Life**
	Yingxin	Zhu	
8	Sally	Shazad	**Personal Comfort Systems**
	Gail	Brager	
9	Rex	Galbraith	**Using Statistics for Thermal Comfort Data**
	Jane	Galbraith	

Workshops provide an opportunity to discuss topics in greater depth and explore detailed issues of methodology, experimental design, semantics, real world constraints and impacts and new thinking and approaches. Some of these discussions are outlined below and reflect current thinking and developments in relation to the individual subjects covered. We include these in this legacy document for the benefit of those who were not able to attend the conference themselves. Each workshop overview starts with the background pitch that their Chairs circulated to attract delegates to attend their own workshop, followed by an overview of the discussions had during the workshop. We hope this Workshops Overview will be useful in a number of ways including:

1) A quick guide to current thinking in important and emerging areas in Comfort.
2) A possible tool for teachers of Comfort studies, at master's level and beyond where individual students can be offered different aspects of comfort to explore.
3) For PhDs / researchers who want to look at one or more of the subjects in detail and at different thinking on them to provide a more nuanced understanding of the field.

The papers presented all appear in full, in the Windsor 2018 Conference Proceedings (on line at: www.windsorconference.com) and in turn each of those papers contain a fuller set of up to date references to follow up on providing a stepped introduction to the subjects covered.

1: The Usage and Interpretation of Comfort Scales

CHAIRS: Marcel Schweiker and Giorgia Chinazzo

Background: Questionnaires and response scales are fundamental elements of the assessment of an individual's perception of indoor environmental conditions in the built environment. They have been used since the beginning of thermal comfort studies nearly 100 years ago until these days. Today, the most widespread thermal comfort indices, the PMV and SET, and the adaptive comfort equation are based on ratings on the 7-point thermal sensation scale from -3 (cold) to +3 (hot). Thereby, the type of scale used together with its interpretation is closely linked to the underlying concept. The current emphasis on the thermal sensation scales and the interpretation that a vote on the three central categories can be regarded as an expression of comfort is closely linked to the paradigm of thermal neutrality as unidimensional measure of comfort. However, such paradigm is questioned by more and more researchers and challenged e.g. by concepts such as thermal alliesthesia focusing on the pleasantness of a thermal stimuli.

Coming back to the usage and interpretation of scales, despite being considered as "thermal comfort scale", thermal perception assessed through the thermal sensation scale requires the researchers' interpretation which part of the sensation scale is considered as comfortable. However, thermal comfort perception is not necessarily equal to the perception of thermal sensation. For example, a feeling of warmth (+2 on the thermal sensation scale) can be evaluated as comfortable due to other influencing factors, such as individual preferences, the country of origin, or the prevailing season.

Findings from studies confirming this assumption question the way data derived using these scales can and should best be analyzed (statistically) and interpreted and whether new and multidimensional approaches need to be developed for thermal comfort assessments. This workshop provided a forum for the discussion of current usages of scales in studies concerning the perception of indoor environmental conditions and future possible developments to tackle such problems.

Workshop Discussions: The start was made by Michael Humphreys who highlighted several of the most relevant issues related to the usage of scales today, such as the vagueness of some words used in questions or the problem of associating scales with a particular color scheme. The workshop continued with two presentations on the topic. First, on challenges in the translation of scales into Arabic language, and then on a qualitative approach to assess peoples' (not researchers'!) concept of thermal comfort.

The principal outcomes of the discussion following these inputs can be summarized in three main themes:

- *Scale translation*. Standardized translations need further improvement and investigations. While translating scales, we must be aware that some words cannot be translated or could have a different/associated meaning in another language (e.g., the word "warm" translated in Arabic is associated with a desirable condition).

- *Scale visual representation*. Great care needs to be taken when using colours or symbols to describe categorical responses, because they can have different meanings in different parts of the world. Same problems can occur with the use of icons and symbols.
- *Scale meaning*. More work needs to be done to understand peoples' interpretation of the wording used in the questions and in the categorical scales (e.g., what does "acceptable" mean?). In addition, the thermal sensation of people and hence their evaluation with scale, could be different across countries since people have different thermal experiences (e.g., cold sensation for someone living in the Philippines is different from someone living in Siberia). Finally, the meaning of the words in a scale can be different in summer and winter. As a general conclusion on this topic, it was argued that a linear representation of the scale makes the interpretation of the response easier.

At the end, all participants agreed that it is necessary to further investigate comfort scales, rethink the way we assess thermal comfort and the terminology we use. Collaborations with sociologist, linguistic and psychologist would be crucial to further investigate the problem. For example, in the field of psychology the word "scale" often refers to a number of items related to a specific construct. Thereby, an item is a single question such as the question "How do you feel right now". Translated to the field of thermal comfort, a construct would be the "perception of comfort" assessed through two or more (often 10 or more) items (=questions). The answers to these questions would consequently be joint to a final composite score thermal comfort scale.

2: Overheating of People and Buildings

CHAIRS: Runa Hellwig and Wouter van Marken Lichtenbelt

Background: In recent years there have been an increasing number of complaints about overheating in buildings all over the world. On one hand, there is a growing agreement that based on the adaptive thermal comfort approach comfort perception depends not only on physiological but on psychological and behavioural factors including climatic and other contextual factors, and that the perception of comfort is dynamic in nature. Conversely overheating has been predominantly assessed based on a static understanding of overheating. Furthermore, today's overheating criteria have been used also to assess future temperature scenarios based on climate change predictions. The workshop aims to discuss existing overheating definitions and the need for more suitable and universal definitions of overheating. Rethinking existing approaches requires raising fundamental questions again: Is the fundamental concept of overheating defined in such a way as to avoid discomfort or to mitigate health problems in populations? What is the impact of the dynamics of temperature changes on the experience of overheating? To what extent is the perception of overheating perception driven by cultural or lifestyle norms or expectations?

Workshop Discussions: The Workshop started with two presentations, the first one investigating the expected variance of future UK heatwave incidents on homes with different passive design features, concluding that the impact will vary widely over the UK and that shading will be an effective mitigation measure for the building stock as increased thermal mass can only be implemented into new buildings' design. The second presentation identified adaptive opportunities available to occupants of homes and the actions taken in relation to the temperatures in their homes. Barriers identified which prevent the occupants from applying certain adaptive opportunities include security concerns and a lack of concern about overheating.

The subsequent interactive part II of the workshop debated lively five overheating related questions before the diverse climatic background of the workshop participants (19).

- *Perception and definition of overheating – how dangerous is overheating?* Overheating depends on the adaptation level and the local climate. A temperature condition that is perceived as overheating in one region could be a common temperature level in another region. In a number of regions cold is still a more severe problem than overheating in terms of mortality rates but this might change. Those not affected yet may be concerned more about overheating in the future. Although the increase in temperature
- *In a heatwave, which characteristics are more stressful to humans?* Besides 'generally elevated temperatures' (8 votes) especially when 'sustained' (15 votes), 'fast increasing temperature' (8 votes) and the 'lack of a cooling down effect during night' (14) as a result of 'low diurnal temperature swings' (9 votes) in heatwaves were identified being major sources of stress during exceptionally warm periods or heat waves.
- *Sleeping temperature should not be above…*: It was reported that 26°C for example in the UK have been discussed controversially whereas 28 to 29°C in a European Mediterranean climate would be fine as well as it would be in China with 29-30°C equalling temperature ranges measured inside quilts with humans sleeping comfortably. From Hong Kong it was reported that elderly seem to be able to sleep in warmer temperatures even in a hot and humid context, whereas younger people tend to use active cooling during night leading to the use of duvets at 20°C room temperature. This is an air-conditioning use trend which needs more attention in the future. From equatorial climate it was reported that sleeping is possible at 27-28°C and 90% relative humidity, also for acclimatised individuals with a temperate climate background. People coming from a cooler climate may learn to not using any cover during night and sleeping uncovered. Freshness of air around the face might be important though. Gentle air movement might support to accept higher temperatures for sleeping. Sleeping temperature practice seems to need more attention in future research.
- *Should vulnerable people be exposed to warmth?* Whether vulnerable individuals should not be exposed to high temperatures in order to protect them or whether they

would benefit from this exposure through improved acclimatisation responses was discussed controversially. A small group of participants (4) was of the opinion that vulnerable people should not be exposed because of the supposed lack of ability to adapt compared to young healthy individuals. 13 participants voted with 'yes'. The question of an appropriate duration for exposure remains though and was one reason for those voting for 'no'. Any healthy (individually adjusted) exposure would help vulnerable to maintain a certain level of adaptability and hence would be supportive to their general health status. More physiological studies are needed to provide more insights into health supportive exposures.

- *What do you think would be an appropriate term to be used in the context of overheating?* 2 participants voted for 'comfortable temperature', 11 for 'acceptable temperature' and 10 for 'healthy temperature' (multiple choice possible). Tolerable temperature was proposed in addition, being a useful term in hot regions. Comfort was seen as loaded with rather different concepts, ideas and understanding and therefore less appropriate. Using the terms 'acceptable temperature' or 'healthy temperature' instead of 'comfortable temperatures' may be supportive in short periods of excess temperatures in buildings during exceptional warm periods or heat waves and may help avoiding energy intensive mitigation measures to overheating.

From the discussion it can be concluded that one major difficulty in overheating assessment is that future temperature scenarios are assessed by people with an experience of today's temperature in a certain location with certain daily thermal practice and hence makes is hard for them to imagine an unacceptably elevated temperature of today might become fairly acceptable in the future. Besides the resulting necessity to enhance people's adaptability and their persuasion that they are able to acclimatise, examples reported in the workshop also highlighted the important role of expectation management and management of emerging common practice in society. Finally, designing buildings using passive strategies and offering adaptive opportunities to allow for human adaptation remains a major task.

3: Personal Comfort Models

CHAIRS: Stefano Schiavon and Christoph van Treeck

Background: A personal comfort models provide a new approach to thermal comfort modelling that predicts an individual's thermal comfort response, instead of the average response of a large population these models are based on environmental parameters (e.g., air temperature, location, relative humidity), occupant feedback (e.g., online voting like Comfy), occupant behaviour (e.g., thermostat setpoints like Nest) and biomarkers (e.g., skin temperature, heart rate). Personal comfort models can be used for the control personal comfort systems but they can also be applied to general mechanical systems and provide a way to collect data to train personal comfort models. Personal comfort models showed significantly higher accuracy in predicting the comfort of an individual than general population models like those for PMV and the adaptive comfort, both in laboratory and field settings. Personal comfort models are not specific to an environment and can be applied to commercial and residential buildings and vehicles, being based on learning algorithms that can improve their performance when new data are collected. This new approach is facing many of the challenges including the large heterogeneity of input parameters, the machine learning algorithms used and thermal comfort metrics used as dependent variables. Problems arise like how can all of these be integrated within mechanical system controls and how can such a model be transported from one environment to another. These will be discussed in the workshop.

Workshop Discussions: This lively, well-attended workshop on personal comfort models.

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. Personal comfort models can be based on environmental parameters (e.g., air temperature, location, relative humidity), occupant feedback (e.g., online voting like Comfy), occupant behavior (e.g., thermostat setpoints like Nest) and physiological parameters (e.g., skin temperature, heart rate, heat flux, etc.). Personal comfort models can be used for the control of personal comfort systems but they can also be applied to control general HVAC systems.

General population models like the PMV and the adaptive comfort have low prediction accuracy with respect to an individual, personal comfort models showed significantly higher accuracy, both in laboratory and field setting. Personal comfort models are not specific to an environment, they can be applied to commercial buildings, as shown by Joyce Kim, and vehicles as shown by Umberto Fugiglando, Christoph van Treeck, and Daniel Woelki. Personal comfort models are based on learning algorithms that can improve their performance when new data are collected and can rely on advanced comfort models including dynamic effects.

This new thermal comfort modeling approach is facing many of the challenges typical of a new technology, there is a large heterogeneity of input parameters, machine learning algorithms and thermal comfort metrics used as dependent variables. Several research questions are emerging and were discussed during the workshop, among them how this can be integrated within mechanical system controls and how the model could be transported from one environment to another.

During the workshop, we discussed how they could be applied to airplane environmental control systems as well. We discussed the different type of sensors that can be used with a focus on skin temperature measured with infrared image tracking or contact temperature sensors. A lively discussion emerged from it, and it is clear that more research is needed before decided which solution works best in different environments.

The challenges that researchers and the industry needs to face head on to ensure the implementation of this new comfort paradigm were also explored and exaborated on and for those interested in further discussions on research, development or implementation projects on this exciting approach to comfort provisions feel free to contact the workshop leaders.

4: Indoor Thermal Comfort: Are We Missing the Diversity Factor?

CHAIRS: Dolaana Khovalyg and Fergus Nicol

Background: The built environment is currently undergoing a transformation towards human-centred design. As our society experiences significant changes relating to increased migration, social mobility and gender equality, our working spaces are becoming more and more diverse. The challenge is now, how to provide thermal comfort and satisfaction to diverse occupants of buildings with different thermal sensation levels? Generally, perception of thermal comfort is a result of physiological and psychological processes, and It is subject to individual differences due to demographics, geography and cognition. For instance, requirements for thermal comfort for adult males and females, children and elderly people differ due to different physiology, metabolic rate, activity level and clothing patterns. Geographic location creates a background for any categories considered – human physiology, climate, thermal management practices may differ in various parts of the world. Are we missing the diversity factor when specifying thermal comfort conditions?

Workshop Discussions: The challenge of the workshop was presented by Dolaana Khovalyg. Taking the instances of gender, age and geographical background as the sorts of situation where diversity can arise, the following questions for the workshop were posed, discussed after the presentation of papers and voted on by the audience:

1. Does the diversity matter? - *Yes (100%, 20 votes out of 20)*
2. Is the variation between contrasting groups greater than the variation between individuals within a group? – *No (75%), No answer (25%)*
3. Should the indoor environment be gender-specific and age-specific? – *No (100%)*
4. Should we account for the diversity in the mixed environment (multicultural and mixed-age) and allow personal adaptation? – *Yes (100%)*
5. Should standardized temperature settings be-refined to take account of this? – *Yes (100%)*
6. Should data collection be refined to examine the diversity effect rigorously? - *Yes (80%), No (20%)*

Two papers were presented in the workshop which addressed these sort of questions:

1. *Responses of German subjects to warm-humid indoor conditions - Aspects of the diversity factor by Michael Kleber and Andreas Wagner* found significant difference in thermal sensation was shown by young female and male participants: males rated cooler in warm humid conditions. The comparison of thermal acceptance from this study with a similar study at a warmer and more humid climate region showed that ethnic origin and long-term adaptation played a role in the perception of warm-humid indoor conditions
2. *Comfort, climatic background and adaptation times: first insights from a post-occupancy evaluation in multicultural workplaces by Luisa Pastore and Marilyne Andersen.* This paper also found that climatic background was a factor in differences between subjects, but that the effect reduced over time, maybe as the subjects acclimatised. These authors also found that there was a big difference between the inhabitants of buildings of different design – so much so that other factors were often overshadowed.

Based on the discussion, there are a number of research strands which could be considered: What variations are specific to a group and is that group one which it is useful to distinguish? An example might be male/female. There are clearly differences between the two but is this a difference of clothing or of physiology? If we are looking at a situation (e.g. and office) where both genders are represented, then is there a difference which is significant in terms of the environment to be supplied? To what extent could the differences be allowed for by provision of adaptive opportunities (see workshop 8)? Are differences which are statistically significant (workshop 9) necessarily psychologically, physiologically or physically significant? Are they different in terms of their impacts on building design?

Some differences in comfort response are significant in most of these dimensions (e.g. schools or hospitals) and here the design of the building is a significant factor. In others there are distinct and separate groups that have to share a space (e.g. an office, a shop or a sports hall with athletes and audience). How can such diversities be allowed for? Geographical change can imply a psychological as well as a physiological dimension. In building practice, culture is largely a function of climate, and design a function of environmental experience. Many of the links between comfort indoors and outdoors conditions, which underpin the version of adaptive comfort used in comfort standards, are driven by the design and construction of individual buildings and their use of mechanical systems.

5: Measuring Comfort in the Real World

CHAIRS: Atze Boerstra and Adrian Pitts

Background: In an ideal world University researchers rely on accurate and advanced measurement systems when objectifying indoor thermal environments in laboratory settings or during field experiments. Systems to achieve this are however not always available or compromises may have to be made. In addition, practitioners such as HVAC system specialists and occupational health and safety professionals in reality often have more limited options available to measure thermal comfort in existing buildings. In the dealing of indoor climate complaints, or when checking a building's performance in the context of a DBFMO contract, they may require different types of measurements of indoor climate environments.

This workshop explored a range of available methods used to objectively quantify thermal comfort as experienced in real buildings and discuss their efficacy and usefulness in practice. The intention was to look beyond the borders of official standards for thermal comfort measurements (as described e.g. in EN-ISO 7726) and not only address the pro's and con's of 'old school' temperature metering and indoor climate analysis but to also look at more innovative ways to measure thermal comfort, for instance by using internet based (temperature/humidity) sensor networks in conjunction with the use of automated occupant questionnaires.

Workshop Discussions: The workshop started with an introduction by Adrian Pitts entitled 'Measuring comfort in the real world, what, where and how; accuracy, use and value'.

After that Nick van Loy talked about ‘Data collection methods for accurate spatial use within rooms’ and Ali Alzaid gave a presentation about ‘Thermal comfort assessment based on measurement and questionnaire surveys in a large mechanically ventilated space’. The last presentation focussed on the ‘Use of indoor climate sensor networks’, and was given by Atze Boerstra.

The second half of the workshop consisted of an interactive and lively discussion that aired as number of points of view and also drew on the expertise of a number of people in the room. Some key points discussed during that part are presented below.

Most attendees agreed with the presenters that measurements of thermal comfort in real life settings come with challenges. There was broad consensus that what, where and how to measure are difficulties when measuring in real world environments and have major implication on the accuracy, the use and value of the data.

The same is true for field measurements that rely on the use of sensor networks. A considerable amount of time was spent further discussing the main problems that one has when applying such networks. Questions that come up in relation to the use of sensor networks were for example:

1. How about the accuracy of the (air temperature, radiant temperature, air velocity and humidity) sensors that are used?
2. Where to locate the sensors / sensor boxes? How to make sure that they are close enough the end-users, right into the comfort / breathing zones?
3. What about verification/calibration, and validation also over time?
4. And how about general robustness of the sensors? Will they last over time or?
5. What about the reliability of the network used? And what works best? Zigbee, wifi, gprs?
6. How about the ergonomics of the interfaces used? How to make sure that end-users and decision makers understand the results? How to make sure that data are transformed into useful information for those involved?
7. What about ICT safety and privacy issues? Are there general rules we can apply? Where to store data safely (taking into account cybercrime issues)?

During the session some attendees stated that sensor networks will never be able to measure as accurately as ‘old school’ equipment or produce information as from climate chamber analysis or grade A university logging devices.

Others instead argued that this is a bit of a non-issue as modern sensor networks have the advantage of quantity and time (a huge amount of sensors built in a building measuring continuously for a year or more). An added advantage in this context is that temperature and other sensors are becoming better and cheaper very fast which is even more promising for the near future.

Furthermore, certain certification systems already ask contractually for built in sensor networks and continuous thermal comfort measurements, e.g. the WELL and the RESET building standard. Another argument considered why not just start-up companies interested in sensors and big data but also thermal comfort researchers should further look into this sensor network trend.

Some (other) observations from the discussion session:

There are still many questions now about measurement strategies using sensor networks. Often parties just built in sensors without a plan, without a clear set of research of project questions that need to be answered.

There are often issues with power supply when a sensor network is built into a building. Should one use battery power or standard power outlets? And how about the network, connectivity of the system in relation to the use of zigbee, wifi, pgrs etc

Another issue is related to measurement frequency. Should we measure every second or every 5 minutes or what? This of course in turn has an impact on both energy use (battery duration) and data storage capacity.

How about occupant behaviour? Will people displace sensor boxes or otherwise frustrate accurate measurements? And will people change their habits when they know that there local thermal environment is monitored? In this context it is good to mention that there probably soon will be a follow-up EIA taskforce on Annex 66 that will focus further on long term indoor climate measurements, occupant behaviour and challenges with the collecting and storage of measured data.

Sensors could play an increasing role in automatic adjustments of building components to save energy. For instance, when sensors are reacting to the number of mobile phones in a room as an indication for the number of people in that room. How far can you go there? And are there limits to this approach e.g. related to privacy issues?

How about the combination of sensor networks and personal comfort systems? The ‘Internet of things’ sensors included in for example heated or cooled chairs can provide information on individual behaviour and preferences. It could even help to find optimal settings for the more central HVAC systems.

Apart from direct continuous measurements, using air temperature, globe temperature and other sensors one could imagine an “Ole” voice at your desk (like Siri) that coaches you to help create the optimal thermal environment just for you.

One of the attendees mentioned that most organisations will be less interested in long term measurements of temperature and other thermal comfort aspects than in air quality data. This is especially true for buildings in city/urban environments with mediocre outdoor air quality (with unhealthy fine particle concentrations outside). So a more successful approach when one wants to apply sensor networks might be to use sensorboxes that have sensors to measure both the thermal environment and indoor air quality parameters like PM 2.5, CO_2 and TVOC.

6. Domestic Comfort and Health at Low Temperatures

CHAIRS: Lyrian Daniels and Dennis Loveday

Background: It is well understood that low temperatures are associated with seasonal ill-health and mortality. Cold climate countries are often very experienced at designing houses (and buildings more generally) that protect occupants from cold conditions. In relatively milder climates, however, there exists an under-appreciation of the health impacts of exposure to cold indoor environments which is in many cases reflected in less stringent building performance standards. Cold housing is very much an emerging issue and research subject in Australia, and other countries like the UK, New Zealand and Japan and topically like to concerns of increasing weather extremes and growing incidences of fuel poverty is many regions. This workshop will explore domestic comfort and health at low temperatures potentially covering topics including the perception of [dis]comfort at low temperatures, cultural norms in heating practices, clothing customs and practices, and the roles and relationships of and between building performance standards and public health policy.

Workshop Discussions: Presentations: Lyrian Daniel and Jonida Murataj

While issues of thermal comfort are central to the Conference, an increasing volume of papers and discussions questioned whether there are other criteria for 'good' indoor thermal environments. Workshop 6 sought to unpack some of the complexities of the relationship between thermal comfort and environments that minimise health risk, particularly at cold conditions in dwellings. With growing economic and social inequality in many countries, the quality of housing that people can access can be critical in moderating their exposure to, or protection from, wintertime cold. Perhaps the broader, shifting socio-economic context of 'comfort' precipitates an approach to 'good' thermal environments that is less about commodities provided by HVAC engineers and more about comfort being an adequate, basic, human right for occupants of all buildings.

Several themes dominated discussion in this workshop:

- *Comfort and adaption at low temperatures.* Following presentation of the two papers, many workshop participants relayed strategies (empirical and anecdotal) for adapting to cool and cold temperatures. These ranged from extreme conditions in Nepal where people adapted by wearing very heavy weight clothing, continual consumption of butter tea and infrequent bathing. In more mild-climate countries such as UK, Australia and southern-European countries, people appeared to have fewer, or perhaps less effective, adaptation strategies: more quickly resorting to heating. In progressing this theme, we may be prompted to consider whether these adaptions should be encouraged in other groups to meet energy conservation goals and whether this is desirable from a health perspective.
- *Short- and long-term health issues.* This topic dominated discussion, revealing a tension between healthy excursions to low temperatures, and how and at what point exposure to cold conditions adversely affects health (both physical and mental). Despite an existing body of evidence on high wintertime mortality and improvements in physical (and mental) health resulting from warm housing interventions, it was clear that more evidence is needed on the relationship between indoor thermal conditions and health outcomes. Importantly, it was noted that different methodological and disciplinary approaches will be required (e.g. social

epidemiology, health economics) for future work in this area, particularly if the goal is to inform policy.

- *Realities of achieving 'good' indoor thermal environments.* Several contextual issues arose in this discussion, specific to the focus on residential buildings: the economic situation of the households: construction practices and condition of existing housing stock, and the appropriateness of specifying indoor conditions that minimise health risk. In particular, these issues may prompt (re)examination of how our research balances approaches to thermal environments underpinned by energy conservation goals (free-running, dynamic, varied thermal ranges), and how it may progress to encompass health concerns.

The discussions in this workshop reveal promising leads in progressing the conference theme 'Rethinking Comfort' and exciting new directions for the Windsor Conference 2020.

7: Physiology, Health and Comfort: Implications for Real Life Impacts

CHAIRS: Wouter van Marken Lichtenbelt and Yingxin Zhu

Background: Research over the last decade has provided evidence of the importance of the impact our thermal environment on our physiology and metabolic health. In some cases environments just outside our thermal comfort zone are shown to provide healthier conditions, just as exercise is often healthier when compared to comfortable sedentary behaviour. On the other hand, during periods of cold and heat acclimation perceived comfort can increase, just as exercise increases our physical condition. Is such temperature training to promote health and well-being feasible in real life situations? During this workshop examples will be given of studies or projects that translate thermo-physiological and thermal-comfort knowledge into real recorded experiences in everyday situations. Papers are invited for this workshop that may encompass: combined laboratory/monitoring studies, monitoring physiological parameters in real life and/or modelling approaches.

Workshop Discussions: Five different propositions were interrogated in this workshop:

Proposition1: Comfort does not equal health.

Votes:
True: 22
False: 1

There was an almost general agreement that temperature training of the body and "training of metabolism" may contribute to health. It was opposed that the healthy temperature range is stricter than the comfort temperature range for elderly. Others stated that regular exposure to elevated and low temperature (heat/cold acclimation) improves resilience to heat/cold. Generally it was agreed that we should distinguish between short-term and long-term effects. There was also a more general comment that we should address well-being next to health.

A remark was made that we should not institutionalise people too much, putting them in boxes. Therefore, freedom of choice of individually-preferred temperature is important. Finally with respect to both heat and cold exposure, we should pay extra attention to include alliesthesia.

***Proposition 2: We have enough evidence to provide guidelines for a healthy thermal environment**.*
Votes:
True: 9
False: 13
It was stated that more multidisciplinary research is needed.
The question was raised: What would be necessary for the researchers to improve and specify advice for guidelines? In order to gather more objective data in everyday life contexts, we must move from the lab to real life living labs. Laboratory experiments are very controlled, may be not representative for normal life living contexts. Indeed, first lab experiments for fundamental understanding, and then moving to field studies. Both of these are still necessary.

The next question was raised as to whether we can at least improve the guidelines, despite the need for more data? Probably yes, we can revise available/initiate new guidelines based on the knowledge that we have developed in recent years.

Proposition (question) 3: How does a healthy indoor environment depend on the regional climate?
There were several cases discussed, e.g. in China, some regions with cold winters have district heating, but slightly warmer areas do not. The people in the warmer climates still face cold winters and have no heating. They are better adapted to cold and thus feel comfortable. It shows that people can adapt to environments outside their thermal neutral zone.
Finally, there was a comment that healthy environment is not just a matter of temperature, but also humidity which is also (maybe even more) related to biological threats. Indeed, IEQ is broader than temperature; other factors need to be addressed, such as noise, which has been shown to affect well-being.

Proposition (question) 4: Seasonal and daytime variation in ambient temperature.
With a more dynamic indoor climate, the differences between indoor and outdoor become less, which may have health effects. Moreover, by being exposed to a larger thermal range more resilience against heat and/or cold may be created.

Highlights

- Variation in indoor temperature, exposure to warm and cold environments may not be (entirely) comfortable, but can be healthy.
- It was generally agreed upon that comfort and health are not necessarily the same.
- Differences between sub-populations should be addressed (e.g. elderly versus young adults)
- More research is needed in both laboratory and real life living lab situations
- Nevertheless, guidelines for indoor climate can be adapted to the already existing knowledge
- We can learn from populations living in more extreme climates and those who are exposed to extremes

- We should not only address the effect of temperature and health, but also other environmental factors and interaction between those.
- We can make more use of alliesthesia to expose people to temperatures out of the thermoneutral zone.

8: Personal Comfort Systems: Providing local individual thermal comfort for occupant satisfaction and reduced energy consumption

CHAIRS: Sally Shahzad and Gail Brager

Background: Developments in the design of office and equipment have significantly enhanced ergonomics and energy efficiency in the workplace. However, several studies have shown that many find their indoor environment uncomfortable, although commercial buildings consume massive amounts of energy on heating, ventilation and cooling. Thermal control in an open plan office is challenging, due to individual differences in perceiving the thermal environment. Personal decisions to adjust the room temperature or ventilation in the office, directly impacts the comfort of other occupants, who may not share the same preferences. Providing occupants with low powered devices to control their local thermal environment allows them to remain comfortable over a wider range of indoor ambient temperatures. In addition, allowing the indoor ambient temperature to vary by even a few degrees can result in large energy savings. This workshop intends to explore advanced personal comfort systems for providing local individual thermal comfort for occupant satisfaction and reduced energy consumption in the workplace. The workshop seeks to discuss the challenges in removing barriers to industry adoption of low-energy personal comfort systems and different assessment methods such as computational modelling, laboratory testing and field research.

Workshop Discussions: Presentations: Sally Shahzad, John Kaiser Calautit, Ziqiao Li, Yiqiang Zhao. Discussion Panelists: Atze Boerstra, and Stefano Schiavon

- *Personal comfort devices.* A heated chair (heated seat and back) for the workplace was tested using CFD with a manikin and a field study in a commercial setting. Comparing standard and thermal chair (with simulated added heat flux at seat and back), CFD showed higher velocities starting at the height of the seated torso, and equal temperatures around the part of the body in contact with chair. Simulation models need to consider dynamic comfort, not just steady state. In another study, a heated armchair (covered with electric blanket) for residential purposes was tested through an experimental climate chamber by measuring heat loss with a manikin, as well as with energy simulations. It was suggested that experimental work might be more informative than CFD, recognizing that modelling conductive contact cooling is very complicated. It was suggested to use other metrics (e.g., surface temperature, equivalent temperature). The practical opportunities and limitations of these devices were questioned, as 2% energy savings in residential isn't likely to motivate people to buy them. Perhaps commercial settings are more appropriate, due to productivity benefits, recruitment and retention, and health implications (e.g. people may like them for back pain etc).

- *Behaviour, body parts and PMV.* PMV is not adequate for modelling responses to personal comfort systems because it doesn't account for behaviour. Also, it is not applicable to assess the thermal performance of local body parts, as it is about the whole body and uniform conditions. Therefore, other methods are required for local comfort, body parts or dynamic conditions.
- *Technologies.* There are a growing number of new technologies (e.g. sensors and apps) to measure the thermal environment more accurately, accessibly and easily. Perhaps new apps can do more than just adjust temperature, but also give people feedback on adaptive behaviours they might take to improve their comfort (and save energy too). One question is how to go beyond averages and capture specific behaviour-based events (i.e., adaptive action taken). One also needs to consider different scales of space – the body, and the physical and social conditions of the environment you're in. Context matters.
- *Dynamic comfort: what do people really want?* There are wide individual differences between people. The nature of thermal preferences of one person is also dynamic, and especially if people have personal control they are likely to vary what they want. The thermal sensation and thermal preference scales each give us specific information on their own; however, the combination of the two allows the researcher to better understand what thermal sensation people really want. A new term was defined: Thermal decision = thermal sensation + thermal preference. 89% wanted to feel something <u>other</u> than neutral, and "decisions" changed dynamically throughout the study. Regarding different body parts, people most wanted back heating, and least wanted heating or cooling of the face.
- *Questions & directions for future work*
  - How will personal thermal comfort change by season, location (e.g. in workplaces)
  - Why do we need personal comfort models? What should a framework include (e.g. physical conditions, perception, behaviour)?
  - Personal vs. shared space. What is the future of the workplace and how do personal comfort systems fit in? Will companies provide personal comfort systems so that people can find their comfort anywhere in the office whether individually or as individuals within a group?
  - How can personal comfort models help us better understand the adaptation of occupants and the adaptive model?

9: Using Statistics for Thermal Comfort Data

CHAIRS: Jane and Rex Galbraith

Background: The workshop will start with a general introduction to thermal comfort data and various types of statistical analyses that have been (or might be) used to help answer questions of interest. This will be followed by presentations and discussion of contributed papers in which statistics plays a substantive role. Participants will be invited to join in the discussion of these and related issues arising in applying statistics to comfort research. We request that participants send examples, with questions and comments, of issues that they have encountered in the analysis and interpretation of thermal comfort data to Jane Galbraith j.galbraith@ucl.ac.uk by 7th March. As well as using appropriate examples in the workshop we hope to provide statistical support to those who contribute examples.

Workshop Discussions: The workshop was introduced by Jane Galbraith. Three papers illustrating uses of statistical methods were presented. Some notes on basic statistics, by Jane and Rex Galbraith, were circulated. These notes are now uploaded to the Windsor website.

The first presentation, by Stephanie Gauthier, was on Moving beyond averages: variations in reported thermal comfort. Stephanie described surveys of thermal comfort sensations and preferences by classes of school children in England and Sweden, where the units of analysis were either classrooms or survey occasions. She focused on variability of the comfort votes, rather than averages, and presented some interesting relationships between variability of votes and commonly used explanatory variables such as operative indoor temperature, outdoor temperature, relative humidity and clothing insulation. Variability was measured both by standard deviations and by inter-quartile ranges. In the discussion, Rex Galbraith noted some general points of statistical methodology, including

- For highly discrete data, such as comfort votes on a 7-point scale, statistics such as medians and inter-quartile ranges, which are based on ordered observations, are poor measures of location and spread, while means and standard deviations are more useful measures.
- Also for measurements on a 7-point scale, there is likely to be an inherent relation between the mean and standard deviation, where the standard deviation becomes smaller when the mean is further away from the centre of the scale. It should therefore be useful to look at both location and spread together (e.g., by plotting the standard deviation against the mean for each unit of analysis) and to try to understand how the explanatory factors might affect both of these.

The second presentation was by Verena Marie Barthelmes on Thermal comfort attitudes, psychological, social and contextual drivers in behaviour modelling with Bayesian Networks. Verena described ongoing work in trying to use Bayesian network software to predict behaviour such as, opening and closing windows. Issues included specification of prior probability distributions and conditional independence relationships, as well as software limitations.

The third presentation was by Harry Kennard on Regression Dilution, Bayesian Analysis and Adaptive Thermal Comfort. Harry discussed a number of practical and statistical issues relating to linear regression analysis in the context of the commonly used adaptive thermal comfort model. As an aside, Harry noted that values of R-squared quoted in such studies were nearly always very small. There was also discussion on the portability of findings between different studies.

Rex Galbraith then introduced the previously circulated notes on basic statistics, which dealt with univariate and bivariate normal distributions, least squares, linear regression models, regression diagnostics, use of significance tests, pooling data, ordinal data, and looking at several variables together. Rex and Jane discussed some of these and related questions raised by participants. An overarching theme was the importance of thinking clearly about the context and purpose of data collection and statistical analyses. Other general themes were: looking at data more widely and appropriate uses and presentation of statistical models.