LEGACY OF THE 1ST INTERNATIONAL CONFERENCE ON COMFORT AT THE EXTREMES: ENERGY, ECONOMY AND CLIMATE

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COMFORT AT THE EXTREMES 2019

CATE 19 LEGACY DOCUMENT

This document reports on the contents and discussions following each of the 15 Workshops held at the conference with some thoughts from individual Workshop Chairs.

The Comfort at the Extremes Conference addressed what must increasingly be seen as THE key issue for the Built Environment in the 21st century. How to stay safely warm or cool in a warming world, with more people, aging populations, unpredictable economies and ever more extreme climate events and trends how can people stay thermally safe in the buildings in which they live and work? All of these questions are set against a background of aging infra-structures, and growing wild card risks of extreme peak energy demands, power system failures, rising consumer expectations and growing security concerns across the board.

At CATE 19, with thanks also to the Jeffrey Cook Trust, we gathered leading international figures from many related fields to discuss inter-related crucial issues, raise questions and scope out ways forward on how to best provide Comfort at the Extremes in the complex political and economic environments we occupy. The 87 delegates were largely drawn from 27 countries in our global network (www.windsorconference.com) of comfort researchers as well as Gulf-based researchers, governments, organisations and industries affected by extreme temperatures. One of the greatest challenges of our age is to design for an evolving 'New Comfort Normal' for buildings and cities as the world heats up, and ensure the Habitability and Passive Survivability of buildings in the decades ahead.

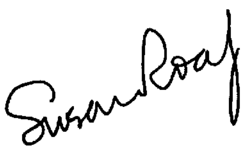
Uses for this Legacy Document on Comfort at the Extremes (CATE):

- **CATE 19 Delegates**: a chance to find out what occurred in parallel workshops
- **Non-attenders at CATE19**: an overview guide to current thinking different aspects of CATE
- **Policy Makers**: a repository of wide ranging ideas on designing and planning for CATE
- **Teachers:** a valuable resource at say Master's level where individual students/teams can be fast tracked into different aspects of and views on CATE for coursework
- **PhD students and Researchers** an entry portal into specialist and related fields with references and some insights into expert thinking on aspects of CATE

The CATE Legacy Document joins the Book of Abstracts and the Proceedings are online on:

www.comfortattheextremes.com

We hope you find it a useful introduction into this emerging subject and please feel free to share it with anyone you feel might be interested in the papers presented and the deliberations of the workshops.



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CATE 19: LIST OF WORKSHOPS AND WORKSHOP CHAIRS

No	Chairs		Workshop Subject
1	Peter Holzer	Philipp Stern	**Resilient Cooling: Low Energy, Low Carbon and Adaptive Design**
2	Wouter van Marken Lichtenbelt	Hannah Pallubinsky	**Physiology, Health and Comfort: Real Life Challenges at Extremes**
3	Rajan Rawal	Fergus Nicol	**Surviving Street Life at the Extreme**
4	Matheos Santamouris	Wolfgang Kessling	**Structures at the Extremes**
5	Kathryn Janda	Hom Rijal	**Well-Being, Health and Air Quality at the Extremes**
6	Risto Kosonen	Bjarne Oleson	**Boosting Comfort Locally with Personal Micro-climate Systems**
7	Jessica Aguera	Susan Roaf	**Behaviours, Opportunities and Expectations as Thermal Defences**
8	Alex Wilson	Runa Hellwig	**Building Resilient Cities in Climate Extremes**
9	Ulrike Passe	Jose Rob. Garcia Chavez	**The role of Natural Ventilation in future Comfort design**
10	Nikolaus Knebel	Manuel Guedes	**Designing Better Homes in Extremely Hot Climates (1)**
11	Craig Farnham	Adrian Pitts	**Evaporative Cooling for Hot Buildings and Cities**
12	Sukumar Natarajan	Daniel Fosas	**Thermally Resilient Design for Transitional Refugee Shelters**
13	Alana Hansen	Grainne McGill	**Comfort, Heath and Mortality in Real Buildings**
14	Ryozo Ooka	Hassam Chaudhry	**Modelling, Comfort and Energy Studies for Extreme Climates**
15	Samuel Amarillo	Hanan Al-Khatri	**Designing Better Buildings in Extremely Hot Climates (2)**

Workshop 1:

Resilient Cooling: Low Energy, Low Carbon & Adaptive Design
Chairs: Peter Holzer and Philip Stern

Peter Holzer introduced the workshop with an overview of the imperative for Resilient Cooling and its definition. He pointed out that rising temperatures are becoming a growing threat to not just comfort loss, but to lives. After decades of research on comfort and energy-efficiency the focus shifts to survival. It is not only about efficiency any more, but also about sufficiency and resilience. Within 25 years the installed stock and cooling capacity of Air Conditioning (AC) has tripled. This surge drives up peak load demands which cause serious strains on electricity networks and increase the occurrence of blackouts. As a result, the resilience of houses against extreme temperature occurrences suffers. Furthermore, the surge of AC makes outdoor spaces even hotter (through the exhaust of hot air) and less liveable and challenges the goals of decarbonisation and climate protection.

Resilient Cooling on the contrary should address:

- Reliability & Failure Safety
- Affordability & Accessibility
- Energy Efficiency & Carbon Neutrality
- Social Inclusiveness

He outlined the work of **IEA Annex 80** (see: http://annex80.iea-ebc.org/) that investigates resilient cooling technologies which perform the following:

1. Reduction of externally induced heat gains
2. Personal comfort improvements apart from space cooling, e.g. offering adaptive options
3. Removing heat from indoor spaces, i.e. sensible cooling both passive and active
4. Removing humidity from indoor spaces, i.e. latent cooling

For the Annex the Resilient Cooling Research Targets are defined as following:

- *Climate conscious building design in a "modern" context*
  Translate vernacular principles to modern needs and expectations. Ventilative Cooling, Cool materials, Solar shading, low E surfaces, etc. Manage expectations, offer adaptive options
- *Hybrid Cooling*
  Introduce AC as a supplement, not a replacement of good building design. Use AC locally and temporarily.
- *Balanced Heating and Cooling*
  Make use of stored summer heat for heating applications in winter
- *Energy Efficient and Carbon Neutral Cooling*
  Increase Energy Efficiency Ratio (EER) and Seasonal Energy Efficiency Ratio (SEER). By peak shaving, load shifting, utilisation alternative heat sinks, utilisation of other processes than electric compression, etc.

Jose Roberto Garcia Chávez presented the second paper in which he Characterised Passive Cooling Systems for Extreme Hot Humid Climates[iii]. He presented results from a pilot test of a Passive Cooling System (PCS) which had been carried out in predominantly hot and humid conditions in the city of Mérida, Yucatan in Mexico. For this field study six modules (0.8 x 0.8 x 0.47 m) have been constructed. The outer shell was constructed of plywood (0.015 m) with a 0.045 m thick layer of insulation (polystyrene foam). Each module has been equipped with different means of passive cooling such as:

- Thermal Mass (TM)
- Thermal Insulation (TI)
- Night Radiative Cooling (NRC)
- Indirect Evaporative Cooling (IEC)
- Solar Control (SC)

Over a period of ten days of a typical overheating period the indoor dry bulb temperatures (DBT) have been monitored and compared to exterior climatic date from the nearest automated meteorological station. Best performance, resulting in an absolute reduction of 5 K during the maximum temperature of the day, showed module 1 which is had been equipped with thermal mass and thermal insulation. Modules 3 (indirect evaporative cooling, thermal mass and solar control) as well as module 4 (night radiative cooling, indirect evaporative cooling, thermal mass and solar control) also showed significant reduction of indoor DBT.

Mr. Garcia Chávez concluded that in particular thermal mass is essential for the reduction of thermal swings and important for the cooling of spaces like the other integrated bioclimatic strategies: thermal insulation, solar control system, convective cooling, nocturnal radiative and indirect evaporative cooling. The experiments will continue during climatic periods of transition and under heating and shall inform the planning of new train stations along the projected Mayan train route.

Nikolaus Knebel then addressed in his presentation on 'Identity through Efficiency'[iii] the prevailing problem contemporary architecture has of relating building performance to local site conditions and climates, which increases energy loads for heating and cooling and leads to non-resilient and generic design models respectively. He argued that during the 1960s through the discovery of fossil fuels the societies of the Gulf region entered into a phase of modernisation which triggered fundamental transformation of traditional cultures. This resulted in unrestricted urban expansion with scattered and generic building designs and massive traffic infrastructure, that provided neither an adequate response to the extreme climate nor created a regionally specific sense of place for its inhabitants. The design challenges of building in an extreme local climate have been widely ignored.

Knebel argued that both, the creation of identity and the achievement of energy efficiency can both done through passive strategies and the architectural design of these features, where on the contrary active strategies are placeless and work everywhere and therefore aims to identify successful passive design strategies for the extreme climate of the Gulf. He refers to Christopher Alexander's "Pattern Language" as a method to gather and communicate information about architecture and gives examples of such patterns for passive designs himself. The following illustrates one of seven patterns presented.

Knebel proposed a 'Roof Over' theory based on the idea that the urban fabric of the Gulf region used to be very dense with narrow alleys between buildings. This shaded the buildings against each other as well as the public spaces in-between. In modernist cities structures are often situated further apart from each other due to car-oriented urban design leading to outdoor spaces which are fully exposed to solar radiation and heated up beyond comfortable conditions.

Therefore, many gains can be made by looking for *Cover* to reduce heat locally by roofing over public outdoor spaces. Despite the very harsh climate of the region – open public spaces can be turned into comfortable places trough all kinds of horizontal layers that passively, moderate sun, light and wind.

The presentation was also very well received. Mr. Knebel's response to the question whether detailed analysis of the building performance of the examples shown had been carried out, was that quantitative verification is underway but that there are no results yet.

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[i] Chávez, J.R. Garcia and A.Carrillo (2019). Characterization of Passive Cooling Systems for an Extreme Hot Humid Climate, Proceedings of the Comfort at the Extremes Conference, 10-11 April, Dubai, pp.59-67.

[iii] Knebel, N. (2019). Identity through Efficiency. (Re-)Discovering Passive Cooling Strategies as an Architectural Idiom for the Gulf Region, Proceedings of the Comfort at the Extremes Conference, 10-11 April, Dubai, pp.68-86.

Workshop 2
Physiology, Health & Comfort - Real Life Challenges at Extremes

Chairs: Wouter van Marken Lichtenbelt and Hannah Pallubinsky

1st speaker: Timothy Adekunle, University of Hartford, USA (see proceedings)[i]
2nd speaker: Hannah Pallubinsky, Maastricht University, NL (see proceedings)[ii]

In this workshop discussions centred on both the findings of the papers and also on the following propositions. Notes on those discussions are included below.

Proposition 1.
A healthy indoor environment is independent on the regional climate

It was generally opined that a healthy indoor environment is <u>dependent</u> on the regional climate, because the indoor environment has always an interaction with outside weather and the seasons. In addition, people's expectations change with regional differences, including cultural aspects. With respect to the latter, the culture may also be claiming what is healthy. Recently, popular USA science stated that the optimal (indoor) temperature must be the Kenyan outdoor temperature. We agree that this is too simple. In general, expectations influence how we perceive an environment, e.g. 'I will get ill when I am in the cold'. Also a typical 'northern' (cultural) idea. Perception may also relate to the way information is provided, e.g. the weather forecast presenter says: *hot* day 33˚C or *warm* day 33˚C. The 'how' affects or changes the mindset of people. Although we know that the indoor environment and comfort depend on the regional climate, we do not yet have sufficient information about *what* is healthy and *how it depends* on local situations.

Finally, it was mentioned that other environmental parameters such as light, outside view, colour of light etc affect our thermal comfort. Light has been shown to also influence thermos-physiology and psychology (e.g. Hue-heat Hypothesis).

Proposition 2.
Thermal comfort = health

The comparison with exercise training was made. Exercise might not be comfortable, but it is very healthy. Sometimes the body needs to 'work' in order to stay healthy and resilient. The same can apply to temperature: temperature training. Sometimes, being outside of the comfort zone can positively affect health. With respect to resilience, an analogy was made: children play in dirt, which positively affects their immune system; use of antiseptic soap: not necessarily healthy, if done all the time. So how about the idea that only comfort can't be healthy. The other way around, being comfortable is not necessarily very healthy. One can be perfectly comfortable but have BMI of 35kg/m2. <u>Acceptable</u> temperature rather than comfortable temperature might be more correct term in context with health. The connotations of the word *comfortable* are not the same as those around *acceptable*.

In addition, it was mentioned that the (comfort) range is important. If the comfort range is (understood) as a wider range rather than a very narrow temperature band, healthier situations can be achieved.

Striving for comfort used to be seen as striving for health in former times (which is also connected with an evolutional principle: the body sends signals to strive for comfort to obtain (food) energy or to save energy. That's why we search for food when we are hungry, so we don't starve, or for a comfortable temperature, so we will not waste energy by, for instance, shivering). However, today, this natural tendency to strive for comfort has been taken it to a different level. We just think we 'need' to be comfortable all the time. Also, comfort is what we know, it is familiar to us, and everything that deviates from it we don't know and suspect to (still) be hazardous. Are other indicators needed than just comfort regarding health? E.g. the metabolic rate needs to be considered. However, we do not yet know what is the best parameter to look at regarding 'health', and we don't know what are the long-term effects of cold and heat.

In addition, a single/uniform temperature can be boring. A more dynamic environment, which maybe sometimes involve temperatures outside the (static) comfort zone, might be even pleasant (alliesthesia) and healthy as well!

In the standards and building regulation medical conditions are nowadays not considered. For instance, do drug dosages need to be adjusted in different temperatures? Yes, probably, for certain drugs, e.g. glucose lowering and hypertension medications, but clarifying studies are needed.

A critical note: Comfort is a subjective concept, whereas health is more quantitative/objective. So maybe we're comparing apples with pears. It may over-complicate the issues to link these two directly.

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[i] Adekunle, T. O. (2019). Stress indexes and thermal comfort in structural timber school buildings during cold and warm seasons, Proceedings of the Comfort at the Extremes Conference, 10-11 April, Dubai, pp.100-118.

[ii] Pallubinsky, H., B. Dautzenberg, E. Phielix, L. Schellen, M.A. van Baak, P. Schrauwen and W.D. van Marken Lichtenbelt (2019). Regular passive exposure to heat induces beneficial effects on cardio-metabolic health, Knebel, N. (2019). Identity through Efficiency. (Re-)Discovering Passive Cooling Strategies as an Architectural Idiom for the Gulf Region, Proceedings of the Comfort at the Extremes Conference, 10-11 April, Dubai, pp.87-99.

Workshop 3:
Surviving street life in extreme climates

Chairs: Rajan Rawal and Fergus Nicol
Reporter: Vishnu Vardhan

Extreme climates encourage the use of mechanical conditioning of indoor spaces to ensure liveability. However, it is not just the indoors which require climatic moderation; urban streets and open spaces require efficient planning to mitigate extreme thermal conditions. This workshop, titled 'surviving street life in extreme climates' touched upon these topics. The three papers presented focussed on the extreme 'warm and humid' to 'hot and dry' climates and discussed the redemptive role of climatic moderators such as the foliage and shade, to help ensure the comfort of the pedestrians.

The first paper, *Impact of trees on passive survivability in extreme heat events in warm and humid regions*, was presented by **Ulrike Passe,** Iowa State University, U.S. (CATE 2019 Proceedings, pp.119-133). The paper concentrated on establishing a scientifically validated model of urban forests through surveys, 3-D modelling, and simulations. The second paper, *Upgrading the outdoor comfort of suburban residential neighbourhoods in the Gulf region*, presented by **Alexander Kader** from the German University of Technology, Oman, was a commentary on the possible mitigation methods to improve the urban landscape of areas with a low population density in Oman (CATE 2019 Proceedings, pp.134-146). The third paper, *Thermal sensation and pedestrian comfort on hot summer days in the hot-humid subtropics*, was presented by **Kevin Ka-Lun Lau**, Chinese University of Hong Kong, Hong Kong (CATE 2019 Proceedings, pp.147-154). This survey-based study presented the subjects' comfort responses in various urban microclimates.

The first paper was set in Midwest America, where tackling the ever-worsening high humidity, urban heat island, and flood-risk problems is important. One possible solution was to plant well planned urban forests. However, at that time there existed no method for quantifying the cooling capabilities of trees in an urban context. This study recorded the location and size of the 55 species of trees in the Capitol East neighbourhood of Iowa. In addition, it monitored the indoor air temperature across multiple air conditioned houses as well as the outdoors to have a climatic context. The tree geometries were normalised into 8 simplistic yet distinct forms and incorporated into the urban model through grasshopper scripts. The output provided a rendered 3-D model of the cityscape which yielded levels of solar radiation and ultimately offered insight into the extent of shade offered by the trees. It was found that the shade could potentially lead to 20% energy savings. The simulation model used for calculating the wind velocity contours also accounted for the evapotranspiration losses of various tree sizes and considered a three-seasonal variation in the leaf density. The CFD simulations were better facilitated with the development of an automatic meshing tool and movable grids. Incorporating the understanding of wind flows around trees in urban parlance offers scope for devising better-designed passive design features. Future projects include using a probability matrix and radiation blockages in the simulations for enhanced accuracy.

The second paper talked about the regions in Oman with a low population density due to the misuse of abundant energy resources. These regions tend to have mono-functional buildings, have unused land, lack vegetation and shade, and offer negligible pedestrian comfort and public support. This study selected a 1 km^2 suburban residential neighbourhood area of Al-Mawalih and proposed the implementation of several strategies such as - urban greening, aiding public walking and cycling, providing shading, reducing 'sealed' area, raising the albedo of the built surfaces, green facades, and sustainability enhancing building design features, and providing ventilation corridors. The proposed plan was simulated using UMI 2.0 (by MIT Sustainability design lab) and the results for 'bicyclability' and 'walkability' were obtained and optimised. The final outcome of this study was to provide guidelines and recommendations with a graphical representation of the 'environmental impact' versus 'human effort or cost' in reference to the possible steps of action. Further studies are proposed which will involve detailed simulations of individual planning strategies.

The third paper focussed on the warm-humid tropical city of Hong Kong. The combination of topographical diversity and dense population spread brings about a plethora of issues to deal with, perception of the urban microclimate being one of them. This study focussed on gathering public responses on their perception of thermo-physiological and psychological parameters in three distinct locales representing the microclimates of the residential, street, and urban-park areas. In addition to the standard thermal comfort questionnaire, the subjects were asked about their perception of the acceptability of aesthetics, acoustics, air quality, convenience, and safety. The findings showed that the people regarded 'aesthetic satisfaction' as the most decisive ambient factor; the survey results also indicated that the acoustics influenced peoples' perception of thermal comfort. Further developments in this study plan to include the choice of colours, greenery, soundscape, and compactness as the influencing parameters in the questionnaire.

Following the presentations, the audience and the authors engaged in a discussion. Ulrike Passe, responding to a few questions, added to her study and elaborated that the simulation model was validated against a series of on-site readings, thereby maintaining consistency with real world situations. She informed workshop that forthcoming simulation models will incorporate satellite data for various soil properties and allow the calculation of the change in Air Quality Index attributable to the effect of trees. Alexander Kader, when asked about the nature of the study, commented that it was more relevant as an 'urban design' exercise, with a study involving a detailed study of physical variables to follow. He suggested that a sustainable, green urban landscape should be a part of everyday life, small parks should be preferred to large ones, and the residential network should be intertwined with these parks. Kevin Ka-Lun Lau told that the biggest challenges he faced during the subjective surveys in the outdoor spaces were to manage with the small time frames and to accommodate the variety of peoples' responses.

The three studies, each emanating from a distinct urban setting, gave a multi-layered insight into the theme of thermal comfort in outdoor conditions. The case of Oman delved into the very fundaments of conceptualising the approach to 'green' urban spaces on a high level. It brought out the challenges, remedial measures, and the probable trade-off scenarios which can help establish an effective urban greening policy. The Midwest American study went a level further in the same direction, through a scientifically validated approach. Their approach allowed the quantification of metrics indicating the effect of the shadow and evapotranspiration on the thermal ambience. They also commented on the appropriate orientation of the building facades and fenestrations with reference to the foliage. With the 'affecting' factors discussed in the first two studies, the Hong Kong based study discussed the 'affected' humans. Their study provided an insight into the multi-dimensional nature of thermal perception and helped bring the focus back to the purpose behind creating comfortable outdoor spaces – for the peoples' comfort. These three studies provided the audience with a deeper insight into the topic and helped create a common consensus that the synergy of multiple-layers of analysis, focussing on the mode, material, and man, will help bring about more comfortable outdoor spaces in the extreme climates.

Workshop 4:
Structures at the Extremes

Chairs: Matheos Santamouris and Wolfgang Kessling

Nowhere is the performance of buildings so critical as in extreme climates or during extreme events. This is where the ability of a structure to withstand extreme temperatures, winds or precipitation may mean the difference between life and death. Such environments are also places where the use of energy is an important factor because if the building does not perform well then the price for that inefficiency must be paid for with high cost and impact energy to the structures comfortable and in extremis, habitable.

Three papers in this workshop demonstrated different facts of the challenge of making and keeping buildings comfortable in extreme weather. A forth paper challenged the existing rating system, undervaluing natural conditioning and ventilation in moderate climates of Australia.

The first paper reported on the retrofit of an existing mosque in the UAE that aimed to ensure occupant comfort while trying to achieve nearly zero energy consumption in the building. It was by **Ayesha Athar and Evangelia Topriska** of Heriot Watt University (CATE 2019 Proceedings, pp.155-173) at the Dubai campus and presented a study undertaken in an existing mosque in Dubai, designed to achieve UAE's nearly zero energy building target of 90 kWh/m2/year. Their first step was to use on-site measurements and operational data to inform design decisions. For the years 2016 and 2017 the identified energy use intensity (EUI) are in the range of 212 to 237 kWh/m^2/year indicating how challenging the net zero targets in the UAE context are. They then modelled the mosque's energy use in the 3D simulation software, IESVE, and use this to estimate overall reduction in energy use due to different passive and active retrofit measures. The presented solutions were fairly standard and in line with Dubai Green Building Regulations and Passive House Standards, targeting on the thermal shell as well as on active systems. The resultant reductions in possible energy use was still high and the potential contribution to further emission reductions using on-site solar PVs systems were also explored. Given enough solar contribution to offset the high energy use intensity of the mosque it was able to meet the rather conservative emissions reductions required. One might wonder how much more could have been saved with more radical passive, locally appropriate, measures applied. Also in the calculation of the impact of building integrated PV systems on the mosque how much cooling demand was reduced by the shading offered by the PV panels themselves? Interestingly, there seem to be no issues with placing PV panels on mosque roofs.

The second paper dealt not with issues around the installed energy systems, but with the fundamentals of the materials and construction of the building itself. The paper on Australian earth building industry asked a hugely important question of whether Australian energy efficiency policy is killing this low energy construction method (CATE 2019 Proceedings, pp.174-188). **Peter Hickson**, President of the Earth Building Association of Australia showed how compliance with the Nationwide House Energy Rating Scheme (NatHERS) methodology is resulting in mud brick buildings not passing the energy efficiency standard test despite they are safer and more comfortable to occupy during extreme weather. Reasons discussed where the limitation in the rating systems not giving value to natural conditioned and ventilated and buildings, rating temperature set points (of systems) whereas comfort can be achieved in some climates with a good passive mass linked ventilation design as well as the focus on rating on thermal shell efficiency. Discussions ensued on the suitability of the methods that are commonly used to benchmark energy performance and as we go forwards into more extreme climate trends and event surely the occupied temperatures that result from a design without the use of imported energy will become the critical factor on the resilience of a building type? The whole approach to why and how such energy standards are set need a fundamental review in Australia where increasing summer temperatures are leading to more deaths in buildings year on year.

Manuel Correia Guedes of the University of Lisbon presented a paper on the structural design of a movable, modular shelter that was designed for the extreme wind conditions of a site in Collins Bay on King George Island in Antarctica (CATE 2019 Proceedings, pp.189-197). Stripping away all but the shape, materials and fixings of the shelter this structure had to be designed and re-designed before and during its erection on site to take into account the nature of the site itself and the prevailing winds that can reach up to 200 km/h in the region. The tent has been erected and is being tested over twelve months on site to see if it can withstand the extremely adverse conditions it is in. It provided a case study of design for the really extremes of climate and showed how much more effort has to go into the contextual considerations of the design of a structure on which, in extremis, may depend the lives of its occupants. Details of thermal comfort have not been discussed, anyhow the new system appears to perform better than the first prototype.

Back again into a hot dry climate, the final paper looked at the performance of a ventilated wall system combined with evaporative cooling in an educational building in hot dry climate. It was presented by Sara Mohamed of the University of Nottingham and started by highlighting the importance of School buildings that can have poor thermal comfort and poor indoor air quality (IAQ), which affect the pupils' health, education and productivity. With means of computational fluid dynamics (CFD) the paper investigated the thermal performance of naturally ventilated walls when adding passive cooling to the wall fabric and looked into passive cooling techniques to enhance thermal comfort and the temperature and ventilation inside the classrooms. The results demonstrated that the proposed passive cooling, in conjunction with outdoor air, could significantly reduce the temperature and enhance the thermal comfort inside the classrooms. As it was modelled, a stunning reduction of the maximum air temperature from almost 44 °C to around 22 °C under an external shade temperature of 46 °C was found. The paper showed the importance of new thinking to explore the performance of not mechanical efficiency but substantial reductions of indoor air temperatures through innovative thinking and structures. The discussion was about the mass flow of the cooled air and overall achieved cooling performance in the space.

Workshop 5
Well-being, Health and Air-Quality

Chairs: Kathryn Janda and Hom Rijal

The CATE 2019 conference showed both the depth and breadth of comfort research, as well as the growing importance of climate change in the built environment field. The conference plenary sessions showed where comfort research needs to stretch and reach, particularly in terms of recasting "comfort" outside the bounds of thermostat set-points in commercial offices. The need to stay alive during hurricanes, heat waves, polar vortexes, and flooding, introduce words like "survivability" and "resilience", which extend the field significantly. Research into how to create better thermal and social conditions in refugee camps asks us to question not just extreme weather, but extreme humanity.

At its heart, the word "comfort" signifies coziness and ease. This has come to be associated with the luxury of air-conditioning in the tropics and wearing tee-shirts inside heated buildings in winter. Going forward, these kinds of activities may be a vanishing luxury. But that does not mean that psychological and physiological well-being need to disappear. Instead, they may need to be remembered and re-imagined as part of a new vernacular that accepts and recognizes the climate rather than trying to overcome and exclude it. Indeed, biological research shows that adaptive behaviour to changing environments may actually be healthier than thermal monotony.

Workshop 5 on health, well-being and air quality explored three different topics within this realm. **McGill, Sharpe, and Devereaux** (2019) considered some of the trade-offs between air-tightness and air-quality, particularly in social housing. They call for a new research agenda to answer urgent questions about the relationships between energy, comfort and health in housing and describe a new research network poised to take on this challenge.

Indraganti's paper (2019) investigates gender differences in environmental satisfaction in offices in Qatar, Japan, India, and seven more Asian countries. Although there were regional differences, she found that women office workers in Asia are 37.3 % ($p<0.001$, N = 22, 343) more likely to be dissatisfied with their thermal environments than their male counterparts. This presentation raised many questions in discussion on the importance of different clothing assemblages worn in the Middle East between not only men in offices but also women in Westernised and non-Westernised outfits. Also discussed was the significance of who typically controls thermostat settings in offices and the role of control in feelings of satisfaction and dissatisfaction within a shared office. Many of these issues have not been resolved, and may, in fact not be easily quantified despite continued investigation. Comfort is a both a state of mind and an environmental condition, so survey responses can be genuinely influenced by variables that are extremely difficult to control for such as: office politics, social dynamics, and cultural aspects.

Interestingly, **Djamila's** (2019) extensive and statistically rigorous meta-analysis on thermal comfort, which covered historic (1982-1994) studies conducted in Thailand, Canada, Australia, Pakistan, and the UK, found different results. Her analysis revealed that gender is not a significant variable in predicting subjects' thermal perception under neutrality. This leaves us to wonder whether comfort expectations are changing over time and place. As women become more empowered, are they becoming less comfortable? Or have they always been uncomfortable, but have earned the right to say so?

Returning to the theme of the conference overall, the theme of Workshop 5 asks us to consider what "well-being" truly is. In developed societies it tends to be associated with "well-having" (Sachs 1992) but maybe CATE should argue for a broader definition based on the evolving need for gender equity and climate resilience.

These conclusions also point to the continued need to involve people in research to be able to find adaptive solutions to evolving environmental, social and cultural change. Research in the built environment tends to focus on hardware (sticks and bricks) rather than software (people and culture). Perhaps the built environment, like a computer, needs both hardware and software to work together to address the challenges of the future.

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Workshop 6
Boosting Comfort Locally with Personal Micro-climate Systems

Chairs: Risto Kosonen and Bjarne Olesen

Only the two chairs and the three speakers participated. None of the presentations were dealing with radiant systems and one dealt with personal system. **James Trevelyan** presented a paper on a localised air conditioning: comfort with sustainable energy demand (CATE19 Proceedings, pp. 338-345). He explained a product providing cooling and increased air velocity to blow on a person. Most interesting was that the device came with a small tent that was cooled by the unit. This was perfectly focused on getting a good sleep in warm environments without mosquitos and cool temperatures.

A very good paper from Mexico by **Adriana Lira-Oliver, Ángeles Vizcarra-de los Reyes, S. Rodolfo S. Vilchis-Martínez, and Gabriela Luna-Alonso** dealt with the traditional building style using Adobe materials/bricks (CATE19 Proceedings pp. 346-363). The paper called 'Phase Change Materials as part of building construction systems and indoor passive thermal regulators within the Sonoran Desert: a zone in Mexico with increasing air temperatures and vulnerability to climate change' described how many new residential buildings now used other materials because people did not think the adobe houses were fashionable or "sexy". Unfortunately, the focus in the new buildings were too much on using insulation and not providing building with thermal mass. Therefore, the paper studied how to combine new materials with Phase Change Materials to get some of the same features as adobe houses. The study showed that adobe material gave the best performance regarding comfort; but the use of PCM did also improve the thermal comfort significantly. Now the researcher will start making experimental testing of with houses with different construction materials.

The last paper was by **C. Heracleous, C. Charalambous, A. Michael, A. Yiannaka, V. Efthymiou** and was on the development of an innovative compact hybrid electrical-thermal storage system for historic building integrated applications in the Mediterranean climate. It dealt with integration of PVs on heritage buildings, showing different methods of achieving it using case studies on existing buildings (CATE Proceedings, pp. 363-376).

Workshop 7

Behaviours, opportunities and expectations as thermal defences

Chairs: Jessica Fernández-Agüera and Susan Roaf

Three papers were presented in this workshop. The first was on the subject of the *Wintry Thermal Environment and Domestic Energy Use in Nepal*. It was presented by **Pokharel Ram and co-written with Hom Rijal and Masanori Shukuya** from Tokyo City University (CATE 2019 Proceedings, pp.377-382). This paper introduced several unique elements to the discussion if climate and comfort. The most glaring was that of altitude, that in Nepal dictates to a large extent the climate of a settlement. The verticality of the country offered a new insight into the impact of elevation on comfort.

The second paper was on *Indoor air quality, cold stress and thermal comfort in multi-family timber frame buildings* by **Timothy O. Adekunle**, University of Hartford, Connecticut, USA (CATE 19 Proceedings, pp383-394). The paper provided an overview of environmental conditions measured in the homes in winter and provided an interesting contrast to the Nepalese study. The mean temperatures measured in the homes we above this measured in the Nepalese ones and there were recorded complaints about the stuffiness and the occasional smells and measurements did show theoretically high levels of humidity and CO2 in the occupied homes. However, these may seem insignificant when set against the Nepalese data where in some homes up to a dozen people may sleep in the same room. Clothing and life styles as well as expectations of what is required as a bare minimum for comfort may affect researchers thinking in such studies.

The third paper in the workshop was on the surface of it very different. It was given by **Kheira Anissa Tabet Aoul** of the Architectural Engineering Department, United Arab Emirates University, UAE. It was on the subject of *Sustainability, Literacy and Higher Education: Paradigms and Challenges in the Built Environment of the Gulf Region* (CATE 19 Proceedings, pp395-406). In this paper Aoul raises the really important question of how best to transform our educational systems into high impact mechanisms for delivering to student's vital education on how they can survive and thrive in a rapidly changing world, with it changing climate. She looked at ways in which her own taught courses address this changing world and shared with the workshop her own endeavours to integrate essential and often basic sustainability and resilience lessons into her education and training programmes.

Based on these three experiences and discussion followed, one essential factor that should be understood when analysing comfort in built environments is that not everyone can afford or has access to the energy resources that would enable them to sustainably apply mechanical solutions to thermal control problems. Such problems are particularly acute in developing regions with extreme climates where the population uses the energy sources within most immediate reach, essentially biomass, to ensure survival.

In the absence of sufficient and reliable electricity grids in many such places, especially remote rural or mountainous areas (such as in Nepal), timber is the primary heat-generating resource. There the need to condition dwelling interiors is often met to the detriment of indoor air quality, attributable both to system inefficiencies and highly sporadic ventilation to save energy. The approach also leads to local pollution, with direct implications for human health and urban ecosystems. The adverse impact on plant cover and concomitant erosion in the areas affected compounds other environmental problems. In other cases, electric supply and grid fragility and the existence of power shortages due to political or economic situations or geography necessitate the use of immediately available energy resources (biomass, diesel generators…) or induce long periods of inappropriate conditions in housing, workplaces, schools, medical facilities and so on.

Resorting to the use of external energy sources for environmental control, the solution of choice in today's scenario even where energy efficiency is well developed, may not be accessible in many areas of the planet. Particularly in the most extreme situations, that may carry high human costs.

Against that backdrop another significant challenge, particularly in cities in developing regions, is the optimisation and improvement of building envelope and passive system performance a pressing need. The aim is to reduce the dependence on external energy, ensuring buildings' role as life support systems in extreme episodes by enhancing both their capacity to serve as shelter and the duration of their autonomous operation in free-running mode with no external support.

One important measure in this regard is to raise inhabitants' awareness of the most suitable and efficient use of resources and handling of set point temperatures, an understanding of buildings' response times and the reestablishment of traditional adaptive solutions. Buildings should, then, accommodate user interaction, enabling them to adjust and control environmental conditions by opening windows (outdoor conditions allowing), controlling solar protection, scheduling thermostats and similar. These circumstances tend to overlap with cultural implications and customs in developing regions as well as with acquired habits of consumption and use, often as an expression of rejection of tradition and a sign of higher social status and personal success.

In many of the planet's extreme climates, in response to the perception of more or less recent 'country wealth', a significant proportion of the population has not had to tackle (or even be unaware of) the issues around maintaining indoor comfort, with solutions often poorly adapted to regional needs. In cities in such areas, mechanical environmental control systems (HVAC) tend to be in permanent operation, maintaining conditions unrelated to climate realities and an artificially supported way of life, even giving rise to paradoxical circumstances

such as uncomfortably cold indoor temperatures in the summertime in extremely warm climates.
As a rule, the political use of energy precludes any awareness of energy vulnerability or of societies' need to improve their climate resilience in buildings and urban agglomerations. Sensitisation measures are required to harmonise environmental concern and the responsible use of resources and disassociate both from the notion of prosperity and societal dynamics in terms of consumption and national reality building, without being presented as a weakness or a limitation imposed on social groups. Certain educational, particularly university-level, initiatives merit mention in this connection, with their invitation to social actors and users to deliberate on the future ecological footprint of today's actions. Sensitisation, education and reflection on different scales in societies facing extreme situations would appear to be the most effective tools to generate change for a less uncertain future.

It really is interesting reading these papers side by side. What they show in effect is an excellent geopolitical cross section from the global poor, through the global middle classes to the global rich. It is a cross section through buildings, through behaviours and perhaps most important, through attitudes. What is striking is that the most un-resilient and vulnerable population in this cross section appears to be the very rich. When the lights go out in the mountain communities of Nepal, it really makes little difference. When they do so in the American timber homes, people are much more likely to suffer during extreme events but it is in the home of the very rich in the Gulf where they are most vulnerable during extreme events, like the failure of a power grid during an extreme heatwave there. Behaviours evolve in a society, hand in hand with the money and energy available to result in building types and societies. The weaker the behavioural link between the natural environment, the climate and the occupants of buildings and the lifestyles they adopt is, the more vulnerable they are to the catastrophic failure of the their artificial life support systems. Aoul is right, we need urgently to educate the young on these physical and behavioural links between our life in buildings and the state of the natural climate and environment outside them, if for no other reason than to help them when the artificial systems fail.

This was a very insightful workshop indeed. The socio-economic expectations of a society or local population frame their buildings, the lifestyles and in turn their manifestation in behaviours. It appears in these three case studies that different societies are more or less connected to the environment around them. The less connected to their environments they are, the less resilient they appear to be, to extreme events. If those connections between nature and populations are woven in threads of behaviours, then it may be possible to transpose behaviours between populations to enhance the resilience of societies less able to survive extreme events. The understanding and harvesting of useful behaviours may well provide a major adaptive opportunity, but only within the context of an understanding of those behaviours within different building types.

Workshop 8
Building Resilient Cities in Extreme Climates

Chairs: Runa T. Hellwig and Alex Wilson

Background: Extreme Climates challenge our current approaches on how people can stay not only comfortable, but also thermally safe and healthy in a warming world. Highly occupied rural settlements need our special attention, as many of them are located in extremes climates populated by low-income population exposed to these extremes. This workshop aims to discuss these challenges and propose ways forward towards building resilience in the complex political and economic environments we occupy.

Presentations: The workshop started with two presentations, the first by **Denise Duarte** (CATE 19 Proceedings, pp. 407-417) introducing the audience to a starting-point framework in order to develop a three-scale (metropolitan, local, building) climate adaptation plan for Sao Paulo, which has a significant density and has seen a temperature rise of 3 ˚C since the thirties. Sao Paulo is expected to grow from today 21 million to 41 million citizens. The framework was based on a review of a wide range of adaptation plans from other places as Germany, which has a long history of planning and addressing climate change but also Barcelona, Paris, London, Sydney and Melbourne, several cities from the U.S. Brazil currently has expressed an intent of a national adaptation plan. National initiatives provide not sufficient support, the federal government is not on board and, unlike the U.S., the states have less autonomy. Therefore, research activities contribute to the three scales for a future climate adaptation plan: urban heat islands and the vegetation changes are examined, climatic measurements/ weather stations downtown and in suburban areas allow to develop data models including the urban heat island effect and the calibration of these models, and future weather data can be used for simulation of future scenarios. The presentation concluded that whereas many mitigation measures are well-known, this does not hold for adaptation plans which need to account for the urban heat island and high urban density. The output of the several research activities will hopefully raise awareness and support governmental or initiatives by the citizens. There is an opportunity to follow IPSS AR6 cycle and aiming for AR& Special Report for Cities.

The second presentation by **Rajan Rawal** (CATE19 Proceedings, pp. 418-439) examined how a net zero energy building in hot dry India can be done and how energy and comfort performances of such a building would be. Space cooling in India uses currently 135 TWh/yr (2017-18) in 20 years this will raise to 600 TWh/yr (2037-38). Ahmedabad, where the building is located, The benchmark energy use per floor area is ~240 kWh/(m^2.yr) and the design target for the net zero energy building of CEPT University – Centre for Advances Research in Building Science and Energy (CARBSE) was 58 kWh/(m^2.yr). The building offers several operational modes. During comfortable outdoor condition, natural ventilation and outdoor spaces can be used. During hot weather, indoor spaces can be conditioned. Monitoring allows analysing a wide range of things: equipment performance, behaviour, on-site weather station, controls on all systems, visual displays, including historic data. The measurement data are used also in teaching, e.g. showing the effect of thermal lag of 2 to 6 hours in maximum or minimum temperatures. It allows to follow up on surface temperature course over several days and shows the energy consumption of equipment, plug loads, lighting, as well as solar generation. Thermal comfort surveys are conducted weekly showing 80 to 90% acceptability.

Discussion: The subsequent discussion focussed of the two presentations and the broader goal to build resilient cities in extreme climates. Rajan Rawal pointed out that the CARBSE building was designed to follow bioclimatic principles for most design decisions. As this building is designed for research and comprises a lot of equipment for several operational modes life cycle assessment of embodied energy would probably not be representative for other Net Zero Energy Buildings.

In the Ahmedabad climate, how often would the AC mode be active and how is it chosen which mode to use? Over half of the time the building is in AC mode and the change of to another mode is determined by outdoor temperature. Further it was discussed how such a building could be scaled up. As it is a building designed for research it can't be scaled up but the learning that has occurred can be shared as e.g. some learning regarding the building envelope of the CARBSE building which could have been done with less intense insulation or as another example the slightly over dimensioned AC systems. There is also the learning that it is possible based on bioclimatic principles to design outdoor spaces as part of the building design which allow people to spent comfortable time outdoors.

Denise Duarte clarified that while the atmospheric urban heat island effect is about 4˚C, the effect occurring on surfaces indicate much more dramatic increases of 20 to 30˚C. Sao Paulo, located on 700 m above sea level, is not even the most challenging climate as it gets a sea breeze. Then it was discussed whether climate adaptation plans for other climates can be used as a role model for the local climates of Brazil? Australia's and California's climate have some similarities with local climates in Brazil. There exist already good examples of a new plan in Curitiba but it has got a milder climate than e.g. Sao Paulo. It was also further discussed that the federal government in Brazil does not take the lead in climate adaptation and so in Brazil laws tend to express an intention of future developments. Applying the Brazil Environmental Code – get points, like a certification system, But, it is a small program—for planting grass, etc. pretty minor incentives The benefit of incentives have been discussed. But since most of city is informal and illegal – law and incentives don't apply there. But there are initiatives by the people, e.g. in the favelas as they organise themselves for informal services like garbage. There could be more of these local initiatives!

Workshop 9
The Role of Natural Ventilation in future Comfort Design

Chairs: Ulrike Passe and José Roberto García Chávez

Background: Natural ventilation generally indicates the supply of fresh air to and removal of stale air from indoor spaces using only the pressure differences induced by natural forces as in direct wind pressure and pressure differences in the form of thermal buoyancy force, due to indoor and outdoor air density due to temperature differences by driven outdoors air movement through specific geometry details of the building itself and its windward and leeward envelope openings.

Natural ventilation serves occupants ventilation requirements and can also provide the removal of heat, moisture and thus cooling the indoor air and providing hygrothermal comfort. Natural ventilation strategies thus depend on local climate conditions, building type proper design of the flow path, and human behaviour as noted later. natural ventilation is considered a major sustainable design strategy due to its omission of electrical energy use. Nevertheless, its utilisation in buildings involves understanding and careful treatment of various relevant aspects including its driving forces and spatial strategies.

Natural ventilation involves different heat transfer mechanisms between the human body and its surrounding environment, which generally occurs in the form of sensible heat, by convection and radiation, and, the form of latent heat, by evaporation of moisture on the skin. Due to the necessity to open windows in many natural ventilation strategies, their concept is closely related to occupancy behaviour and in addition occupancy perception of comfort. The suitable and smart control of these heat transfer mechanisms is the basis for achieving the maximum hygrothermal comfort conditions with the minimum energy consumption for the space accclimatisation of buildings.

In natural ventilated buildings the perception of comfort is much more a multi-sensory experience than in mechanically ventilated and cooled spaces. Occupants control and these multi-sensory experiences become extremely important and concern the research community on multiple levels. (It has to be noted, that the workshop took place in an undercooled air-conditioned class room with most workshop participants complaining one way or another about uncomfortably low temperatures.) Natural ventilation can save significant energy for moving air and for cooling (removing heat and moisture), but it needs very careful design considerations and a thorough understanding of occupant behaviour.

Two papers were presented in the Workshop addressing the workshop theme in interesting and diverse ways.

A paper on Modelling Natural Ventilation in Commercial Buildings Using Data-Driven Methods was presented by **Romana Markovic, Jérôme Frisch and Christoph van Treeck** (CATE19 Proceedings, pp. 458-479) described a thermal comfort study in hybrid designed buildings, where natural ventilative cooling and ventilation strategies and mechanical ventilation interchange is often met with automatic control strategies programed in the building automation system using a variety of comfort set points based on adaptive and predictive mean vote occupancy requirements. These strategies often lead to very complex control algorithms. The authors explored how data driven models can support the often erratic occupant behaviour in non-automated window opening scenarios. The presentation focused on the results of a long-term research project in commercial buildings based on modelling the interactions of their occupants relative to operable windows. The research dealt with two case study buildings located in Germany under natural and mixed mode ventilation strategies and explored the way Data-Driven-Methods can assist in sometimes unpredictable and uncertain occupant behaviour in scenarios of non-automated operable windows. Thus they addressed the question: how can the power of machine-learning support the operation interactions of occupants by controlling the active systems predictively anticipating what occupants might do with the windows instead of controlling the windows anticipating what occupants might want as their comfort conditions.

The second paper in this workshop was titled A Paradigm Shift in Comfort Design for Singapore and was a case study presented by **Wolfgang Kessling** from Transsolar Energietechnik GmbH, Munich, Germany, co-authored with **Martin Engelhardt** (CATE19 Proceedings, pp. 469-368). Reporting on a built-project for the School of Design in Singapore, designed to be net zero energy building with its homogenous tropical hot and humid climate. Dr. Kessling started his presentation by stressing the fact that most buildings in Singapore have as a fixed standard very low temperature air conditioning systems and this in turn provokes high-energy consumption patterns. He explained that a more sustainable approach could be applied by implementing a Hybrid System Design, based on the Adaptive Comfort Model, which can provide more advantages, such as reducing investment costs as well as energy demands for ventilation and space cooling, whilst presenting lower dependence on mechanical systems. Dr. Kessling described in detail the design process and the supported dynamic model simulation providing a relative higher space ambient temperature setting, of about 28°C in combination with breeze and abundant fresh air. The design goal to integrate natural ventilation in this situation provided a challenge to the clients, future occupants and the design teams. Wolfgang Kessling highlighted a few often unchallenged characteristics of the space needs for air conditioning system using large ductworks in suspended ceilings. One big advantage of low-energy cooling using chilled surfaces combined with natural ventilation is the increase of usable space. A properly designed naturally ventilated or hybrid building requires conscious design regarding siting and shading as well as a shallow floor-plate. This means as a building in the tropics, the orientation to prevailing winds and sun was critical and led to the position of the facades and opening scenarios**.**

In this case, the return air system could be eliminated completely. Additional considerations for hybrid and naturally ventilated buildings is the air velocity across the occupant body using either the natural breeze and when that is not sufficient, additional electrically run fans. An interesting discovery was reported by the design team, that very little industry standards exist related to the spacing and positioning of fans for optimum user comfort and controls. The challenge to provide natural ventilation by implementing this very low energy cooling system using cool indoor building surfaces assisted by low energy fans and combined with some other passive cooling design strategies such as a suitable façade orientation and solar control systems have provided an acceptable comfort perception from occupants.

Discussion: The following discussion was very lively and interesting starting with the urgent pledge to conduct more research regarding the achievement of personal hygrothermal comfort when using fans. For example, which individual controls expose more of the body to air movement and which set of speeds and which directions provide most comfort satisfaction. The room exchanged anecdotal knowledge and concluded, that comfort with fans relates not just to the air speed itself, but the variability of air speed over the occupant body, ideally addressing the body horizontally for maximum surface exposure. Research was reported, that constant air flow is not as attractive as changing air flow for positive and optimum comfort sensation and even joy. This means that even if the air flow is induced potentially be buoyant air. The occupant body should ideally be exposed to air moving horizontally. This led to a vibrant conversation about the opportunities for stack effect ventilation, which can bring in air in for cooling, but should not be confused with the full multi-sensory experience of air movement around the body, which relates to perceived air speed. These comments were followed by further conversation about the complexity of breeze comfort and ventilation, which also relates to the indoor outdoor connection vs fan driven comfort. A research questions which warrants further attention.

The speaker cautioned to investigate natural ventilation for all its component and requirements, for exchanging air, vs temperature of the air vs comfort via air movement. In the presented case study, the fan grid was overlaid with patterns of chairs and optimization was also driven by cost.

Notable in both presentation was the goal to provide the occupants with full freedom about the control of the openable windows. In the Singapore case study, the window operation and the fan operation was completely left for the occupants to decide, when to open and when to turn on or off, yet the windows would report their opening position to the building automation system and shut off the tempered air in order to save energy. The switch on of the fans is thus totally optional and independent of the provision of temperate air, because the energy it takes to run a fan is fairly negligible.

The next discussion point was the impact of vegetation, which was not quantified in the case study, but considered very important as large scale vegetation in front of the windows contribute to the invitation to open the façade and provides a more transient environment without the often experienced thermal shock in highly cooled environments. The author reported, that the vegetation surrounding the building certainly aids the reduction of common thermal shock situation, typical for conventional air-conditioned situations. Thus the only essential integration of occupancy control with the building automation systems (BAS) which cut across both papers was the fact that occupants were allowed to do what they wanted with the windows to keep comfortable.

For the RWTH modelling research the next topic is currently to develop the controls based on the model predictive control (MPC) strategies developed in the recent past. The current understanding is thus, that occupants do whatever they want, thus the HVAC system has to be designed to anticipate what the occupants do to roll back the system and thus save energy. The reasons for opening behaviour can be manifold, it can be humidity a driver, but given the 20 million data points the most consistent correlation was the CO_2 level. When that was in the rise windows would get opened. Thus the modelling is not attempting to anticipate what the occupant might want and do it for them, but to anticipate what the occupant might do and alter the active systems to save energy. The occupant is complete in charge of their personal controls and thus comfort. Thus the recent studies, that occupant behaviour and opportunity for control as a large contributor to satisfaction has taken root in the conversation. The control algorithms is protecting the energy, while the occupants are in charge of their comfort and if the windows are open too long and the environment gets uncomfortable, they will close the windows to allow the active systems to kick in. thus the occupant also receives some kind of 'training'.

The educational building case study in Singapore has now become a precedent for other buildings on the Singapore campus as other buildings get renovated and built, not the exact design, but the conceptual ideas. While it took time to convince the clients, they are now very proud of their building.

The discussion concluded with the challenge to retain comfort with natural ventilation under more extreme conditions. Romana Markovic made a very interesting point, that modelling occupancy and modelling extreme climate has many similar features and this would lead to interesting new data driven modelling research questions. In general, driven by the Singapore case, the participants agreed, that buildings design with full occupancy control is the answer. Buildings designed for natural ventilation with hybrid added cooling provide excellent comfort with adaptive comfort, and the limits to comfort perceptions have not yet been reached. Well-designed buildings with personally controlled fans can keep the occupant comfortable even at temperatures around 30 degrees Celsius. The possibilities have not been reached and the design and engineering community can still push the envelope further, keeping occupants comfortable AND saving energy often wasted for cooling.

As a final point, it was stated that the combination of suitable natural ventilation strategies associated with appropriate low-energy hybrid cooling systems, based on the application of the adaptive comfort model was an important method for achieving optimum comfort conditions, with maximum energy savings. This is a sustainable sound approach directly related to the reduction of energy consumption and the mitigation of Global Climate Change.

Workshop 10
Designing Better Homes in Extremely Hot Climates (1)

Chairs: Nikolaus Knebel and Manuel Correia Guedes

Theme
The workshop's theme of designing better homes in extremely hot climates was approached through four case studies from countries from hot and dry or humid climate zones that experience rapid economic development and demographic growth and urbanization: Iraq, Saudi Arabia, India and the Philippines. Many questions arose including: what measures can be taken to ensure that the many buildings that are yet to be built, as well as retrofitted, can be designed to perform energy efficiently. The four studies did not present building prototypes, but explored key building parameters such as users' comfort expectations, the application of reference models through building codes or standards (ASHAE, Passivhaus, etc.) as well as building laws that influence the emergence of certain building typologies.

The first paper presented was *Energy Retrofit for Buildings in Iraq: Insulation Parametric Study* by **Saif Rashid et al.** (CATE19 Proceedings, pp.479-490). This theoretical study looked at the impact of insulation on the thermal performance of a multi-story residential unit in an existing building in Iraq. The study found that insulation measures can reduce the energy demand for cooling (and periodically also for heating), but suggest that further measures like e.g. Externals shading should be utilized as well. Reflecting on the policy framework in which these measures are embedded, the study suggests that the Iraqi building code needs to be revised in order to take an adaptive comfort approach into account, as is done e.g. In the recent Saudi building code that deals with a similar climatic condition. The problem of applying high levels of insulation without reducing direct gain by shading is an important lesson to take on board.

Thermal Comfort and Energy Use of Affordable Housing in Ahmedabad, India by **Garima Kamra et al.** reported on an empirical study investigates the energy demand of users in selected, existing affordable housing compounds in Ahmedabad, India (CATW19 Proceedings, pp.491-508). In contrast to the other presented papers in this workshop it is important to notice that these compounds are not designed in a vernacular style, but straight-forward modernist designs with a low-cost construction method mainly in concrete. The study found that users adapt to intermittently uncomfortable indoor thermal conditions by using low-tech solutions to mediate the discomfort, such as adding clothing insulation, turning on/off fans, closing/ opening doors, and windows. The energy demand in these compounds remains as being baseload driven. Here, the problem lies with outdated and inefficient appliances. The paper suggests that government subsidies therefore focus on supporting the upgrading of these appliances to bring down the electricity demand in these compounds.

The third paper reported on *a modelling study of a Passivhaus in a Tropical Climate* by **Roy Sigalingging et al.** (CATE19 Proceedings, pp.521-533). This theoretical study looked at the feasibility of applying Passivhaus standards to a building in the tropical climate of the

Phillipines through modelling the performance of the buildings with IES software. It finds that following the Passivhaus standards in designing and constructing the buildings would achieve a significant, however not fully satisfactory, stabilization of indoor temperature and humidity levels. In order to optimize the performance of the building, a deviation from the standard was tested and the ground floor temperatures were coupled with the ground by removing the floor insulation layers over the floor slab. This results in an overall lower energy consumption. In conclusion of these findings, the study suggests the need to develop a hybrid approach to design if the Passivhaus method is to work in this climates, blending the Passivhaus standards with local vernacular building principles.

In the final paper, **Hanan Al Khatri** reported in the *Effects of an Improved Saudi System of Houses' Setback On Indoor Thermal Comfort Conditions* (CATE19 Proceedings, pp. 509-520). This research investigated the relationship between the related setback building rules in the buildings code and the thermal performance of residential units in Saudi Arabia. Simulations of different volumetric arrangements with house walls set on the plot boundary showed a significant reduction in cooling loads under the new rules. A contrasting investigation was undertaken into cases from Muscat, where such a setback rule is not yet applied, and its finding reinforced the conclusions of the first study on the benefits of the new regulations.

Discussion: Leaving the usual methodological questions about input data in simulation studies aside, the following issues arose of relevance to the whole conference:

Universal building codes vs local climate conditions and comfort expectations:

- In the Iraqi case study, the codified comfort expectations as specified in an *imported building code* were found to be not suitable for the climate local conditions potentially resulting in overdesigned cooling systems.
- In the Philippine case study the universal Passivhaus standards were found to be only partially applicable for the given climatic conditions, which means that a designer of local solutions needs to address more local factors and less import concepts from other climate zones.
- In the Saudi case the revised building code now allows for climatically more suited building typologies (back-to-back courtyard houses) reflecting the traditional typology and resulting in more energy efficient performance.

A general conclusion points to the imperative of locally relevant and developed regulations for the built environment to reduce energy use and enhance low carbon comfort.

Comfort expectations vs societal affluence:

In the Indian case study, the comfort expectations of users of affordable housing units were met in passively cooled buildings, however, such user behaviour changes with rising incomes and thus the so-called "AC-surge" in emerging markets in hot climates is an issue of grave concern. Here, at least, is a positive example of what is possible with a common sense approach that hopefully will not get lost with rising economic levels. It is obviously doubly important that this low key, low tech range of comfort options are promoted not only to increase the affordability of comfort for the poorer populations, but also to do so in a heating climate.

Workshop 11
Evaporative Cooling

Chairs: Craig Farnham and Adrian Pitts

Three presentations were given in this workshop starting with an overview paper from the workshop Chair. These were followed by a discussion period from which the main points are recorded below.

Craig Farnham gave a presentation on 'Evaporative cooling summary of personal research and other research in Japan' (CATE19 Proceedings, pp. 533-542). Farnham works in Osaka, Japan, a city with the worst heat island in the country. Has been working in evaporative cooling (EC) research there for 10 years and he went over some of the key rationales for the technology and his work in it. The material is covered in his paper in which he reviews of EC types and history, and provides an over view of the physics of EC – 'free' cooling which has the useful property for Osaka that the hotter it gets the better EC works. He touched on the main types:

- Direct (including misting), working with a constant enthalpy process and aiming for a ¼ to ½ of possible effect, typically 2-3^{0}C cooling achieved.
- Indirect involving a constant moisture content process / desiccant cooling, using desiccant to dry air then indirect to regenerate it with more moisture.

Is EC worth it? Achieving cooling of about 2^{0}C or 3^{0}C, and in some cases only 1^{0}C, The answer is 'yes'. Heat stroke cases rise rapidly at about 33^{0}C-34^{0}C so 1^{0}C has an important impact for people benefitting from it. With mist EC, small droplets evaporate quickly and too big droplets cause wetting, a 'Magic' of mist and raised water temperature. For this even high temperature water can be used as it evaporates quickly. Higher temperatures can have some value as they can counteract legionella problems.

Small temperature drops and the use of mist has a big influence on thermal comfort at higher temperatures, potentially contradicting PMV calculations and assumptions. Tests using warm air with mists were undertaken. Most people think its cooler in mist even with warmer temperature water and this proved to be the case.

Examples were given of EC methods and research:

- Zero Energy Cool Tree (shading combined with mist) – benches became cooler too – more people liked this
- Mist with sunshades – more general examples – different colours and meshes – shade improves impact of EC mists even just small areas of shade
- Perceptions of mist on train station concourse – mist visible 3m up - people who noticed mist more likely to vote improved comfort – so psychological impact might be responsible
- Spot cooling a/c with mist added as supplement – also improves reaction
- Semi-open spaces misting tests still has impact (but not in fully enclosed as humidity gets too high)

- Wind plus mist in area under building – positive impact on comfort
- Measurement types
- Mist as artificial sweat effect of 3-10W/m2 increase
- Cool louvres – wetted surfaces over which air flows
- Rotating spray-wetter EC screen (with advertising?)

Presentation 2 was on the 'Performance evaluation of Indirect Evaporative Cooler (India)' and given by **Shoumik Desai** (CATE19 Proceedings, pp. 543-563). After describing the research questions and objectives Desai started by looking at an evaluation of low energy cooling systems, including case studies with data collection of environmental energy and thermal parameters.

Case Study One was undertaken from July to December 2018 in a food processing factory with 50-60 workers on the premises from 8am to 6pm. Plans and photos were included, with descriptions of instrumentation and equipment monitoring. Results including statistical checking, graphs comparing outdoor air, supply air, and indoor air temperatures also outdoor, supply and indoor air RH, wet bulb and dew point temperature effectiveness shown. Also average hourly energy consumption over a 5 month period was included, with a monsoon period. He sets out his quantifications for the relationship between CoP and cooling capacity for two reported cases, as well as correlations with wet bulb depression and WBT/DBT data and water consumption related to outdoor RH. 1840 comfort surveys were carried out including reported comfort and thermal acceptance plus preference votes. He reports a 5^0C cooling effect with a CoP of 5, resulting in an impact of 40% more than other use of energy eg 7kW compared to 5kW. The supply air of his system had a RH 78% over a one hour stabilisation time. he identified some issues with power consumption of the systems investigated and poor performance in the air flow system. Occupants voted that the environment was 'hot' showing that the evaporative cooler still needs modification the to achieve required cooling levels and may need to improve the air supply system.

The third presentation was on Dry Mist Systems and their Impact on Thermal Comfort in Singapore, by **Zheng Kai** (CATE19 Proceedings, pp. 564-581) which in his absence was presented to audience by Craig Farnham. This study used atomisers of three different types to produce dry mist, and was based on the premise that work on this subject has a definite research gap, in that thermal comfort predictions don't seem to work in theory with such systems while they may in practice. The system reported on uses two high pressure jets for which the droplet size was measured. Tests were undertaken at the university campus in Singapore for which the environmental parameters, the various participants and the experimental set up were described including time periods. The climate profile temperatures and relative humidity with and without misting were recorded as were the impacts of thermal sensation and skin wetted-ness votes. The latter was recorded as a negative sensation / expectation from wet skin, which may differ from the results of other studies. Also reported were the physiological effects in terms of skin temperatures for different parts of body. His conclusions were that one should not use such EC systems in high wind speed ad he reported a heightened tolerance for humid air in Singapore, concluding that SET* has smaller role in determining comfort in that climate and culture.

Considerable interest was shown in the subject and its potential as an economical and effective method of achieving outdoor and indoor comfort in more extreme conditions.

- Questions followed such as how does a mechanical 'Cool tree' compare with a natural tree in terms of its cooling effect? Suggestions were posited around the idea that possibly a combination of spray, plus air speed has a bigger impact than their separate effects. The personal human response may be stronger with one that the other.
- Concerns were expressed over water quality issues like fear of legionella caused by such systems. In Japanese studied system the water flow is purged each day with hot water. No other responses from the audience on this were forthcoming,
- How can warm mist be perceived as cooler? Test done on this used an ultrasonic evaporator so added no heat and there were some discussions around this point.
- Train station cooling in semi-open spaces – how much water use is involved? The answer was that nozzles in these systems use two litres water per hour. An example was given that if 400 nozzles are involved using 800 litres per hour ie. This requires less than 1 m^3 of constant water flow. Different nozzles have different flow rates and patterns and sell for different prices. Nozzles last about two years on average
- How to calculate number of nozzles required? Separation and thus reach from one nozzle depends on the radius of a cone sprays. It is necessary to avoid interaction of sprays to avoid things getting wet, but different systems incorporate different effects including the use of oscillating fans.
- Are systems used at high humidities? Generally not above about 70% RH.
- Is there any impact on equipment and systems nearby from higher humidity? Probably not, given how A/C is used indiscriminately anyway.
- Wind tower cooling with cooled basement how does it work? – not clear from diagram – ask Prof Roaf.
- How does water evaporate from a pool? Some discussions ensued about this that proved inconclusive but people agreed that moving the water is perhaps a better of increasing evaporation rates.
- Is there any validation using software? Yes there is some standard software on the market, although ideal droplet evaporation is difficult to achieve in field experiments.
- Question were asked about Indian factory and how it works. Some basic discussions followed including some regarding the maintenance of systems.
- Are there other case studies that can be followed? There are two underway in Osaka.

Workshop 12
Thermally Resilient Shelter Design

Chairs: Daniel Fosas and Sukumar Natarajan

Rationale: Shelters, unlike other buildings, are by definition, temporary. Modern requirements for shelters often arise in remote locations or in response to large humanitarian crises. Indeed, we are currently experiencing the largest forced migration of people on record, with current estimates at nearly 69M people - a population the size of the UK. Hence, adequate refugee shelter is a pressing issue. Understandably, in a developing humanitarian crisis, thermal conditions are usually not given high priority. However, as the lifetime of camps is extended, many otherwise temporary encampments get converted into a more permanent state, and are termed "transitional" by the aid agencies. Some studies have suggested the average lifetime of such transitional shelters is 17 years. The core issues we wish to explore with this workshop, are hence:

(i) how low-cost high-resilience shelters can be designed and
(ii) how one may consider aspects of culture, tradition, politics and other socio-economic norms whose interaction with the built environment significantly affect performance.

Contributions: Four presentations were made to the workshop that addressed not only the housing of forcibly displaced populations, but also the thermal performance of portable structures under cold extreme conditions.

Paszkiewicz & Fosas[i] presented an interdisciplinary work between social sciences and environmental engineering on how refugee agency can articulate improved housing solutions for all the agents involved. They report on the experiences on the Jordanian refugee camps of Azraq and Zaatari and the Ethiopian camp Hitsats as examples of practices witnessed in other camps around the world. The active decision-making by camp dwellers reveals as a humanizing factor that can, at the same time, paliate cultural and technical shortcomings of current solutions such as thermal discomfort. The potential bottom-up top-down framework is proposed and envisaged as an active dialogue between camp dwellers, authorities and professionals. Authorities would focus on the provision of a flexible infrastructure based on technocratic considerations.

Architects and anthropologists could ignite and mediate conversations between camp dwellers and authorities on how to best empower refugees to develop their own shelter solutions compatible with technical requirements. Due attention must be paid to the immediate outdoor space from a planning perspective as past experiences reveal that this is a space with the greatest potential for active decision-making by camp dwellers in the long-term.

Rosa et al.[ii] drew the attention to current trends in forcibly displaced populations. They reflect on the high levels of displacement recorded in recent years, the potential climate-change related displacements in the new decades and the shortcomings of current solutions. They present both a quantitative study on the simulated thermal conditions of selected shelters in Jordan, Afghanistan and South Sudan and a qualitative evaluation of the adequacy of currently implemented solutions. Authors concluded that the Jordanian shelter provides a thermally resilient solution in relation to the other two.

Emerging aspects in the qualitative evaluation are speed of construction of shelter, the need to consider thermal comfort in the design process and their adaptability to house different types of individuals and families. Based on the results obtained, Rosa et al. (2019) recommended three strategies to improve the thermal performance of the Jordanian shelter, namely increased ventilation, increased insulation and control systems that facilitate the control of natural ventilation by occupants.

Pinelo Silva et al.[iii] and **Correia Guedes et al.**[iv]presented two studies about a novel shelter solution for extremely cold climates based on the Mongolian yurt. They both reflect on the methodology to deliver a successful solution for a remote location in Antarctica. Pinelo Silva et al. (2019) demonstrate an iterative process to minimise the wind load imposed on the structure while accounting for optimal insolation and safe access to the shelter during after blizzards. They stressed the importance of building prototypes at the intended location to test the real buildability of the shelter design and how locally-sourced materials can be used to build windbreaks that benefit both the structural integrity of the shelter and its thermal performance. On the other hand, Correia Guedes et al. (2019) reflect on the lessons learned from the ageing of the research stations currently present at the location. They found in the Mongolian yurt a relevant precedent for this climate since it is a typology that minimizes both structural wind load and thermal losses.

However, they highlighted the importance of careful re-evaluation of the elements that build up the yurt. The structural solution needs a robust top ring to bind timber elements together, aspect that requires a careful manufacturing process to deliver expected resistance. The skin of the yurt is made of a highly-insulating lightweight multi-layer fabric that allows heating the tent up to 12 °C with just occupant heat gains for an external temperature of -20 °C. Internal temperatures where 5 °C above external ones when unoccupied thanks to the high absorptivity of the external materials.

Discussions: Attendees reflected on the need of clarifying the requirements for shelter solutions. Shelter provision is heavily influenced by the motivating crisis, agents involved and the high uncertainty on what resources might be available to implement a shelter solution and the trade-offs between habitability, costs and lifespan of solutions.

With regards to the planning of camps, Prof. Roaf recommended ‘thermal landscaping’ as a means to influence the thermal conditions that shelters need to deal with. Building on the experience of nomad communities in desert conditions, she noted that Azraq could have benefitted from perimetral trenches to protect the shelters from the strong prevailing winds of this location.

Given the current situation, the overall consensus was that there is an urgent need to define a *process* of how to define and deliver shelter solutions, not prescriptive recommendations of particular shelter designs.

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WORKSHOP 13
Comfort, Health and Mortality in Real Buildings

Chairs: Alana Hansen and Grainne McGill

Introduction: The broad range of temperatures occupied in buildings globally shows the amazing ability of people to adjust themselves, and their environments, to stay comfortable and healthy. However, it is well known that some people are more at risk of adverse health effects in hot conditions, particularly the elderly and the young who may have less-than-optimal ability to adequately self-regulate their body temperature in the face of more extreme conditions. In this workshop there were two presentations focussed on the thermal comfort and adaptive capacity of such sub-populations in different climatic and geographic regions.

Firstly, **Indrika Rajapaksha** presented a paper on 'Adaptive behaviours of elderly for cooling in Tropics (CATE19 Procs., pp.621-635): Field studies in naturally ventilated aged care homes'. This study was undertaken in the tropical climate of Colombo, Sri Lanka, with the third highest proportion of elderly people in Asia. The study found that indoor environments in naturally ventilated aged-care homes were overheated in buildings with low air movement, in-operable windows and often no fans. Properties with less mechanical interventions typically had more design features such as verandas. Bedrooms were given most attention, although older residents often preferred to spend time in communal areas. At present the design is not supportive of the thermal preferences of the elderly residents who want cool areas and breezes. Architecture could therefore be improved to incorporate open outdoor areas and courtyards for comfort cooling, providing users with sufficient opportunities to adapt when exposed to sub-optimal conditions. It is particularly difficult for sick elderly patients who are bed-bound and have limited mobility, unless the bed is located close to a window. During the lively discussion that followed it was revealed that there is a lack of funding for the state owned aged-care facilities, together with a lack of architects involved in the design of aged care homes. At present the design of care homes fails to meet the needs of residents in terms of opportunities for adaptation to the high temperatures.

The second paper by Chryso Heracleous summarising her field study of comfort conditions in educational buildings in Cyprus (CATE19 Procs., pp.636-649). With indoor temperatures in the selected classrooms in summer ranging from 32-34ºC, the importance of cross ventilation to remove hot air in the free-running buildings was clear. In winter, closed classrooms gave best operative temperatures but resulted in poorer indoor air quality (i.e. high CO_2 levels) which can hinder student health and productivity. Issues were raised in the post-presentation discussions like the requirement of pupils to wear standardised uniforms in many schools that offer limited opportunities for adjustment to varying climatic conditions. Also, even in classrooms with open windows, curtains are often closed during the day to avoid glare, with a likely effect on air movement. Potential barriers to window opening included security issues and control issues as only pupils sitting adjacent to windows tended to operate them.

In summary, the presentations were complementary, demonstrating problems with over-heating in care homes and classrooms, buildings that should provide a protective and supportive environment in which to live and work. **Several key challenges were identified:**

i) The lack of studies on such vulnerable groups was highlighted, particularly concerning the presence of adaptive opportunities.
ii) Access to, and interventions for, such groups for research purposes is often difficult for logistical and ethical reasons.
iii) Questionnaire designs for thermal comfort research were important for vulnerable groups and it was suggested that sometimes pictures with facial expressions could be used.
iv) Especially for complex and vulnerable groups, one size does not fit all when meeting the needs of a range of users and occupants with different thermal requirements. It was highlighted that both the elderly in care and children in school are often not in a position of power in terms of thermal comfort preferences, as others make decisions for them. In aged care facilities the nursing staff are active and have different thermal requirements to the vulnerable and sedentary residents, many of whom do not wish to complain. Similarly, in a school environment the thermal needs of the teachers may differ significantly from that of the students; yet they are usually in control of heating and ventilation systems. Therefore, these groups are not only at particular risk due to reduced thermal regulation, but have restricted ability to adapt to their environment. Different thermal comfort needs of staff and their vulnerable charges is therefore a challenge for building designers.

Overall, the Workshop demonstrated a need for architects to respond to subtle and challenging social issues and processes relating to the provision of aged care and educational buildings. Evidence from the research presentations showed there were several lessons to be learnt that can then be used to inform policies, primarily that it is a key imperative to improve thermal comfort conditions of buildings designed for use by the most vulnerable at different ends of the age spectrum. It is clear that we need better thinking in relation to the functional design of buildings for function in terms of aged care and schooling is not always apparent and opportunities for adaptive behaviours can be restricted. There is a lack of consideration of how buildings are actually used and a need to adapt to future processes and future conditions. Climate chamber studies are not sufficient to explore these important issues. To prevent temperature-related health effects in vulnerable occupants there is a pressing need to measure *real buildings* in *real world conditions*, particularly in extreme climates.

Workshop 14
Modelling, Comfort and Energy Studies for Extreme Climates

Chairs: Ryozo Ooka and Hassam Chaudhry

Background: Simulation models provide valuable insight into thermal comfort in buildings based on passive design, materials, user behaviour, and cooling loads. The accuracy of these models is therefore vital. It is essential to keep advancing simulation methods in order to continue optimising opportunities for providing thermal comfort in extreme climates. Four papers here explored comfort and energy modeling for extreme climates, within the context of the key global challenges today of rising energy consumption and Urban Heat Islands.

The first paper by **Tania Sharmin** (CATE19 Proceedings, pp.650-664) was on the 'Impact of urban geometry on indoor air temperature and cooling energy consumption in cities'. Using numerical methods the study explored rises in cooling and energy demands when compared traditional and formal landscapes in Bangladesh. The work suggested that traditional forms of building arrangement have a better micro-climate than the formal urban environment. The study showed that significant improvements on the indoor conditions of the adjacent buildings can be achieved by optimising solar and air flow design by modifying urban geometry, and incorporating diversity to achieve better indoor and outdoor conditions.

Gustavo Cantuaria then presented on the 'Studies of the thermal effect of glazed facades and vegetation on the UHI in Brasilia' (CATE19 Proceedings, pp.665-679). The work looked into the development of Brasilia from its early years and how traditional architecture has given way to modern methods of high-rise construction, thus increasing the Urban Heat Island magnitudes. This paper again pointed out that modern design solutions had higher impacts than previous solutions emphasizing the importance of natural ventilation for comfort and low cost cooling.

Daniel Attoye presented on 'Innovation in Construction: The case of BIPV customization in extreme climates' (CATE19 Proceedings, pp.680-691). In this study, an investigation was carried out into factors that determine the use of Building Integrated Photovoltaic systems such as cost, aesthetics and power production. This paper presented a review of BIPV customisation case studies, which show possible cooling load reduction up to 1.9% and energy efficiency increase up to 10% in referred BIPV custom strategies. It also highlighted the fact that building occupants were over 90% in favour of the use of solar energy to power their office.

Alan Meier finally presented a paper on the 'Non-intrusive assessments of thermal discomfort in real time' (CATE19 Proceedings, pp.692-707). A very interesting piece of work on using inspiration from hand-movements, body gestures and Microsoft's Kinect technology to replicate comfort signals in humans. These complex signals using hand and body gestures, if modelled correctly, could provide an early indication on people's perception of their environment, therefore reducing energy consumption. They posited that prolonged tracking of these gestures can be converted into a metric, the Thermal Comfort Index (TCI) that reflects a person's current thermal comfort. The TCI could then drive an HVAC system and provide a highly-personalized thermal environment.

WORKSHOP 15
Designing Better Buildings in Extremely Hot Climates (2)

Chairs: Samuel Domínguez-Amarillo and Hanan Al-Khatri

There was a huge interest at the CATE 19 conference on *real building solutions for extreme climates*. Four papers were presented for discussion.

The first reported on the thermal and energy demand of Middle Eastern solar decathlon prototypes and was presented by **Ferran Yusta** of University of Bordeaux (CATE19 proceedings, pp.708-739). It outlined a fascinating journey for designers who were not familiar with the design requirements of very hot climates, through the use of vernacular archetypes and cooling systems that were interrogated using standard European modelling approaches and tools. Each of the fifteen registered teams from around the world proposed different architectural solution to achieve a low energy consumption, in the presentation each was analysed and a new classification was suggested relating solutions to different climatic season, with a discuss of their efficacy. A broad palette of options was presented but this raised the question of how to choose optimal solutions for particular sites.

The second paper approached the issue from another direction. Having built a zero-energy building to their own design **Nikolaus Knebel and Mike Wassmer** of the German University in Oman then carried out a full evaluation of the contribution of the PV system to the energy demands of the house (CATE19 Proceedings, pp.740-753). The findings were so positive that the authors were moved to use this case study building as evidence of the benefits of moving most housing to the use of PVs and to recommend policies for the region to promote the wider us on PVs on buildings. This showed that with a well-designed low energy building, coupled with optimised solar contributions really low energy buildings are possible, even in extremely hot climates.

It is all very well starting with a well-designed modern eco-house, but how much more difficult is it to achieve comfort in vernacular homes in warm-humid climates? In their paper on the *Responsiveness and resilience of existing dwellings in warm-humid climate zone to changing climate* **Khadeeja Henna, Aysha Saifudeen and Monto Mani,** from the Sudesi lab, Centre for Sustainable Technologies, Indian Institute of Science, Bangalore, India presented a study done to evaluate the ability of vernacular dwellings to respond to possible climate change variations and maintain comfortable conditions in the ensuing indoor environments (CATE19 Proceedings, pp.754-769). This study also investigated the climate responsiveness and thermal performance of dwellings that are undergoing modern transitions, based on a real-time and simulation assessment of a vernacular habitation in Suggenahalli village, India. It showed that there is continual evolution of new and old solutions as people try to improve their own comfort and reduce the costs of achieving that.

Omar Al-Hafith, K. K. Satish and Pieter de Wilde of Plymouth University looked at building performance in an even more extreme climate (CATE19 Proceedings, pp.770-780). In their study of *An Adaptive Thermal Comfort Model for Residential Buildings in Iraq,* they looked at what the temperatures were that people actually found acceptable in a climate of a country where temperatures can fall below freezing in winter and reach to over 50^0C in summer. To do this they conducted comfort surveys in four Iraqi cities for a year. Nearly 4800 thermal comfort votes were recorded by 90 participants. The results show that the lower thermal comfort Globe temperature in winter is 17 °C and the highest acceptable Globe temperature in summer is 33 °C. In light of some of the other more extreme limits for acceptable temperatures presented at the conference these seem to be reasonably conservative acceptable limits for such an extreme climate.