ANNEX 69

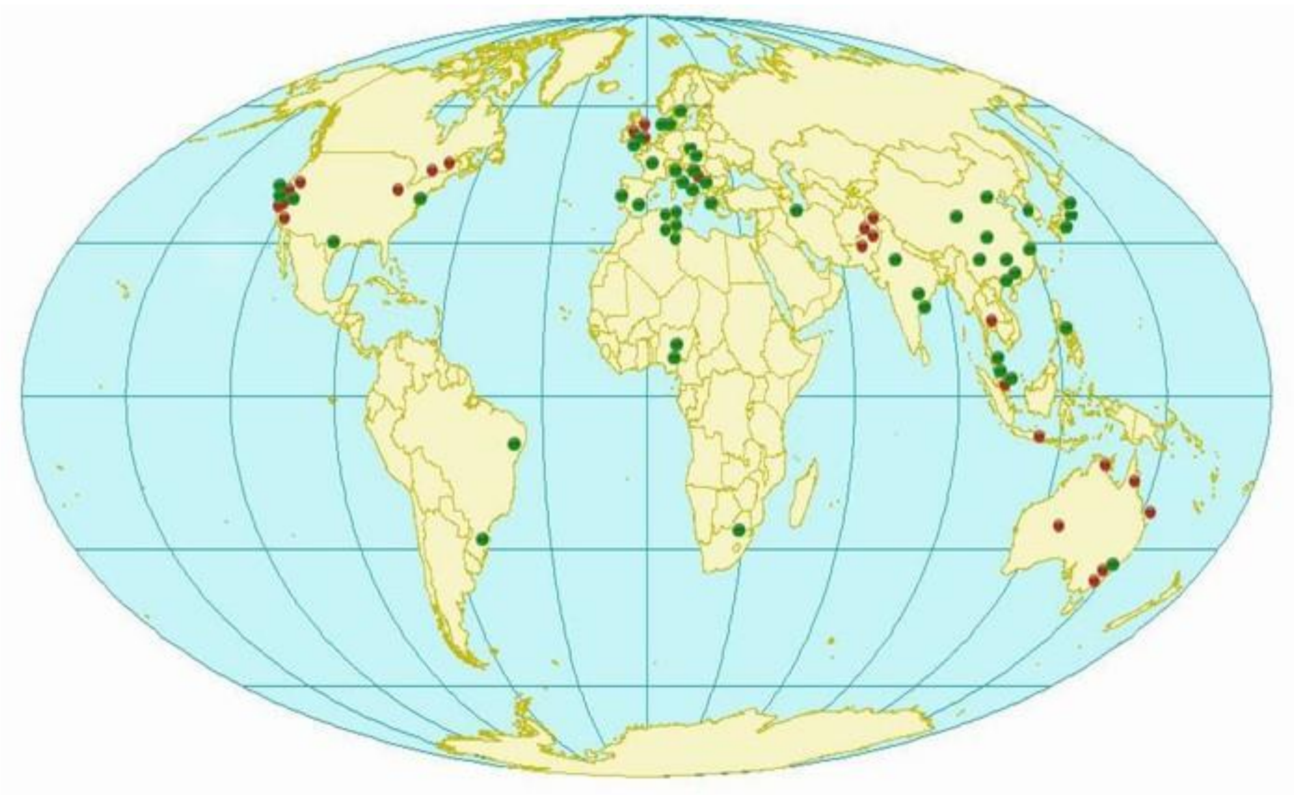
EBC
Energy in Building and Communities Programme

International Energy Agency

# Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (EBC Annex 69) Deliverable 1: Development of the ASHRAE Global Thermal Comfort Database II

## Energy in Buildings and Communities Technology Collaboration Programme

June 2020



Technology Collaboration Programme
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# Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (EBC Annex 69) Deliverable 1: Development of the ASHRAE Global Thermal Comfort Database II

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# Preface

## The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 31 member countries and 11 association countries, and to increase energy security through energy research, development, and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

## The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of 'low tech', robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

## The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
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Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89: Implementing Net Zero Emissions Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities (*)
Working Group - Building Energy Codes

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# Preamble

Reductions in energy use and provision of comfortable indoor environment to occupants are both key objectives of the building sector all around the world. However, establishing the appropriate balance between these often competing issues is challenging. Is it possible to achieve thermal comfort in buildings without increasing energy use?

The key point is to understand the occupants' real thermal demand. To maintain the indoor environment variables within narrow range is known to consume copious energy, but is the steady iso-thermal environment with minimal variations really necessary for thermal comfort? Previous studies have shown that staying in a steady thermal environment for long time periods may actually be harmful to human body, since it weakens the physiological thermoregulatory resilience and acclimation when people are finally exposed to heat stress. We now have enough evidence to show that tight control of indoor temperatures drives high energy costs and greenhouse gas emissions, and may not always provide benefit for occupant comfort and health. The current indoor environment standards for mechanically heated and cooled buildings are based on the PMV-method for specifying an acceptable comfort temperature range. The same standards also include an adaptive approach for office buildings relying on operable windows instead of mechanical cooling systems (ISO 7730, 2005; CEN 15251, 2012; e.g. ANSI/ASHRAE, 2013).

The Annex 69 project was approved unanimously at the Executive Committee Meeting of the IEA Energy in Buildings and Communities Programme, held on 14th November 2013 in Dublin, Ireland. The Annex will focus on the fundamental question of how to describe the mechanisms of occupant adaptive thermal comfort in buildings, as well as the application of the thermal adaptation concept in design, evaluation and control of built environments in order to reduce energy use. The participants will collaborate to establish a worldwide database of building performance, to develop and improve the adaptive method in indoor thermal environment standards, and to propose guidelines for using the adaptive approach in low energy building design, operation, refurbishment, and new personal thermal comfort systems. The project has three subtasks:

Subtask A: Collecting field data on comfort and occupant responses, and research into models of adaptation

Subtask B: Criteria and guidelines for adaptive comfort and Personal Thermal Comfort Systems in standards

Subtask C: Case studies - Practical learnings from exemplary adaptive buildings, supporting Subtasks A & B

In total 14 countries organizations including universities and research institutes have participated in the project. Preparation phase started in January 2015 and lasted until December 2015. The Working phase started in January 2016 and lasted for three years. The Reporting phase started in January 2019 and plans to end in December 2019.

Through Annex 69, we hope to provide scientific description and clear understanding of how to develop quantitative description of occupants' adaptive thermal comfort in buildings, which is a fundamental science question related to the appropriate design, evaluation and control methods of indoor environment in order to reduce building energy use.

# 1. Online available global thermal comfort field study Database II

The ASHRAE Thermal Comfort Database I (de Dear, 1998) was compiled in the late 1990s with the purpose of testing the adaptive thermal comfort hypothesis and developing a model (de Dear and Brager, 1998), and in 2004 the resulting model went on to form the empirical basis of ASHRAE's adaptive thermal comfort standard for occupant-controlled, naturally conditioned spaces (ASHRAE 2004). That project collated indoor thermal environments and their simultaneous subjective thermal comfort evaluations from 52 field studies conducted in 160 buildings worldwide between 1982 and 1997.

In the two decades since its inception, the ASHRAE Thermal Comfort Database I was mined for diverse research questions well beyond the scope of its original purpose. It also became the first port of call when a question regarding thermal comfort and HVAC practice arises.  For example, the current provisions for elevated airspeed in ASHRAE Standard 55 (ASHRAE, 2017) were based exclusively on the analysis of Database I (Arens et al., 2009), as was the dynamic clothing model implemented in the current ASHRAE Standard 55 to estimate indoor clothing insulation levels from 6:00 am outdoor meteorological observations (Schiavon and Lee, 2013).

New thermal comfort research involving field data collection has grown dramatically since the Database I was launched twenty years ago, and so it seemed timely to consolidate the large amount of new data into an even larger repository.

Annex 69 supported a project sponsored by ASHRAE in 2014 - 2018 to collect and organize all possible subsequent field studies, resulting in a greatly expanded database of real-world comfort. Sixty six researchers worldwide joined the effort. The ASHRAE Global Thermal Comfort Database II, covering data from 5 continents and 23 countries, contributed by 47 field research projects ranging from 1995 to 2016 (Licina et al. 2018). All data submissions have been subjected to a rigorous quality assurance process. ASHRAE Database II includes approximately 81,846 complete sets of objective indoor climatic observations with accompanying "right-here-right-now" subjective evaluations by the building occupants who were exposed to them. Each record in the database comprises detailed information under 49 thermal comfort variables, which can be categorized into *basic identifiers*, *personal information*, *subjective thermal comfort questionnaire*, *instrumental indoor environment measurements*, *calculated comfort indices*, *available indoor environmental controls*, and *outdoor meteorological information*. Besides the six parameters in Fanger's PMV model, records in the database also cover various climate zones, building types, ventilation types, age groups, and all seasons as well as both genders, making it possible to further analyze the impart of demographic and contextual factors on thermal comfort thus deepening our understanding on the mechanism of adaptive phenomenon.

The new database also includes analysis and visualization tools (https://cbe-berkeley.shinyapps.io/comfortdatabase/) that provide a user-friendly interface for researchers and practitioners to explore and navigate their way around the large volume of data in the databse. The interacted visualization tool offers convenient data filters to help users select the specific subset of their interest efficiently. Major filters include continent/country, cooling strategy, building type, indoor climatic parameter range and human factors, etc. Various types of graphs shall be generated to reveal the statistic characteristics of the selected data, such as bar/boxplots (for summarizing the distribution of certain variables), multinominal probits (for regressing satisfaction on thermal sensation), and heatmap (for visualizing the acceptance at each binned outdoor and indoor temperature to generate an adaptive comfort zone), etc. Furthermore, a Query Builder tool is developed, which allows users to filter the database according to a set of selection criteria, and then download the results in a generic comma-separated-values (.csv) file format.

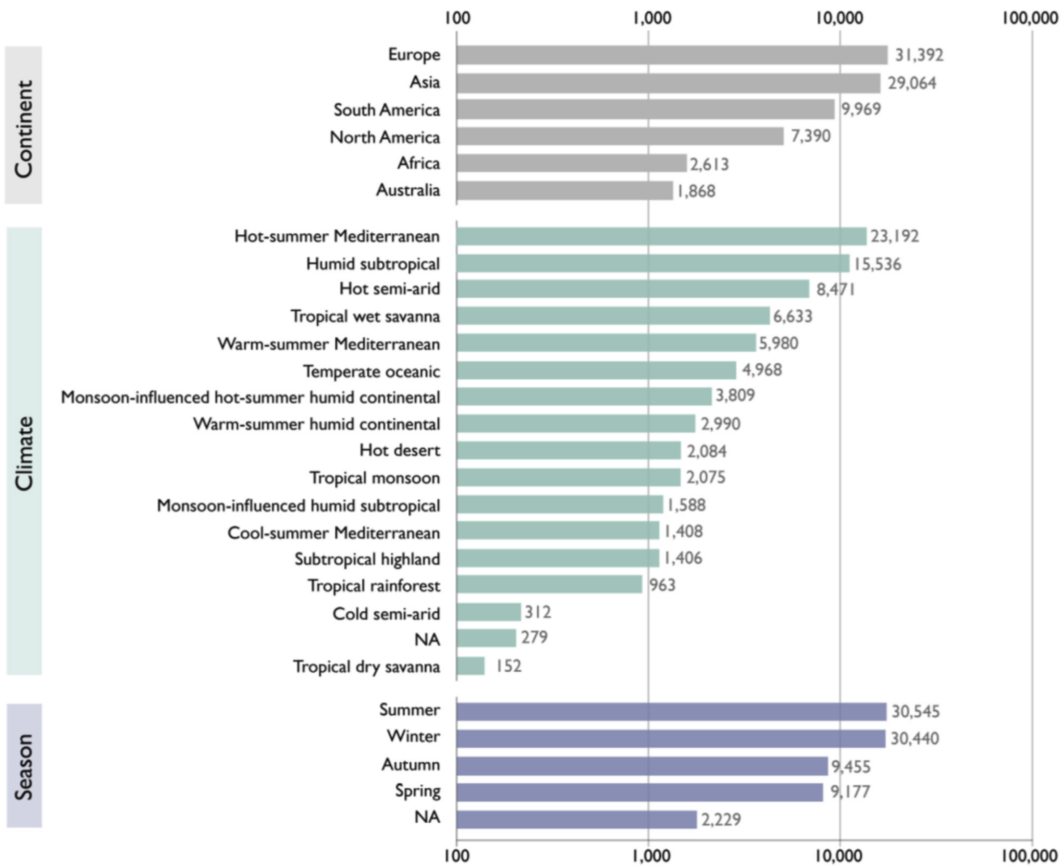


Fig. 1 Distribution of thermal comfort data in Database II by continent, climate and season (Licina et al. 2018)

Database II is an online, open-source. The database is in active use and can be downloaded (http://www.comfortdatabase.com/). There have been 682 downloads and 2000 views by June 2020. The paper describing Database II (Licina et al. 2018) received the journal *Building and Environment* Best Paper Award in 2018. So far, there are 69 journal papers that have cited this paper.

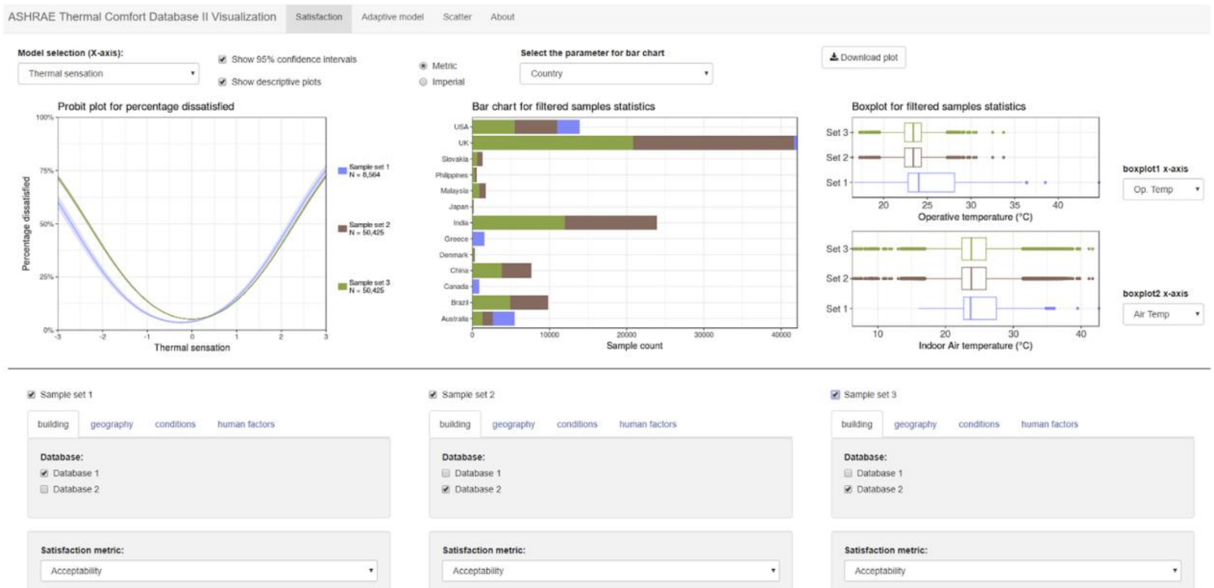


Fig. 2 Example of "Satisfaction" page of the thermal comfort visualization tool (Licina et al. 2018)

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# 2. Relative analyses using the Database II

Several original researches based on data of ASHRAE Database II have been published by the members of Annex 69 community since 2018. The Database II has been used to test metrics and models such as the PMV/PPD (Cheung et al., 2019) ,the ISO/EN thermal environmental classification schemes (Li et al., 2019) and the Griffith's method for determining individual's thermally neutral temperature (Rupp et al., 2019). It has been used to revisit the original adaptive comfort model and suggesting nudges to theory, standards, and practice (Parkinson et al., 2020). It has been used to support the development and validation of new explanatory adaptive model (Ji et al., 2020). It has been used to analyze indoor climatic or individual parameters such as air temperature, radiant temperature (Dawe et al., 2020) and clothing insulation (Wang et al., 2019) in operating buildings. It has been used to analyze individual and group differences (Wang et al., 2020), as well as the impact of demographic and contextual factors on thermal comfort (Zhang et al., 2019). Here is a brief summary for these studies.

## 2.1 Topic A: Revisitation or development of metrics, standards and models

**Parkinson et al., 2020: Nudging the adaptive thermal comfort model**

**Abstract:** "The release of the largest database of thermal comfort field studies presents an opportunity to perform a quality assurance exercise on the first generation adaptive comfort standards (ASHRAE 55 and EN15251). The analytical procedure used to develop the ASHRAE 55 adaptive standard was replicated on 60,321 comfort questionnaire records with accompanying measurement data. Results validated the standard's current adaptive comfort model for naturally ventilated buildings, while suggesting several potential nudges relating to the adaptive comfort standards, adaptive comfort theory, and building operational strategies. Adaptive comfort effects were observed in all regions represented in the new global database, but the neutral (comfort) temperatures in the Asian subset trended 1–2°C higher than in Western countries. Moreover, sufficient data allowed the development of an adaptive model for mixed-mode buildings that closely aligned to the naturally ventilated counterpart. We present evidence that adaptive comfort processes are relevant to the occupants of all buildings, including those that are air conditioned, as the thermal environmental exposures driving adaptation occur indoors where we spend most of our time. This suggests significant opportunity to transition air conditioning practice into the adaptive framework by programming synoptic- and seasonal-scale set-point nudging into buildings".

**Ji et al., 2020: Development of the Predicted Thermal Sensation (PTS) model using the ASHRAE Global Thermal Comfort Database**

**Abstract:** "In this study, existing thermal comfort models were reconsidered and analysed. A new predicted thermal sensation (PTS) model was developed, in which Gagge's two-node model was used for the calculation of thermal regulation. This model was established using data from the ASHRAE Global Thermal Comfort Database and the index of standard effective temperature (SET). This model could not only predict hu- man thermal sensations in various environmental conditions, but also reflect the discrepancies in thermal adaptation in different taxonomies. PTS models were developed for the classification of different climatic zones in China. In addition, worldwide PTS models were proposed for the typical climate types. Some of the data from field studies were introduced to validate these models. The rationality and accuracy were demonstrated, indicating that the PTS model was a practical, flexible, and effective choice for guiding building construction, as well as for evaluating an actual thermal environment. Moreover, further directions for the model's future development were indicated."

**Li et al., 2019: A data-driven approach to defining acceptable temperature ranges in buildings**

**Abstract:** "Current thermal comfort standards use Predicted Mean Vote (PMV) classes as the compliance criteria despite previous critiques. The implicit assumption is that a narrower PMV range ensures higher thermal acceptability among building occupants. However, our analysis of a global database of thermal comfort field studies demonstrates that PMV classes are not appropriate design compliance criteria, and reinforces the need for a new and robust approach to thermal comfort compliance assessment. We compared two statistical methods to derive acceptable temperature ranges from occupant responses applied one to the ASHRAE Global Thermal Comfort Database II. Derived acceptable temperature ranges in real buildings (7.4K-12.2K) using this new method are wider than the current standards mandate (2K-6K). Our findings support the call for a relaxation of suggested temperature ranges in thermal comfort standards so as to minimize unnecessary space conditioning. The proposed data-driven statistical methods to determine temperature design compliance criteria are viewed as an important step forward in the age of continuous and pervasive monitoring and the associated large databases of building comfort measurements."

**Cheung et al., 2019: Analysis of the accuracy of the PMV – PPD model using the ASHRAE Global Thermal Comfort Database II**

**Abstract:** "The predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) are the most widely used thermal comfort indices. Yet, their performance remains a contested topic. The ASHRAE Global Thermal Comfort Database II, the largest of its kind, was used to evaluate the prediction accuracy of the PMV/PPD model. We focused on: (i) the accuracy of PMV in predicting both observed thermal sensation (OTS) or observed mean vote (OMV) and (ii) comparing the PMV-PPD relationship with binned OTS – observed percentage of unacceptability (OPU). The accuracy of PMV in predicting OTS was only 34%, meaning that the thermal sensation is incorrectly predicted two out of three times. PMV had a mean absolute error of one unit on the thermal sensation scale and its accuracy decreased towards the ends of the thermal sensation scale. The accuracy of PMV was similarly low for air-conditioned, naturally ventilated and mixed-mode buildings. In addition, the PPD was not able to predict the dissatisfaction rate. If the PMV model would perfectly predict thermal sensation, then PPD accuracy is higher close to neutrality but it would overestimate dissatisfaction by

approximately 15-25% outside of it. Furthermore, PMV-PPD accuracy varied strongly between ventilation strategies, building types and climate groups. These findings demonstrate the low prediction accuracy of the PMV–PPD model, indicating the need to develop high prediction accuracy thermal comfort models. For demonstration, we developed a simple thermal prediction model just based on air temperature and its accuracy, for this database, was higher than PMV."

## 2.2 Topic B: Analysis or prediction on indoor parameters in operating buildings

**Dawe et al., 2020: Comparison of mean radiant and air temperatures in mechanically-conditioned commercial buildings from over 200,000 field and laboratory measurements**

**Abstract:** "We assessed the difference between mean radiant temperature ( t r ) and air temperature ( t a ) in conditioned office buildings to provide guidance on whether practitioners should separately measure t r or operative temperature to control heating and cooling systems. We used measurements from 48 office buildings in the ASHRAE Global Thermal Comfort Database, five field studies in radiant and all-air buildings, and five test conditions from a laboratory experiment that compared radiant and all-air cooling. The ASHRAE Global Thermal Comfort Database is the largest of these three datasets and most representative of typical thermal conditions in an office; in this dataset the median absolute difference between t r and t a was 0.4 ◦C (with 5 th , 25 th , 75 th , and 95 th percentiles = 0.2, 0.2, 0.6, and 1.6 °C). More specifically, the median difference shows that t r was 0.4 ◦C warmer than t a (with 5 th , 25 th , 75 th , and 95 th per- centiles = −0.4 °C, 0.2 °C, 0.6 °C, and 1.6 °C). The laboratory experiments revealed that in a radiant cooled space t r was significantly ($p < 0.05$) cooler than t a (average difference −0.1 ◦C), while in the all-air cooled space t r was significantly ( $p < 0.05$) warmer than t a (average difference + 0.3 ◦C). These observations indicate that t r and t a are typically closer in radiant cooled spaces than in all-air cooled spaces. Although the differences are significant, the effect sizes are negligible to small based on Cohen's d and Spearman's rho. Therefore, we conclude that measurement of t a is sufficient to estimate t r under typical office conditions, and that separate measurement of t r or operative temperature is not likely to have practical benefits to thermal comfort in most cases –this is especially true for buildings with radiant systems. Furthermore, spatial and temporal variations in t a can be greater than or equal to the difference between t r and t a at any one location in a thermal zone, thus we expect that such variations typically have a greater impact on occupant thermal comfort than the differences between t r and t a ."

**Wang et al., 2019: Optimal clothing insulation in naturally ventilated buildings**

**Abstract:** "This study focuses on clothing behavior of occupants regarding their 'neutral' thermal sensations inside buildings. Statistical analyses were performed with an aim to better understand how building occupants can achieve thermal comfort by adjusting their clothing insulation. The proposed neutral clothing insulation model can be used to determine whether clothing adjustment can sufficiently offset indoor temperatures in naturally ventilated building contexts. Thermal comfort parameters and diverse contextual variables recorded in the ASHRAE Global Thermal Comfort Database II were analyzed to define the key factors to be used in the estimation of clothing insulation values corresponding to neutral thermal sensations. The results of the analysis indicated that climate, season, building type (such as office, school, or residential), and indoor and outdoor temperature variations were the key contextual variables to be considered for understanding occupant clothing behavior. Different types of statistical models were also compared to derive the most useful model for predicting the ideal or optimal clo-values inside buildings."

## 2.3 Topic C: Revelation or confirmation on the individual and contextual differences

**Wang et al., 2020: Revisiting individual and group differences in thermal comfort based on ASHRAE database**

**Abstract:** "Different thermal demands and preferences between individuals lead to a low occupant satisfaction rate, despite the high energy consumption by HVAC system. This study aims to quantify the difference in thermal demands, and to compare the influential factors which might lead to those differences. With the recently released ASHRAE Database, we quantitatively answered the following two research questions: which factors would lead to marked individual difference, and what the magnitude of this difference is. Linear regression has been applied to describe the macro-trend of how people feel thermally under different temperatures. Three types of factors which might lead to different thermal demands have been studied and compared in this study, i.e. individual factors, building characteristics and geographical factors. It was found that the local climate has the most marked impact on the neutral temperature, with an effect size of 3.5 °C; followed by country, HVAC operation mode and body built, which lead to a difference of more than 1 °C. In terms of the thermal sensitivity, building type and local climate are the most influential factors. Subjects in residential buildings or coming from Dry climate zone could accept 2.5 °C wider temperature range than those in office, education buildings or from Continental climate zone. The findings of this research could help thermal comfort researchers and designers to identify influential factors that might lead to individual difference, and could shed light on the feature selection for the development of personal comfort models."

**Zhang et al., 2019: Impacts of demographic, contextual and interaction effects on thermal sensation—Evidence from a global database**

**Abstract:** "Previous studies have demonstrated that non-thermal factors may affect occupants' thermal response in the indoor environment. The effects of demographic and contextual factors on thermal perception have been extensively studied, yet in previous studies, confounding variables have not been commonly controlled; it is also not known how these factors interact with each other. The current study leverages on the largest global thermal comfort database to date and explores the impacts of available demographic and contextual factors, including gender, ventilation mode, building typology, season and climate, on occupants' thermal sensation, along with their two-way and three-way interaction effects. Results indicate that all tested demographic and contextual factors except ventilation mode significantly affect occupants' thermal sensation. Under the same indoor environmental and outdoor climatic conditions, males perceive the environment as being significantly warmer than females in all contexts; males' thermal sensitivity is also consistently lower than females'.

Thermal sensations in multifamily housing are significantly lower and closer to neutral than in office buildings under the same exposure conditions, yet it is likely to be the combined effects of building typology and ventilation mode. All else being equal, occupants in office buildings have less seasonal variation in thermal sensation than classrooms and multifamily housing. Residents in a warmer climate deem the same indoor thermal environment significantly cooler than residents in a cooler climate; this climatic adaptation is more pronounced in females than in males. Occupants' sensitivity to indoor air temperature, humidity and air movement significantly vary between different ventilation modes under different seasons."

**Rupp et al., 2019: Thermal sensitivity of occupants in different building typologies: The Griffiths Constant is a Variable**

**Abstract:** "The Griffiths method is widely used in thermal comfort studies to derive building users' comfort temperature, or thermal neutrality as it is sometimes known. A single value (so called the Griffiths Constant, typically 0.5/ °C) is prescribed as a representation of thermal sensitivity of building occupants to indoor temperature variations, which in turn is used to estimate indoor thermal neutrality from a subject's actual thermal sensation vote at a measured room temperature. Despite the Griffiths Constant of 0.5/ °C having been used widely across the thermal comfort research literature and in some generic standards, the constant was derived exclusively from office building data and its applicability across different typologies is yet to be rigorously validated. The objective of this study is to quantify how sensitive people are to temperature variations inside a building, and to investigate if thermal sensitivity differs between different contexts (including building typologies, modes of ventilation, outdoor climatic types, and genders). A collection of thermal comfort field studies in different building typologies containing around 11,500 datasets was used to statistically derive building users' thermal sensitivity, i.e. the rate of change in thermal sensation per unit change in indoor temperature within a day. Our results suggest that occupant thermal sensitivity does vary depending on building typologies and building ventilation mode. In naturally ventilated spaces users are about half as sensitive to temperature variations as in air-conditioned spaces. Age, gender and climate are found to be factors that can also influence thermal sensitivity of building occupants. Our findings imply that reliance on a universal thermal sensitivity value, the Griffiths Constant, in comfort temperature (neutrality) calculations should be avoided because it is in fact a variable."

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ANNEX 69

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