Energy in Buildings and
Communities Programme

International Energy Agency

EBC Annex 69 Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings

Project Summary Report

Technology Collaboration Programme
by iea

Energy in Buildings and
Communities Programme

International Energy Agency

EBC Annex 69 High Temperature Cooling and Low Temperature Heating in Buildings

Project Summary Report

Edited by
Yingxin Zhu, Richard de Dear, and Bin Cao

Participating countries in EBC: Australia, Austria, Belgium, Brazil, Canada, P.R. China, Czech Republic, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Republic of Korea, the Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, Türkiye, United Kingdom and the United States of America

This edition published in 2023 by the EBC Executive Committee Support and Services Unit.

Additional copies of this report may be obtained from:
EBC Executive Committee Support and Services Unit (ESSU)
C/o AECOM Ltd
The Colmore Building
Colmore Circus Queensway
Birmingham B4 6AT
United Kingdom
www.iea-ebc.org
essu@iea-ebc.org

Cover picture: Example of thermal imaging
Source: EBC Annex 69

Contents

Project Summary

The adaptive thermal comfort has been identified as a key point to establish the balance between reducing building energy use and providing a comfortable indoor environment for occupants. Adequate evidence have shown that strict indoor temperature control can result in high energy costs and greenhouse gas emissions, and may not always be beneficial to the comfort and health of the occupants. The development of adaptive thermal comfort provides criterion and inspiration for the design and operation of low energy buildings. It is indicated that people living in different climate zones share different acceptable range of indoor temperature and adaptive responses. The application of adaptive thermal comfort should take seasons and climates into consideration.

As long as indoor temperature is maintained within the acceptable range, people can achieve thermal comfort through three kinds of adaptive methods: physiological, psychological and behavioral response mechanisms. The stable indoor thermal environment based on the Predicted Mean Vote (PMV) model is not always necessary and incapable of signifying the actual thermal demand of all the occupants. In order to break through the difficulties in the building energy-saving technology, it is important to figure out the actual thermal demand of the occupants and thermal adaptation mechanisms. Moreover, adaptive thermal comfort provides occupants with opportunities to control their personal environment, which can improve occupant satisfaction with indoor thermal environment beyond the levels normally achieved through strict adherence to the PMV.

Therefore, it is essential to conduct systematic and profound research on adaptive thermal comfort. If the building's services systems could be running in a "part-time and part-space" mode depending on its occupants' individual demand instead of the "whole-time & whole-space" mode prevalent in many buildings today, energy use could also be reduced.

This project aimed to develop an analytical and quantitative description of occupants' adaptive thermal comfort in buildings. It provided appropriate design strategies, assessment methods and control algorithms for the indoor environment. The fundamental issue was to balance the comfortable indoor environment and building energy efficiency.

The objectives of this project were:

- Establish a global thermal comfort database with quantitative descriptions of occupant thermal adaption responses;
- Accomplish a revision of indoor environmental standards based on the adaptive thermal comfort concepts;
- Application of the adaptive thermal comfort concept to achieve low energy intensities in buildings;
- Provide guidelines for developing personal thermal comfort systems according to perceived-control adaptation.

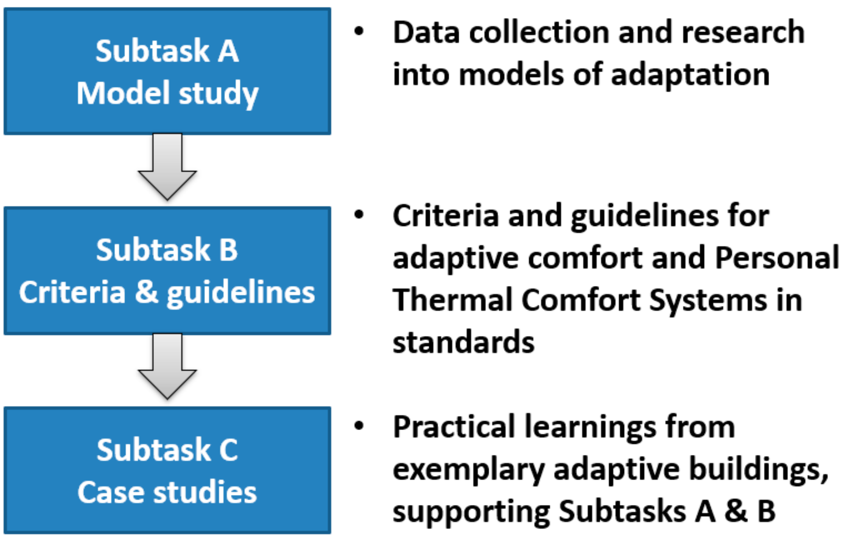

Figure 1: Subtasks of the Annex

Project duration
2015 - 2022 (completed)

Operating Agent

Prof Yingxin Zhu
Department of Building Science
School of Architecture
Tsinghua University
P.R. CHINA
zhuyx@tsinghua.edu.cn

Prof Richard de Dear
Indoor Environment Quality Lab
Faculty of Architecture
The University of Sydney
AUSTRALIA
richard.dedear@sydney.edu.au

Participating countries
Australia, Canada, P. R. China, Denmark, Germany, Japan, R.Korea, The Netherlands, Norway, Sweden, UK, USA

Further information
www.iea-ebc.org

Project Outcomes

1. Background

How to balance occupant comfort in the indoor environment against building energy efficiency has become a critical challenge for the buildings sector in the 21st century. Extant research suggests that strict indoor temperature control incurs excessive energy penalties and greenhouse gas emissions, and yet may not guarantee optimal occupant comfort and health. Adaptive thermal comfort has emerged in recent research as a more appropriate strategy for the design and operation of low-energy buildings. Therefore, a more detailed understanding of the actual mechanisms underlying occupant adaptive processes seems timely. People living in different climatic and cultural settings may have significant differences in their adaptive responses, and so architectural design strategies along with their related indoor environmental engineering practices should be more closely contextualized than is the case in most contemporary design thinking.

To date the Predicted Mean Vote (PMV) occupant comfort index has been widely used as a design tool for stable indoor thermal environments intended for invariant occupancies. As its name suggests, PMV predicts the average comfort requirements of occupants, not the actual thermal demand of specific individuals at any particular point in time. In order to break through the difficulties in developing energy-saving built environments and related technologies, the key lies in understanding actual thermal demand of occupants. People are not passive recipients of conditions provided to them by their built environment. They are active participants interacting in the human-environment system through multiple feedback loops operating at perceptual, physiological and behavioural levels.

The theoretical system of thermal adaptation and associated adaptive comfort model have had a discernible influence on thermal comfort research and built environmental practices. The adaptive thermal comfort approach provides occupants with agency to control their person-environment system through physiological and psychological adaptation, as well as direct behavioral interventions, all purposively aimed at improving satisfaction with their indoor environment.

Indoor environmental standards are intended for application to mechanically heated and cooled buildings rely on the PMV method to specify acceptable temperature ranges which require stable indoor thermal environments all the time. In contrast, the adaptive model confers degrees of freedom for personal environmental control on occupants. Accommodating individual differences in comfort expectations can improve occupants' satisfaction with a building's indoor climate beyond levels attainable through strict application of the PMV model of uniform and invariant comfort. If the mechanical services of the building can operate in a "part-time and part-space" mode according to the individual demands of occupants, as opposed to PMV's "whole- time and whole-space" mode, optimizing both occupant thermal comfort and building energy efficiency cease being mutually exclusive objectives.

These observations on the connection 3 between thermal comfort paradigms and building energy demand highlight the urgent need for an in-depth and systematic understanding of the adaptive approach to thermal comfort.

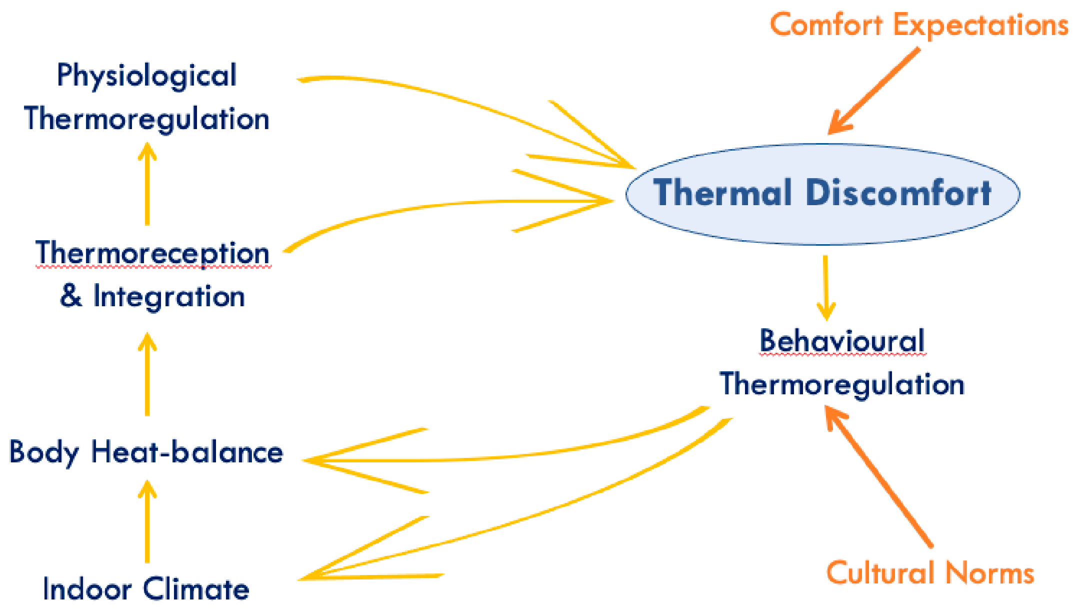

Figure 2: Thermal discomfort drives the feedback loop between occupants and the indoor climate. This schematic encapsulates the adaptive comfort principle as articulated by Nicol et al. (2012): If an occupant finds the indoor environment of their building uncomfortable, they will purposively adjust either themselves, the building, or the building services, in such a way that extinguishes the discomfort.

2. Objectives

Developing a quantitative, analytical understanding of occupants' adaptive thermal comfort in buildings is a building science research question related to practical questions of appropriate design, evaluation, and control methods of the indoor environment to reduce building energy consumption. The objective of this Annex was to answer both these interconnected research and practice questions. Specifically, this Annex aimed:

1. **To establish a worldwide database with a quantitative description of occupants' thermal adaptation.** Large-scale field investigations were conducted in the participating countries. The information collected includes concurrent indoor thermal environmental conditions, occupants' thermal reactions to those conditions, their adaptive behaviors in response to those conditions, and the concurrent energy demand of the building, if feasible. Extant field study results were collated to enrich the database further. A standardized data format was defined prior to the investigation. Based on the field information, a worldwide database was established. Data from mixed-mode buildings, free-running buildings, and mechanically cooled/heated buildings will be represented. Efforts were paid to clarify the mechanism of thermal adaptation based on the database and related research achievements. With larger and analytically richer empirical evidence in the new EBC Annex 69 Project Summary Report database, the adaptive model is expected to evolve from "black box" to "grey box."

2. **To develop new or improved indoor thermal environment criteria based on adaptive thermal comfort concept.** Based on the studies of physiological, psychological, and behavioral adaptation, the appropriate ranges of indoor environmental variables are expected to be determined to meet people's demands of thermal comfort in diverse climatic regions of the world. The results may improve the current indoor thermal environment standards, which, to date, have relied primarily on steady-state first principles and associated comfort models.

3. **To provide evidence-based for promotion of adaptive comfort application.**

– To propose passive building design strategies to achieve thermal comfort with low energy consumption. Case studies were conducted in the participating countries, which focused on the best practices of building design with passive strategies and the relationship to human thermal adaptation. This study provided suggestions to the building designers on using passive design methods to achieve thermal comfort in an "adaptive" way, which will save energy.

– To provide guidelines for new cooling/heating devices based on perceived/individual control adaptation. Considering people's adaptive potential to the thermal environment and the positive effect of perceived control on thermal comfort, new cooling/heating devices were developed to meet the occupants' thermal demand locally and individually. Partial contacting cooling/heating methods may be one of the hot points. Intelligent control may also be involved.

3. Activities and deliverables

3.1 Activities

In order to address the specific project objectives, the research and development work in the project were divided into three activities

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

This activity collected extant thermal comfort research field data from the participating countries. New investigations and experiments were also performed under this projects framework. Based on this large volume of data, the thermal adaptation mechanisms were analyzed to more fully understand the processes of physiological, psychological, and behavioral adaptation.

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

This s activity focuses on the application of adaptive thermal comfort theory for energy conservation in buildings. Based on the adaptive thermal comfort concept, the participants tried to develop indoor thermal environment standards, propose building design strategies, and provide guidelines for new cooling/heating devices.

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

This activity conducted case studies in the participating countries, focusing on the best building performance practices. This study provided suggestions to the building designers on how to use appropriate design methods to achieve thermal comfort in an "adaptive" way, which will save energy.

3.2 Deliverable 1: Global Thermal Comfort Database II

This project 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. The result is known as ASHRAE Global Thermal Comfort Database II, and it includes data from five continents and 23 countries, contributed by 47 field research projects. In the database, there are 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, 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. Figure 3 shows the distribution of data by continent, climate and season. Database II is accessible online and open- source. It is in active service and can be downloaded (www.comfortdatabase.com/). The database also includes analytical and visualization tools that provide a user-friendly interface for researchers and practitioners to explore and navigate their way around the large volume of data in the database (https://cbe-berkeley.shinyapps.io/comfortdatabase/). The paper describing Database II (Veronika Földváry Ličina et al., 2018) received the journal Building and Environment Best Paper Award in 2018.

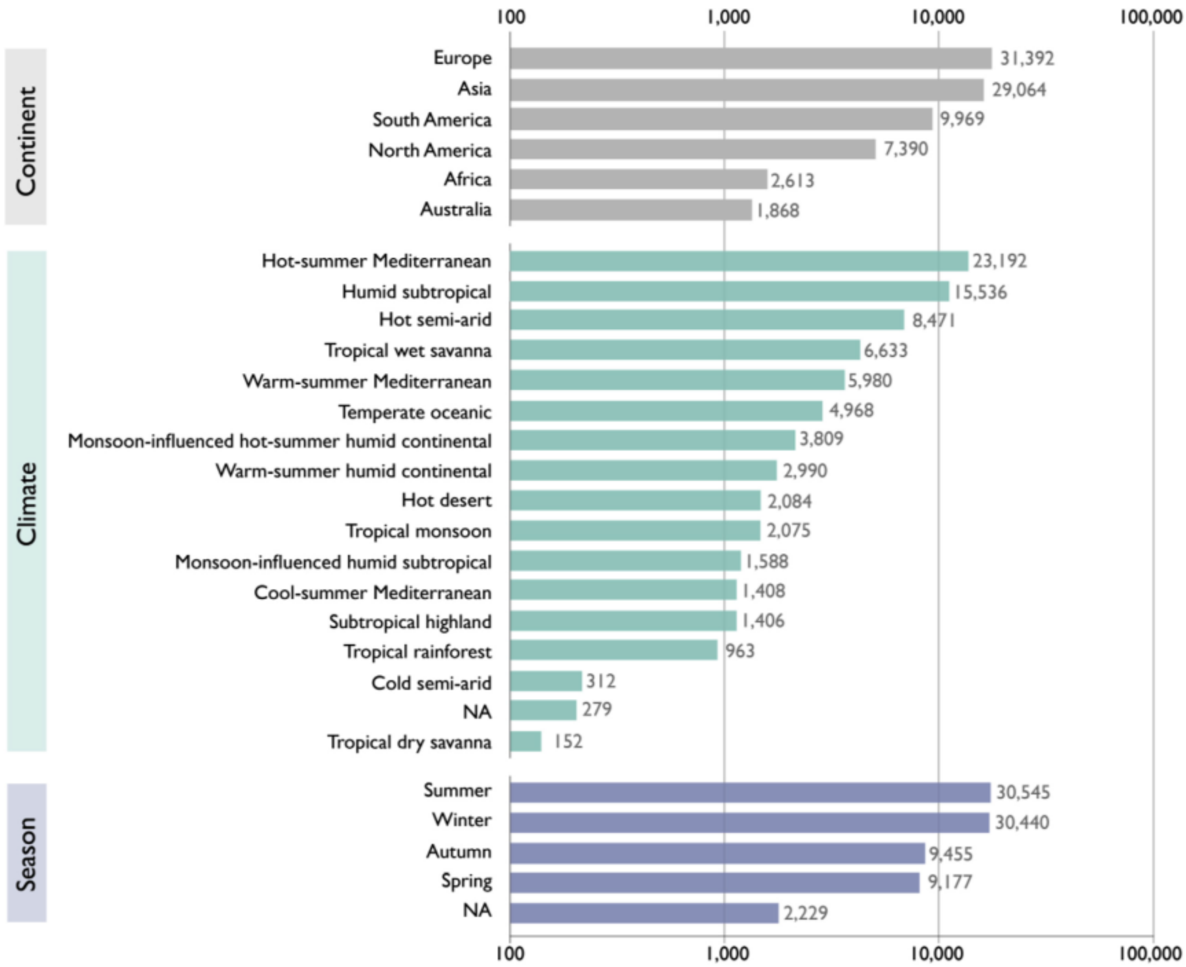

Figure 3: Distribution of thermal comfort data in Database II by continent, climate and season based on (Veronika Földváry Ličina et al., 2018)

3.3 Deliverable 2: Models and criteria for the application of adaptive thermal comfort in built environment

Within the framework of this project, the existing international standards were compared with respect to their way of incorporating adaptive thermal comfort, with an overview of the latest developments in standardization efforts. New research related to adaptive mechanisms was conducted, including methodological aspects such as differences in the perception of scales used to assess thermal perception or the value of alpha in the running mean outdoor temperature. There were new findings related to long-term clothing trends and a novel approach to creating thermosensitivity maps of individual body parts. New approaches for modeling individual adaptive mechanisms in the context of heat balance models were also developed, which includes the adaptive thermal heat balance approach (ATHB) applied to the PMV, standard effective temperature (SET), and thermoneutral zone (TNZ) as shown in Figure 4, as well as the PTS-model based on SET. The methods to assess the accuracy of thermal comfort models are summarized, and the true value in the assessment of the accuracy of existing and new thermal comfort models was discussed.

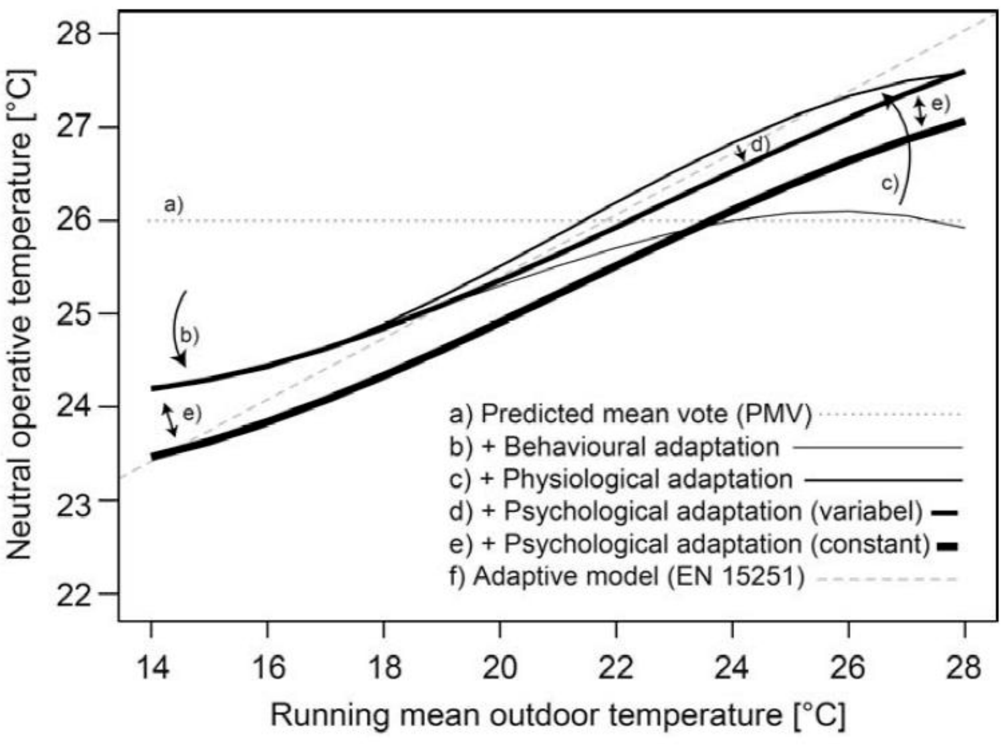

Figure 4: Effect of step-wise application of the ATHBPMV approach based on (Marcel Schweiker and Andreas Wagner, 2015).

3.4 Deliverable 3: Guidelines for low energy building design based on the adaptive thermal comfort concept

The benefits of applying the adaptive principles in buildings include energy savings, resilience to climate change, improved usability and thermal satisfaction, and improved health and well-being. A framework was developed to adopt the adaptive comfort principles in the design and operation of buildings. The main elements of the framework consist of the building context, adaptive responses and actions, the building planning and design, the adaptive opportunities design, and the operational planning and operation. Each of these subsections includes guidelines to facilitate the integration of adaptive principles. Considerations and recommendations for adopting adaptive comfort in conditioned buildings are also presented, including advice for facilitating free-running mode in building operation as often as possible and ways to integrate the use of the adaptive principles in permanently or long season conditioned spaces. The guidelines are provided on a general level of understanding so that it is possible to apply the knowledge in different types of building usage, different climate zones, and occupant groups.

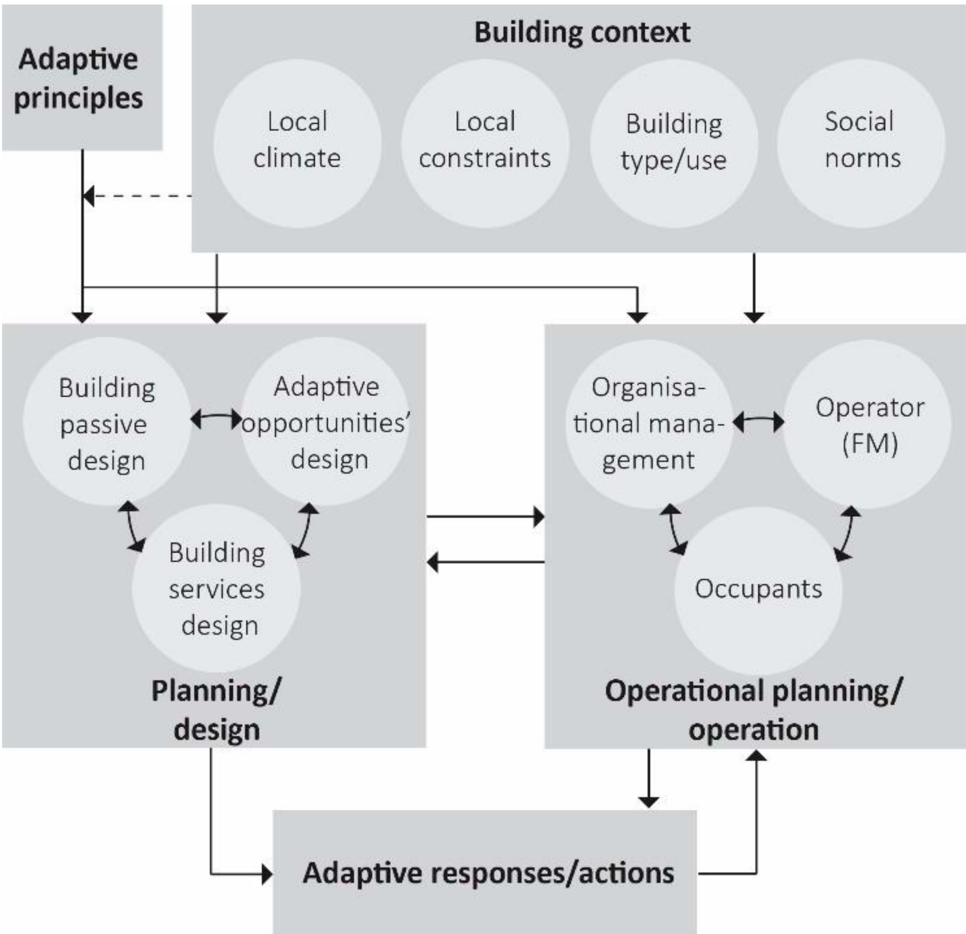

Figure 5: Framework for adopting the adaptive principles in planning and operation of buildings based on (Runa T. Hellwig et al.,2019)

3.5 Deliverable 4: Guidelines for Personal Thermal Comfort Systems in Low Energy Buildings

The conventional HVAC technologies, designed and operated to maintain homogeneous thermal conditions and air quality throughout the built volume, need to be reimagined for a localized application in the form of personalized comfort systems (PCS). PCS operates by focusing their conditioning on the immediate surroundings of an occupant and allowing the unoccupied zones to remain in an unconditioned or semi- conditioned state. The reduction of the conditioned air volume helps reduce the overall energy use, while the provision of individual control helps improve the thermal comfort and air quality for the occupants. This guideline categorizes the types of PCS, identifies and defines the important PCS characteristics on a device-by-device basis, and explains the research methods for assessing PCS performance. Figure 6 shows the ascertainment of appropriate PCS category. PCS can serve as retrofit solutions in the existing buildings or be integrated into modern-day buildings to achieve a high energy efficiency vis-a-vis heating and cooling while offering their occupants a comfortable, personalized thermal experience.

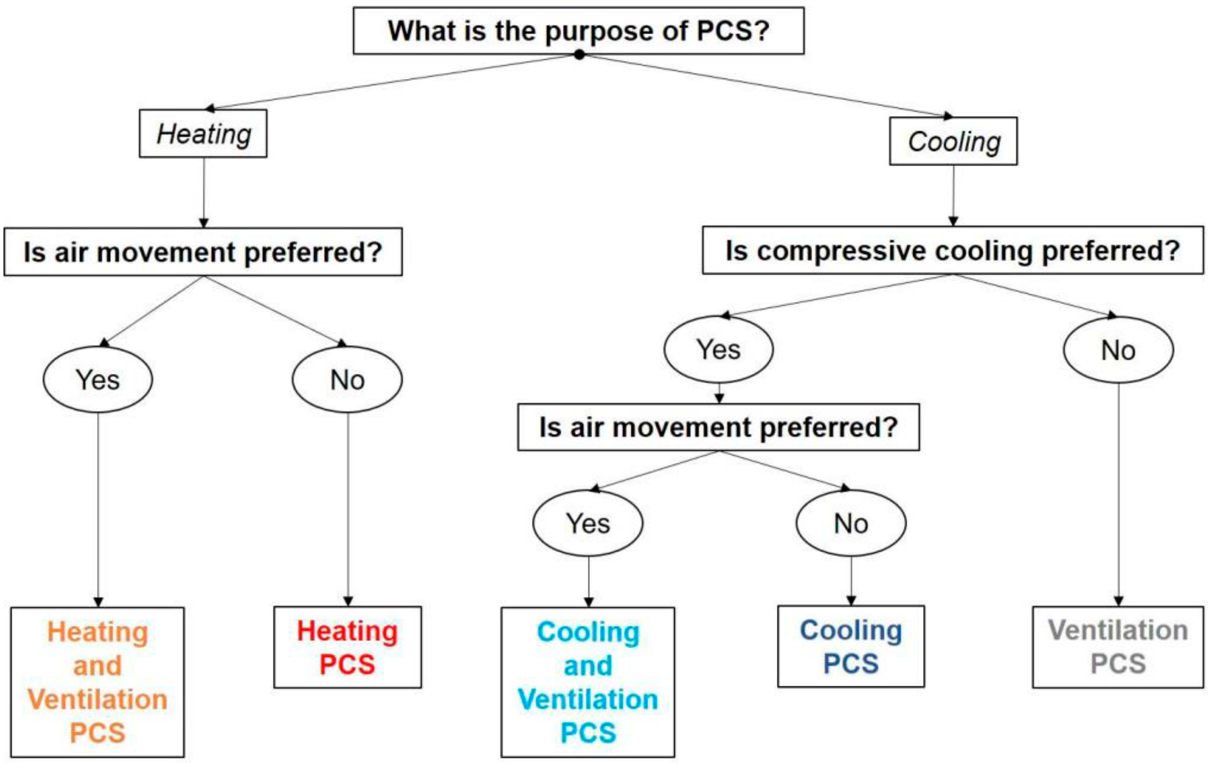

Figure 6: PCS selection flowchart based on (Rajan Rawal et al., Guidelines for Personal Thermal Comfort Systems in Low Energy Buildings)

4. Outcomes

This project developed an analytical and quantitative description of occupants' adaptive thermal comfort in buildings. It provides appropriate design strategies, comfort assessment methods, and control algorithms for indoor environments. The underlying rationale of the project was to balance comfortable indoor environments alongside building energy efficiency. This project comprised of four key components:

1. Establish a global thermal comfort database with quantitative descriptions of occupant thermally adaptive responses;

2. Propose a revision of indoor environmental standards based on adaptive thermal comfort concepts;

3. Application of the adaptive thermal comfort concept to achieve low energy intensities in buildings;

4. Provide guidelines for developing personal thermal comfort systems.

The Global Thermal Comfort Database II comprises empirical data from five continents and 23 countries, contributed by 47 field research projects. In the database there are approximately 82,000 sets of objective indoor climatic observations paired with "right-here-right-now" subjective thermal environmental evaluations by the building occupants. Database II is online and open- source. Online data analytics and visualization tools are provided for researchers and practitioners to explore and navigate their way around this large repository of this project's comfort data.

The existing international standards were compared on the extent of their permissible thermal variability and compatibility with adaptive thermal comfort processes. New research into adaptive mechanisms was conducted, including methodological aspects such as linguistic differences in the subjective rating scales used to quantify thermal perception, and the speed of adaptive comfort responses to dynamics in outdoor climatic environments. Novel approaches to the modeling of individual adaptive mechanisms within the context of the classic heat-balance thermal comfort models were also developed. Methods of quantifying the predictive accuracy of thermal comfort models are summarized.

A new framework was developed to embed adaptive comfort principles in the design and operation of buildings, structured around five elements: the adaptive principles, the building context, the adaptive responses, the design phase, and the operation of the building. The framework and associated guidelines are generic, thereby facilitating their application across different building typologies, occupancy patterns, climate zones, and occupant groups. Fourteen exemplar buildings were investigated to derive practical learnings and recommendations.

Appliances enabling individual building occupants to manage their own thermally comfortable microclimate within a climate-responsive building are collectively referred to as PCS.

They come in a variety of types and can be used for heating, cooling, ventilation, or various combinations thereof. By focusing on the microclimate of the individual occupant rather than the entire space inside a building, PCS offers significant potential to optimise occupant comfort while simultaneously reducing overall energy demand of the building. This project established a guideline for PCS based on latest peer-reviewed research publications, which presents a classification scheme for PCS, defines important PCS characteristics device-by-device, and develops a protocol for assessing PCS comfort performance.

The project deliverables have widely benefited building planners (architects, engineers, sustainability certification consultants/councils) and building operators (facility managers, operators, owners, and tenants), HVAC manufacturers, building science research and education communities, and end-users wishing to explore energy-efficient solutions without compromising occupant thermal comfort.

Project Participants

Country	Organization
Australia	· The University of Sydney · University of Wollongong
Canada	· British Columbia Institute of Technology
China	· Tsinghua University · Xi'an University of Architecture and Technology · Shanghai Jiaotong University · Harbin Institute of Technology · Dalian University of Technology · Tongji University · South China University of Technology
Denmark	· Technical University of Denmark · Aalborg University
Germany	· Karlsruhe Institute of Technology
India	· CEPT University
Japan	· Tohoku University · Waseda University · The University of Tokyo · Tokyo City University · Toyohashi University of Technology

Country	Organization
Korea	· Yonsei University
The Netherlands	· Maastricht University
Norway	· NTNU Norwegian University of Science and Technology
Sweden	· Umea University · Chalmers University of Technology
UK	· Oxford Brookes University · London Metropolitan University · University of Southampton · Loughborough University · University College London
USA	· UC Berkeley · The Catholic University of America · University of Southern California

Project Publications

1. Zhao RY, Fan CY, Xue DH, Qian YM. Air Conditioning (3rd edition). Beijing: China Architecture & Building Press; 2000 (in Chinese).
2. Models and criteria for the application of adaptive thermal comfort in built environment, 2020, multiple authors
3. Guidelines for low energy building design based on the adaptive thermal comfort concept, 2020, multiple authors
4. Guidelines for Personal Thermal Comfort Systems in Low Energy Buildings, 2021, multiple authors

EBC and the IEA

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 IEA participating 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. The mission of the IEA Energy in Buildings and Communities (IEA EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

– Integrated planning and building design
– Building energy systems
– Building envelope
– Community scale methods
– Real building energy use

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 (*):

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 CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 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 (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings (*)
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements (*)
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings (*)
Annex 73: Towards Net Zero Resilient Energy Public Communities (*)
Annex 74: Competition and Living Lab Platform (*)
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables (*)
Annex 76: Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions (*)
Annex 77: Integrated Solutions for Daylight and Electric Lighting (*)
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

Annex 79:	Occupant-centric Building Design and Operation
Annex 80:	Resilient Cooling
Annex 81:	Data-Driven Smart Buildings
Annex 82:	Energy Flexible Buildings towards Resilient Low Carbon Energy Systems
Annex 83:	Positive Energy Districts
Annex 84:	Demand Management of Buildings in Thermal Networks
Annex 85:	Indirect Evaporative Cooling
Annex 86:	Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87:	Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88:	Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89:	Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90:	Low Carbon, High Comfort Integrated Lighting
Annex 91:	Open BIM for Energy Efficient 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

www.iea-ebc.org