International Journal of Research Publication and Reviews, Vol 5, no 11, pp 4624-4629 November 2024

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Comprehensive Literature Study on Thermal Comfort

Saud Ur Rehman Chaudhary[1], Haque Medha[2] , Md Aminul Haque[2] , Adil Mahmood[3]

[1*]School of Civil Engineering, Chongqing University, E-mail : saudurrehman6@gmail.com

[2*]School of Electrical Engineering, Jiangsu Normal University , Email: marjiamedha1524@gmail.com

[2*]School of Electrical Engineering, Jiangsu Normal University, E-mail: sizanaminul1437@gmail.com

[3*]School of Mechatronic Engineering, Jiangsu Normal University, E-mail: adilmahmood2001@gmail.com

Introduction:

Thermal comfort refers to a condition where an individual's experience of thermal environment is in accordance with its own sensation of the internal environment and it is defined as the subjective condition in which an individual feels that there is no other feeling than neutral temperature between itself and the given condition without a sense of sweating [Rohrmann 1979]. Thermal comfort, a concept from environmental engineering and human physiology is, "that condition of mind that expresses satisfaction with the thermal environment," according to ASHRAE Standard 55. Thermal comfort is a subjective state, driven by a variety of environmental and personal factors, but it must be achieved in order to maintain the right temperature both in homes and commercial buildings. The demand for sustainable building design and energy efficiency have made thermal comfort a critical issue in the past few decades. It aims to explore the various dimensions of thermal comfort, including its definitions, theoretical frameworks, influencing factors, methods of assessment, and implications for building design and policy.

The complexities of achieving thermal comfort within automotive environments. Their study primarily focuses on the evaluation of air-flow and temperature fields inside passenger compartments, aiming to enhance thermal comfort while conserving energy. The computational fluid dynamics (CFD) simulations is used to predict thermal sensations and comfort levels under varying conditions. The dynamic nature of thermal comfort in transient environments, such as vehicles, where rapid changes in external conditions significantly impact occupants' thermal perception is highlighted. The importance of integrating advanced HVAC systems that can adapt to these fluctuations to maintain comfort. **(Alahmer et al. 2010)**

The conceptual frameworks and methodologies for assessing thermal comfort in both indoor and outdoor settings has been presented. The researchers distinguish between thermal sensation and thermal comfort. Specifically, they point out that thermal sensation gauges the degree of thermal stimulus, whereas thermal comfort is a subjective assessment of one's level of satisfaction with the thermal surroundings. The Predicted Mean Vote (PMV) and the Actual Sensation Vote (ASV) are two examples of models and indices used to predict thermal comfort that are discussed. The PMV model's limitations are discussed, specifically its assumption that comfort is static and its inadequacy in non-uniform environments. They advocate for more holistic approaches that consider individual differences, acclimatization, and psychological factors in comfort assessments. **(Shooshtarian et al. 2020)**

A study has been carried out that focuses on the individual thermal comfort in place of the group of people. This needs to be carried out in a sense that it is observed and divided into three categories. There is no difference between the inter groups thermal comfort e.g., for the male and female, for the young and old. However, a small group of research shows that there is significant difference in the thermal comfort of a male and female and young and old. So, a study of personalized air conditioning is put forward with three factors. First is the individual physiological and psychological response, second learning the individual thermal comfort using machine learning, and finally, accommodating individual difference with Personalized Comfort Systems. **(Wang Zhe et al. 2018)**

Background:

A complex interplay of factors influences thermal comfort, which is a state of mind that expresses satisfaction with the temperature of the surrounding environment. Because it has such a profound effect on human productivity, health, and well-being, this idea is essential in disciplines like environmental design, architecture, and HVAC (heating, ventilation, and air conditioning) engineering. In order to achieve thermal comfort, it is necessary to balance a number of environmental factors, including air temperature, humidity, airflow, and surface radiation. Additionally, personal factors like clothing insulation and metabolic rate play a critical role in how individuals perceive thermal comfort. Standards like ASHRAE 55 and ISO 7730 provide guidelines and models to assess and design environments that optimize thermal comfort. These standards consider diverse climates, activities, and clothing to ensure a broad applicability. Advanced technologies and sustainable practices, such as passive solar design, adaptive thermal comfort strategies, and the use of smart materials, are increasingly employed to enhance thermal comfort while reducing energy consumption. Understanding and implementing thermal comfort principles is essential for creating indoor environments that promote comfort, efficiency, and sustainability.

Factors Influencing Thermal Comfort:

Thermal comfort is influenced by a complex interplay of environmental, personal, and psychological factors. Key environmental factors include:

- **Air Temperature**: The primary determinant of thermal comfort, with optimal ranges varying based on season and activity level.
- **Humidity**: High humidity can exacerbate feelings of warmth, while low humidity can make the air feel cooler.
- **Air Movement**: Adequate air movement can enhance comfort by increasing heat loss through convection and evaporation.
- **Radiant Temperature**: The temperature of surrounding surfaces can significantly impact perceived thermal comfort.

Personal Factors Influencing Thermal Comfort:

- **Metabolic Rate:** Higher metabolic rates generate more body heat, affecting thermal comfort.
- **Clothing Insulation**: The amount and type of clothing worn can either retain or dissipate body heat.
- **Age and Gender**: Thermal preferences and sensitivity can vary based on age and gender, with older adults and women often preferring warmer conditions.
- **Acclimatization**: People acclimatized to certain climates may have different thermal comfort thresholds.

Psychological factors, such as individual preferences, expectations, and previous experiences, further complicate the assessment of thermal comfort. For instance, a person's satisfaction with the thermal environment can be influenced by their perceived control over it. Higher levels of perceived control often correlate with higher levels of comfort, even if the physical conditions are less than ideal.

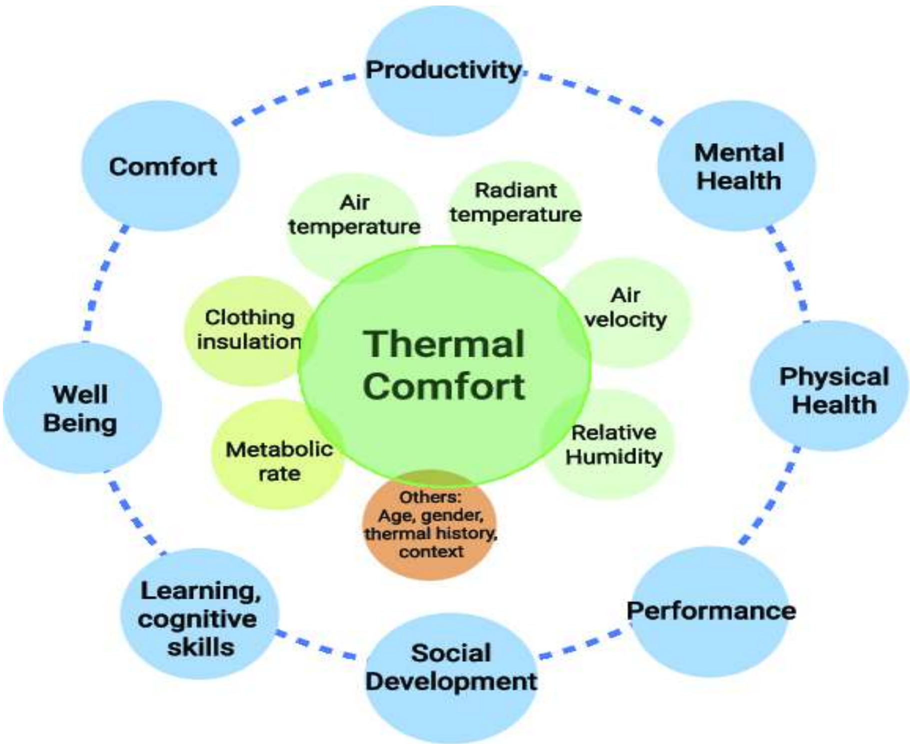

Fig. 1: Thermal comfort factors

Literature Review:

A recent advancement in the thermal comfort is being carried out. Study in last decade shows the prime focus is on three components, i.e., experimental design, data collection and modelling techniques. All these three components varies under their own boundaries to collect the perfect and accurate data as much as it could be. It is studied that the model incorporating human factors has huger level of predictability accuracy than those that completely depends on the environmental factors. The study identified several gaps and challenges, such as the need for standardized, high-quality data and more sophisticated individual-specific models. It has been concluded that future research should focus on developing more comprehensive databases and utilizing advanced sensor technologies to enhance personal thermal comfort modeling, ultimately benefiting practical applications like individual comfort monitoring. **(Feng Yanxiao et al. 2022)**

The thermal comfort models are designed to predict individual thermal comfort more accurately than aggregate models, which often fail to account for personal preferences and physiological differences. The main focus on several key aspects of personal comfort models: data collection methods, participant demographics, environmental variables, modeling techniques, and performance indicators has been dealt in last couple of decades. The study identify significant variability in the types of buildings, climates, and seasons studied, as well as a lack of a standardized framework for model development and evaluation. This variability makes it difficult to compare results across studies. The dominance of machine learning techniques in developing these models and discusses the associated challenges, such as the "black box" nature of these algorithms has been emphasized. It is suggested that incorporating physiological sensing technologies, like wearable sensors, could enhance model accuracy and responsiveness. They also emphasize the need for more diverse data and unified methodologies to improve the reliability and applicability of personal thermal comfort models in real-world settings. **(Martins L.A. et al. 2021)**

A understanding on how different factors influence human thermal comfort within various built environments is any important aspect of study carried out massively is last decade or two. For the thermal comfort, controlled and semi controlled experiments, and field studies in buildings are done followed by the evolution of thermal comfort standards, highlighting the significant contributions of Fanger's model and the adaptive thermal comfort model. Both models have their strengths and limitations, but the adaptive model is particularly noted for considering the dynamic interactions between humans and their environment. In controlled environment experiments, research often uses climate chambers to isolate variables and study specific influences on thermal comfort. Key factors such as personal control, thermal history, individual preferences, weight, gender, and age are analyzed. These studies provide insights into how these variables affect individual thermal comfort, emphasizing the need for personalized conditioning systems that can cater to diverse needs. Semi-controlled environment experiments bridge the gap between controlled lab settings and real-world conditions. These studies examine the influence of environmental controls and building layout on thermal comfort. Personalized conditioning systems again emerge as a significant focus, demonstrating their potential to improve comfort in semi-controlled environments. **(Rupp R.F. 2015).** Field studies in real buildings extend the research into practical, everyday settings. The studies conducted in kindergartens, schools, universities, offices, residential buildings, and other types of buildings. These studies often focus on specific demographic groups, such as children or office workers, and consider the impact of gender, adaptive behaviors, and personal preferences on thermal comfort. The field studies reinforce the importance of contextual factors and individual variability in achieving optimal thermal comfort. The role of naturally ventilated, air-conditioned, and mixed-mode buildings in maintaining thermal comfort is also very key. It highlights the challenges and opportunities associated with each type of building system, suggesting that mixed-mode buildings might offer the best balance between energy efficiency and thermal comfort.

The PMV model which is developed by P.O. Fanger in 1970 and most widely used index to assess thermal comfort by predicting the average thermal sensation of people in a specific environment for the thermal comfort in a hospital during the Covid-19 time phase. The studies indicate that a conducive thermal environment significantly affects the health, wellbeing, and productivity of hospital occupants. The studies compared PMV predictions with actual thermal sensation votes (TSV) from occupants. The findings suggest that while the PMV model is a useful tool, it sometimes underestimates or overestimates the actual thermal sensation experienced by individuals, particularly in diverse hospital environments. Moreover, there is a notable gap in research related to productivity influenced by thermal comfort in hospital environments, signaling an area needing further investigation. In this four research questions are answered. Health wellbeing and productive, accuracy of PMV, targeted audience, and indoor air quality. The main focus is the importance of thermal comfort in hospitals, pointing out the necessity for further research to enhance patient recovery, staff efficiency, and overall hospital operation. The insights gained from this review are crucial for developing better-designed hospital environments that cater to the nuanced needs of their occupants. **(Pereira PFC et al. 2020)**

The importance of thermal comfort in indoor environments is discussed, pointing out that people spend most of their time indoors and that thermal comfort significantly influences their well-being and productivity along with the complexity and subjectivity involved in defining and achieving thermal comfort, using the foundation works for current standards like ASHRAE Standard 55 and EN ISO 7730. The analysis shows that the Predicted Mean Vote (PMV) model is the most commonly used thermal comfort model, followed by data-driven and adaptive methods. PMV, developed by Fanger, predicts the average thermal sensation of a large group of people based on factors such as air temperature, radiant temperature, humidity, airspeed, clothing insulation, and metabolic rate. It is noted that PMV is widely used, newer models continue to emerge, addressing various limitations and expanding applications to diverse contexts, such as sleeping environments and the needs of the elderly. It categorizes the control strategies into several types, primarily focusing on temperature control but also exploring other methods like the design of building elements and the use of natural ventilation. It is observed that most advanced control strategies are applied in office and commercial buildings, likely due to budget constraints and the significant impact on occupant comfort and productivity. However a gap can be seen regarding the practical implementation of these strategies for vulnerable populations, such as the elderly or those with specific health conditions. A valuable insights into the current state of thermal comfort control research is given, emphasizing the need for more inclusive studies that address the diverse needs of all building occupants. It also calls for further development and practical implementation of advanced control strategies to enhance thermal comfort in various indoor environments. **(Grassi B. et al. 2022)**

There is a gap between sustainability and the understanding of thermal comfort. Their main goal is to close the knowledge gap regarding the applicability and suitability of current thermal comfort indices in tropical and subtropical areas, which are marked by high humidity and temperatures. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines are used to accomplish this, guaranteeing a comprehensive and uniform review procedure. According to the study, comparatively less research has been done in tropical and subtropical areas, with the majority of studies on thermal comfort taking place in temperate and continental climates. The most commonly used index for assessing outdoor thermal comfort is the Physiological Equivalent Temperature (PET), which was used in 72% of the studies that were reviewed. Less frequently, or in 21% of the studies, are other indices like the Discomfort Index (DI) and the Universal Thermal Climate Index (UTCI). More than 90% of studies used Operative Temperature (OT) and the Predicted Mean Vote (PMV) index as the main markers of thermal comfort in indoor settings. The study reveals a significant finding that the thermal comfort indices commonly used tend to underestimate the comfortable ranges for tropical and subtropical regions. This underestimation points to a need for indices that are better tailored to the unique climatic conditions of these regions. Additionally, it is argued that the thermal comfort requirements of populations living in tropical and subtropical climates are not adequately represented by current indices, which may have consequences for public health, building design, and urban planning. **(Patle S., Ghuge V V. 2022)**

According to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), it is a judgment call impacted by a number of variables. Thermal comfort is studied using two main models: the adaptive model, which takes into account human adaptation to environmental changes, and the stationary model, which uses a thermal balance approach and the predicted mean vote (PMV) index.Several variables commonly used in thermal comfort studies are identified. The most frequently used variables are those associated with the PMV model, which includes factors like air temperature, humidity, air velocity, and mean radiant temperature. However, recent focused is mainly on new variables that account for individual differences in thermal perception, such as metabolic rate and clothing insulation. The study underscores the importance of selecting appropriate variables for thermal comfort assessments to enhance the accuracy of these evaluations. While the PMV model variables are widely used, there is a growing recognition of the need to incorporate variables that reflect individual differences in thermal comfort perception. This shift aims to provide more personalized and accurate assessments of thermal comfort. A gap is filled by integrating all variables influencing thermal comfort and linking them to their measurement tools. The findings suggest that while traditional variables remain important, new variables should be considered to account for individual differences. This comprehensive understanding of thermal comfort variables and their measurement tools is essential for developing more accurate and personalized thermal comfort assessments, ultimately contributing to improved indoor environmental quality and occupant well-being. **(Mamani T. et al. 2022)**

Strategies for Optimizing Thermal Comfort

Various strategies can be employed to enhance thermal comfort in buildings.

Passive Design Strategies

- **Insulation**: Proper insulation reduces heat loss in winter and heat gain in summer.
- **Natural Ventilation**: Utilizing wind and thermal buoyancy to cool and ventilate spaces.
- **Thermal Mass**: Materials with high thermal mass can absorb and release heat, stabilizing indoor temperatures.

Active Design Strategies

- **HVAC Systems**: Efficient heating, ventilation, and air conditioning systems are essential for maintaining thermal comfort.
- **Advanced Controls**: Smart thermostats and building management systems can optimize indoor climate.

Personal Control

Providing occupants with control over their thermal environment, such as adjustable thermostats or operable windows, can enhance satisfaction and comfort.

Mixed-Mode Buildings

Combining natural ventilation with mechanical systems can optimize comfort while reducing energy consumption.

Discussion:

The traditional thermal comfort indices, predominantly developed for temperate climates, exhibit limitations when applied to tropical and subtropical regions. The most widely used indices, such as the Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET), often underestimate the comfort ranges for these climates. This discrepancy arises because these indices were calibrated under conditions that do not fully encapsulate the thermal dynamics and human acclimatization in hotter, more humid environments. Thus, there is a pressing need for indices tailored to the unique climatic conditions of tropical and subtropical regions.

High temperatures and humidity, characteristic of tropical and subtropical regions, present unique challenges to thermal comfort that are not as prevalent in temperate climates. The physiological and psychological adaptations of the local populations significantly influence their thermal comfort levels. These adaptations include changes in clothing, behavior, and even metabolic rates, which are not adequately accounted for in the existing indices. This highlights the necessity of incorporating adaptive thermal comfort models that consider these region-specific adaptations.

One of the critical insights is the significant impact of thermal comfort on urban planning and building design. Architects and urban planners are encouraged to incorporate passive cooling strategies, such as natural ventilation, shading, and the use of reflective materials, to enhance thermal comfort in buildings. Moreover, the integration of green spaces and water bodies in urban designs, which can mitigate the urban heat island effect and improve outdoor thermal comfort.

Conclusion and Future Research Directions:

The limitations of existing thermal comfort indices when applied to tropical and subtropical regions. It demands the creation of fresh, area-specific indices as well as standardized techniques to improve the precision and usefulness of thermal comfort evaluations. The review's conclusions have important ramifications for policy-making, building design, and urban planning, highlighting the need for a more specialized approach to thermal comfort in these areas. Subsequent investigations ought to concentrate on creating flexible models and carrying out extended-duration analyses to guarantee that thermal comfort benchmarks adjust in tandem with shifting weather patterns and human actions. It is necessary to create new thermal comfort indices with a focus on tropical and subtropical regions. A wider range of variables, such as physiological, psychological, and environmental factors, should be included in these indices.

Furthermore, longitudinal research is necessary to comprehend both the possible effects of climate change and the long-term trends in thermal comfort. For a comprehensive understanding of thermal comfort, interdisciplinary approaches combining knowledge from physiology, sociology, urban studies, and climatology are essential.

References:

1. Alahmer, Ali, et al. "Vehicular thermal comfort models; a comprehensive review." *Applied thermal engineering* 31.6-7 (2011): 995-1002.

2. Shooshtarian, Salman, Cho Kwong Charlie Lam, and Inji Kenawy. "Outdoor thermal comfort assessment: A review on thermal comfort research in Australia." *Building and Environment* 177 (2020): 106917.

3. Wang, Zhe, et al. "Individual difference in thermal comfort: A literature review." *Building and Environment* 138 (2018): 181-193.

4. Feng, Yanxiao, et al. "Data-driven personal thermal comfort prediction: A literature review." *Renewable and Sustainable Energy Reviews* 161 (2022): 112357.

5. Martins, Larissa Arakawa, Veronica Soebarto, and Terence Williamson. "A systematic review of personal thermal comfort models." *Building and Environment* 207 (2022): 108502.

6. Rupp, Ricardo Forgiarini, Natalia Giraldo Vásquez, and Roberto Lamberts. "A review of human thermal comfort in the built environment." *Energy and buildings* 105 (2015): 178-205.

7. Pereira, Pedro Filipe da Conceição, Evandro Eduardo Broday, and Antonio Augusto de Paula Xavier. "Thermal comfort applied in hospital environments: a literature review." *Applied sciences* 10.20 (2020): 7030.

8. Grassi, Benedetta, et al. "A review of recent literature on systems and methods for the control of thermal comfort in buildings." *Applied Sciences* 12.11 (2022): 5473.

9. Patle, S., and V. V. Ghuge. "Evolution and performance analysis of thermal comfort indices for tropical and subtropical region: a comprehensive literature review." *International Journal of Environmental Science and Technology* (2024): 1-42.

10. Mamani, Tamara, et al. "Variables that affect thermal comfort and its measuring instruments: A systematic review." *Sustainability* 14.3 (2022): 1773.

11. Lai, Dayi, et al. "A comprehensive review of thermal comfort studies in urban open spaces." *Science of the Total Environment* 742 (2020): 140092.

12. Dzyuban, Yuliya, et al. "Outdoor thermal comfort research in transient conditions: A narrative literature review." *Landscape and Urban Planning* 226 (2022): 104496.

13. Cheng, Yuanda, Jianlei Niu, and Naiping Gao. "Thermal comfort models: A review and numerical investigation." *Building and environment* 47 (2012): 13-22.

14. Zhang, Jinhao, et al. "Thermal comfort investigation of rural houses in China: A review." *Building and Environment* (2023): 110208.

15. Fard, Zahra Qavidel, Zahra Sadat Zomorodian, and Sepideh Sadat Korsavi. "Application of machine learning in thermal comfort studies: A review of methods, performance and challenges." *Energy and Buildings* 256 (2022): 111771.

16. Martínez-Molina, Antonio, et al. "Energy efficiency and thermal comfort in historic buildings: A review." *Renewable and Sustainable Energy Reviews* 61 (2016): 70-85.

17. Kumar, Pardeep, and Amit Sharma. "Study on importance, procedure, and scope of outdoor thermal comfort–A review." *Sustainable Cities and Society* 61 (2020): 102297.

18. Yuan, Feng, et al. "Thermal comfort in hospital buildings–A literature review." *Journal of Building Engineering* 45 (2022): 103463.

19. Zhao, Qiantao, Zhiwei Lian, and Dayi Lai. "Thermal comfort models and their developments: A review." *Energy and Built Environment* 2.1 (2021): 21-33.

20. Aghamolaei, Reihaneh, et al. "A comprehensive review of outdoor thermal comfort in urban areas: Effective parameters and approaches." *Energy & Environment* 34.6 (2023): 2204-2227.