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Role of Air Conditioning Systems in Indoor Thermal Comfort

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Abstract

Thermal comfort is a fundamental aspect of IEQ that has a direct impact on the health, well-being, satisfaction, and productivity of occupants. With the rise of urbanization and building occupancy, the demand for efficient air conditioning systems that can provide a comfortable indoor environment has grown more significant. The basic fundamentals that affect thermal comfort, such as clothing insulation, metabolic rate, air temperature, relative humidity, air velocity and mean radiant temperature are discussed. The study also examines the advanced enhancement methods for air conditioning systems such as optimized supply and return air configurations, Variable Air Volume (VAV) systems, demand controlled ventilation, smart thermostats, adaptive control, and zonal cooling systems. The use of computational fluid dynamics, artificial intelligence, smart sensors and personal cooling technologies is gaining prominence in recent literature to enhance thermal comfort and decrease energy use. The results suggest that the intelligent and adaptive HVAC systems can have a substantial impact on the indoor environmental quality, the satisfaction felt by occupants, and the energy efficiency of buildings. The review provides valuable insights into current developments and future directions for achieving sustainable and occupant-centered thermal comfort management in modern buildings.

Keywords; Thermal Comfort; Air Conditioning Systems; HVAC Optimization; Indoor Environmental Quality; Energy Efficiency.

INTRODUCTION

The concept of thermal comfort is one of the most important topics in the area of indoor environmental quality, and is a key factor in determining health, well-being and productivity for the people that occupy a building. With the world becoming more urban and industrial, people are spending more and more of their time, whether at work or at home, inside residential, commercial, institutional, and industrial buildings [1], [2]. Therefore, maintaining indoor comfortable environment is one of the main goals in designing and operating buildings. Thermal comfort is usually described as the state of mind that reflects satisfaction with the thermal environment, and is affected by ambient temperature, relative humidity, air velocity, mean radiant temperature, clothing insulation and metabolic rate. As the indoor temperature control technology, air conditioning has developed into one of the most successful technology for indoor environment in different climatic condition to ensure the comfort of the occupants in the interior [3]. Modern air conditioning systems have not only the function of controlling temperature but also of controlling indoor air quality, humidity, air distribution and ventilation. Heat, ventilation and air conditioning (HVAC) technologies have made it easier for HVAC units to control the indoor environment, which improves the satisfaction of the occupants and reduces energy consumption [4]. But, with greater focus on energy efficiency, sustainability and design for the occupants, there is a need for improved air conditioning strategies to achieve superior comfort and energy efficiency. With the recent advances in computational fluid dynamics (CFD), smart sensors, artificial intelligence, and adaptive control systems, new opportunities have emerged for the optimization of air conditioning system performance [5].

These technologies enable more effective management of airflow, real-time environmental monitoring and customized comfort solutions. Thus, the understanding of how air conditioning systems affect thermal comfort and what strategies are effective in improving it are critical to creating sustainable and comfortable indoor environments. This study discusses the principles, technologies and optimization methods of advanced air conditioning systems to enhance thermal comfort in indoor environment [6], [7].

Importance of Air Conditioning Systems in Modern Buildings

The air conditioning system is one of the most essential parts of modern buildings as it helps to provide an indoor environment in a building that is comfortable regardless of the outside weather conditions. These systems control indoor climate in residential, commercial, healthcare, educational and industrial buildings to maintain occupant comfort and building efficiency by controlling indoor temperature, humidity, airflow and air quality [8]. The demand for efficient air conditioning systems is expanding, as urbanization and the need for comfortable indoor environments grow with the rising global temperature. Modern HVAC systems provide thermal comfort, but also benefit energy management, building health, and building sustainability. This integration with smart technologies, automation systems, and energy-efficient control strategies further solidifies their position in creating sustainable, occupant-friendly buildings [9], [10].

The importance of air conditioning systems in modern buildings can be summarized as follows:

- Maintaining optimal indoor temperature and humidity levels for occupant comfort.
- Enhancing indoor air quality through filtration, ventilation, and contaminant removal.
- Improving occupant health by reducing exposure to airborne pollutants, allergens, and excessive heat.
- Increasing workplace productivity, concentration, and cognitive performance.
- Supporting thermal comfort in extreme climatic conditions throughout the year.
- Protecting sensitive equipment and electronic devices from overheating and moisture-related damage.
- Contributing to energy-efficient building operation through advanced control and monitoring technologies.
- Supporting green building initiatives and sustainable construction practices.
- Providing customized thermal environments through zonal and personalized cooling systems.
- Facilitating the integration of smart building technologies for automated climate control and energy optimization.

Relationship Between Thermal Comfort, Health, and Productivity

Thermal comfort is strongly related to human health, well-being and productivity, and therefore plays an important role in the design and operation of indoor environments. An indoor environment with acceptable thermal conditions allows people to do their daily activities efficiently and reduce physiological and psychological stress. Excessively hot, cold, humid or poorly ventilated conditions can, on the other hand, cause discomfort, fatigue, dehydration, headaches and decreased concentration [11]. Exposure to the unfavorable thermal environment for long periods of time can also heighten the risk of respiratory issues, cardiovascular stress, and other health consequences. There is a direct link between thermal comfort and work productivity, as well as cognitive performance. Research has demonstrated that workers in thermally comfortable environments demonstrate greater accuracy in judgements, decision making, and concentration [12]. Thermal conditions are important in education because proper thermal conditions can enhance learning efficiency, concentration, and academic achievement. In the same way, medical facilities need to have optimal thermal conditions for patient recovery, staff efficiency, and infection control [13].

The psychological health of the occupants and the overall satisfaction of the built environment are also related to the thermal environment inside the building. Indoor spaces that are comfortable are less stressful, more pleasant and create a perception of improved environmental quality. With the emphasis on occupant-centred design for more contemporary buildings, thermal comfort is an important goal for the architect, engineer and the facility manager [14]. The use of advanced air conditioning systems is a key component of achieving this goal as they offer more control over the temperature, humidity and air flow. So, achieving thermal comfort is not only a strategy to create a healthier indoor environment, it also has a substantial impact on the achievement of a better level of productivity, organizational performance and quality of life [15].

Factors Influencing Thermal Comfort

The thermal comfort depends on both environmental and personal factors which affect the perception and response to the thermal surroundings of the individual. Internationally accepted thermal comfort standards like ISO 7730 and ASHRAE Standard 55 stipulate that there are six main factors that influence thermal sensation and thermal comfort perception. The factors can be classified as environmental and personal factors, where the former refers to the surrounding environment; the latter, to the physical status of the person living in the environment and their actions. This is because the relation between these variables is crucial in the design and operation of air conditioning systems for optimum comfort and energy efficiency [16].

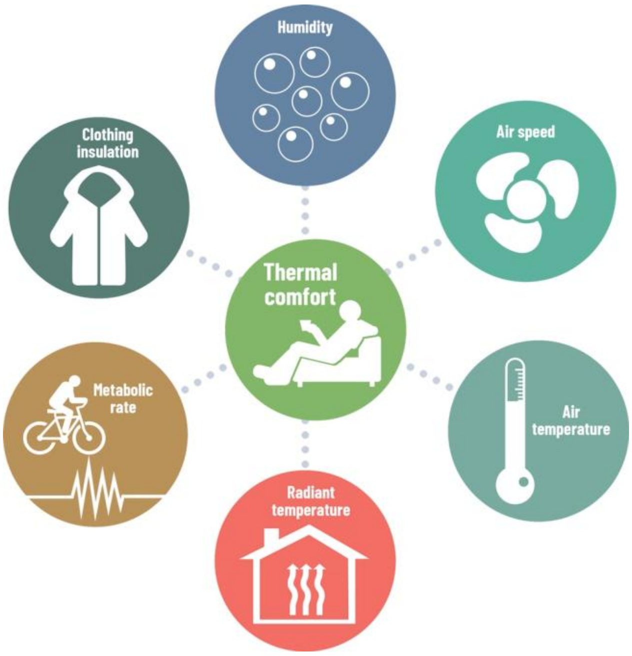

Figure 1: Factors Influencing Thermal Comfort

ENVIRONMENTAL FACTORS

1. **Air Temperature:** One of the most important parameters that influence thermal comfort is the air temperature. It describes the air temperature around a person, and directly affects the rate at which the human body exchanges heat with the environment. If air temperature is too high, the body's capability to dissipate heat reduces, causing feelings of heat and discomfort. On the other hand, low air temperatures enhance the heat loss from the body, leading to a low temperature feeling of the occupants. To control the temperature inside the building, air conditioning systems are used to achieve the thermal conditions in the comfort zone recommended by international standards. Temperature control is an important factor in making indoor spaces comfortable, healthy and productive for occupants.

2. **Relative Humidity:** Relative humidity is the percentage of water vapor in the air to the maximum amount of water vapor possible in the air at the same temperature. The evaporative cooling mechanism of the body, by sweating, is greatly affected by humidity. When the relative humidity is high, the rate of sweat evaporation from the persons decreases and the people feel hotter than the temperature of the air. However, dry air at the other end of the spectrum can result in dry skin, eye irritation and respiratory discomfort. The optimal range for indoor relative humidity is 40-60%, which is recommended to ensure thermal comfort and reduce health related problems. Humidity control is therefore a crucial process of modern air conditioners.

3. **Air Velocity:** Air velocity refers to the speed at which air moves within an indoor space. It affects thermal comfort by influencing convective heat transfer and sweat evaporation from the skin surface. Increased air movement enhances heat dissipation and creates a cooling sensation, particularly in warm environments. However, excessive air velocity may produce drafts that cause discomfort, especially in cooler conditions. Proper design of supply and return air outlets is necessary to achieve uniform airflow distribution and prevent localized discomfort. Advanced HVAC systems often employ controlled airflow strategies to balance cooling effectiveness and occupant comfort.

4. **Mean Radiant Temperature:** Mean radiant temperature (MRT) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer between the human body and surrounding surfaces equals that in the actual environment. It accounts for the thermal influence of walls, ceilings, floors, windows, and other surfaces surrounding an occupant. Even when air temperature remains constant, hot or cold surfaces can significantly affect thermal sensation through radiant heat exchange. For example, occupants seated near sunlit windows may experience discomfort due to increased radiant heat gain.

Consequently, maintaining appropriate surface temperatures through insulation, shading, and HVAC design is crucial for achieving overall thermal comfort.

PERSONAL FACTORS

1. **Clothing Insulation:** Clothing insulation refers to the thermal resistance provided by clothing and is commonly expressed in units known as clo. Clothing acts as a barrier to heat transfer between the human body and the surrounding environment, thereby influencing thermal sensation. Heavier clothing provides greater insulation and reduces heat loss, making it suitable for cooler conditions. Conversely, lightweight clothing facilitates heat dissipation and is preferred in warmer environments. Since clothing selection varies according to climate, culture, and personal preference, it is considered a critical personal factor in thermal comfort assessment. Air conditioning systems should accommodate variations in clothing insulation when determining indoor comfort conditions.

2. **Metabolic Rate:** Metabolic rate represents the amount of heat generated within the human body as a result of physical activity and physiological processes. It is typically measured in met units and varies depending on the nature and intensity of an individual's activities. Occupants engaged in sedentary activities, such as office work, generate relatively low metabolic heat, whereas individuals performing physical tasks produce substantially higher amounts of internal heat. An increase in metabolic rate generally raises the body's cooling requirements and alters thermal comfort preferences. Therefore, building designers and HVAC engineers must consider occupant activity levels when establishing indoor thermal conditions to ensure comfort across diverse occupancy scenarios.

Together, these environmental and personal factors interact dynamically to determine thermal sensation and comfort perception. Effective air conditioning system design requires a comprehensive understanding of these variables to create indoor environments that support occupant health, well-being, and productivity while maintaining energy-efficient operation.

Table 1: Factors Influencing Thermal Comfort

Category	Factor	Description	Effect on Thermal Comfort
Environmental Factor	**Air Temperature**	The temperature of the air surrounding occupants within an indoor environment.	Directly affects heat exchange between the human body and the environment. High temperatures cause overheating, while low temperatures lead to cold discomfort.
	Relative Humidity	The amount of moisture present in the air relative to the maximum moisture the air can hold at a given temperature.	High humidity reduces sweat evaporation and increases discomfort, whereas low humidity can cause dryness of the skin, eyes, and respiratory tract.
	Air Velocity	The speed and direction of air movement within a space.	Moderate airflow enhances cooling and comfort by increasing convective heat transfer, while excessive airflow may create drafts and discomfort.
	Mean Radiant Temperature (MRT)	The average temperature of surrounding surfaces such as walls, ceilings, floors, windows, and equipment.	Influences radiant heat exchange between occupants and surrounding surfaces, significantly affecting thermal sensation even when air temperature remains constant.
Personal Factor	**Clothing Insulation**	The thermal resistance provided by clothing, usually expressed in clo units.	Higher insulation reduces body heat loss in cold conditions, while lighter clothing improves heat dissipation in warm environments.
	Metabolic Rate	The rate at which the human body generates heat through physical activity and biological processes, measured in met units.	Higher activity levels increase internal heat production and cooling requirements, influencing thermal comfort preferences.

Air Conditioning System Enhancement Techniques

The increasing demand for occupant comfort, energy efficiency, and sustainable building operation has driven the development of advanced air conditioning system enhancement techniques. Traditional air conditioning systems often operate under fixed settings that may not adequately respond to variations in occupancy, environmental conditions, and individual comfort preferences [17]. Modern enhancement strategies focus on improving airflow distribution, optimizing cooling performance, reducing energy consumption, and providing personalized comfort. The integration of advanced control technologies, smart sensors, and adaptive management systems has significantly improved the ability of HVAC systems to maintain comfortable indoor environments while minimizing operational costs. The following sections discuss major enhancement techniques that contribute to thermal comfort optimization in indoor spaces [18].

Optimization of Air Supply and Return Configurations

The arrangement of air supply diffusers and return vents plays a critical role in determining indoor airflow patterns, temperature distribution, and thermal comfort. Improper placement of supply and return outlets can result in uneven temperature zones, stagnant air regions, and occupant discomfort. Optimized air distribution systems ensure uniform cooling by effectively circulating conditioned air throughout the occupied space. Computational Fluid Dynamics (CFD) simulations are widely employed to evaluate airflow behavior and identify the most efficient configurations for air supply and return locations. Properly designed configurations enhance air mixing, reduce temperature stratification, improve indoor air quality, and increase overall HVAC efficiency. Consequently, optimizing air distribution remains one of the most effective methods for enhancing thermal comfort and reducing energy consumption [19].

Variable Air Volume (VAV) Systems

Variable Air Volume (VAV) systems represent a significant advancement over conventional constant air volume systems. Instead of supplying a fixed quantity of conditioned air, VAV systems adjust airflow rates according to the cooling or heating requirements of different zones within a building. This dynamic control mechanism enables more precise temperature regulation and improves occupant comfort. VAV systems typically employ sensors and automated dampers to monitor indoor conditions and modify airflow accordingly. By delivering only the required amount of conditioned air, these systems reduce fan energy consumption and improve overall energy efficiency. Their ability to accommodate varying occupancy levels and thermal loads makes VAV systems particularly suitable for commercial buildings, offices, and educational facilities where comfort requirements change throughout the day.

Demand-Controlled Ventilation

Demand-Controlled Ventilation (DCV) is an intelligent ventilation strategy that adjusts outdoor air intake based on real-time occupancy levels and indoor air quality conditions. Traditional ventilation systems often operate at fixed ventilation rates regardless of the number of occupants, leading to unnecessary energy consumption. DCV systems utilize sensors, such as carbon dioxide (CO_2) detectors, occupancy sensors, and air quality monitors, to determine ventilation requirements accurately. When occupancy increases, the system introduces additional fresh air to maintain acceptable indoor air quality. Conversely, ventilation rates are reduced during periods of low occupancy, thereby conserving energy. By balancing ventilation effectiveness with energy efficiency, DCV systems contribute significantly to thermal comfort, occupant health, and sustainable building operation [15].

Smart Thermostat Integration

Smart thermostats have emerged as an effective tool for enhancing air conditioning system performance through automated temperature control and intelligent decision-making. Unlike conventional thermostats, smart thermostats continuously monitor indoor environmental conditions, occupancy patterns, weather forecasts, and user preferences to optimize HVAC operation. Many smart thermostat systems incorporate machine learning algorithms that adapt to occupant behavior over time, enabling more accurate and efficient temperature regulation. Remote accessibility through mobile applications further allows users to monitor and adjust indoor conditions from any location. The integration of smart thermostats improves thermal comfort by maintaining stable indoor temperatures while simultaneously reducing energy consumption and operational costs.

Adaptive Control Strategies

Adaptive control strategies involve the use of advanced algorithms and real-time feedback mechanisms to continuously adjust HVAC system operation in response to changing environmental and occupancy conditions. These strategies account for variations in outdoor weather, internal heat gains, occupancy density, and individual comfort requirements. Unlike traditional fixed-control approaches, adaptive systems dynamically modify cooling capacity, airflow rates, and ventilation settings to achieve optimal thermal conditions. Artificial intelligence, machine learning, fuzzy logic, and predictive control techniques are increasingly being incorporated into adaptive HVAC systems. Such technologies enhance system responsiveness, improve energy efficiency, and provide superior thermal comfort by maintaining indoor conditions closer to occupants' preferred comfort levels [20].

Zonal Cooling and Personalized Comfort Systems

Zonal cooling systems divide a building into multiple independently controlled thermal zones, allowing different areas to receive customized cooling based on occupancy and thermal requirements. This approach addresses the challenge of varying comfort preferences among occupants and eliminates unnecessary cooling of unoccupied spaces. Individual zone control can be achieved through separate thermostats, dampers, and airflow regulation devices. In addition to zonal cooling, personalized comfort systems have gained attention as an innovative method for enhancing occupant satisfaction. These systems provide localized control of temperature and airflow through devices such as personalized air diffusers, desk-mounted fans, and microclimate conditioning units. By delivering comfort directly to individual occupants, personalized systems reduce overall energy demand while improving thermal satisfaction. Consequently, zonal and personalized cooling technologies are increasingly recognized as effective solutions for achieving both occupant comfort and energy-efficient building operation [21].

Collectively, these enhancement techniques demonstrate the ongoing evolution of air conditioning technologies toward intelligent, adaptive, and occupant-centered solutions. Their implementation contributes significantly to improved thermal comfort, energy conservation, and sustainable indoor environmental management.

LITERATURE REVIEW

(Hanafi et al., 2025)[22] assesses two HVAC setups' thermal comfort and airflow performance in a university lecture hall to improve indoor environmental quality and learning environments. The study, which was carried out in Classroom 1303 at October 6 University in Egypt, used ANSYS® FLEUNT simulations to examine the distribution of thermal and air flow under two different configurations. The findings showed that the systems differed significantly from one another. Case 1 showed unequal cooling due to a temperature differential of 6–8°C between the front and rear sections, irregular airflow velocities of 0.5–0.7 m/s near the windows, and insufficient air mixing. Additional variations were seen in the relative humidity, which varied from 32 to 42%. Case 2, on the other hand, produced a steady relative humidity of 38–42%, balanced airflow velocities of 0.3–0.5 m/s, and a constant temperature gradient of 2–3°C. Using “the Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD)” indices, thermal comfort analysis revealed that Case 2 performed better than Case 1, with PPD values continuously below 10% and discomfort levels surpassing 25% in specific places. In comparison to the free-standing air conditioner, these results highlight the hidden ceiling-mounted system's capacity to provide stable environmental conditions, improved airflow distribution, and constant thermal comfort.

(Chien et al., 2025) [23] offers a three-dimensional model of a tiny office for the analysis and evaluation of Vietnam's thermal comfort. The "Predicted Mean Vote index (PMV)" is used to measure thermal comfort satisfaction. The CFD simulation is used to calculate PMV while accounting for the effects of "radiation, air flow, temperature field, and wind speed". Additionally, two distinct airflow rates—0.4 and 0.56 m3s-1—were taken into consideration. The findings indicate that only the majority of users in the return air vent region are dissatisfied with the thermal comfort at the airflow of 0.4 m3s-1, although 70% of users surrounding the supply air vents are pleased. The proportion of persons who were pleased with thermal comfort in locations close to the supply air vent rose by 95% when the airflow was 0.56 m3/s, and the return air vent area's thermal comfort also improved.

(M. Wang et al., 2026) [24] Investigated the summer thermal comfort of three riverside parks in Chongqing: Jiulongtan Park, Coral Park, and Jiangtan Park. The results indicate that the greatest air temperature was 43.7 °C, while the maximum black globe temperature was 61.6 °C. The hydrophilic layer documented the maximal wind speed (1.64 ± 0.39 m/s), while the elastic layer exhibited high PET values (36.00–46.10 ◦C). Regression analysis revealed neutral PET values between 32.49 and 35.74 °C. Conversely, there was a negative relationship between PET and wind speed. This investigation establishes a scientific basis for the optimization of shade, ventilation, and hydrophilic areas in hot-humid mountain-water cities by highlighting the combined effects of "river-valley topography, elevation stratification, waterfront microclimate, and landscape components on outdoor thermal comfort".

(MOHAN et al., 2026) [25] In order to optimize the indoor thermal environment in a computer lab at a civil engineering department in Madurai, Tamil Nadu, India, which is renowned for its hot, semi-arid climate, the thermal comfort and indoor air quality are assessed and various roof and HVAC configurations are assessed using CFD simulations. In order to optimize thermal performance for the construction of educational facilities, the study's conclusions advocate for the use of gypsum-board roofing in conjunction with active cooling, as they emphasize the importance of air conditioning and material selections in achieving the highest possible thermal comfort. Scenario III (active cooling + gypsum roof) showed a 15% better thermal distribution and a 24% lower temperature than Scenario I (reinforced cement concrete roof).

(Jiang et al., 2026) [26] aims to thoroughly characterize and evaluate the performance characteristics of interior thermal and moisture conditions in modern timber buildings, as well as to identify the primary contributing factors and their underlying mechanisms. The results demonstrate that timber-framed buildings have distinctive indoor hydrothermal properties over concrete structures, including rapid temperature response, robust humidity buffering ability, and superior thermal insulation performance that keeps indoor relative humidity consistently within the thermally comfortable range. However, problems still exist, such as summertime overheating and increased mould development hazards in hot, humid weather. Furthermore, the PMV model exhibits a significant forecast deviation for thermal comfort in timber-framed buildings; thus, its application requires calibration that considers both the hydrothermal properties of timber materials and the psychological adaption of occupants.

(Zambrano & Baldini, 2025) [27] This research suggests a distinctive numerical framework for evaluating the impact of "non-uniform indoor environments on physiological responses, heat balance, and thermal comfort", thereby promoting the state-of-the-art. The system combines a computational fluid dynamics model with thermoregulation through an effective and scalable co-simulation methodology. Heat Deviation Reference and Heat Deviation Reference The framework also introduces two additional metrics: temperature. While the latter converts this data into equivalent temperatures, the former measures variations in metabolic and perceptible heat from a reference state in order to quantify changes in human heat balance. The framework's use was illustrated using a case study that examined a personal radiant cooling system's performance. The results demonstrate that although radiant asymmetry is low and latent heat exchange is decreased, the heat balance is not brought back to acceptable levels at 25 °C and 28 °C air temperature. Furthermore, the perceived temperature is lower than the air temperature by up to 2 °C. The limitations, possible uses, and future prospects of this study are finally examined.

(Stiborova et al., 2025) [28] evaluates a kindergarten's indoor environment and thermal comfort. This case study includes both simulated analysis and experimental data. In one of the kindergarten classes, experimental measures were carried out throughout the winter to gather information on “indoor air temperature, relative humidity, and carbon dioxide concentration”. A model was created in the DesignBuilder programme using this data plus the classroom's operating records during the measurement period. This model was used in two simulations: one for energy and the other for computational fluid dynamics (CFD). The model was calibrated to closely match the measured data. The outcome is a qualitative regional distribution of thermal comfort attributes. The results of the tests and simulations show an adverse indoor environment in terms of thermal comfort, which might be used as a foundation for creating a more appropriate room ventilation system.

(Akyüz et al., 2024) [29] examines energy use, thermal performance, and "indoor environmental quality (IEQ)" in terminal buildings. This study employs a comprehensive thermal analysis to identify significant heat loss sources, such as thermal bridges in walls and windows, which significantly increase the amount of energy needed for heating. The urgent need for better ventilation systems is highlighted by IEQ tests, which reveal that high passenger densities and a lack of mechanical ventilation commonly result in CO2 levels above prescribed thresholds. According to calculations of energy requirements that are based on the TS 825 standard and actual consumption data, optimizing furnace settings could result in a 22% reduction in heating energy with no additional expenditure. The replacement of double-glazed windows with windows with superior U-values and the addition of thermal insulation to the building envelope have been demonstrated to generate substantial energy savings and reduced CO2 emissions, all of which have favorable repayment periods, according to economic analysis and simulations. The results highlight how crucial it is to match operational norms with global standards like ASHRAE and CIBSE in order to maximise energy efficiency and guarantee thermal comfort.

CONCLUSION

Thermal comfort optimization has become a fundamental objective in the design and operation of modern indoor environments due to its significant influence on occupant health, well-being, and productivity. This review examined the key environmental and personal factors affecting thermal comfort and highlighted the critical role of air conditioning systems in maintaining favorable indoor conditions. The analysis of recent advancements demonstrates that enhanced HVAC technologies, including optimized air distribution configurations, Variable Air Volume systems, demand-controlled ventilation, smart thermostats, adaptive control mechanisms, and personalized cooling solutions, offer substantial improvements in thermal comfort and energy performance. Furthermore, recent studies reveal the increasing importance of computational fluid dynamics, artificial intelligence, machine learning, and real-time sensing technologies in predicting occupant needs and optimizing HVAC operations. These intelligent systems enable more precise control of indoor environmental parameters while reducing energy consumption and operational costs. Despite significant progress, challenges related to energy efficiency, occupant diversity, and climate adaptability remain important research areas. Future developments should focus on integrating smart control technologies, occupant-centric design approaches, and sustainable building practices to achieve higher levels of thermal comfort and environmental performance. Ultimately, enhanced air conditioning systems will play a pivotal role in creating healthier, more comfortable, and energy-efficient indoor spaces for future generations.

REFERENCES

[1] A. Victoria, P. Florido, M. M. Ouf, W. O. Brien, N. Cooper, and H. Awad, “Thermal Comfort and Passenger Responses in Airports,” *E3S Web Conf.*, vol. 689, no. 06007, pp. 1–7, 2026.

[2] R. Yadav, S. Singh, and D. B. Sures, “Investigation the Advisable Position of Split Air Conditioning Unit on Classroom Using Computational Fluid Dynamics (CFD),” *Int. J. Innov. Sci. Eng. Manag. Investig.*, vol. 3, no. 3, pp. 32–43, 2024.

[3] X. Wang and Y. Pan, “Utilizing computational fluid dynamics (CFD) for simulating airflow and heat distribution to enhance thermal comfort in enclosed space,” *J. Phys. Conf. Ser.*, 2025, doi: 10.1088/1742-6596/2949/1/012049.

[4] A. L. Slimani, S. Mazouz, and S. Nekhila, “Computational Fluid Dynamics-Based Quantitative Assessment and Performance Optimization of Thermal Comfort in Hyper-Arid Climate Office Buildings,” *Sustainability*, vol. 17, no. 10229, pp. 1–43, 2025.

[5] Z. R. B. Sahari, A. S. A. Nohe, and M. S. Bin Othman, “Thermal comfort in indoor and outdoor spaces: a methodology,” *Int. Multidiscip. Acad. Conf.*, 2025.

[6] L. Wang, M. Ismail, and H. S. Basher, “Energy Efficiency and Comfort Performance of Airport Terminal Buildings: A Systematic Review,” *Sci. Technol.*, vol. 33, no. 5, pp. 2357–2394, 2025.

[7] Azmatullah, B. Suresh, and S. Singh, “Examine Thermal Comfort Inside The Indoor Swimming Pool Through Various Configuration of Inlet and Outlet Vents,” *Int. J. Innov. Sci. Eng. Manag.*, vol. 4, no. 1, pp. 46–55, 2025, doi: 10.69968/ijisem.2025v4i146-55.

[8] M. M. Othayq, “CFD Investigation on the Thermal Comfort for an Office Room,” *Buildings*, vol. 15, no. 2802, pp. 1–26, 2025.

[9] M. H. Al-zuriqat and B. Obeidat, “Computational fluid dynamics – based assessment of thermal comfort parameters in residential buildings in Amman: Implications for indoor environmental quality,” *J. Ecol. Eng.*, vol. 26, no. 5, pp. 383–400, 2025.

[10] D. Kumar and S. Singh, “A Review on the effect of air distribution in Protected Occupied Zone Ventilation,” *Int. J. Innov. Sci. Eng. Manag.*, vol. 2, no. 3, pp. 72–75, 2023.

[11] S. Ur, R. Chaudhary, H. Medha, A. Haque, and A. Mahmood, “A Comprehensive Literature Study on Thermal Comfort,” *Int. J. Res. Publ. Rev.*, vol. 5, no. 11, pp. 4624–4629, 2024.

[12] Y. Kang, H. Yuk, H. H. Jo, and S. Kim, “Indoor thermal environment assessment of a historic building for a thermal and energy retrofit scenario using a CFD model,” *Case Stud. Therm. Eng.*, vol. 63, 2024, doi: 10.1016/j.csite.2024.105330.

[13] L. Yang, Z. Chen, and M. Zhen, “Effects of thermal-acoustic interaction on airport terminal’s indoor

thermal comfort: A case study in cold region of China," *J. Build. Eng.*, vol. 86, p. 108834, 2024, doi: 10.1016/j.jobe.2024.108834.

[14] Y. Xia, T. Xu, C. Shi, L. Tian, T. Zhang, and H. Fukuda, "Research on indoor thermal comfort of traditional dwellings in Northeast Sichuan based on the thermal comfort evaluation model and EnergyPlus," *Energy Reports*, vol. 12, pp. 5234–5248, 2024, doi: 10.1016/j.egyr.2024.11.012.

[15] K. Ratajczak, Ł. Amanowicz, K. Pałaszynska, F. Pawlak, and J. Sinacka, "Recent Achievements in Research on Thermal Comfort and Ventilation in the Aspect of Providing People with Appropriate Conditions in Different Types of Buildings—Semi-Systematic Review," *Energies*, vol. 16, no. 6254, 2023.

[16] Y. H. Yau, H. S. Toh, B. T. Chew, and N. N. N. Ghazali, "A review of human thermal comfort model in predicting human–environment interaction in non-uniform environmental conditions," *J. Therm. Anal. Calorim.*, vol. 147, pp. 14739–14763, 2022, doi: 10.1007/s10973-022-11585-0.

[17] H. S. Malik, W. Khalid, A. Jabbar, A. Munir, and A. Waqas, "Comparative Analysis of Thermal Comfort Surveys with CFD Simulations," *Master Conf. People Build.*, 2022.

[18] V. T. Joshi, "ANALYZING AND IMPROVING THERMAL COMFORT AND AIR QUALITY OF INDOOR SPACES USING CFD," 2022.

[19] J. Liu, S. Zhu, M. K. Kim, and J. Srebric, "A Review of CFD Analysis Methods for Personalized Ventilation (PV) in Indoor Built Environments," *Sustainability*, vol. 11, no. 4166, pp. 5–7, 2019.

[20] A. G. Kotopouleas, "Thermal comfort conditions in airport terminal buildings," 2015.

[21] T. S. Rajput and A. Thomas, "Computational Fluid Dynamics (CFD) based spatial mapping of indoor air quality and thermal comfort in the indoor environment," *Int. Build. Perform. Simul. Assoc.*, 2023.

[22] A. M. Hanafi, T. A. Abdo, N. A. Abbass, Y. M. Diab, M. G. Abdelfatah, and M. A. Ibrahim, "Optimizing Thermal Comfort and Air Quality in University Classrooms: A CFD- Based Comparative Analysis of HVAC Configurations," *Int. J. Eng. Appl. Sci.*, vol. 2, no. 1, pp. 17–31, 2025.

[23] N. B. Chien, V. T. Ngoc, N. D. Vinh, T. M. Thang, and H. H. Phung, "CFD Simulation Analysis of Thermal Comfort in a Small Office," *Evergr. - Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, vol. 12, no. 04, pp. 2216–2222, 2025.

[24] M. Wang, H. Zhang, J. Zhang, and J. Ao, "A Study on Summer Thermal Comfort in Chongqing Riverside Parks: Based on Microclimate Measurements and Thermal Comfort Evaluation," *Sustainability*, vol. 18, no. 4990, 2026.

[25] A. MOHAN, V. R, and R. DEIVENDIRAN, "THERMAL COMFORT ANALYSIS IN AN EDUCATIONAL BUILDING IN A HOT CLIMATE AREA USING CFD," *Therm. Sci.*, vol. 30, no. 1, pp. 275–285, 2026.

[26] L. Jiang *et al.*, "Thermal Environment and Thermal Comfort of Modern Timber Buildings: A Systematic Review," *Buildings*, vol. 16, no. 1966, pp. 1–38, 2026.

[27] J. M. Zambrano and L. Baldini, "Integrating CFD and thermoregulation models: A novel framework for thermal comfort analysis of non-uniform indoor environments," *Energy Build.*, vol. 335, 2025.

[28] P. Stiborova, A. Badurova, O. Sikula, and I. Skotnicova, "EVALUATION OF THERMAL COMFORT USING DYNAMIC SIMULATION: A CASE STUDY OF A KINDERGARTEN CLASSROOM IN THE CZECH REPUBLIC," *Slovak J. Civ. Eng.*, vol. 33, no. 3, pp. 20–28, 2025, doi: 10.2478/sjce-2025-0016.

[29] M. K. Akyüz, E. Açıkkalp, and Ö. Altunta¸, "Thermal Performance, Indoor Air Quality, and Carbon Footprint Assessment in Airport Terminal Buildings," *Buildings*, vol. 14, no. 3957, 2024.