Heating, Ventilation and Air-Conditioning (HAVC) Systems: A Critical Review

Ritik Singh Rawat[1], Ankit Goyal[1], Priyavrat Kumar[1]

[1]Department of Mechanical Engineering, Technocrats Institute of Technology and Science
Anand Nagar, BHEL Opposite Hathaikheda Dam,
Bhopal, Madhya Pradesh 462021

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Abstract - *HVAC (heating, ventilation, and air conditioning) systems are essential for maintaining comfort and good indoor air quality in a variety of environments, including homes and businesses. The HVAC industry is changing toward smart, sustainable, and energy-efficient solutions as a result of growing environmental concerns and technical advancements. With an emphasis on smart technology, energy-efficient designs, the incorporation of renewable energy sources, and advancements in air quality control, this article explores contemporary trends in HVAC. It also discusses the difficulties the industry faces and suggests possible avenues for further research.*

Key Words: HVAC (Heating, Ventilation, and Air-Conditioning), controllable environments.

1.INTRODUCTION

Models of HVAC systems evaluate the electrical, heating, and cooling energy needs of their constituent parts using mass and energy conservation concepts. These three processes are combined in an HVAC system, which stands for heating, ventilation, and air conditioning [1–3]. It controls a building's ventilation, humidity, and quality. Room Temperature: Measuring devices that adapt to the needs of passengers are used to maintain the temperature in the passenger compartment [3]. Humidity: To keep passengers comfortable, the HVAC system regulates humidity levels [4]. Air Purification: The technology filters the air to get rid of dust and bacteria to improve passenger comfort. A key concept since the introduction of HVAC systems is "thermal comfort," which ASHRAE defines as a sense of contentment with the thermal environment. This comfort affects HVAC efficiency and is essential for health. According to Boyle's 1660s research, the average human body temperature is 37 degrees Celsius, with only a few exceptions. Excess body heat must be released via the skin to maintain a metabolic rate of 1 W/kg; during physical exercise, this rate can rise to 5 W/kg. This is equivalent to about 100 W during working hours for an average adult. When skin temperatures drop below 33 degrees Celsius, the body loses heat depending on a number of external conditions [5].

Air temperature is a crucial indicator of thermal comfort, but in order to properly evaluate heat stress, it must be considered in conjunction with other variables. In order to ensure at least 80% occupant comfort, current standards like ASHRAE 55-2004 and ISO 7730 specify a "comfort zone" that takes into account both personal characteristics (clothing, activity level) and thermal components (radiant temperature, humidity, air temperature, and air velocity). Participants in controlled laboratory tests evaluated their level of comfort under static conditions, which served as the basis for these standards. Additionally, they set limits on the temperature differential between the neck and ankles; according to ASHRAE 55-2004, this difference cannot be greater than 5.4 degrees Fahrenheit [6].

The impact of different levels of thermal sensitivity on adaptive comfort models was investigated by Rupp et al. (2022) using information from the "ASHRAE Global Thermal Comfort Database II." They used five essential steps in their methodology: i) taking a pertinent subset out of Database II; ii) estimating the neutral temperature using conventional techniques.

Griffiths' method consisted of the following steps: iii) iterating each step with new thermal sensitivity settings; iv) creating adaptive comfort models for both naturally ventilated and air-conditioned workplaces using data from Europe and the world; and v) assessing the different models created. The findings suggest that the temperature sensitivity of building occupants is influenced by various ventilation methods. In particular, office employees in naturally ventilated spaces were less sensitive to temperature fluctuations than those in climate-controlled spaces. One important conclusion is that geographic location and thermal sensitivity have a substantial impact on the "adaptive model relationship" between outdoor temperatures and inside neutral temperatures, with European occupants showing more sensitivity to temperature changes than those in other countries. Given that adaptive comfort standards are based on the adaptive model connection, this realization has significant ramifications for the planning and administration of naturally ventilated and mixed-mode buildings.

As part of their investigation, [10] looked at a multi-person workplace with air-cooling equipment in Guangzhou, China. Researchers looked into the relationship between gender and different environmental variables and how these affected users' propensity to engage in adaptive behaviors. Using logistic regression, a probabilistic prediction study of behavioral adaptations to temperature extremes was carried out. Users only accepted a 1-degree Celsius increase over the neutral interior temperature in the study's hot climate. When consumers adjusted, the inside temperature felt about 1 degree Celsius higher in hotter weather and lower in colder weather, according to the thermal sense survey. The probability of adaptive behavior was strongly impacted by both indoor and outdoor temperatures ($P < 0.005$). Overall, the accuracy of the regression analysis was over 70%. The "adaptive probabilistic prediction model" for cold and hot behaviors was developed using the findings that the crucial temperatures for interior thermal contentment and dissatisfaction were 26°C and 28°C, respectively. Interestingly, hot adaptation behaviors were first observed in males at about 22°C, about 3°C below the temperature at which females began to adjust.

[11] Research on the flow patterns and loss characteristics related to rectangular expansions has been prompted by the widespread usage of rectangular air ducts in ventilation systems. Initially, semi-empirical techniques were used to analyze the Borda-Carnot loss under the assumption that the inlet velocity profiles were constant and completely formed. According to the study, traditional loss formulas that rely on uniform inflow have a tendency to underestimate losses; in the case of each rapid expansion, the errors can reach 3%. In the study's second phase, the precise flow behavior and loss characteristics in a square-to-square rapid expansion with an area ratio of 2.78 were experimentally analyzed. The Reynolds number range that was the focus of the investigation was 0.36×1050.36×105 to 1.8×1051.8×105, which is normal for ventilation systems. Accurate observations of wind speeds and turbulence were obtained using laser Doppler anemometry. The findings demonstrated that the downstream consequences of a square-to-square expansion are much more extensive than those of an axisymmetric expansion, with a full flow development path that is 1.5 to 2 times longer and a flow reattachment length that is 1.5 to 2.5 times longer [12].

Temporary, asymmetric sun radiation and uneven air temperature were identified as major elements in a study that looked at how people perceive temperature in cars compared to their experiences in homes and offices. 24 participants and 62 trials in three distinct outdoor driving settings were included in the study. According to the study, there are two primary reasons why people perceive different temperatures: 1) notable climate variations between summer cooling and winter heating, and 2) sudden variations in sun radiation during transitional seasons. Four models of temperature feeling were examined and compared with the data: the transitory outdoor thermal sensation model, the dynamic thermal sensation model from Berkeley, the University of California model, and the projected mean vote model. According to the findings, none of the models could predict with any degree of accuracy how passengers would feel about the temperature while driving. This disparity was largely caused by the driver's exposure to abrupt variations in the sun's angle. The study thus created a novel thermal sensation model that takes into consideration variations in the driver's thermal burden brought on by abrupt variations in sun radiation. A dynamic, fluctuating temperature environment within automobiles was then used to assess the new model's dependability [13].

On the departure level of a large airport terminal in China, research looked at the patterns of passenger and service counter activity. To examine passenger flow patterns, the researchers employed agent-based simulation that included survey data. The findings demonstrated that the design occupant density in each sector closely matched the real situation at the airport, with only 3.6% of the simulated occupant density exceeding the design density. Due to changes in the allocation of passengers by time and place, the maximum occupancy on the departure floor varied between 54.8% and 64.4%. The results indicate that by modifying the quantity of mechanical external air according to real occupancy rates, airport HVAC systems have a substantial chance to lower energy usage. In particular, the mechanical outdoor air's "maximum actual demand" for cooling load was only 25 W/m^2, as opposed to the design figure of 47 W/m^2. [14]

In a four-person electric automobile, a study was carried out in both winter and summer. The temperatures of the inside air and surface, along with the heat fluxes on different surfaces, were measured during the heating and cooling stages. Furthermore, it took longer to reach the ideal interior temperature when the vehicle was moving because more heat was transported from the outside to the inside by convection at the exterior of the cabin [15].

A numerical model was created in research [16] to estimate airflow in a passenger bus compartment during the summer, and the correctness of the model was verified using experimental measurements. In the bus's cabin, the heating, ventilation, and air conditioning (HVAC) system caused a great deal of turbulence. The simulations comprised both seated and reclined manikins, which were used as heat sources. The turbulent airflow was simulated using the V2f turbulence model. Both with and without the manikins, the degree of comfort in the compartment was evaluated at two distinct temperatures and air speeds. The shape of the box was also altered to make the manikins more comfortable. The results showed that passengers experienced discomfort due to inconsistent temperatures caused by an inefficient layout. Better thermal conditions for both seated and sleeping passengers resulted from a redesign that made the airflow more symmetrical.

[17] As a result, improving system efficiency may be crucial to advancing environmental preservation and sustainability. By describing the temperature and performance characteristics of VACR systems utilized in the food transportation industry under real-time settings, the study

fills a vacuum in the literature. Field data gathered from refrigerated service vehicles throughout the year was used to calculate duty cycles. Fixed A/C-R systems provided the initial data, which was subsequently moved to mobile VACR units for additional analysis. For more thorough testing, a test bed was also established at the LAEC. Mathematical models of the steady-state and transient thermal performance and properties of VACR systems were developed. These models were then validated using field and lab data to do a thorough examination of the VACR systems' thermal performance.

By modeling the creation and optimization of HVAC (heating, ventilation, and air conditioning) systems in passenger trains, a study emphasizes the growing significance of enhancing product quality and energy efficiency. It is still difficult to get the information regarding real working conditions, though. The study offers techniques for describing common HVAC conditions in trains in order to address this. First, Monte-Carlo simulations based on simulated train trips were used to develop an extensive database of HVAC settings that were designed to mimic real-life conditions. This method used simulated rail rides to overcome the problem of not having enough real-world data. Additionally, the system provided flexibility in taking into account different train types, operational profiles, climate conditions, and rail networks. The collected data was then subjected to methods and time-domain signals that describe typical days (ROC-signals). Design choices are guided by these findings, which are utilized to inform both static and dynamic system models. An example of the use of this strategy is the urban and suburban railway system in Switzerland [18].

A study that described the approach used to calculate the energy consumption of HVAC systems in light rail vehicles. A modular simulation model that provided access to crucial system characteristics was created in order to predict the energy consumption of the HVAC system [18]. The HVAC system is combined with a "dynamic thermal vehicle model" in this model, which also takes operating and meteorological data into account. Data from climate-controlled wind tunnel testing was used to identify the vehicle model through data-based system identification. The model's parameters' physical meaning was revealed through the use of a gray-box modeling technique. The brief sample interval (Ts = 10 s) allows for the observation of the effects of transient switching operations. An easy-to-use graphical user interface (GUI) was combined with the thermal simulation model to enable speedy processing of simulation data, provide time-domain findings, and precisely determine the HVAC system's yearly energy usage. The correctness of the model was verified using actual data from a Vienna tram line. Results from both short-term and long-term simulations were reliable and consistent. Solid work and ANSYS software simulations were used to construct the ventilation design [20–23].

A survey of available literature indicates a lack of research targeted to increasing thermal comfort requirements within cars. While modern vehicles are equipped with several new technologies, their HVAC systems typically require modifications to stay pace. This study intends to address the shortcomings noted by past research, stressing the impact of vehicle compartment architecture and the strategic placement of air inlets and outputs.

In this experiment, the thermal comfort of passengers within a train cabin will be assessed. The cabin fits four individuals, contains a glass window, and is fitted with an air inlet located at its base, alongside three outlets situated at the opposite end. A steady-state thermal simulation will be done for four separate situations, altering the position of the air intake vent and the window. The outcomes of these simulations will then be examined to identify their consequences.

Air conditioners Air conditioners are supposed to manage both the temperature and humidity of the air, adjusting to current conditions to deliver either cooling or warming. Typically, they utilize a basic refrigeration cycle to reduce indoor temperatures, however evaporation may also be applied in some cases. [7].

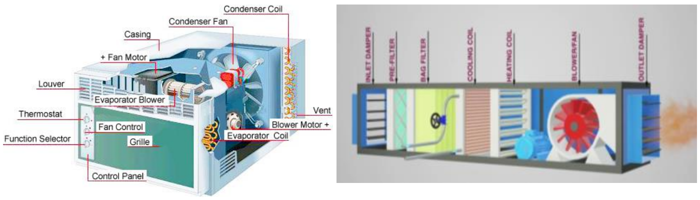

Figure 1 (a) Air conditioner, (b) AHUs

AHU- An air handling unit is a device that comprises heating and cooling coils, fans, air control dampers, and filters. It begins by pulling in exterior air and mixing it with recirculated air from within the structure. This mixed air is then either heated or cooled before being transported throughout the structure via a duct system [8].

Dehumidifiers/ Heater In the air stream, the system contains a condenser coil beside a dehumidifier evaporator. Warm, dehumidified air is produced as it goes through the condenser coil, which shares the same air route as the evaporator coil. The air is then warmed as it flows over the condenser coil [9].

Filters (Pre & HEPA)
Pre –Filters Pre-filters are designed to remove bigger undesired particles from the air, such as dust, insects, hair, pollen, and fibers. These filters are extensively employed in public spaces, industrial facilities, and transportation systems. Pre-filters also extend the lifespan of the HEPA filters within air purifiers. However, not all pre-filters are identical in design or efficiency.

HEPA Filters: HEPA stands for "High Efficiency Particulate Air." These filters are capable of catching 99.97% of particles as small as 0.3 microns. HEPA filters are crucial in situations needing contamination control, including disk drive manufacturing, semiconductor production, healthcare institutions, food processing, nuclear plants, and households, as well as in vehicles.

Dust Extractor Dust extractors are electrical devices used to capture or remove undesired airborne dust particles. Commonly utilized in coal preparation plants, loading stations, and subterranean locations, these devices may comprise scrubbers, cloth filters, cyclones, spray towers, or electrostatic barriers.

Ducting (for distribution of regulated air) Ducts are integral to HVAC systems, installed behind walls to remove hot or contaminated air and deliver cold, clean air, ensuring thermal comfort in indoor environments.

Supply Fans Also known as intake fans or make-up air blowers, supply fans are used to introduce fresh, clean air into an area at a higher rate than regular airflow. This prevents negative pressure in locations where air is withdrawn faster than restored. Supply fans are often used in laboratories, chemical industries, hospitals, welding rooms, spray booths, and are a crucial component of HVAC systems, helping to maintain clean air in passenger compartments.

Smoke Detectors Smoke detectors are sensors that detect smoke, alerting a potential fire. In large buildings, they provide signals to fire alarm systems, producing audible sirens and visual indicators. Typically small, circular, and encased in plastic casings, smoke detectors are deployed in high-risk areas for early fire detection.

Damper Dampers are used in heating or cooling systems to adjust or cut off airflow in unused rooms, hence controlling room temperature and climate. They can be manually operated with an external handle or automatically controlled by electrical or pneumatic motors coupled to thermostats or building automation systems.

Humidity sensor Humidity sensors measure and monitor the amount of water in the surrounding air, which is an important aspect in many applications such as consumer goods, industrial processes, biomedical equipment, and environmental monitoring. High humidity levels can cause pain and interfere with the operation of sensitive equipment like electronics and high-voltage devices, which require controlled settings for best performance.

Heating & Cooling coil Heating and cooling coils are essential components of HVAC systems, adjusting air temperatures to ensure proper equipment operation and indoor comfort. These coils, which come in a variety of sizes and diameters, are commonly employed in industrial and residential applications to maintain desirable thermal conditions.

Working of a HVAC System A well-designed HVAC system guarantees the effective transmission of clean air for future usage. Each component contributes significantly to maintaining air quality and delivering a comfortable and controlled atmosphere.

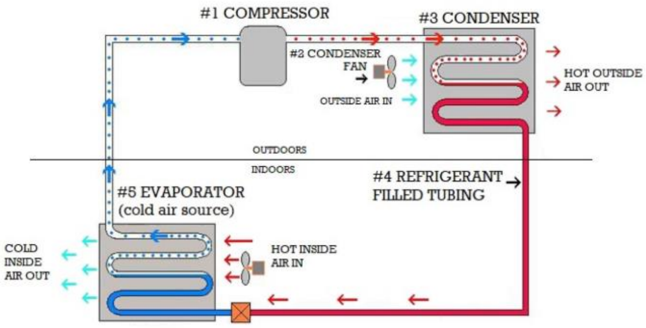

Figure 2 Basic Components of HVAC System

SOLIDWORKS

In this study, CAD modeling was carried out using SOLIDWORKS, a comprehensive platform that supports all stages of the product development process, including CAD, CAM, CAE, and CAAD. SOLIDWORKS provides a wide range of design capabilities, including surface modeling, shape design, mechanical system design, wireframe modeling, and electrical system design.

ANSYS

The ANSYS Workbench Structure Modeler was used to create the geometry of the compartment and perform subsequent analysis within the ANSYS framework. Incorporating plane symmetry made the geometry easier to maintain. The compartment was planned to house four people and included amenities like as mattresses, air conditioning, and ventilation systems with intake and output ductwork. A thorough examination of the resulting outcomes was done. Accurate solutions were obtained using Computational Fluid Dynamics (CFD) analysis.

CONCLUSION

This study gives a thorough examination of the fundamental characteristics of HVAC systems, such as their functionality, kinds, and components. It also provides a literature assessment of current advances aimed at increasing HVAC system efficiency and thermal comfort for occupants in regulated indoor settings. The review investigates different aspects that influence HVAC performance, including clothing, humidity, air temperature, air velocity, and external radiation, and suggests ways to improve.

The findings are particularly important for the future development of car HVAC systems and sophisticated hybrid automobiles. It underlines the need of designing vehicle compartments for optimal and effective air distribution from the HVAC system, resulting in greater thermal comfort and fewer blind spots within the cabin. Further research is needed to determine the impact of inlet and outflow location in vehicle compartments. Furthermore, the power consumption of HVAC systems remains a major concern, necessitating research into improving energy efficiency.

To attain more exact and accurate thermal comfort assessments, future study could include criteria such as clothing, seasonal variations, human activities, body temperature swings, and the sun's location. These characteristics could provide further information about improving HVAC performance and occupant comfort.

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