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A study of Passenger Thermal Comfort in a Medium Distance Flight

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Abstract - Recent decades have seen an increase in the interest of airlines in providing more comfortable environmental conditions for passengers. Nowadays, passengers in air transportation are demanding in terms of comfort. The ability to resolve problems in aircraft cabins is becoming crucial in ensuring passengers' happiness with their flights. It has been accommodated by major aircraft manufacturers such as Boeing and Airbus have been working to improve the comfort of their aircraft cabins. Thermal comfort for humans is one of the most severe issues addressed in buildings and aircraft. Providing thermal comfort for passengers and crew members is a complex problem in an aircraft because thermal comfort is affected by temperature and elements such as relative humidity, air velocity, environment radiation, activity level, and the insulation provided by clothing. The current study has introduced the following factors: human metabolic rate, insulation of clothing, and gender, which are human factors. The other factors are environmental factors: mean radiant temperature, low relative humidity, and colored light, low relative humidity, mean radiant temperature, colored light Many related studies and literature reviews have been conducted on the thermal comfort of indoor environments in ground-level buildings. However, only a few studies have been conducted on the thermal comfort of medium distance flight. Towards that aim, this work attempts to assemble a collection of publications on passenger thermal comfort that are relevant to studies on the thermal comfort of airline cabins.

Index Terms – Thermal Comfort, Aircraft Cabin, Air Conditioning System.

INTRODUCTION

Nowadays, passengers in air transportation are demanding in terms of comfort. The ability to resolve problems in aircraft cabins is becoming crucial in ensuring passengers' happiness with their flights [1]. It has been accommodated by major aircraft manufacturers such as Boeing and Airbus have been working to improve the comfort of their aircraft cabins [2]. The European Union funded two well-known cabin comfort research and development projects: The Friendly Aircraft Cabin Environment (FACE) and the Ideal Cabin Environment (ICE). Many other academics have also performed studies into the thermal comfort of airplane cabins, including the Scientific Community [3]. Regarding cabin-related difficulties, passenger thermal comfort is one of the most important considerations, and it has emerged as a vital market competition factor for the aviation business [4]. People began using airplanes in the last few decades. It is worth noting that the number of people who travel rises steadily each year. Every year, about two billion people fly around the world by air flight, and that figure is expected to rise by 4.2% in the next two decades. Due to the massive number of passengers, we must ensure their well-being, safety, and comfortable. The typical aircraft cabin and a particular microenvironment differ significantly from other built environments. It is compact and crowded, and passengers are subjected to low air pressure and low humidity. All of these aspects combine to create passenger comfort in the cabin. These include the thermal environment, noise, vibration, air quality and pressure [5]. The factors depicted in Figure 1 are generally particular to the building environment, whereas the airline cabin environment is more complicated than the building environment. Accordingly, the factors affecting the thermal comfort of passengers in aircraft are described in Figure 1. The current work has stated the following factors, human metabolic rate, insulation of clothing, and gender, which are human factors. The other factors are environmental factors: mean radiant temperature, low relative humidity, and colored light, low relative humidity, mean radiant temperature, colored light [2].

FIGURE 1
INFLUENCING FACTORS OF THERMAL COMFORT IN AIRCRAFT

According to the (ASHRAE)-American Society of Heating, Refrigerating, and Air Conditioning Engineers, human thermal comfort is defined as the state of mind that reflects happiness with the surrounding environment (ASHRAE Standard 55). A significant topical concern confronting people today is preserving thermal comfort for those who live in buildings or other enclosed areas, such as airplanes or automobiles. It is critical to have a high level of thermal comfort, especially when it comes to the comfort of passengers on an aircraft. This is reasonable since it affects the degrees of distraction experienced by passengers on board, destroying the company's reputation [5]. A person's psychological state of mind is described by the term "thermal comfort," which is typically used to refer to whether or not the individual is feeling too hot or too chilled. This demonstrates that passengers travelling on a medium-distance trip must fly comfortably to reach their destination on time and without incident. The study of thermal comfort in an aircraft is necessary since more people are travelling over short distances these days, and thermal comfort is one of the most important variables contributing to the comfort of the passengers [6]. A highly subjective term, thermal comfort is a profoundly personal experience. This is because it involves personal taste in terms of comfort level and incorporates a variety of temperatures. As measured by their sensors, individuals' internal and external temperatures have different effects, with one working towards restoring deep body temperature and the other moving away from it. Hot individuals will find satisfaction in a cool sensation; nevertheless, when the body is too cold, the sensation will be unpleasant [7]. Meanwhile, the temperature of the skin fluctuates and does not maintain a consistent pattern. Apart from that, different body regions respond differently to temperature changes due to the presence of fats within the skin. Additionally, wearing clothing has a distinct impact on temperature variations and the distribution of skin temperature than not wearing clothing [8].

Nowadays, thermal comfort for humans is one of the most severe issues addressed in buildings and aircraft [1]. Providing thermal comfort for passengers and crew members is a complex problem in an aircraft because thermal comfort is affected by temperature and elements such as relative humidity, air velocity, environment radiation, activity level, and the insulation provided by clothing [9]. All of the above factors are critical in ensuring that all passengers and crew members onboard the aircraft, including the pilots and cabin crew members on duty, are comfortable in their surroundings [10]. Mould growth can be encouraged by high levels of humidity found inside (National Center for Healthy Housing, 2008). High humidity may be caused by the improper architecture of the air ventilation system or by an insufficient exchange of air that happens indoors. The ASHRAE has ventilation guidelines to assure acceptable indoor quality (ASHRAE Standard 62). In response to the present energy and financial crisis, new technologies for controlling indoor temperatures have been developed [11]. Under various parameters of noise, vibration, and heat exposure, Zhou et. al [12] examined the blood pressure of healthy young male adults and hormones. The researchers discovered that the passenger's diastolic pressure and angiotensin levels significantly increased after the combined exposures. A synergetic impact was observed between heat and noise stresses on the skin, rectal temperatures, and sweat [13]. According to the findings, vibration had inhibitory effects on body temperature but a synergetic effect on skin temperature and sweat quantity. More research is needed to confirm the combined thermal comfort effects of temperature, noise, and vibration [14], [15]

It is critical to maintaining the passenger cabin's air quality in a comfortable and healthy state during the flight for both the passengers and the cabin crew. The number of people who travel by plane has been increasing steadily over the years, and the air quality inside planes has been a significant source of concern [5]. The (ASHRAE) has contributed to developing standards for air quality inside airplanes (ASHRAE Standard 161). In addition to providing the passengers with their well-deserved care, it is critical to monitor their health while onboard to minimize any discomfort during the medium-distance flight. If this is not monitored, it will harm the aircraft's reputation [16].

According to the Milano et. al [17], approximately 1,300 reports of smoke or odors inside a large passenger aircraft operated by a British airline have been received in England since 2010. Air pressure is low for humans to breathe independently at the altitudes reached by commercial jets. The majority of the occupants of an aircraft are transported by pilots, cabin staff, and passengers. It is necessary to maintain their thermal comfort level in order for the flight to run well. There are a variety of factors that contribute to their thermal comfort level and their heat production. Individuals differ in their level of comfort with their surroundings [9]. However, heat generation will vary depending on how much electrical equipment are present onboard the flight, in addition to the typical heat generated by the aircraft itself, as specified in the standards indicated previously [7]. The thermal comforts can be realized with the standards, which are based on them. When passengers board flights frequently or travel as part of their profession, they are subjected to persistent low-level leakage, which they may or may not be conscious of [12], [18].

When determining metabolic rates, a variety of parameters have been taken into consideration. Everyone has a different rate of metabolism than the next. These rates can be reduced when a person engages in specific activities or when he or she is exposed to specific environmental factors [19]. As a result of their different metabolic rates, even persons in the immediate vicinity can sense a significant temperature difference, making it extremely difficult to achieve an appropriate temperature for everyone in a specific area or place, particularly in an aircraft in this situation [17], [20]. It is possible to stay warm by wearing multiple layers of insulating clothing throughout the winter or on rainy days in tropical climates. Further, when engaging in vigorous physical activity, multiple layers of clothes can inhibit heat loss, which can result in overheating due to the combination of the two factors [21]. A person's insulating properties are increased and thickened proportionately to the number of clothes worn. Air movement and relative humidity may reduce the insulating properties of clothes, depending on the type of material used to make the clothing [5].

Individuals differ in their thermal sensitivity. It is higher for those with a lower tolerance to non-ideal thermal conditions than those with a higher tolerance. Those who are 14 to 60 years old are regarded to be in the adult category, which includes pregnant women, the disabled, and those between 14 and 60 years old and are considered to be in the adult category [4]. Existing research demonstrates that the body's sensitivity to hot and cold surfaces grows with age. According to the findings, the body's ability to regulate its temperature gradually diminishes after 60 years. This is primarily due to the more sluggish response of the body's counteraction mechanisms, which are responsible for keeping the body's core temperature at a comfortable level at all times [22]. Although the differences in thermal preferences between men and women appear minor, there are some disparities. Females are likely than males to be more responsive to changes in temperature. Females are also more prone than males to be uncomfortable with the room's temperature, and they will notice when the temperature is too hot or too cold before most men [23]. The majority of the time, ladies will prefer greater temperatures than lower temperatures. Although females are more sensitive to temperature

changes, males are more sensitive to relative humidity levels. This is a more subjective aspect that is dependent on the individual's preference [7].
Many related studies and literature reviews have been conducted on the thermal comfort of indoor environments. However, only a few studies have been conducted on the thermal comfort of medium distance flight respectively. Towards that aim, this work attempts to assemble a collection of publications on human thermal comfort that are relevant to studies on the thermal comfort in airline cabins.

AIR CONDITIONING SYSTEM IN AIRPLANES

Temperature and humidity are the two most significant factors affecting the air's quality while being heated or cooled. Air conditioning aims to enhance thermal comfort and air quality in occupied spaces like buildings and vehicles [20]. Comfort ability has become a significant consideration for airline customers in the aviation industry. It is becoming increasingly more accessible for people to travel by air due to inexpensive flights and the airlines are now able to accommodate persons of various abilities. This is the reason customers who travel frequently should be allowed to relax in their seats [5]. According to Maier et. al [24], air conditioning and pressurization are two highly crucial components for any modern airplane capable of flying at high altitudes. These components help to create a comfortable environment for the people on board. Since the human body cannot endure the effects of low pressure in the atmosphere, air conditioning and pressurization systems are essential components of modern aircraft design [23]. A similar statement is made by the Mitani et.al [25], who claims that the air conditioning system provides a safe and comfortable atmosphere for crew members and passengers in the airplane cabin. It is then necessary to introduce considerable amounts of chilled fresh air into the pressurized cabin to maintain a comfortable cabin atmosphere while also ensuring proper cooling and ventilation for the avionics and electronics systems [26].
According to Sun et al. [27], the pneumatic air conditioning (PAC) is the commercial air conditioning system used in aircraft. Besides, it is an air conditioning and cooling system that uses air pressurization as a medium for both cooling and heating. The air conditioning system and the pressurization system of an airplane are critical for passengers and cabin staff on board. As previously stated, the pressurized air within the airplane serves as the medium for air conditioning [28]. Rodrigues et.al [29] investigated the reliability of an airplane's air conditioning system using field data from a specific type of commercial aircraft that had been subjected to real-world operation and climatic conditions. According to the study's findings, the aircraft's air conditioning system that operates in extreme weather conditions and sandy terrain encounters a higher failure rate than that predicted by the aircraft manufacturer [30].
The air conditioning system in an airplane is responsible for providing ventilation and temperature regulation in the occupied spaces and areas. There are two independent air conditioning packs as well as a ram air ventilation system in the configuration [31]. Generally, the air conditioning packs operate in parallel to maintain the desired temperature in the respective compartment. Each of the aircraft's air conditioning packs is generally supplied with bleeding air from the aircraft's engine on the right side of the body airplane [17]. The auxiliary power unit (APU) provides direct power to the left pack. The bleed airflow to each pack is controlled by a pressure regulating shutdown valve, activated by the lights on the air conditioning panel that corresponds to the relevant pack switch lights. According to the manufacturer, this follows the Northwest Air link Flight Crew Operating Manual and should be the same for all Boeing 737 flights [32].

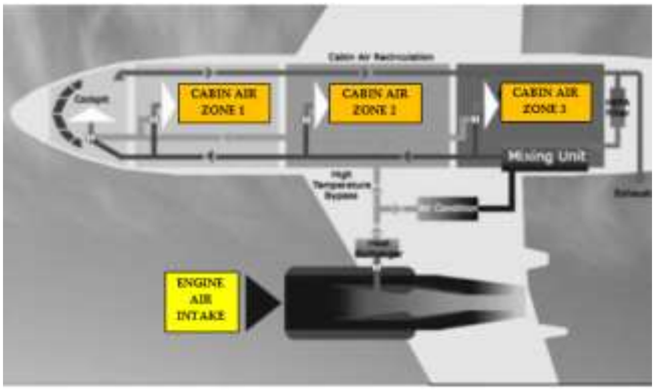

FIGURE 2
AIR CONDITIONING SYSTEM IN AIRPLANE

According to Dumas et al. [33] , the Air Conditioning System conditions the fresh air coming from the bleed air system before distributing it to the cockpit and cabin zones at a specified mass flow rate. The bleed air system is supplied by hot outside air drawn into the airplane by a fan propeller and through the airplane's wings [34]. It is reported that an Air Conditioning System has several functions, including the provision of sufficient fresh air to ensure that passengers on board the flight receive adequate oxygen and the removal of odors from all compartments of the aircraft, particularly the passenger cabin, according to a single source of information. Following that, it maintains the temperature in each cabin within a comfortable range ranging from 15°C to 35°C. After that, the Air Conditioning System is utilized to feed air for cabin pressurization to maintain an appropriate outlet pressure [35]. The air cycle in the air conditioning system and the vapor cycle in the air conditioning system are the two types of air conditioning systems found in most commercial airplanes. These two systems are widely found in aircraft. Following Cabin Environmental Control Systems, the air conditioning system's air cycle is used on most turbine-powered aircraft because it uses engine bleed air during the conditioning process. In contrast, the vapor cycle air conditioning system is often used on reciprocating aircraft because it is similar to the air conditioning systems found in homes and automobiles, respectively [36].

I. Environment Control System (ECS).

The environmental control system (ECS) is the most commonly utilized air conditioning system in an airplane, as illustrated in Figure 1. The ECS of an aircraft is responsible for providing air supply, thermal management, and cabin pressurization for all members of the flight crew, including the pilots and the passengers. In addition to avionic cooling, smoke detection, and fire suspension, the ECS of an aircraft is usually to have other functions [9], [17]. ECS systems like pneumatic, air conditioning, and pressurization controls are positioned on the overhead bleed air, cabin press, and air conditioning panels. The forced ventilation air used to cool the cockpit instrument panels keeps them cool [25].
According to published studies, ECS consists of a small number of air conditioning systems because the airplane has many separate compartments with various ventilation or air cycle options [11], [37]. Various air conditioning systems are used in airplanes, including the pneumatic system, which supplies pressurized air as the air conditioning medium. The air conditioning system receives pressurized air and circulates it throughout the cabin aircraft cooling system and passenger cabin air conditioning [20].
Duan et al [38] reported that ECS is considered as significant and crucial system that ensures that the comfy cabin condition in the aircraft is achieved and maintained by keeping all of the crucial parameters of air conditioning such as temperature, pressure, and composition within acceptable limits. This is usually accomplished by circulating an airflow for thermal control and intensive care, if necessary, within the acceptable limits. In addition, it is indicated that environmental control systems (ECS) for vehicles operating in harsh climates are in high demand [39]. However, they typically only focus on the inside of the vehicle. The environmental control of the outside of the vehicle is usually referred to as the environmental protection system (EPS) [17] .

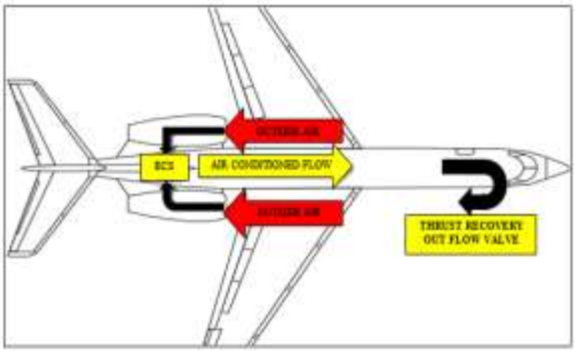

FIGURE 3
ENVIRONMENT CONTROL SYSTEM (ECS) IN AIRPLANE

II. Air Distribution and Ventilation System

The installation of an air distribution system is a requirement in all buildings and transportation, which is necessary for air circulation [40]. The air distribution system in a commercial airplane cabin is critical in maintaining a healthy and comfortable environment for passengers and crew members on board the trip [41]. Inadequate monitoring of the air inside the airplane cabin might result in contamination. The primary aim of implementing a properly functioning air distribution system in an airplane's cabin is to distribute air equally throughout the cabin while minimizing the formation of layers and extreme temperature fluctuations in different aircraft containers, according to the manufacturer [42]. This is further addressed by Tu et. al [43], who states that air should enter and exit the cabin in a uniform manner, and as a result, low pressure ducting is insulated to reduce heat loss, thermal mass, and pressure within the cabin. After exiting the air conditioning pack, the exhaust air is connected to the pressurized nose. It is mixed with filtered air collected through the recirculation fans and then channeled into the combination hose. The air from the hose is routed to overhead line nozzles in each airplane section, creating a positive pressure environment [44].
On pressurized airplanes, cabin air circulation is controlled by a network of air ducts that run from the pressurization source into and across the cabin. The air is ducted to and discharged from ceiling vents, where it circulates and flows out of floor level vents before returning to the ductwork [45]. The ventilation system includes valves to select the pressurization air supply, ventilation air, and temperature trim air, as well as in-line fans and jet, pumps to boost flow in specific regions of the cabin. The air handling system also includes a heating system and a cooling system [7]. The mixing air conditioning system in an airplane cabin is responsible for supplying the conditioned air in the cabin. A high velocity of conditioned air is provided at the ceiling level [46].
However, a low velocity of conditioned air is withdrawn at the floor area, near the wall surface. The supplied air is mixed with the air already present inside the cabin to achieve a uniform heat transfer throughout the cabin [13]. Furthermore, it can handle a significant cooling load on flights under various operating situations. A proper air distribution system for airplanes has not yet been developed because it is still undergoing additional research and development. Although several studies have been conducted on the existing system, there are still defects due to the various air pollution diseases that originate and spread through the aircraft's air distribution system [20]. Ventilation is the process of altering or replacing the air in a room to maintain good indoor air quality levels [47]. During this procedure, the air is exchanged from or outside the building and circulated within the building. When used with air conditioning, ventilation can also eliminate unwanted odors and dampness from an area. Maintaining

adequate indoor air quality in buildings or autos is one of the most significant aspects to consider [20]. Natural ventilation, mechanical ventilation (forced ventilation), and hybrid ventilation are the three most common types of ventilation used in buildings. Specific customers may require local ventilation based on the room's scale where the air conditioning is installed. In agreement with Yu et.al [48], the ventilation function is carried out by a ventilation monitoring system composed mostly of electrically driven fans and valves as well as sensors, controllers, and software, among other components. According to Cao et.al [35], the air ventilation system of an airplane currently has significant shortcomings when it comes to cooling high heat loads, which might result in unpleasant dryness, noise, or the dispersal of pollutants. The combining ventilation system is employed in the conventional process that is used in an airplane. Modifications to the conventional system, on the other hand, are required in order to generate a better atmosphere and to provide thermal comfort in an aircraft's passenger cabin. As a result, new ventilation principles are being researched and developed [10].

The ventilation system must operate under standard conditions to give each passenger of the aircraft an airflow containing at least 0.55 pounds of fresh air/minute, as determined by the aircraft manufacturer [49]. When using a conventional commercial cabin air recirculation system, the air provided into the cabin is approximately 50% fresh outdoor air drawn either from the engine's compressor stage or the Auxiliary Power Unit, and approximately 50% recycled air that has been filtered [42]. The aircraft ventilation system is generally supplied by an air conditioning unit attached to the aircraft ventilation system. This ground pneumatic source delivers the air required to run the aircraft's environmental control system and Auxiliary Power Unit while the aircraft engine is turned off [21].

CONCLUSION

Several factors affect the thermal comfort of the human body and environment in airplanes, specifically for the domestic flight. The study has reviewed the following factors affecting the thermal comfort among passengers: human metabolic rate, insulation of clothing, and gender, which are human factors. The other factors are environmental factors: mean radiant temperature, low relative humidity, and colored light, low relative humidity, mean radiant temperature, colored light. The air conditioning systems in this paper described the unique characteristics of air conditioning systems used in airplanes applications and requirements, which differ significantly from those of air conditioning systems used in stationary environments. The heat load for both cooling and heating purposes of an aircraft air conditioning system must be accurately established during the conceptual design phase because it will directly impact the system configuration. The air distribution system in a commercial airplane cabin is critical in maintaining a healthy and comfortable environment for passengers and crew members on board the trip. When used with air conditioning, ventilation can also eliminate unwanted odors and dampness from an area.

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