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Improvement in Indoor Air Quality in Urban Pakistani Regions by Reducing Particulate Matter Size Concentration

Muhammad Haroon [1], Bertug Ozarisoy [1,*] and Hasim Altan [2,*]

[1] Sustainable Environment and Energy Systems (SEES) Graduate Program, Middle East Technical University Northern Cyprus Campus, Kalkanli, Guzelyurt, Turkey; muhammad.haroon@metu.edu.tr

[2] Department of Architecture, College of Architecture and Design, Prince Mohammad bin Fahd University (PMU), Khobar, Dhahran 34754, Saudi Arabia

* Correspondence: ozarisoyb@gmail.com (B.O.); hasimaltan@gmail.com (H.A.)

Abstract: This paper describes the indoor air pollution in urban (Lahore, Faisalabad, Gujranwala, Rawalpindi and Karachi) Pakistani regions while considering the outdoor air and the health and wellbeing of the occupants present indoors. It also aims to assess previous methodological approaches Such as Air Conditioning Systems, used by developed countries to improve air quality to demonstrate the improvements that can be made in air quality in Pakistani urban areas. This research also investigates the causes, concentration and effects of poor air quality in Pakistani urban areas such as particulate matter ($PM_{2.5}$), carbon oxides (CO_x), nitrogen oxides (NO_x), sulphur oxides (SO_x) and volatile organic compounds (VOC's). The average concentration of these pollutants in Pakistan's indoor air is, particulate matter (PM): [100 – 250 µg/m³ for $PM_{2.5}$, 200 – 600 µg/m³ for PM_{10}] 1 – 20 ppm for carbon monoxide (CO), nitrogen oxides (NO_x): [50 – 100 µg/m³ for NO_2, 20 – 40 µg/m³ for NO], 20 – 50 µg/m³ for sulfur dioxide (SO_2), volatile organic compounds (VOCs): 0.1 – 0.5 ppm for formaldehyde, 5 – 10 µg/m³ for benzene and 20 – 30 µg/m³ for toluene. It should be noted that these concentrations can differ depending on the origin of pollution, location, and time of day. The literature review is made up of a combination of descriptive research methods that are used to inform the research background of ambient and indoor air quality, thus the literature review provides a theoretical and methodological background about the air pollution and its improvement in different parts of the world. According to the World Air Quality Index, Pakistan is the third most polluted country in terms of average $PM_{2.5}$ concentration which is 14.2 times the WHO annual air quality guideline value. As a result, it is suggested that a $PM_{2.5}$ concentration reduction program be implemented in urban Pakistani regions' indoor air.

Keywords: Indoor air quality; particulate matter ($PM_{2.5}$); IAQ Assessment; health and wellbeing

1. Introduction

In the present era, the quality of indoor air has become a matter of significant concern for nations across the globe. This is primarily due to the substantial amount of time that individuals spend indoors. It is crucial to prioritize and improve the air quality in indoor spaces as it directly impacts human health. Pakistan, in particular, faces a critical challenge as indoor air pollution poses a grave threat to public well-being. According to the World Air Quality Report 2020, several urban areas in Pakistan have gained notoriety for being among the most polluted in the world. This report relies on the assessment of average annual concentrations of fine particulate matter ($PM_{2.5}$) to determine the severity of air pollution. Tragically, the repercussions of indoor air pollution encompass an increased risk of respiratory and cardiovascular ailments, as well as a heightened susceptibility to cancer (Pravin P Parekh et., 2001). The annual average concentration of particulate matter ($PM_{2.5}$) in some of the cities are: (World Air Quality Report, 2022)

Table 1. Annual average concentration of particulate matter (PM$_{2.5}$) of Pakistani urban regions.

City	Annual average concentration of PM$_{2.5}$
Lahore	107.5 µg/m^3
Faisalabad	104.6 µg/m^3
Gujranwala	102.9 µg/m^3
Rawalpindi	98.6 µg/m^3
Karachi	74.9 µg/m^3

The levels of PM$_{2.5}$ found in these regions go beyond the recommended limit set by the World Health Organization (WHO). The WHO advises that the annual average concentration of PM$_{2.5}$ should not exceed 10 µg/m^3.
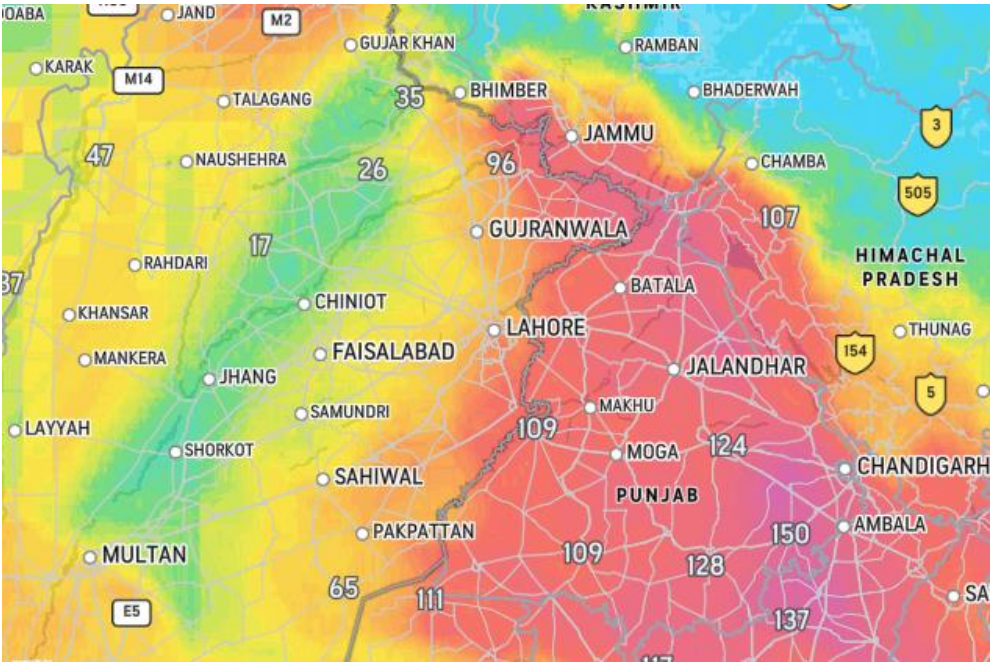

Figure 1. Map of Pakistani urban region which are in danger zone for PM$_{2.5}$ concentrations (AccuWeather, 2023).

According to a study by the Environmental Protection Agency of Pakistan (EPA), indoor air pollution in Pakistan is four times higher than outdoor air pollution. In addition to this, Air pollution is responsible for 22% of Pakistan's deaths, as the World Health Organization (WHO) reported. Various studies have shown that much of the outdoor PM generated by biomass burning can migrate to the indoor environment via advection (via open windows/doors) or infiltration (via door and window gaps or enclosed structures), resulting in elevated indoor PM concentrations (Muhammad Shehzaib Anjum et al., 2021) (Barn et al., 2008) (Balasubramanian, 2017). This study aims to look into the sources and concentration levels of indoor air pollution in Pakistan's urban areas and assess the effectiveness of various intervention strategies for improving indoor air quality (Badar Ghauri et al., 1994). The following is how this paper is structured: Section 2 reviews the literature on ambient and indoor air quality in different countries of the world, the concentration of pollutants in ambient and indoor air, and some methodologies they used to improve air quality. Section 3 describes the study's methodological details, which Pakistan can adapt in order to improve air quality, Section 4 presents the findings, and Section 5 discusses the implications of the results and makes recommendations for future research. Some of the sources of ambient and indoor air pollution in Pakistan are described in the literature review section.

2. Literature Review

The primary cause of ambient air pollution in Pakistan stems from industrial emissions. Numerous industries, particularly in urban areas, release significant quantities of particulate matter, sulfur dioxide, nitrogen oxides, and other pollutants into the atmosphere (Ian Colbeck et al., 2009). Outdated and inefficient technologies employed by these industries contribute to the air pollution problem. Another major contributor to air pollution is the transportation sector, which has witnessed a rise in vehicle numbers due to the expanding urban population. This increase in vehicles results in high emissions, aggravated by poor fuel quality and inadequate vehicle maintenance. Agricultural burning during the winter season also plays a significant role in air pollution, as farmers burn leftover crops and organic waste, releasing substantial amounts of particulate matter and pollutants (Smith, 2011). Additionally, brick kilns and open waste burning significantly add to the air pollution issue. Brick kilns, using coal and other fossil fuels, emit high levels of particulate matter and other contaminants, while open waste burning involves the combustion of municipal solid waste, plastics, and other materials, releasing harmful pollutants into the atmosphere (Chow, 2012; Ö. Özden et al., 2008).

In Pakistan, indoor air pollution is primarily driven by various factors including the burning of biomass and fossil fuels, smoking, construction materials, and the use of chemical products in daily life. These sources of pollution have a significant impact on human health, particularly for vulnerable populations such as children and the elderly who spend a substantial amount of time indoors. The consequences of poor indoor air quality are further compounded by the widespread reliance on traditional cooking and heating methods, notably wood-burning stoves, particularly in rural areas. These practices release substantial amounts of harmful pollutants into indoor environments. Additionally, inadequate building maintenance, substandard heating and cooling systems, and insufficient ventilation exacerbate the indoor air pollution issue in Pakistan (Muhammad Naveed Anwar et al., 2021). Many buildings lack proper ventilation systems, and the utilization of air conditioning and heating systems is limited, resulting in elevated levels of indoor pollutants.

Recognizing the significance of indoor air quality improvement for public health, a research strategy was undertaken to address the reduction of indoor air pollutants. To contribute to the existing knowledge, a comprehensive review was conducted, focusing on evaluating different interventions aimed at enhancing indoor air quality (Jones, 1999). A crucial objective of this study was to assess the effectiveness of interventions, particularly in the realm of improved ventilation. Prior to 2020, relevant studies and examples shed light on the potential utilization of mechanical ventilation systems (MVS) or natural ventilation systems (NVS) as effective measures to achieve better indoor air quality. These solutions are determined by the type of building, its use, and its operation (M. Gil-Baez et al., 2021) (Tariq Ahmed et al., 2021), the use of portable air cleaners, the use of high-efficiency air conditioners, and the implementation of smart window control behaviour in Pakistan. The findings of this study may provide decision-makers with new insights into how to improve IAQ.

Indoor air quality (IAQ) pertains to the air quality inside and in the vicinity of buildings and structures. It has been proven to significantly influence the health, comfort, and overall well-being of individuals occupying these spaces. Ensuring proper maintenance of IAQ is crucial due to the substantial amount of time people spend indoors. Inadequate indoor air quality can result in various severe health issues, such as headaches, fatigue, respiratory conditions, and even potentially life-threatening ailments like lung cancer.

According to previous research, the smoke haze incident in Singapore in 2019 resulted in an increase in $PM_{2.5}$ concentrations, consequently leading to a decline in the quality of both ambient and indoor air (Phuong T.M Tran et al., 2020). Several researchers have documented the various indicators and requirements for Indoor Air Quality (IAQ), encompassing indoor air pollutants, their types, and concentration limits. Pollutants such as formaldehyde, benzene, carbon dioxide (Olivier Ramalho et al., 2015), particulate matter, and radon have been identified as contributors to IAQ concerns. A total of 26 standards and certifications were examined from six different countries, and they were classified into three categories: basic, green, and health levels (Wenjuan Wei et al., 2015). The basic

level was identified as the fundamental and most crucial factor for ensuring indoor air hygiene. The green level focuses on enhancing indoor air quality while prioritizing energy efficiency and sustainability. On the other hand, the health level aims to promote the well-being and health of occupants. Notably, Chinese standards for organic pollutants and particulate matter are considerably more stringent across all three levels, from basic to health. However, when it comes to inorganic pollutants, the latter two levels rarely impose stricter requirements than the basic level. It is important to note that currently, even health-level standards do not encompass IAQ requirements specifically for epidemic prevention (Guanqiong Wei et al., 2022). An essential aspect of Indoor Air Quality (IAQ) involves assessing the levels of carbon dioxide, total volatile organic compounds (TVOCs), $PM_{2.5}$, and PM_{10} indoors. (Phuong T.M. Tran et al., 2021) In a study conducted on natural ventilation in classrooms during the COVID era in a Mediterranean climate, the concentrations of outdoor and indoor pollutants were examined, yielding the following findings (M. Gil-Baez et al., 2021) (Krystallia K. Kalimeri et al., 2016) (Maria Chiara Pietrogrande et al., 2021):

Table 2. Concentration outdoor and indoor pollutants in classrooms in Mediterranean Climate.

Outdoor pollutant concentration range	
Type of pollutant	**Concentration Range**
Particulate Matter ($PM_{2.5}$)	$0.62 - 3.61$ µg/m³
Particulate Matter (PM_{10})	$0.74 - 4.30$ µg/m³
Total volatile organic compounds (TVOC's)	$84.17 - 306.32$ µg/m³
Indoor pollutant concentration range	
Type of Pollutant	**Concentration Range**
Particulate Matter ($PM_{2.5}$)	$2.04 - 34.86$ µg/m³
Particulate Matter (PM_{10})	$1.14 - 15.76$ µg/m³
Total volatile organic compounds (TVOC's)	$206.99 - 589.71$ µg/m³

Investigators have recently conducted studies on the presence of potentially toxic elements (PTEs) bound to $PM_{2.5}$ in indoor air. Some of the identified PTEs include Zinc, Iron, and Manganese (Jose A. Becerra et al., 2020). It is important to note that PTEs can have detrimental effects on human health. The concentration of PTEs bound to indoor air was examined in various countries, namely China, Poland, Italy, Spain, Taiwan, Turkey, Iran, and Chile, during the period from January 1, 2000, to March 10, 2020. Here is the rank order of PTE concentration in indoor air observed during that time frame:

Table 3. Concentration and Rank order of PTE's (Potentially toxic elements).

Type of PTE	Concentration
Zn	17.32 ng/m³
Fe	14.49 ng/m³
Mn	7.40 ng/m³
Rank Order:	
Zn (17.32 ng/m³) > Fe (14.49 ng/m³) > Mn (7.40 ng/m³)	

Among the countries examined, Poland and China exhibited higher concentrations of potentially toxic elements (PTEs) compared to other countries. Additionally, zinc concentration was found to be higher than the concentration of other PTEs in the indoor air (Yadolah Fakhri et al., 2022). Researchers conducted a comparative case study in Alexandria, Egypt, to analyze the levels of PM_{10}, $PM_{2.5}$, CO, and CO_2 in urban residences. (Abdel-Salam M. M., 2015) The study focused on both ambient air and indoor air, while also considering the impact of seasonal variations on these pollutant concentrations.

Table 4. Seasonal average concentration of indoor pollutants in homes in Alexandria, Egypt.

Winter Season	
Type of Pollutant	**Average concentration Range**
Particulate Matter (PM_{10})	119.4 ± 30.9 µg/m³
Particulate Matter ($PM_{2.5}$)	85.2 ± 25.8 µg/m³
Carbon Monoxide CO	1.6 ± 0.8 ppm
Carbon Dioxide CO_2	692.4 ± 144.6 ppm
Summer Season	
Type of Pollutant	**Average concentration Range**
Particulate Matter (PM_{10})	98.8 ± 21.8 µg/m³
Particulate Matter ($PM_{2.5}$)	67.8 ± 14.9 µg/m³
Carbon Monoxide CO	0.5 ± 0.5 ppm
Carbon Dioxide CO_2	558.2 ± 66.2 ppm

The study's results revealed that both PM_{10} and $PM_{2.5}$ concentrations exceeded the air quality guidelines set by the World Health Organization. This highlights the significant impact of increased human activity on air quality, particularly during the winter season when indoor pollutants accumulate, leading to a deterioration in overall air quality (Abdel-Salam M. M., 2021).

A study was conducted in primary school buildings across five Central European countries, namely the Czech Republic, Hungary, Italy, Poland, and Slovenia. The research focused on assessing the indoor air quality in sixty-four primary schools during the 2017-18 heat wave. Various parameters, including volatile compounds (aldehydes), $PM_{2.5}$ mass, carbon dioxide (CO_2), radon, and physical parameters, were investigated. The hazard rating scale values for most parameters were found to be below one, with a single exception (Ramen Munir Baloch et al., 2020). However, 31% of the school buildings exhibited hazard index values significantly exceeding one (Batterman, 2006). The average excess lifetime cancer risk values for radon and formaldehyde exceeded the permissible threshold of 1×10^6. Additionally, the concentration of $PM_{2.5}$ mass exceeded the 24-hour and annual guideline values recommended by the World Health Organization. Alarmingly, 80% of the schools failed to meet the recommended CO_2 concentration levels of 1000 ppm. The study's findings identified $PM_{2.5}$, radon, formaldehyde, and CO_2 levels in classrooms as the primary concerns regarding indoor air quality (Máté Szabados et al., 2021).

The importance of indoor air quality (IAQ) and the right of individuals to breathe clean air have been highlighted in the literature. Numerous studies have explored strategies to improve IAQ, including a comparative evaluation of portable air cleaners (PACs) and air conditioners (ACs) in enhancing indoor air quality. In this particular approach, real-time measurements of black carbon mass concentration and particle number concentration were employed to assess $PM_{2.5}$ levels. The results demonstrate that portable air cleaners (PACs) effectively reduce $PM_{2.5}$ exposure in indoor spaces. PACs are especially beneficial for vulnerable individuals such as infants, pregnant women, and the elderly. On the other hand, air conditioners primarily provide thermal comfort but are energy-intensive and contribute to carbon dioxide emissions. Additionally, ACs have a lower particle removal efficiency, posing potential health risks. The comparative evaluation indicates that PACs are more effective in improving indoor air quality compared to ACs. To further optimize IAQ, it is recommended to use PACs with fans, as they offer a cost-effective solution suitable for individuals with lower socioeconomic status. Additionally, employing higher-efficiency air conditioners equipped with MERV 14-16 filters can enhance their particle removal capabilities and overall performance in air purification (Balasubramanian et al., 2007) (Phuong T.M Tran et al., 2020).

One approach proposed is to utilize smart control of window behavior as an effective means of reducing indoor $PM_{2.5}$ pollution, without the need for portable air cleaners. The main objective of this strategy is to develop a reinforcement learning approach that can automatically adjust window actions in real-time to mitigate the presence of $PM_{2.5}$ particles with an aerodynamic diameter of less than 2.5 µm in naturally ventilated buildings. To achieve this, a deep Q-network (DQN) is employed

to train a window controller capable of effectively managing window behavior using low-cost sensors. This ensures consistent reduction of PM$_{2.5}$ levels with a resolution of 1 minute.

To evaluate the efficiency of this strategy, two simulations were conducted: one in a virtual typical apartment located in Beijing, and another in a real apartment in Tianjin. The proposed reinforcement learning window-control algorithm, known as the I/O (Indoor to Outdoor) ratio algorithm, demonstrated impressive results. It achieved an average reduction of 12.8% in indoor PM$_{2.5}$ concentrations over the span of one year. In comparison to both the I/O algorithm and real window behavior, the proposed algorithm outperformed, showcasing reductions of 9.11% and 7.40% in indoor PM$_{2.5}$ concentrations, respectively, in the real apartment setting. The simulation conducted in the virtual typical apartment also yielded promising outcomes, effectively reducing indoor PM$_{2.5}$ concentrations through the implementation of the proposed reinforcement learning window control algorithm. In fact, it achieved an average reduction of 12.80% in indoor PM$_{2.5}$ concentration over the course of a year when compared to the baseline I/O ratio algorithm (Yuting An et al., 2021).

Air conditioning systems are electrical devices that have been specially designed to regulate both temperature and humidity levels. They can also aid in the removal of PM$_{2.5}$ particulate matter from indoor air to some extent. Certain air conditioning systems, such as those equipped with high-efficiency particulate air (HEPA) filters, are particularly effective in trapping and filtering out PM$_{2.5}$ particles, thereby contributing to an improvement in the overall quality of indoor air. The primary goal of air conditioning systems is to create a more comfortable and enjoyable environment, primarily for the occupants present. (Student Lesson, 2023)

Research conducted on air conditioning systems has revealed the existence of different types of these systems that are utilized to improve both indoor thermal comfort and indoor air quality (IAQ) (B.F. Yu et al, 2008). Investigations conducted recently have focused on analyzing the impact of air conditioning systems on the removal of PM2.5 particulate matter and the subsequent improvement of indoor air quality, which is crucial for human health and well-being. The current research primarily revolves around three types of air conditioning systems: those equipped with High-Efficiency Particulate Air (HEPA) Filters, systems that allow Multi-stage filtration systems, and Air conditioning systems with activated carbon filters. These studies underscore the importance of utilizing advanced air conditioning technologies to enhance indoor air quality.

Table 5. Pros and cons of the Air conditioning system.

Method	Pros	Cons
Air Conditioning System	● Enhanced air purity ● Regulating humidity levels ● Safeguards against device overheating ● Increased productivity levels in workplaces. ● Heat provider during winter (LAC Temperature Control, 2023) (Linquip Technews, 2023)	● Elevated energy expenses ● Exacerbation of respiratory issues ● Adverse environmental consequences (Berkeys Plumbing. A/C. Electrical, 2023) (Comfy Home Heating Cooling, 2023)

2.1. AC's with High-Efficiency Particulate Air (HEPA) Filters

Air filters known as High-Efficiency Particulate Air (HEPA) filters are mechanical filters that feature a pleated design. These filters are renowned for their ability to eliminate at least 99.97% of airborne particles measuring 0.3 microns (μm) in size, including dust, pollen, mold, bacteria, and various other contaminants. By incorporating High-Efficiency Particulate Air (HEPA) filters into air conditioning systems, there is a notable improvement in indoor air quality (IAQ), specifically in reducing the presence of particulate matter PM$_{2.5}$ (EPA United States Environmental Protection Agency, 2023).

Table 6. Particles that HEPA filters capture.

Particle type	Size
Smoke	0.01 – 1 micron
Dust	0.05 – 100 microns
Bacteria	0.35 – 10 microns
Dust mite debris	0.5 – 50 microns
Spores from plants	6 – 100 microns
Human hair	70 – 100 microns
Mould	20 – 200 microns

The filtration systems usually follow a multi-step filtration process. This process involves the use of a prefilter designed to capture larger particles, a MERV 17 filter to effectively remove residual contaminants, and a carbon filter that specifically targets odors and scents. (Atmospemp Heating, Air Conditioning & Plumbing | A Service Experts Company, 2023)
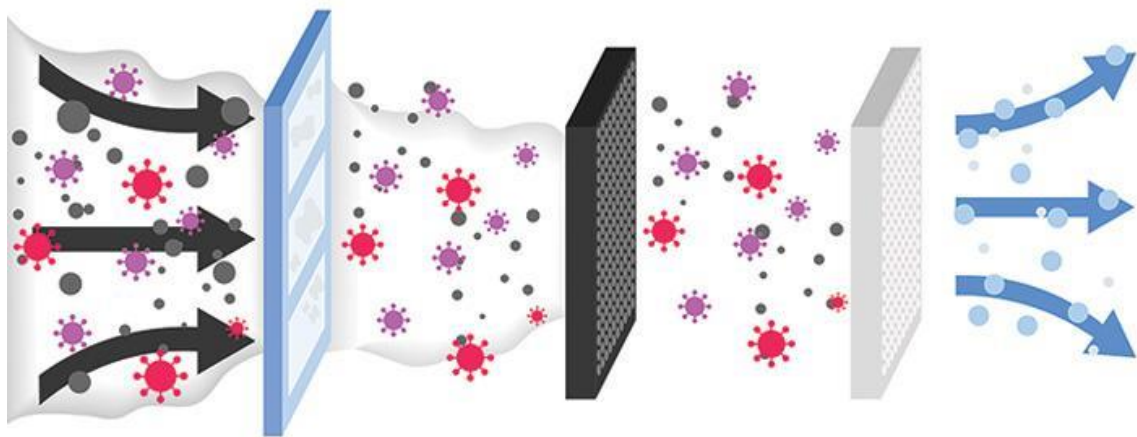

Figure 2. Working Schematic of pre filters & HEPA filters (Protect COVID - 19 National Core Study, 2023).

The integration of HEPA filters into air conditioning systems is instrumental in improving indoor air quality (IAQ) by efficiently trapping airborne particles. However, it is important to take into account factors such as system design, maintenance needs, and potential energy impact to ensure the maximum effectiveness of air conditioning systems equipped with HEPA filters. (Solberg, 2023)

2.2. ACs with Multi-stage filtration system

For the purpose of enhancing indoor air quality (IAQ), air conditioning systems can be equipped with multi-stage filtration systems. These systems incorporate a range of filters, each with varying levels of filtration efficiency, specifically designed to target and eliminate airborne particles of different sizes, including PM_{10} and $PM_{2.5}$.

In the initial stage of the filtration process, Pocket filters are employed to effectively capture larger particles (PM_{10}) such as dust and pollen, from the air supply and recirculation in air conditioning systems. These filters are energy-efficient due to their low-pressure drop. The subsequent stage focuses on filtering the majority of $PM_{2.5}$ particles. Cassette filters are particularly advantageous in this stage as they possess a high dust holding capacity and consistently efficient particle separation. The final stage aims to maintain cleanliness and sterility in the indoor air by utilizing HEPA filters. HEPA filters, specifically those classified as H14, exhibit high efficiency in eliminating over 99.995% of particles, germs, and viruses from the air. This greatly reduces the risk of indoor infections. (Freudenberg, 2023)

Multi-stage filtration systems integrated into air conditioning systems play a pivotal role in improving indoor air quality (IAQ) by effectively capturing a diverse range of airborne particles. To

optimize the performance of air conditioning systems equipped with multi-stage filtration, it is essential to ensure appropriate system design, regular maintenance, and careful consideration of the associated energy implications. (Sanalife, 2023)
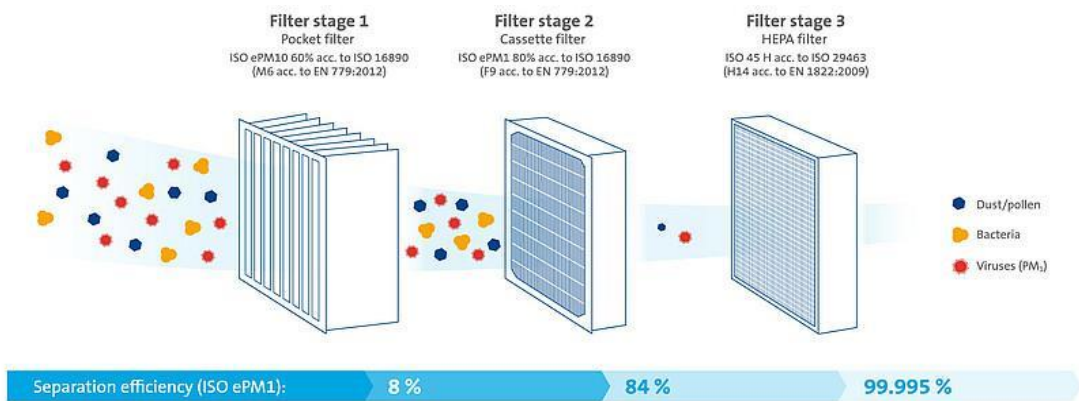

Figure 3. Working Schematic of Multi-stage filtration system (Freudenberg Innovating Together, 2023).

2.3. ACs with Activated Carbon Filter

Activated carbon air filters contain a bed of carbon enclosed in a cloth or mesh material. These filters effectively purify the air by eliminating gaseous compounds. Standard air filters are unable to capture small molecules such as odors and volatile organic compounds (VOCs), allowing them to pass through. However, activated carbon filters are designed to trap and remove these molecules from the indoor air, thereby enhancing the air quality in your home. (HVAC Training Shop, 2023)

Figure 4. Air Condition System Active Carbon Filter (HaoAirTech, 2023).

Air conditioning systems can be enhanced to improve indoor air quality (IAQ) by incorporating activated carbon filters. These filters, also known as activated charcoal, consist of a highly porous material with a large surface area for adsorption. They are effective in trapping and adsorbing various pollutants, including $PM_{2.5}$ particles, gaseous pollutants, odors, and volatile organic compounds (VOCs), thus efficiently eliminating them from the indoor air circulated by the air conditioning system. By utilizing activated carbon filters in air conditioning systems, IAQ can be improved by addressing specific airborne pollutants that standard particulate filters may not effectively capture. (Kitchenarena, 2023).

3. Materials and Methods

3.1. Site Description

This study focuses on Lahore, Pakistan, considered the country's most polluted city and is located in Punjab, where continuous efforts are being made to improve the IAQ. The study area is distinguished by densely populated districts and various building types, such as houses, apartments, schools, offices, and hospitals with limited ventilation, all influencing indoor air quality. It lies in BSh. Subtropical steppe zone of Köppen–Geiger climate classification zone (WORLD MAPS OF KÖPPEN-GEIGER CLIMATE CLASSIFICATION, 2023). This climate subtype is characterized by its location in subtropical regions and its relatively dry conditions. The "B" in BSh represents a dry climate, while the "S" indicates that it is a subtropical climate. The "h" signifies a hot climate. In the BSh climate zone, temperatures are generally high throughout the year. Summers in Lahore are extremely hot, with average temperatures reaching around 40°C or even higher in some cases. Winters are mild and short, with average temperatures around 15-20°C.
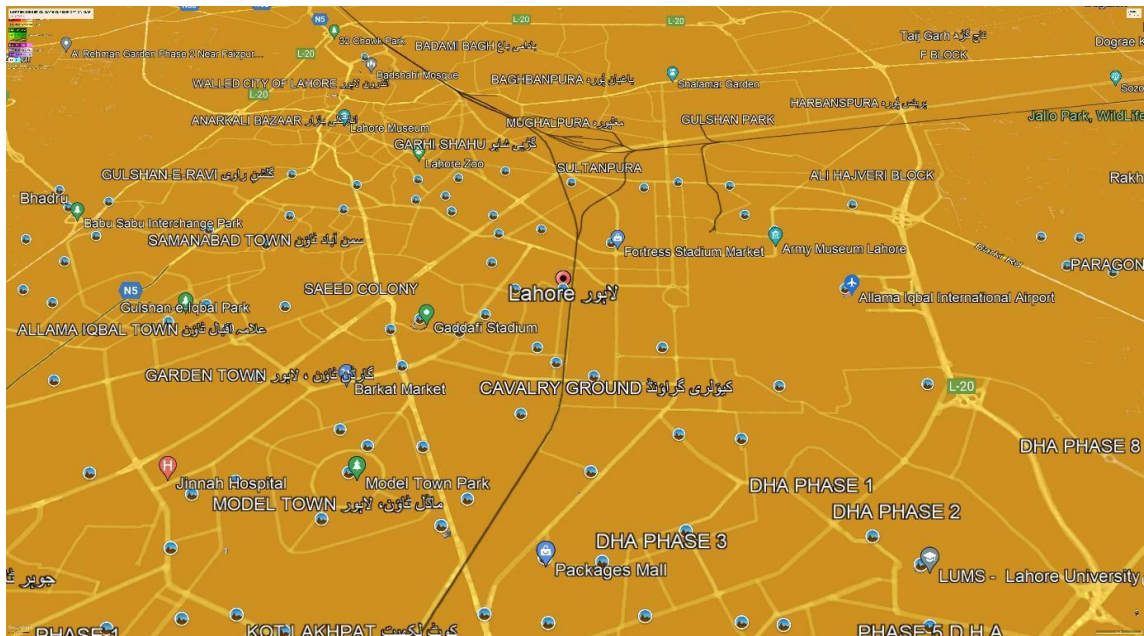

Figure 5. KÖPPEN-GEIGER CLIMATE CLASSIFICATION MAP LAHORE, PAKISTAN (Google Earth Pro, 2023).

3.2. Conceptual Framework

The chosen methodology for my research is a mixed method strategy, incorporating both qualitative and quantitative approaches. To address the issue of improving indoor air quality in Pakistan, I will utilize the widely adopted method of air conditioning systems, commonly employed in developed countries. In order to gain a comprehensive understanding of the urban regions in Pakistan, I will employ the Clima tool, which offers a range of valuable insights such as climate summaries, temperature and humidity data, psychometric charts, and natural ventilation patterns.

By analyzing the gathered dataset, I will then compare it with the proposed air conditioning system method using the ASHRAE Global Thermal Comfort Database II Visualization. This approach aims to enhance the indoor air quality in urban Pakistani regions. One notable advantage of employing air conditioning systems is their ability to regulate humidity levels effectively while providing efficient cooling and ensuring thermal comfort within indoor environments.
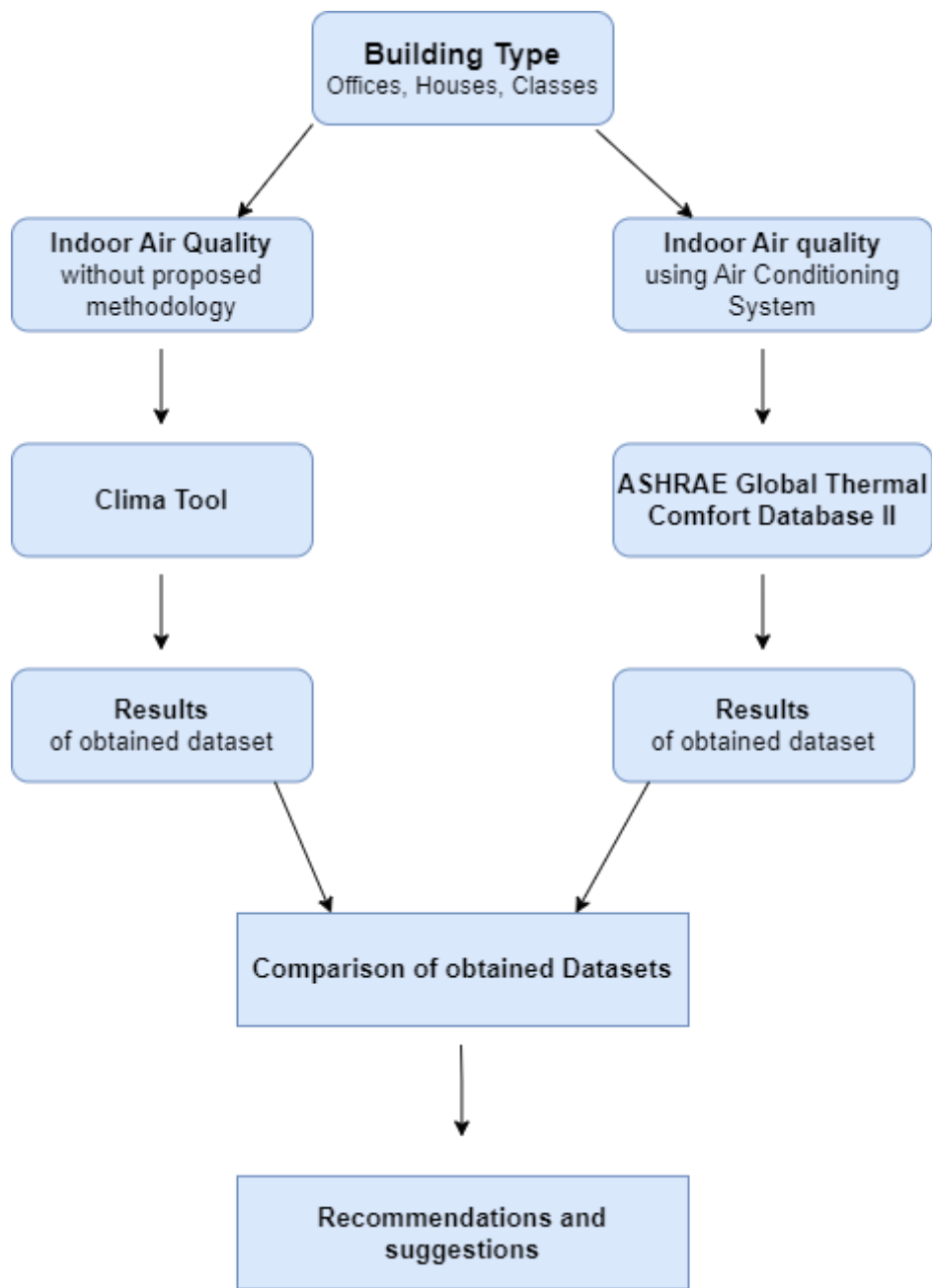
Figure 6. Flow design of conceptual framework (Draw.io, 2023).

Table 7. Pros and Cons of Conceptual Framework.

Pros of Conceptual Framework	Cons of Conceptual Framework
Comprehensive approach: The comprehensive approach of this conceptual framework takes into account various factors related to indoor air quality in a range of building types, such as offices, houses, and classrooms. This wider scope allows the framework to be utilized effectively in diverse settings.	**Limited consideration of specific building types:** The framework includes offices, houses, and classrooms, it may not cover all conceivable building types, potentially limiting its applicability in specific contexts.
Data Analysis: Obtaining and analysing datasets from both Clima and ASHRAE Global Thermal Comfort Database II adds a quantitative dimension to the research. This allows for	**Possible lack of comprehensive data:** The presence of inadequate or incomplete data, depending on its availability and quality, poses a

objective assessment and comparison of indoor air quality.

Utilization of tools and Databases: This research uses the Clima Tool and the ASHRAE Global Thermal Comfort Database II. The utilization of specialized tools and databases enhances the accuracy and reliability of the analysis.

Potential for recommendations: Utilization of Both tools and databases includes a dedicated step for offering recommendations and suggestions. This showcases the research's practicality as it provides actionable insights for Improving indoor air quality.

risk that the research analysis may lack accuracy and reliability.

Possible bias towards certain methods: The research reliance on specific tools or databases, such as the Clima Tool or ASHRAE Global Thermal Comfort Database II, and using air conditioning systems as a method may limit the consideration of alternative methodologies.

Lack of consideration for external factors: This research primarily focuses on indoor air quality; it may not adequately address external factors that can impact indoor air quality, such as outdoor pollution sources or ventilation systems.

3.3. Tool and Database

This research utilized two key resources: the CBE Clima Tool and the ASHRAE Global Thermal Comfort Database II. The CBE Clima Tool was employed to extract various parameters including climate summaries, temperature and humidity data, psychometric charts, natural ventilation patterns, and heat stress maps. These parameters were essential for the research analysis. Furthermore, the ASHRAE Global Thermal Comfort Database II was utilized to obtain datasets and plots related to building types, satisfaction metrics, and conditioning types for indoor thermal comfort. These datasets and plots were integral for evaluating and understanding indoor thermal comfort in the research.

The CBE Clima Tool is an open-source web application that enables architects and engineers to effectively analyze and visualize climate data for climate-adapted building design. It offers a user-friendly interface with an interactive world map as the main landing page. Through this map, users can access a vast collection of publicly available weather data files. These files are sourced from reputable repositories such as EnergyPlus and Climate.OneBuilding.org. Additionally, users have the flexibility to upload their own valid EPW files for data analysis. The tool not only provides data visualization but also facilitates data organization, manipulation, and interpretation in a straightforward manner. (Giovanni Bettia et al., 2022)

The ASHRAE Global Thermal Comfort Database II, also known as the Comfort Database, is an online and open-source resource that contains comprehensive datasets of objective indoor climatic observations, along with corresponding subjective evaluations provided by the building occupants who experienced those conditions. The primary purpose of this database is to facilitate diverse research inquiries regarding thermal comfort in real-world settings. It offers a user-friendly web interface that allows users to apply various filters based on multiple criteria. These criteria include building typology, occupancy type, demographic variables of subjects, subjective thermal comfort states, indoor thermal environmental criteria, calculated comfort indices, environmental control criteria, and outdoor meteorological information. Additionally, a web-based interactive tool has been developed to visualize thermal comfort, providing end-users with a quick and interactive way to explore the data. (Veronika Földváry Ličina et al., 2018)

4. Analysis and Results

After extracting the data from the EPW file of Lahore, Pakistan weather station from Climate.OneBuilding.Org, it was uploaded to the Clima tool. The obtained data was then compared with the ASHRAE Global Thermal Comfort Database II using the proposed methodology. The resulting measurements and comparisons are outlined below:

4.1. Obtained Datasets from Clima Tool

The left side of graph in Figure 7 illustrates the variation in daytime dry bulb temperatures in the Lahore region over the course of a year. The vertical axis represents the temperature in degrees Celsius, while the horizontal axis represents time in years. From the graph, we can observe that the highest recorded temperature during the year is 45°C, while the lowest recorded temperature is 1°C. These values represent the extreme points on the graph. To better understand the overall temperature trend, we can look at the measures of central tendency. The mean temperature, which is the average of all the temperature values on the graph, is calculated to be 26.55215°C. The mean is influenced by extreme values, so in this case, it takes into account both the high and low temperature extremes. Another measure we can consider is the median temperature, which is the middle value when all the temperature values are arranged in ascending order. In this case, the median temperature is 28°C. Unlike the mean, the median is not affected by extreme values, providing a representation of the temperature that is more typical or representative of the data. Additionally, we can examine the quartiles of the data. The first quartile, denoted as Q_1, is 20°C, indicating that 25% of the temperature readings on the graph fall below this value. It represents the boundary between the lowest 25% of the data and the upper 75%. On the other hand, the third quartile, denoted as Q_3, is 33°C, representing the boundary between the lowest 75% of the data and the upper 25%. In other words, 75% of the temperature readings on the graph fall below this value.
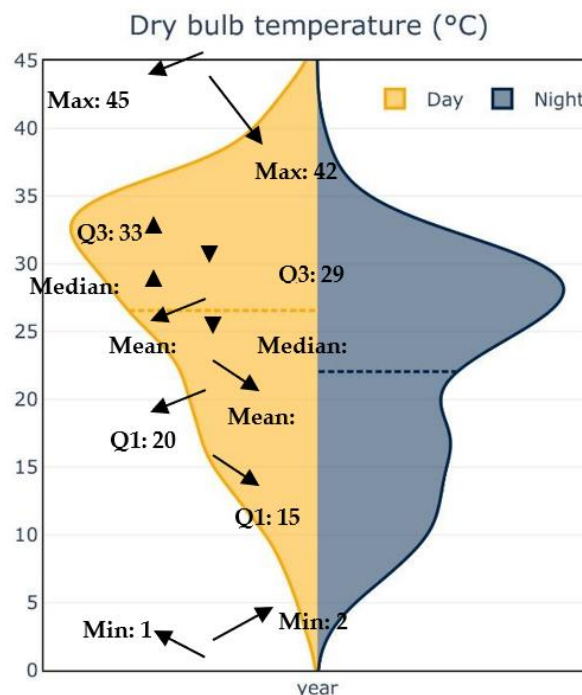

Figure 7. Dry Bulb temperature during day & nighttime (CBE Clima Tool, 2023).

Based on the analysis of daytime dry bulb temperature data in the Lahore region indicates that extreme temperatures are prevalent, with a recorded high of 45°C and a low of 1°C. However, the measures of central tendency, such as the mean temperature of 26.55215°C and the median temperature of 28°C, suggest that the overall temperature trend is moderately warm. This raises the question of whether the extreme temperature values are outliers or if they represent a significant climatic event. Further investigation into the factors influencing temperature extremes in the region is warranted to better understand their implications for local climate patterns and potential impacts on human activities and ecosystems.

The right side of graph in Figure 7 illustrates the nighttime dry bulb temperatures in Lahore throughout the year. The Y-axis represents the temperature in degrees Celsius, while the X-axis represents the time in years. Upon closer examination of the graph, it becomes evident that the

highest recorded nighttime temperature throughout the year is 42°C, whereas the lowest recorded temperature is 2°C. To gain insights into the typical temperature characteristics, we can analyze the measures of central tendency. The mean temperature, calculated by summing all the temperature values on the graph and dividing them by the total number of values, is determined to be 22.06189°C. The mean is influenced by extreme values, taking into account both the highest and lowest temperature points. In contrast, the median temperature, which represents the middle value when the temperature values are arranged in ascending order, is found to be 24°C. Unlike the mean, the median is not influenced by extreme values and provides a representation of the central or typical temperature reading. Furthermore, we can explore the quartiles of the data. The first quartile, denoted as Q_1, has a value of 15.5°C, indicating that 25% of the temperature readings fall below this value. Q_1 marks the boundary between the lowest 25% of the data and the upper 75%. On the other hand, the third quartile, denoted as Q_3, has a value of 29°C, signifying that 75% of the temperature readings fall below this value. Q_3 represents the boundary between the lowest 75% of the data and the upper 25%. This prompts the question of whether the extreme temperature values are exceptional events or if they reflect noteworthy nocturnal climatic patterns.

By considering these statistical measures, we can gain a more comprehensive understanding of the day and nighttime temperature distribution and trends in the Lahore region throughout the year.

Table 8. Descriptive Statistics of dry bulb temperature throughout the year, Lahore.

Month	Mean (°C)	Std (°C)	Min (°C)	1% (°C)	25% (°C)	50% (°C)	75% (°C)	99% (°C)	Max (°C)
Jan	11.35	4.68	1	3	8	11	15	21	22
Feb	15.71	5.25	6.1	6.67	11.88	15.55	19.82	25.73	26.6
Mar	21.44	5	10	12	17	21	26	31	32
Apr	27.54	5.04	17	18	23.9	27	32	38	39
May	32.48	5.28	21	22	29	32	36	43	44
Jun	33.03	5.35	19	22	29	33	37	44	45
Jul	31.34	3.35	23	25	29	31	33.5	40	41
Aug	30.53	3.24	23	24	28	30	33	38	38
Sep	29.2	3.52	20	22.6	26	29	32	36	37
Oct	25.42	5.07	15	15.22	22	25	29	36	36
Nov	19.84	4.83	10	11	16	19.9	24	30	31
Dec	13.38	4.99	2	3.72	10	13	17	24	25
Year	24.31	8.76	1	5	17.9	26	31	41	45

In Lahore, the dry bulb temperature exhibits variations throughout the year, as shown in Table 8 and the accompanying graphs. The data highlights that the temperature range within which people feel comfortable thermally is between 18°C and 24°C. During the winter season (December, January, and February), individuals may experience a slight sensation of cold. Conversely, from May to September, which corresponds to the summer season, the temperature exceeds 40°C, significantly surpassing the ASHRAE adaptive comfort limit of 24.5°C. This raises concerns about the impact of these extreme temperatures on human health, well-being, and productivity, as well as the potential implications for energy consumption and the need for adaptive measures in buildings and urban planning.

The presented graph in Figure 8 depicts the annual variation of relative humidity in Lahore. It showcases the monthly distribution of humidity levels throughout the year, with the vertical axis representing the percentage of relative humidity and the horizontal axis indicating the months from January to December. The graph highlights that the recorded maximum humidity value reaches 100, while the minimum value stands at 16. Notably, the graph incorporates distinct colour schemes: the grey section represents the range of humidity considered comfortable, the blue colour denotes the overall range of relative humidity, and the sky-blue shade indicates the average relative humidity for the region over the year. The graph suggests that relative humidity becomes a significant concern for

individuals, particularly from July to October, posing challenges for indoor comfort. These findings raise important questions about the impact of high humidity levels on human health, comfort, and productivity, as well as the need for effective indoor humidity control strategies and building design considerations.
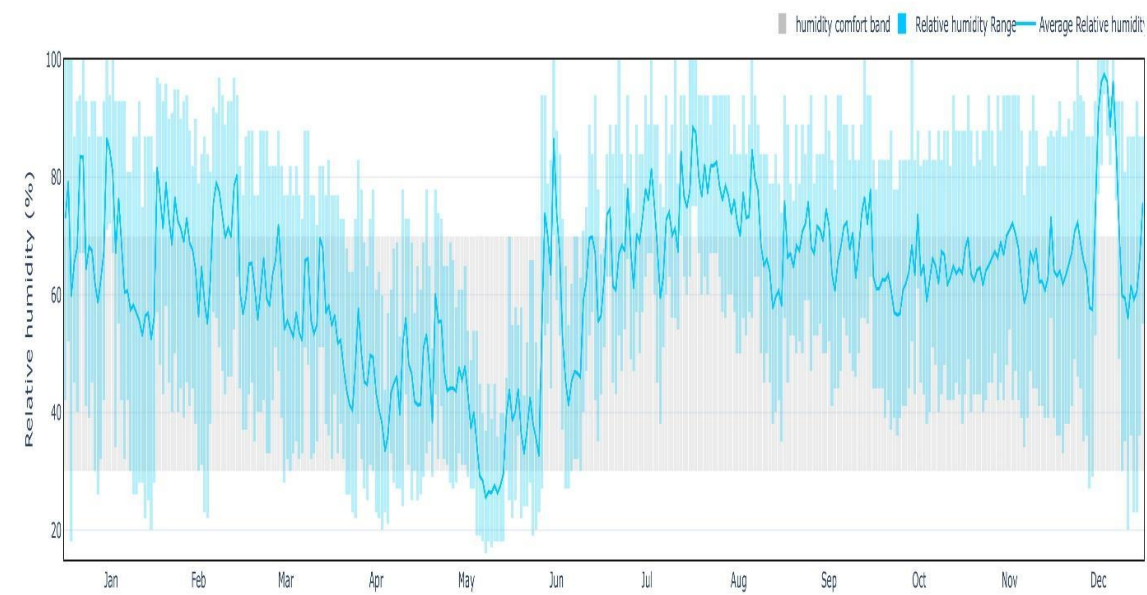

Figure 8. Yearly Relative humidity chart of Lahore (CBE Clima Tool, 2023).

This graph in Figure 9 is a Psychometric Chart (MARINHAS, 2019) illustrating the characteristics of the case study location. It visualizes the relationship between temperature and humidity ratio. The y-axis represents the humidity ratio measured in grams of water per kilogram of air, while the x-axis represents temperature in degrees Celsius. The chart also includes a color-coded band indicating different temperature ranges.
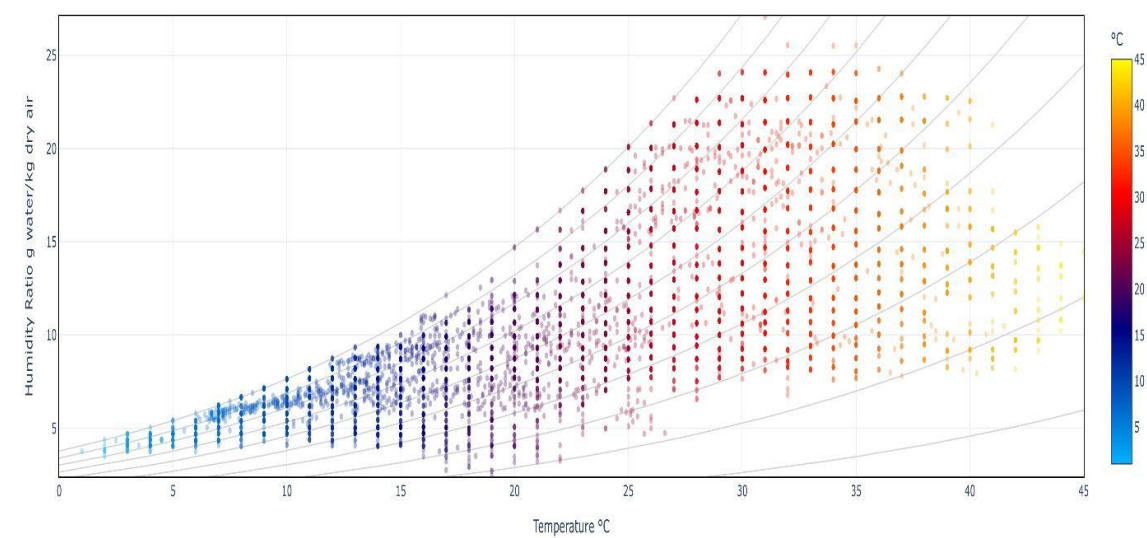

Figure 9. Psychometric Chart (CBE Clima Tool, 2023).

When examining the graph from left to right, it shows a progression from low sensible heat to high sensible heat, indicating an increase in temperature. Moving from bottom to top on the graph signifies an increase in absolute humidity or humidity ratio, reflecting a higher amount of moisture in the air per kilogram of dry air.

Based on the data points on the graph, we can infer that when the temperature is kept constant, the humidity ratio in the air also increases, and vice versa. The blue dots on the graph represent the winter season, with maximum temperatures around 17-18°C, while the red and yellow dots correspond to the summer season, characterized by maximum temperatures reaching approximately 45°C in the specific case study location. These results pose important questions about the impact of temperature and humidity ratio variations on indoor thermal comfort and energy efficiency. This research argument revolves around exploring effective strategies for managing temperature and humidity levels within indoor environments, particularly during the summer season with extreme temperatures.

The bar chart represented in Figure 10 is the annual natural ventilation (Chen, 2001), levels at the case study location. The x-axis represents the months of the year, ranging from January to December, while the y-axis displays the percentage of natural ventilation. Analysis of the graph reveals a concerning issue from May to September, where there is a significant decrease in natural ventilation. Consequently, these months pose significant challenges for indoor occupants, as there is minimal airflow and it becomes increasingly uncomfortable to stay indoors during this period. The discovery suggests that there is limited air movement during these months, creating difficulties for individuals indoors in terms of indoor air quality, thermal comfort, and general wellness. This highlights the importance of additional research to explore the specific factors that contribute to reduced natural ventilation during this period, including weather patterns, building design (Yuguo Li et al., 2000) and orientation, and potential obstacles to airflow. Understanding the causes and consequences of diminished natural ventilation is essential for developing effective approaches to improve indoor air quality and comfort, address potential health risks associated with inadequate ventilation, and optimize energy-efficient ventilation systems in buildings within the studied location.
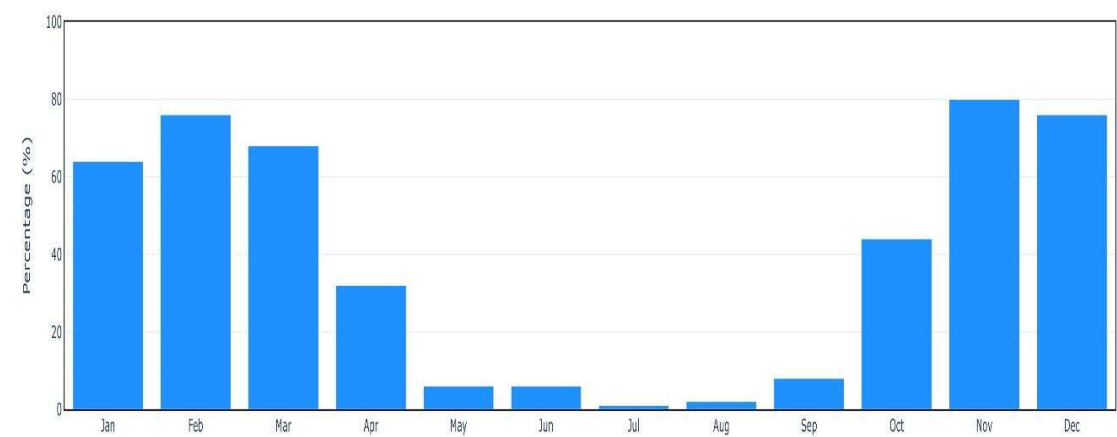

Figure 10. Natural Ventilation Yearly Bar Chart (CBE Clima Tool, 2023).

This chart displayed in Figure 11 is the distribution of thermal stress based on UTCI (Universal Thermal Climate Index) (Peter Bröde et al., 2012) (Krzysztof Błażejczyk et al., 2018) throughout the year. The x-axis represents the months from January to December, while the y-axis shows the percentage of thermal stress distribution. Different colours in the color-coded band indicate various levels of thermal stress, with maroon indicating extreme heat stress. Upon closer examination of the graph, it becomes evident that from April to October, there is a significant prevalence of extreme or very strong heat stress. This poses a high risk of heat stroke for occupants staying indoors during these months. Additionally, the chart reveals a concerning pattern of minimal or negligible no thermal stress, indicating a challenging situation at the case study location. These findings bring up crucial inquiries concerning the consequences of long-term exposure to extreme heat stress on human well-being, productivity, and overall quality of life. It is imperative to examine the factors that contribute to the high occurrence of extreme heat stress, including local climate conditions, urban

heat island effects, building design, and indoor heat mitigation strategies. Moreover, exploring effective adaptation measures, such as thermal insulation, shading techniques, and active cooling systems, becomes essential for enhancing indoor thermal comfort, minimizing the risk of heat-related illnesses, and bolstering the resilience of individuals and communities in the studied location.
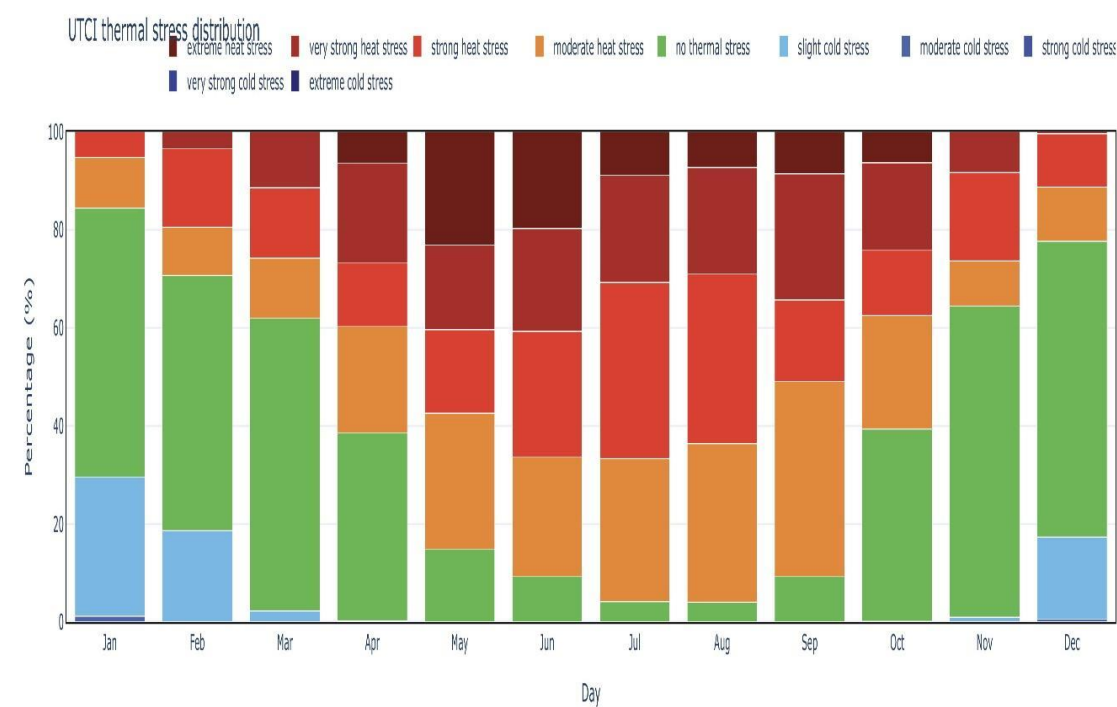

Figure 11. Universal thermal climate index (UTCI) heat stress map (CBE Clima Tool, 2023).

4.2. Obtained Datasets from ASHRAE Global Thermal Comfort Database II

The box plot in Figure 12 represents the distribution of indoor air temperature in various settings such as houses, classrooms, and offices, based on different conditioning methods: air conditioning, mix mode, and natural ventilation. The focus of the analysis is on the occupants' comfort level.
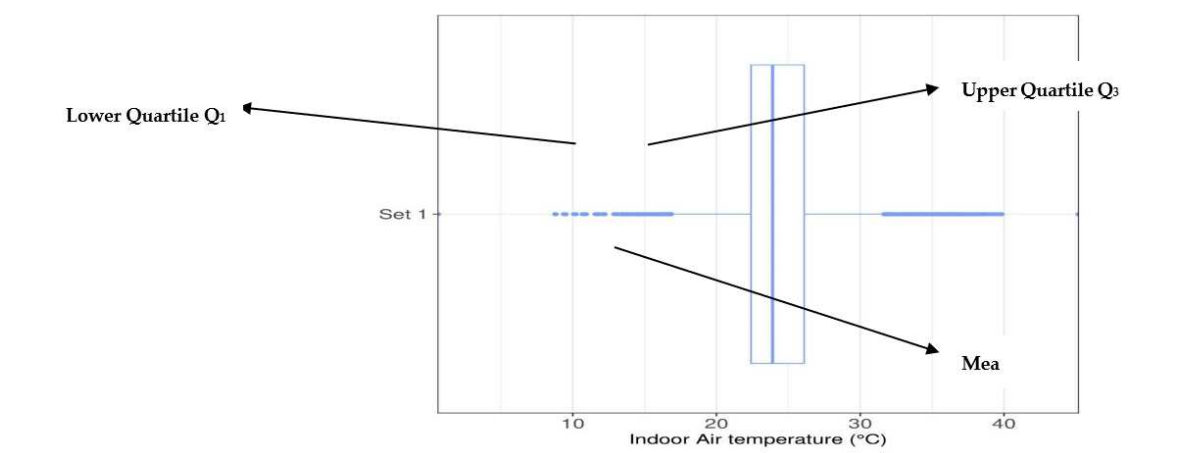

Figure 12. Boxplot for the distribution of Indoor air temperature (ASHRAE Global Thermal Comfort Database II Visualization, 2023).

Upon examining the box plot, it becomes evident that the dataset contains numerous outliers, indicating some extreme temperature values that deviate from the norm. Additionally, when considering the average temperature, it is noticeable that the lower quartile is closer to the mean than

the upper quartile, suggesting a positive skew in the data distribution. This skewness is further supported by the length of the upper whisker being longer than the lower whisker. (M. Hubert et al., 2008)

The majority of the data points fall within the range of 23°C to 27°C, indicating that most indoor environments are maintained within this temperature range to ensure comfort for the occupants while using these conditioning types.

These findings prompt significant inquiries concerning the efficiency of various methods for achieving and sustaining thermal comfort. It is vital to investigate the factors that contribute to the occurrence of extreme temperature values and outliers, including variations in building design, equipment efficiency, occupant behavior, and control systems. Additionally, exploring strategies to enhance temperature control and thermal comfort, such as optimizing conditioning systems, employing energy-efficient design principles, and adopting occupant-centered approaches, becomes essential. These efforts aim to improve the overall indoor comfort experience and well-being of occupants across different environments.

This box plot in Figure 13 visualizes the distribution of Predicted Mean Vote (PMV) (Toby Cheung et al., 2018) values in houses, classrooms, and offices, considering different types of conditioning methods: air conditioning, mix mode, and natural ventilation. The main objective is to examine the comfort level experienced by occupants in these settings.
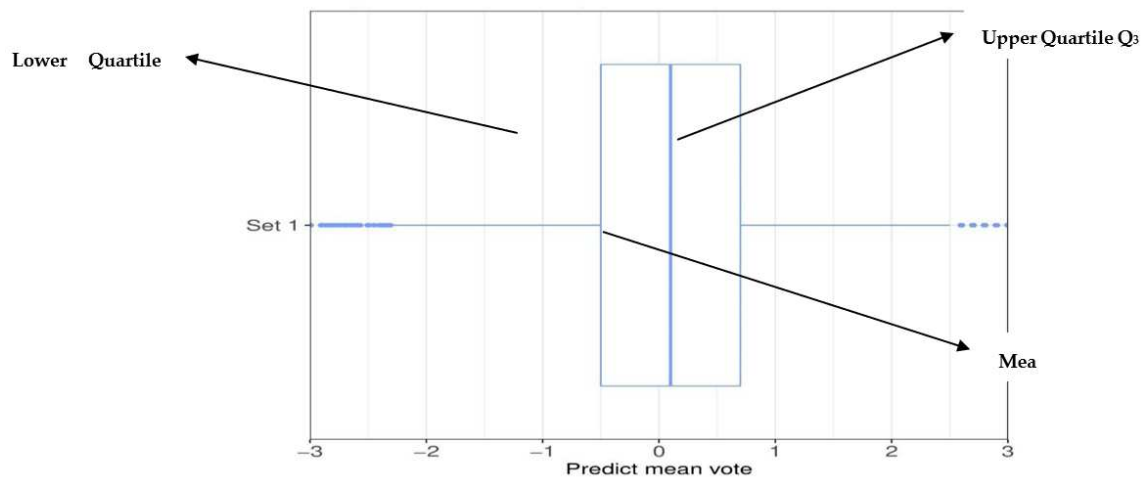

Figure 13. Boxplot for the distribution of PMV values (ASHRAE Global Thermal Comfort Database II Visualization, 2023).

Upon analyzing the box plot, it becomes apparent that the dataset contains outliers, indicating the presence of a few PMV values that significantly deviate from the overall trend. When looking at the central tendency of the data, we observe that the mean is positioned equidistant from both the lower and upper quartiles, suggesting a symmetrical distribution. This symmetry is further supported by the similar lengths of the upper and lower whiskers.

The majority of PMV values cluster within the range of -0.5 to +0.7, indicating that occupants generally perceive a neutral thermal sensation within this interval. This suggests that the different conditioning methods employed in these environments effectively provide a comfortable indoor experience, where individuals do not experience extreme sensations of either heat or cold.

This scatter plot in Figure 14 depicts the relationship between indoor air temperature and PMV (Predicted Mean Vote) in classrooms and offices with different conditioning types: air conditioning, mix mode, and natural ventilation. The Y-axis represents PMV values, ranging from -3 (cold sensation) to +3 (hot sensation), with zero indicating a neutral thermal sensation. The X-axis represents indoor air temperature in °C. The plot shows a modest positive correlation between the variables, indicating that as one variable increases, the other tends to increase as well, and vice versa. Within the temperature range of 20°C to 25°C, the data points cluster around PMV values close to zero, indicating a state of thermal comfort. However, as the temperature exceeds 25°C, the positive

correlation suggests an upward trend in PMV values and an associated increase in UTCI heat stress. It is important to note the presence of a few outliers in the dataset. These research findings suggest the importance of maintaining indoor air temperatures within the range of 20°C to 25°C to achieve optimal thermal comfort for occupants. However, exceeding this range can lead to discomfort and potentially pose health risks associated with heat stress. Additionally, it is crucial to explore effective strategies for mitigating heat stress and improving thermal comfort. This includes investigating adaptive thermal comfort models, advanced control systems, and personalized comfort solutions. These approaches are essential to ensure the well-being and productivity of occupants across various types of conditioning and settings.
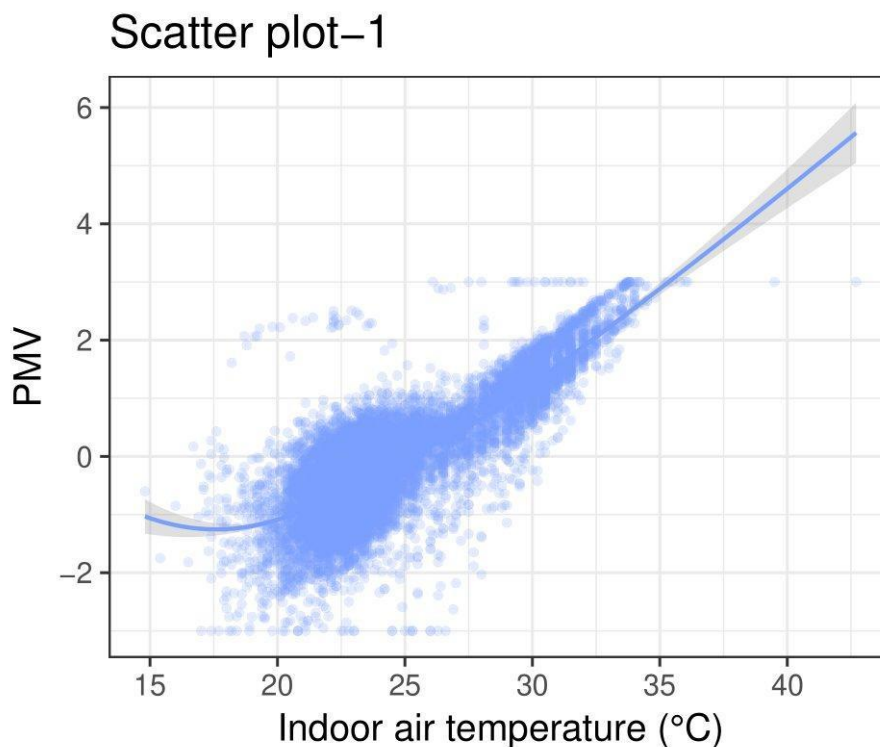

Figure 14. Scatter plot relationship between PMV and Indoor air temperature (ASHRAE Global Thermal Comfort Database II Visualization, 2023).

This scatter plot in Figure 15 illustrates the relationship between thermal sensation and indoor air temperature, considering different conditioning types such as air conditioning, mix mode, and natural ventilation. The observations were conducted in classrooms and offices. The Y-axis represents thermal sensation values, ranging from -3 (feeling cold) to +3 (feeling hot), with zero indicating a neutral thermal sensation. The X-axis represents indoor air temperature in °C.

The graph indicates a positive correlation between the two variables in the temperature range of 17°C to 25°C. This implies that as one variable increases, the other also tends to increase, and vice versa. For the temperature range of 25°C to 30°C, there appears to be no significant relationship between the variables. However, beyond 30°C, the positive correlation resumes.

During the initial positive correlation range of 20°C to 25°C, the data suggests a prevalence of neutral thermal sensation, indicating that people generally feel thermally comfortable within this temperature range (Salvatore Carlucci et al., 2021). As the temperature exceeds this range, the positive correlation indicates an increase in neutral thermal sensation, along with a rise in UTCI heat stress. It is worth noting that the dataset contains some outliers as well. (Shaoxing Zhang et al., 2023)
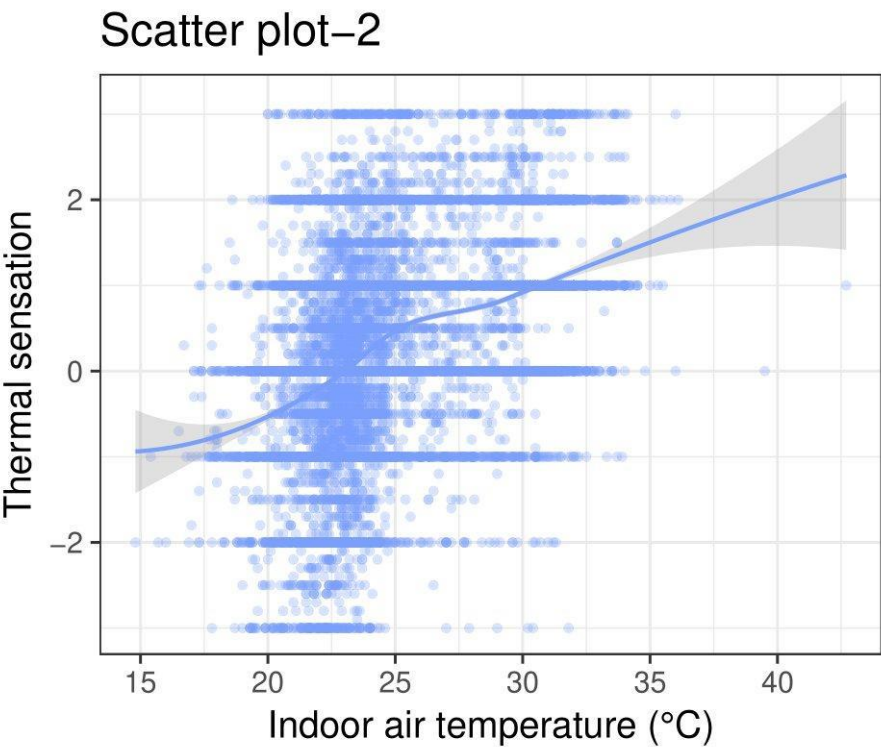
Figure 15. Scatter plot relationship between TSV and Indoor air temperature (ASHRAE Global Thermal Comfort Database II Visualization, 2023).

The graph in Figure 16 displays the ASHRAE adaptive model (Rupp, 2022), where acceptability is used as the satisfaction metric. The x-axis represents the average monthly outdoor temperature in °C, while the y-axis represents the indoor radiant temperature in °C. The graph includes a satisfaction band that spans from zero percent (pink colour) to 100 percent (green colour). The data was gathered from various building types such as houses, classrooms, and offices, employing different conditioning methods like air conditioning, mix mode, and natural ventilation.
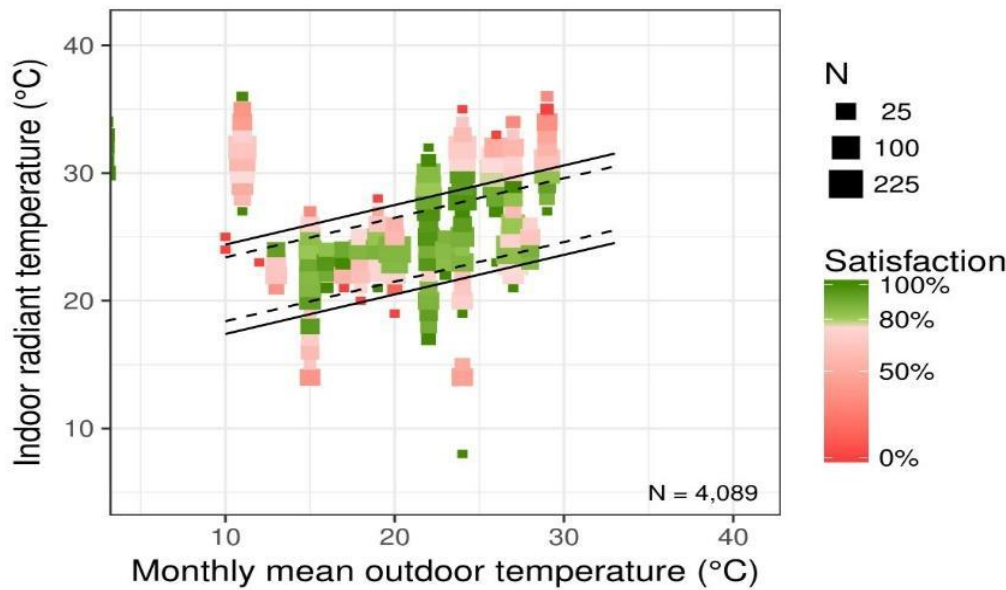

Figure 16. ASHRAE thermal comfort adaptive model between indoor radiant temperature and monthly mean outdoor temperature (ASHRAE Global Thermal Comfort Database II Visualization, 2023).

The graph reveals a positive correlation between the two variables, indicating that as one variable increases, the other also tends to increase, and vice versa. The solid black line represents the ASHRAE 55 comfort zone (Rajan Rawal et al., 2022). Upon closer examination, it is evident that the majority of the datasets fall within this comfort zone when using the specified conditioning methods.

Furthermore, the green datasets on the graph signify that most individuals feel thermally comfortable when the outdoor temperature is around 23°C, with an indoor radiant temperature range of 17°C to 27°C. However, it is important to acknowledge that the dataset contains some outliers as well. This information suggests that optimizing indoor conditions, such as radiant temperature, based on the ASHRAE adaptive model (Thomas Parkinson et al., 2020), can enhance occupant satisfaction and thermal comfort in various building types and under different conditioning methods.

4.3. Summary of Overall Findings

This plot in Figure 17 serves as a summary of the various plots and datasets described earlier. It illustrates the relationship between PMV (Predicted Mean Vote), plotted on the x-axis, and the percentage of people dissatisfied. The graph exhibits a general curve represented by a black line. The curve begins at a PMV value of -3, indicating 100% dissatisfaction. As the PMV value increases from -3 to 0, the plot demonstrates a negative correlation with the percentage of dissatisfied individuals. At a PMV value of zero, the percentage of dissatisfaction approaches zero, indicating that PMV zero represents a neutral thermal sensation (Wenjie Ji et al., 2020), where nearly all individuals feel thermally comfortable. From 0 to +3 PMV value, the plot shows a positive correlation between the two variables, indicating that at a PMV value of 3, considered a hot sensation, the percentage of dissatisfied individuals is 100%.
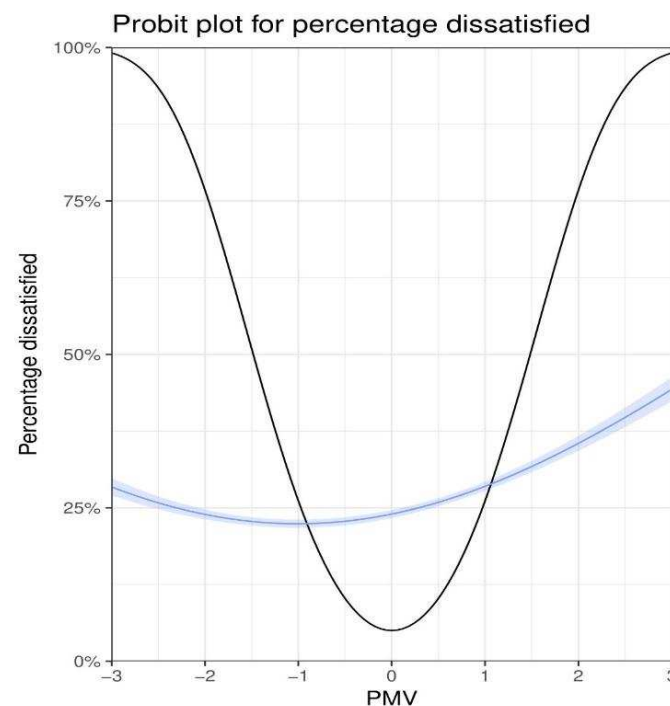

Figure 17. Satisfaction graph between PMV and percentage dissatisfied (ASHRAE Global Thermal Comfort Database II Visualization, 2023).

Now, examining the obtained data sets represented by a blue line, different conditioning types such as air conditioning systems, mix modes, and natural ventilation systems were used in various building types including houses, classrooms, and offices, with the satisfaction metric set as comfort. The datasets demonstrate that using these conditioning types, starting from a PMV value of -3, the percentage of dissatisfied individuals is slightly above 25%. As the PMV value approaches zero, the percentage of dissatisfied individuals decreases to less than 20%, indicating a negative correlation

within this range. Beyond a PMV value of zero, the percentage of dissatisfied individuals increases up to 45%, revealing a positive correlation within this range. This suggests that employing these conditioning types can enhance people's indoor thermal comfort, as the percentage of dissatisfied individuals decreases.

The research's inability to encompass every imaginable type of building may result in it lacking comprehensive solutions for specific challenges and complexities associated with certain structures. For instance, hospitals demand distinct considerations such as medical equipment, infection control measures, and specialized infrastructure for patient care. Similarly, manufacturing facilities have unique requirements pertaining to production lines, safety regulations, and the handling of hazardous materials.

By not encompassing all possible building types, the research may lack the necessary depth and specificity required to address the complexity of these specialized contexts. Consequently, professionals working on projects involving non-standard building types might find the framework less applicable or less helpful in guiding their decision-making processes.

5. Discussions

The data obtained from various sources highlights the positive impact of implementing air conditioning systems or incorporating natural ventilation in buildings on the indoor air quality in urban areas of Pakistan. Particularly during the scorching and humid months of May through September, these strategies have proven to be highly effective in creating a thermally comfortable environment for people. The key finding of this research indicates that adopting such conditioning methods can lead to a reduction of up to 25% or even less in the percentage of individuals who express dissatisfaction with their indoor conditions. This study also brings attention to the noteworthy contribution of Air Conditioning Systems in maintaining occupant comfort and effectively removing $PM_{2.5}$ particulate matter from indoor air.

5.1. Climate change and its impact on thermal comfort

The effects of climate change can greatly influence thermal comfort, which pertains to the personal interpretation of comfort in relation to temperature and other surrounding conditions. The global rise in temperatures caused by climate change has resulted in more frequent, intense, and prolonged heat waves, especially in urban regions. These high temperatures can contribute to heat stress, dehydration, and heat-related illnesses, thereby undermining thermal comfort. The changing climate is causing shifts in seasonal patterns, resulting in warmer temperatures during traditionally cooler seasons. This alteration can disturb the natural process of adjusting to temperature changes, posing difficulties in attaining thermal comfort during transitional periods. Climate change alters climatic conditions and precipitation patterns, potentially leading to shifts in climate zones. This can disrupt the adaptation of buildings and infrastructure to local conditions, making it challenging to maintain optimal thermal comfort.

5.2. Possible Limitations

The study focuses specifically on Lahore, which may limit the generalizability of the findings to other urban areas in Pakistan or other countries. The unique characteristics of Lahore, such as climate, building structures, and population density, may influence the effectiveness and applicability of the identified approaches and technologies.

The study may involve a specific sample of buildings or households, which could introduce selection bias. For instance, if the study primarily focuses on certain types of buildings or occupants who already have access to advanced air conditioning systems, the findings may not represent the broader population accurately.

While the study highlights the potential improvements in air quality through advanced air conditioning systems, it may not thoroughly explore the cost implications of adopting and

maintaining such technologies. The feasibility and affordability of these systems for various segments of the population may significantly impact their widespread adoption and scalability.

5.3. Future Recommendations

Given the positive impact of air conditioning systems on indoor air quality and occupant comfort, it is recommended to encourage the installation and use of air conditioning systems in buildings, particularly in urban areas of Pakistan. This can help create a thermally comfortable environment for people, especially during the hot and humid months. Alongside air conditioning systems, it is important to promote the incorporation of natural ventilation strategies in buildings. Natural ventilation can complement air conditioning systems and help improve indoor air quality by bringing in fresh air and removing pollutants. Design guidelines and building codes can be developed to encourage the incorporation of natural ventilation features in buildings. Given the finding that air conditioning systems contribute to the effective removal of $PM_{2.5}$ particulate matter from indoor air, it is recommended to monitor and control $PM_{2.5}$ levels in buildings. This can be achieved through the use of air quality monitoring devices and implementing filtration systems that target $PM_{2.5}$ particles. Regular maintenance and replacement of air filters should be emphasized to ensure their effectiveness.

6. Conclusions

This research study aims to address the pressing concern of indoor air pollution in urban areas of Pakistan, specifically focusing on Lahore. It emphasizes the importance of considering not only outdoor air quality but also the health and well-being of individuals within indoor spaces. The primary objective of this investigation is to assess previous approaches, particularly the use of Air Conditioning Systems in developed countries, to demonstrate the potential improvements in air quality that can be achieved in urban areas of Pakistan.

The study examines the causes, concentrations, and impacts of various pollutants, such as particulate matter ($PM_{2.5}$), carbon oxides (CO_x), nitrogen oxides (NO_x), sulfur oxides (SO_x), and volatile organic compounds (VOC_s). By analyzing these factors, the research aims to provide a comprehensive understanding of the air pollution scenario specific to Lahore and similar urban areas in Pakistan.

The findings of the study highlight the significant role that Air Conditioning Systems can play in ensuring the comfort of occupants while also aiding in the removal of $PM_{2.5}$ particulate matter from indoor air. To achieve this, the study explores the use of tools such as the Clima tool and the ASHRAE global thermal comfort database II. These resources facilitate the assessment and improvement of indoor air quality through the optimization of air conditioning systems.

Specifically, certain air conditioning systems equipped with advanced features like High-Efficiency Particulate Air (HEPA) filters, multi-stage filtration systems, and activated carbon filters are identified as highly effective in capturing and filtering out $PM_{2.5}$ particles. Consequently, these systems significantly contribute to improving indoor air quality, ensuring healthier and safer environments for occupants.

In summary, this study provides a comprehensive examination of indoor air pollution in urban areas of Pakistan, with a focus on Lahore. By highlighting the potential enhancements in air quality achievable through the adoption of advanced air conditioning systems and associated filtration technologies, the research underscores the importance of prioritizing both outdoor and indoor air quality for the well-being and health of urban residents.

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