# COLLATION OF TECHNIQUES USED FOR ENHANCING THERMAL COMFORT AND VENTILATION OF A BUILDING

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**ABSTRACT-**

**Ventilation inside a building is a governing factor since it can drastically affect the mood and health of the occupants living inside.Ventilation majorly influences the heat level existing inside a building since it directly affects the flow of air and humidity in a space.Therefore, a review of the literature is carried out to identify the significance and methods of achieving optimum natural ventilation and heat inside buildings around the world.In the reviewed literature, the studies were conducted using either simulation tools like ANSYS AIM, Cradle scSTREAM, Star CCM+, DesignBuilder, FLUENT 6.2 Software, etc. or by experimental methods using sensors like a 2D ultrasonic wind sensors, 3D ultrasonic anemometer, hygrometer,air velocity transducers, and thermometers,or by the use of mathematical models. Each method displayed its varying ability in providing relevant results based on different situations. The analysis results from the reviewed literature revealed how different factors govern the thermal comfort and ventilation level inside a building, including building's orientation (saving up to 105% of annual energy consumption), ventilation types, number of openings, types of windows, window to wall ratio, the position of staircases, layout of the building, etc.Comparative studies showed that Cross-ventilation provides better airflow than single-sided ventilation and also reduces air conditioning usage by 70%. The thermal comfort level of the building can change up to 20-55% by varying the window to wall ratio. Modern techniques such as wind catchers, wing jetter systems, etc. havealso been reviewed in this study.The significance of these optimizing parameters has been discussed in this paper.**

**KEYWORDS: Natural Ventilation, Thermal Comfort, Orientation, WWR, Air velocity, Air Temperature, Humidity, etc.**

## I. INTRODUCTION

There is a significant rise in demand for sustainable buildings which improves the quality of living with comparatively less usage of resources, energy, etc. than the traditional buildings. The increase in pollution and other climatic changes around the world has started to affect the quality of life of the people. A major factor governing these changes is the consumption of energy in every form. The world is now shifting towards a mindset of achieving the essential requirements with minimal use of energy sources.

The construction industry in its way is providing a shared contribution by the use of eco-friendly materials and by the construction of sustainable/energy-efficient buildings. Simple use of already existing techniques in an efficient way can have a major impact on the building's overall energy consumption and in turn, produce cost-effective methods. Many factors influence the building's energy consumption. Some of those factors can be optimized using design techniques to improve the ventilation and heat effects due to natural occurrences like Sunlight, wind, weather/climate, humidity, etc.

Ventilation inside a building is a governing factor since it can drastically affect the mood and health of the occupants living inside. A comfortable and healthy environment of an indoor workspace improves the work efficiency of the occupants. Ventilation also affects the heat level existing inside a building since it directly affects the flow of air and humidity in a space. Therefore, building Designers and Engineers give importance to its significance and consider this as one of the key factors to be taken into account during the designing phase of the building.

Ventilation is the process of replacing unwanted stale air with fresh air. In the absence of proper ventilation, buildings might become more vulnerable to stagnant air which might lead to a sharp increase in the accumulation of fungi and bacteria (due to an increase in moisture level). It also influences energy efficiency and air quality, controls odors, and prevents the spread of diseases related to respiration.

The main aim of ventilation is to provide thermal comfort inside the living spaces of the building. According to *ANSI/ASHRAE Standard 55*, "Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation". The thermal comfort in the building can be determined using a number of ways, the most commonly used approach being PMV, whose use is examined in this paper.

Thermal comfort level can be visualized using a psychrometric chart and an expansion of this chart by addition of parameters like air movement, mean radiant temperature, skin wittedness, metabolic rate, the behavior of occupants which aids for better representation of thermal comfort **[4]** has been reviewed in this paper.

The building envelope between indoors and outdoors present in the focal interface plays a part in controlling changes in the climatic conditions outdoors and providing residents with thermal comfort. Thus, determining the heating or cooling loads of the building.

In recent times, air-conditioning and other advanced mechanical systems have provided indoor thermal comfort in a building. The use of air conditioners increases energy consumption and has had harmful effects on human health and on the environment. Natural ventilation is regarded as one of the extremely effective passive cooling solutions, allowing the occupants of the building to benefit from a healthy indoor environment and comfort. Their performance mainly depends on the combination of different architectural factors such as ventilation method, kind of opening, window-to-wall ratio, floor area, and building orientation, etc.Natural ventilation uses the wind pressure and stacking force of natural forces in order to direct air movement through buildings[22]. Refers to outside airflows in an inside setting due to the pressure difference caused by natural forces. A building wind affects the air ventilation, infiltration, and heat increases or losses linked with it.
The application of single-sided, cross-ventilation and the amount of difference one can achieve using these has been reviewed using studies carried out at different locations in various climatic conditions. The studies conducted have used different BIM software to carry out the analysis of Ventilation (CFD simulation) and heat level inside the building space. Simulation software contributes to deal with climate adaptations. They are adopted by engineers forthe evaluation of different design alternatives. These tools give an understanding of the building's performance. It enables the architect to estimate and optimize the building envelope's thermal performance, energy performance, and occupant thermal comfort.

This paper provides an overview of what natural ventilation methods are appropriate in order to provide an optimum level of thermal comfort and indoor air quality inside a building. The purpose of the study is to raise awareness of the usage of existing technologies to minimise energy resource dependency and further increase the ventilation and heat optimization techniques in a building.

## II. METHODOLOGY

Literature research was done to determine the significanceand methods of achieving optimum natural ventilation and thermal comfort inside buildings around the world. The approach adopted for the literature review was carried out in four different phases: Identification, Collection, Classification, and Analysis. Identification and listing of Keywords: The study focused on the variables affecting the heat and ventilation as well as the method of analysis. The keywords used were heat, natural ventilation, thermal comfort, airflow, orientation, multi-story building. The Collection of literature was done using SCOPUS or Google Scholar(Scopus indexed). From the collected bibliography, the most relevant articles were filtered and classified into sub-divisions based onair velocity, and temperature, window design, orientation, etc. These papers were then analyzed in detail to identify and define a set of parameters/factors affecting the heat and ventilation of the building and the methods adopted to analyze them.

## III. LITERATURE REVIEW

The literature review is sub-divided into sections of Determination, Optimization techniques,and Modern Techniques. The first section deals with the determination of optimum thermal comfort level using questionnaire surveys and mathematical models including methods used to analyze the ventilation level. The second section deals with the parameters and methods used to attain optimum thermal comfort temperature and minimum ventilation level inside a building. The final section discussesdifferent techniques other than traditional techniques like wind catchers, solar chimneys, etc., and how they can improve ventilation inside a building.

### 3.1 DETERMINATION OF THERMAL COMFORT LEVEL

- This study was conducted by **M.S. KamarulAiniet al.(2019)**. It was done for the Dewan Sultan Ibrahim (DSI), UTHM, Malaysia. Here, heat analysis is carried out to know the thermal sensation of the auditorium. The study is carried out in two ways to find out the thermal comfort status of the auditorium. The Quantitative Measurement was done by 4 in 1 metre kit, while the students were given a questionnaire for subjective measurement. From the questionnaire, it was seen that a comfortable temperature sensation was felt by most (80 percent) of the pupils in the auditorium. 89 percent felt that because of the proper operation of the air conditioning system, DSI was pleasant. The ICOP IAQ 2010 (ACT 514) was used to determine the sampling points. When compared the result at DSI to standard, Temperature 24 $^{o}$C, Relative Humidity 65.17% fall in range while air velocity of fully mechanized ventilation system is taken as 0 m/s which did not fall in the range. PMV of -0.45 means PMV is not achieved while PPD of less than 9% is considered good. Environmental parameters and the seasonal effect could have been carried out in this study.

- This research was done by **Doris HooiChyee Toe (2013)** The study was for residential buildings keeping thermal comfort as a priority. Heat analysis was done by finding the neutral operative temperature for each climate namely, hot-dry, hot-humid, and moderate climates. A comfortable range of temperature changes for the specified climates was detected and analysed in the estimated neutral operating temperature. ASHRAE RP-884 database is used and data from the database were categorized for each of the three climate groups. For data analysis, adaptive equationsof thermal comfort from EN15251 and ASHRAE standards are compared with linear regression lines equations developed for the three climates mentioned. These regression lines differ from the standards in their outdoor temperature ranges and gradients. When compared with the standards the regression lines have a gradient nearly twice as steep. The analysis done was able to help predict the acceptable comfort limits of occupants from the neutral operative temperature. Probit models is used to collect the thermal sensation votes so thatthe temperature range for each climate can be determined, from which the "comfortable" temperature ranges were set. Even at 2 °C below the neutral operating temperature, 86% of the occupants felt comfortable in the hot-humid conditions. 80% of people felt comfortable at 6 °C below and 2 °C above the neutral operative temperature for hot-dry climates. For a moderate climate, occupants feel comfortable at 1.5 $^{o}$ C above and 2.5 $^{o}$ C below the predicted neutral temperature. The regression line coefficient of moderate and low airspeeds for the hot-humid climate was found to be 0.54 and 0.57 respectively which shows both airspeeds have little impact on thermal comfort. It is seen that higher neutral operative temperatures are suitable for low relative humidity than for high relative humidity for hot-dry climates while such a result is not so clear in hot-humid climates. An increased airspeed allowance could be introduced.

- This research was conducted by **Vincent J.L. Gan et al., (2019)**.This study is done in Hong Kongfor their public housing sector. A BIM model of the flat is designed then to assess the indoor temperature and flow fields CFD simulation is done so that the occupant's thermal comfort could be analyzed for different periods. Airflow rate is also determined via air change per hour (ACH). By calculating heat transmission via natural ventilation and other heat sources, BES predicts the thermal load. April and July seasons are analyzed for heat gain. 12 PM and 7 PM is the time taken to conductCFD simulations. The standard temperature for thermal comfort is set at 21 $^{o}$C -26 $^{o}$C.If we look at the temperature of outdoor air at noon of 23 $^{o}$C which means that natural ventilation transports cold air into the flat but other sources of heat such as solar radiation and metabolic heat gains, increase the indoor temperature up to 37 °C. At night the temperature of indoor air is in the range of 20 $^{o}$C – 21 $^{o}$C so thermal comfort can be maintained at night. Airflow rate for Natural ventilation is in the range of 0.2 $m^3$/s - 0.275 $m^3$/s for Inlets and 0.13 $m^3$/s – 0.413 $m^3$/s while for mechanical ventilation is 0.12 $m^3$/s. In July noon the temperature is 2 $^{o}$C- 4 $^{o}$C more than of April noon, so using mechanical ventilation causes hourly energy consumption to be 50% more than that of April. In July, the maximum comfortable temperature reaches 26 °C to 27 °C at night., and if occupants can accept this thermal comfort energy consumption can be decreased. Other ventilation criteria such as airflow, wind direction can be considered in future studies.

- A psychrometric chart is a visualization tool widely utilized in building system design and operation to understand the properties of air**.** To this chart **Eric, Prageeth, Clayton, Forrest(2019)** introduced a new contour shading method which provides a better representation of different levels of thermal comfort condition based on extra parameters includingair movement, mean radiant temperature, skin wittedness, metabolic rate, the behavior of occupants. The interpretation of this chart is done using color gradient i.e. when the temperature required or airspeed condition exhibited by the color gradient corresponds to the color legend in the system, then energy balance is considered favorable for comfort. A mismatch between the plotted point color and that of the gradient at the location of a given point would represent an uncomfortable scenario.

3.2 OPTIMIZATION TECHNIQUES

- **Kechun et. El (2012)** simulated an office building in Chongqing, China it was found that 33% of total hours there, one can experience human comfort temperature (18-26 C) naturally. When the number of ventilation sources was introduced and increased, it was observed that the number of comfort hours of the building also increases. Night ventilation helps in reducing the indoor temperature during the daytime which contributes to energy saving as it reduces air condition turn-on time. It was found that till addition of 4 ventilations/hour at night gives a significant reduction in energy consumption while 5 or more makes very little difference.

- **Zheng Cheng, Lingling Li, William (2016)** carried out a case study for a gymnasium in a university indoor multisport facility located at State College, PA in the northeastern part of the US mainland to access the natural ventilation potential on the thermal comfort and acceptable indoor air quality in a gymnasium. The simulation of this building is done using IES-VE software. Different parametric alternative cases were made by varying factors like equivalent floor ratio, opening distribution, and opening to floor ratio of the standard simulation model. The combination of 80% equivalent floor ratio, 4% opening floor ratio, with added rooftop vent for opening distribution, provides the best thermal comfort and indoor air quality in the building. It was observed that increasing the equivalent floor ratio and opening floor ratio both allow for better ventilation. Enlarging east openings provide better ventilation when compared to the west. The provision of rooftop vents helps with the buoyancy effect thus promoting better air exchange.

- Different ventilation patterns were studied to find which pattern gives the best circulation of air by **TarekMeakhail (2015)** using CFX-Task flow software for the airflow simulations in the Egyptian

Construction industry where they considered a small-scale building model which is roughly one-tenth the scale of a typical full size, after analyzing the simulation results for different ventilation patterns it was concluded that Full-open ventilation gave the best results in terms of air circulation and equal distribution of air in the rooms aiding to better indoor thermal comfort.

- **Iftikhar A. Raja. et al. (2001)** developed a regression model in the European construction industry to find the influence of having access to using different ventilation controls and indoor temperature by doing different surveys on the occupant's behavior which revealed that occupants who had greater access to different controls face a lower level of discomfort than the occupants with comparatively lesser access.

3.2.1 INFLUENCE OF WINDOW DESIGN & ORIENTATION

- **Abdelsalam et al. (2017)** explored different window designs by CFD analysis using DesignBuilder software to assess energy and shading performance while determining the natural ventilation in the outdoor environment as well as its effect on the indoor airflow using the weather data of Dubai, UAE; ANSYS-CFX software was used. It was found that the best cross-ventilation performance was observed when the inlet window took up 50% of the wall area and the outlet window 20% of the wall area. It was discovered that the operating temperature was reduced when high-pressured wind openings are larger than low-pressure leeward openings.The larger the open area of inlets, the higher the airflow.Maximum ventilation rates can be achieved when windward, leeward openings are placed in opposite directions of the building with the north having the larger opening and the smaller opening in the south direction. When an external horizontal shading device is introduced to the southern opening an improvement in airflow can be achieved.

- A comparative study by **Fang Ruan and Nianping Li (2016)** on different types of windows i.e., side hung, sliding windows, up-down folio Window, multi sash mid pivoted folio window with vertical deflectors used in a room with a single opening in the Chinese construction industry by conducting an experiment and simulating it using CFD model using FLUENT 6.2 Software. A comparison was made based on wind speed and air mass flow rate at different outdoor velocities. It was found that Up down folio window and Mid-Pivoted multi-sash window resulted in good wind speed and air volume flow rates for different wind directions when compared to the two conventional ones.

- **Wanda, Anik, Luciana (2006)** considered two houses in Penjaringansari, one facing north and the other facing east with the same external. The temperature in both houses is noted down along different seasons at different times of the day in three bedrooms and a living room using a manual thermometer, humidity meter, or digital thermometer. Despite the same external conditions both the houses' indoor temperature showed significant difference hence it was concluded that indoor temperature in the house is highly influenced by building orientation to the sun position. Overall, the north-facing house was cooler when compared to east facing one. The temperature in the middle of the living room, as well as bedrooms in the east-oriented house, had a higher temperature compared to the north-oriented one.

- **Shakila Pathirana1 et al. (2019)**analysed the influence of the orientation, building design, zones, and window to wall ratio in the natural-ventilated houses, on the thermal comfort and lighting energy requirements in a hypothetical tropical humid location in Katuanyake, Sri Lanka. Design Builder simulation software was used to develop 300 distinct models of two-storey buildings with flat roofs to achieve lighting power and adaptive thermal comfort. Three building shapes were selected, i.e. rectangle, square and L-shaped; for 4 windows to the wall ratios and 24 orientations, the orientation of each model was altered. It was accounted that the WWR had the potential to change the thermal comfort by 20–55% whereas the lighting electricity by only 1.5–9.5%. Itwas deducedfrom the analysis that thermal comfort level is a governing factor in deciding the WWR. In this study, Only Flat roof type was considered and the Effect of shading due to neighboring buildings and other external obstruction are not taken into account.In the future, the significance of the zone sizes, building shapes, WWR, and building orientation should be analysed individually and collectively in order to investigate different roof kinds.

- **Aiman Albatayneh1 et al. (2018)** investigated, using DesignBuilder simulation software, the impact of building orientation on a Jordanian building's overall thermal performance. For simulation, a typical residential building that corresponds to 60% of the buildings in Jordan was chosen. Preliminary data were collected using the Jordan building code for obtaining thermal transmittance of the structure (U-values). The simulation was carried out after the gathering and input of preliminary data. A proper orientation has been identified to increase thermal comfort and reduce energy use.When the long axis of the building faced north/south, the optimal orientation allowed for the absorption of the winter solar radiation in the module and prevented the primary wind stream. The larger windows in the northern hemisphere should be in the southern walls to heat the building more. In comparison with the base case building, the building's orientation has the potential to reduce thermal energy by over 35%. Further studies on orientation impacts on the various types of buildings can be carried out.

- This study was done by **AimanAlbatayneh et al. (2018)**. It is done in Australia for the housing sector to check the thermal performance of residential buildings. Four different house modules were prepared; Insulated Brick Veneer (InsBV),Cavity Brick (CB), Insulated Reverse Brick Veneer (InsRBV), and Insulated Cavity Brick (InsCB). To assess the thermal performance, the Insulated Cavity Brick (InsCB) module was used. Data collection was done by installing more than 100 sensors that would record data every 5 minutes of the external weather and the indoor environment using Datataker DT600. Since only the natural energy parameters are considered for this study, theoverall thermal performance was mainly affected by weather conditions. In the winter season, the exterior surface received less incident solar radiation on the western and eastern walls, but due to the low sun altitude in the sky, the incident solar radiation on the Northside increased significantly. Most winds come from the East and West direction and if the wind speed is high then the heat lost/gain has more effect on Eastern and Western walls compared to Northern and Southern walls. The annual energy requirements are found to be least when the building is oriented to the North direction followed by East, West, and then South. Heat losses could be minimized in the winter months by at least three times if the Window orientation is North instead of South. External shading can be considered as a future scope. The result from this module can be compared to the other three modules to assess their performance in each season.

- This research is done by **Miguel Mora-Pérez, Ignacio Guillén - Guillamón, et al. (2015).** It is done for an academic building for the construction industry of Spain in Valencia. In this paper, the relation between Environment, location, and their effect on natural ventilation is examined. Analysis of wind speed, its direction, and airflow distribution in and around the building is done. This analysis is done using CFD simulation. A 3D computational model is developed with Star CCM+. In order to calculate turbulent phenomena, the Reynolds-averaged Navier-Stokes equations (or RANS equations) are employed. To represent turbulence k–e model is used. Full-scaled measurement design drawings are used to design the computational geometry. The boundary country is set by a wind tunnel with the east face is simulated as velocity inlet profile and the west face as the pressure outlet condition. The wind enters through the eastern side of the wind tunnel and passes through the westerly face. With the finite volume method (FVM), the 3D mesh is used. To verify the CFD analysis, the findings must be compared with full-scale wind velocity measurements. Since the measurements for indoor air velocity cannot show the accuracy of the CFD model, on-site wind measurement is performed using three "hotwire" air speed transmitters that measure air speed from 0 to 5 m/s with ±0.03 m/s precision. The building is located at location 1, in a wind recirculation area that is not suitable for natural ventilation. It is seen that for Location 1, the building receives wind flow from the North openings and the East opening and leaves through the South opening. For Location 2 the South and West opening are the inlet while wind leaves through the North openings. Due to bigger openingson the South and East side for Location 2 compared to one narrow opening on the North Side of Location 1, So Location 2 requires an internal air renovation of 13.1 percent less time. Location 2 also has a better air sweep effect so it has been concluded that this location provides improved building performance from the perspective of natural ventilation.The fluctuation of wind can be taken into account in future studies.

3.2.2 INFLUENCING AIR VELOCITY & TEMPERATURE

- A parametric window study conducted by **GhadaElshafei et al (2017)**in a residential building of 5 floors using Design builder software in the Egyptian construction industry where they increased the size of the windows in different rooms and additional windows were placed which resulted in the increase of average air velocity by 6 times and decrease in temperature by 1.1 times thus improving the ventilation i\n the rooms and reducing temperature.

- **AugiSekatia et. al. (2020)**compared the thermal comfort in two Dutch Style churches having low ventilation in Hot-humid tropical regions of Indonesia which showed that the church has 40cm height low ventilation has a 4% higher air velocity and a lesser indoor humidity level when compared with the church having 70cm height low ventilation.

- **Durva Gupta, VaibhavRaiKhare (2021)** evaluated, using the Cradle scSTREAM (CFD) simulation software, the thermal comfort of a naturally ventilated hostel building in a hot-humid environment in Jaipur, India. The thermal comfort of various natural ventilation strategies was assessed and the data collected and the model used to measure the thermal comfort range in accordance with the ASHRAE-55 standard were verified by means of a 3-D building model. Cross ventilation increased air velocity by 0.5 m/s, whereas night ventilation reduced air temperature by 2.0–2.5 °C. Cross ventilation improved airflow throughout the building with efficiency.By using various natural ventilation strategies, thermal comfort can be regulated simultaneously. Various ventilation solutions including the modelling of solar chimneys, wind catcher designs, and the impact on future climate scenarios can be further studied.

- This case study is done by**CharlesBerville,GeorgeChitaru, et al.(2018)**from UTCB Faculty of Building Services. This is done for a self-service restaurant in Romania. This study compares a mixed flow ventilation system with a displacement ventilation system using the computational fluid dynamic analysis (CFD) by analyzing parameters such as air temperature and velocity distribution in occupied spaces, draft effect. Based on the result of the simulation, the best ventilation system suitable for the restaurant is recommended. Heating, cooling, and humidity loads are taken using Romanian Standards.Air parameters like the required fresh air flow rate and different types of heat gains are taken from Romanian Standards.The Space Claim's ANSYS AIM module was used to develop the virtual model, which analyses just one quarter of the open restaurant area. A mathematical solver configuration and corresponding boundary values are entered to get the results of the parameters. Results suggest that mixing ventilation gives more draft sensation than displacement ventilation. This is the case because of the combination of high inlet velocity and high turbulence of flow. Air velocity is between 0.2 m/s and 0.25 m/s in a displacement ventilation situation, whilst the average temperature is between 22 °C. The average velocity is about 0.3 m/s to 0.35 m/s for mixing ventilation, while the average temperature is about 25 °C. If we look at the mixing ventilation system, the temperature variation is uniform on the height of the room, and combined with low inlet velocity draft sensation is significantly less. For displacement ventilation case, the temperature distribution is almost uniform across the room while it increases slowly with height with almost 30 $^{o}$C near the ceiling. A study on different positions of inlets and their angle of introduction can be done.

- **Md. SarwarJahanTalukdar et al., (2020)** conducted an adaptive thermal comfort study in Mymensingh university classroomslocated in Bangladesh's hot and humid Climate. The study began with the determination of different climatic parameters, such as outdoor and indoor temperature, air velocity,and relative humidity using instruments Presto Hygro-Thermometer for air temperature and relative humidity, the Hold peak HP-866B for air velocity, and then conducting various surveys on the occupant's behavior based on their votes on thermal perception, preferences, and thermal sensation. It was discovered that higher air velocity decreased the discomfort caused by humidity, and students prefer a drier environment.This study is very limited for the occupant's thermal comforts only and since the results are for only one season an adaptive comfort model cannot be developed which would need data for all seasons.

- **Sara Omrani et al. (2017),** using full in-situ assessment of single sided and cross ventilation types, investigated the thermal comfort impact of a high-rise case study unit. For this study, a 36-storey residential structure in Brisbane, Australia was used which can operate in both cross-ventilation and single-sided modes. Different equipment including a 2D ultrasonic wind sensor, a 3D anemometer, air transducers, thermometers and hygrometers were used in the summer for measuring temperature, relative humidity, and air velocity on two consecutive days. At 1.2m above ground level, all equipment was mounted.Comfort models for interior thermal conditions have been assessed using Standard Effective Temperature (SET*) and extended Predicted Mean Vote (PMV) models. The direction of the wind had little influence on the air direction and was predominantly controlled by ventilation type. Indoor heat levels were reported to be in the comfort zone over 70% of the time during the cross-ventilation process whereas single-sided ventilation was observed for just 1% of the time. The SET analysis demonstrated that single sided ventilation was on average 3°C hotter than cross ventilation. Because all measures were taken at 1.2 m from the floor in this investigation, measurements at various heights can thus be beneficial to detect thermal conditions for sleeping and standing residents in future research. A detailed study may be carried out on different levels at different places.

3.3 MODERN TECHNIQUES FOR IMPROVED NATURAL VENTILATION

- A review is writtenby **Naghman, Yuehong, Saffa (2008)** on the various wind-driven ventilation techniques based on research and study on existing knowledge. Their workings, advantages, disadvantages, and other important properties have been discussed. This consists of both traditional techniques like window openings, atria and courtyards, wing walls, chimney cowls, and modern techniques such as wind catchers, wing jetter systems, turbine ventilators, etc. A classification has been made based on operation and wind interaction of different techniques namely passive, direct passive, or active techniques. A systematic comparison is made among all the techniques based on their features, flow rates, and applications for easier understanding. A future study can be done to see the economically beneficial technique by doing a cost-based comparison.

- **Tariq Ahmed et al. (2021)** examined the ability of natural ventilation for appropriate heat-wave resistance, optimal thermal comfort, and good indoor air quality. The data examined have been covered throughout the previous 20 years, i.e. from 2000 to 2020 using Google Scholar search engine. A review of the literature in this research showed that single-sided ventilation offers the least thermal comfort whereas cross ventilation has demonstrated higher efficiency in reducing indoor temperature.In comparison to cross-ventilation and single-sided, wind catchers and solar chimneys nonetheless provided significantly greater airflow. It was shown that cross-ventilation during heatwaves and future climatic conditions could not satisfy interior thermal comfort criteria. Finally, in warmer weather, the system can produce high ventilation rates and maintain indoor temperatures around 8oC below outdoor temperatures (>35oC). Further study of these systems in the light of the expanding air pollution and warmer environment is urgently required, against future climate scenarios and the use of filters controlled natural ventilation, particularly with solar chimneys/wind catchers must also be done.

- **Yuguo Li & Per Heiselberg (2003)** examined recent developments on methods of analysis for natural and hybrid ventilation in buildings. In order to design and evaluate natural and hybrid ventilation, a wide range of analytical methods have been initiated. CFD was found appropriate in every area of the building or some part of the complex structure to predict detailed flows. Multi-zone methods also offered opportunities for full-building performance modelling. More progress on multi-zone methods is needed, which includes the formation, multiplicity of solutions, and improved mathematical methods for managing equations for multi-zone methods.

## IV. TABLE SUMMARY

| Reference # | DESCRIPTION | METHODOLOGY | RESULT | RESEARCH GAP/ FUTURE SCOPE |
|---|---|---|---|---|
| [1] | Thermal comfort study to evaluate the sensation of thermal comfort level inside an auditorium.<br><br>(KamarulAini, M. S., Wan Noor Hanani, W. Z., MohdArif, R., Nor Haslina, H., NurAini, M. A., and HarisFadzillah, H. , 2019) | The quantitative measurement was performed using 4 in a 1-meter kit anddistribution of a questionnaire to the students for the subjective measurement. | PMV of -0.45 means PMV is not achieved while PPD of less than 9% is considered good | Environmental parameters and the effect of different seasons can be carried out in this study |
| [2] | Heat analysis for each climate namely, hot-humid, hot-dry, and moderate climates<br><br>(Toe, D. H. C., and Kubota, T. , 2013) | Adaptive thermal comfort equations from EN15251 and ASHRAE standards results are compared with linear regression lines equations developed for three different climates mentioned. | The regression line coefficient of moderate and low airspeeds for hot-humid climate shows was found to be 0.54 and 0.57 respectively | An increased airspeed allowance could be introduced. |
| [3] | CFD Simulation to assess the indoor temperature and flow fields to evaluate the occupants' thermal comfort for different periods.<br><br>(Gan, V. J. L., Deng, M., Tan, Y., Chen, W., and Cheng, J. C. P. , 2019) | CFD simulation was conducted at 12 PM and 7 PM. | At night the indoor temperature is in the range of 20 °C – 21 °C so thermal comfort was maintained at night. Airflow rate for Natural ventilation was in the range of 0.2 $m^3/s$ - 0.275 $m^3/s$ for Inlets and 0.13 $m^3/s$ – 0.413 $m^3/s$ while for mechanical ventilation is 0.12 $m^3/s$. In July noon the temperature is 2 °C- 4 °C more than of April noon, so using mechanical ventilation causes hourly energy consumption to be 50% more than that of April. In July, night temperature reaches 26 °C – 27 °C which is the maximum comfortable temperature | Other ventilation criteria such as airflow, wind direction can be considered in future studies. |
| [4] | Introduced an expansion in the psychrometric chart to further its scope in thermal comfort analysis<br><br>(Eric Teitelbauma, | A new contour shading method is introduced which provides a better representation of different levels of comfort condition based on parameters of air | Allows for manipulation of MRT and airspeed while checking heat balance or thermal comfort, interpretation of this chart to be done using a color gradient | Relies on abstract MRT values.<br>Skin temperature is assumed and lacks accuracy. |

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|---|---|---|---|---|
| | PrageethJayathissa, Clayton Miller , Forrest Meggers, 2019) | movement, mean radiant temperature, skin wittedness, metabolic rate, the behavior of occupants | | |
| [5] | Discussed the property of natural ventilation and their impact on energy savings on the office building in Chongqing, China<br><br>(Kechun Sun Weijun Zhang,2012) | Simulation using software DesT-c to find the change in ventilation rate with increasing natural ventilation source | In Chonqing it was found that 33% of total hours falls under human comfort temperature (18-26 C) with an increase in the number of ventilations there is an increase in the number of comfort hours notably up to 4ventilation/hour | The impact of orientation and external observation was not considered.<br>Source of ventilation not specified. |
| [6] | Determined the natural ventilation potential on the thermal comfort and acceptable indoor air quality in a gymnasium<br><br>(Zheng Cheng a, Lingling Li a , William P. Bahnfleth b, 2016) | The simulation is done using IES-VE software by varying factors of equivalent floor ratio, opening to floor ratio, and opening distribution to the standard simulation model | The combination of 80% equivalent floor ratio, 4% opening floor ratio, with added rooftop vent for opening distribution provides the best thermal comfort and IAQ in the gymnasium | Natural ventilation's impact on energy saving potential is not studied.<br>Air velocity and humidity not considered |
| [7] | Different ventilation patterns are observed to determine one that allows the highest air circulation<br><br>(TarekMeakhail, 2015) | Used CFX-Task flow software for the airflow simulations considering a small-scale building model | Full-open ventilation gave the best results in terms of air circulation and equal distribution of air in the rooms | The observation was done with a small-scale model hence results might be inaccurate |
| [8] | A regression model was developed to determine the relationship between using different ventilation controls and temperature.<br><br>(Iftikhar A. Raja. et al, 2001) | Conducted surveys on the occupant's behavior | It was found occupants who had greater access to different controls have lesser discomfort than the occupants having lesser access | Limited to occupant’s behavior only analysis cannot be applied on a larger scale |
| [9] | Explored different window designs to determine the window design in terms of orientation, window to wall ratio, and shading that facilitates maximum cross ventilation<br><br>(AbdelsalamAldawoud, 2017) | A CFD analysis with DesignBuilder software is conducted to evaluate energy and shade efficiency while ANSYS-CFX software is used to measure natural ventilation and effects of the indoor air flow in the external environment. | The best cross ventilation was observed when the inlet window was 50% and outlet window being 20% of wall area with the largest opening facing the north direction and external horizontal shading device is introduced to the southern opening | The simulation was done only for the hot humid climate so the results cannot be accepted universally. |
| [10] | A comparative study was conducted on different window types of Side hung, Sliding, Up-down folio, multi sash mid pivoted folio window | Simulation using CFD model using FLUENT 6.2 Software | Up down folio window and Mid-Pivoted multi sash window allows for better wind speed and air volume flow rates for different wind direction when compared to | Did not discuss industrial implementation of these type of windows |

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| | based on wind speed and air mass flow rate.<br><br>(Fang Ruan and Nianping Li 2016) | | the two conventional ones | |
| [11] | Determined the relation between the direction of solar radiation and the orientation check the best alternative for thermal comfort of the house<br><br>(Wanda W. Canadarma , AnikJuniwati , Luciana Kristanto, 2006) | The temperature in two houses with different orientation with the same external conditions are noted down along different seasons at different times of the day by a manual thermometer, humidity meter, or digital thermometer | As the houses' indoor temperature measured showed a significant difference it was concluded that indoor temperature in the house is influenced by building orientation to sun position. The north-oriented house was cooler compared to the east-oriented. | The traditional method was adopted so chances of human or instrumental error occurrence. |
| [12] | Study on the impact ofthe window to wall ratio (WWR), building shape, zones and, orientation,on thethermal comfort in the naturally ventilated house.<br><br>(Pathirana, S., Rodrigo, A., and Halwatura, R., 2019) | The models were developed for three building shapes and each model's orientation was simulated and analyzed for 24 orientations using Design Builder software. | The square shaped residences with the centered staircases had the maximum electricity lighting energy, while the L-shaped had the least. The WWR was said to be able to modify thermal comfort by 20–55% while lighting electricity by just 1.5–9.5%. | A detailed analysis is necessary to assess individually and collectively the importance of the building shape, zone size & location, the WWR, and the building orientation. |
| [13] | Effect of the building orientation on the overall thermal performance in Jordan.<br><br>(Albatayneh, A., Mohaidat, S., Alkhazali, A., Dalalah, Z., and Bdour, M. , 2018) | Simulation using Design builder software | In the Northern hemisphere, the long axis should face the north/south<br>and the larger windows should be located in the southern walls for best orientation. | Other building layouts/shapes were not considered. |
| [14] | Study on the thermal performance of residential buildings.<br><br>(Albatayneh, A., Alterman, D., Page, A., Moghtaderi, B. , 2018) | Data collection was done by installing more than 100 sensors that recorded data every 5 minutes of the external weather and the indoor environment using Datataker DT600. | For high wind speeds coming from East and West, the heat lost/gain has more effect on Eastern and Western walls compared to Northern and Southern walls. The annual energy requirements are found to be least when the building is oriented to the North direction followed by East, West, and then South.<br>Heat losses could be minimized in the winter months by at least three times if Window orientation is North instead of South | External shading can be considered as a future scope. The result from this module can be compared to the other three modules to assess their performance in each season. |
| [15] | Analysis of wind speed, its direction, and airflow distribution and their | Using Star CCM+, CFD simulation was done and The | A region of space located with bigger openings will provide a better air sweep | The fluctuation of wind can be taken into account in future studies. |

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| | effect on natural ventilation in and around the academic building of Spain in Valencia is examined.<br><br>(Mora-Pérez, M., Guillén-Guillamón, I., and López-Jiménez, P. A. , 2015) | Reynolds-averaged Navier-Stokes equations (or RANS equations) was used to compute the turbulent phenomena and to represent turbulence k–e model. | effect and can reduce air renovation time by 13.1% Lesser is the air renovation time better is the ventilation. | |
| [16] | A parametric window study was conductedin a Residential building<br><br>(GhadaElshafei, alazimNegmb, Mahmoud Badyc, Masaaki Suzuki, Mona G. Ibrahim, 2017) | Simulated using Design builder software where they increase the size of the windows in different rooms and additional windows were placed | An increase in average air velocity by 6 times and a decrease in temperature by 1.1 times resulted in improving the ventilation in the rooms. | Did not study the effect of the increase in window size and additional windows on the daylight performance |
| [17] | Compared the thermal comfort in two Dutch Style churches having low ventilation in Hot-humid tropical regions of Indonesia (AugiSekatia, ErniSetyowati, GagoekHardiman, 2020) | Experimental study | The church with 40cm height low ventilation has a 4% higher air velocity and a lesser indoor humidity level when compared to the church with 70cm height low ventilation. | No information given on relative humidity and outdoor Temperature as the churches analyzed were located 400km apart |
| [18] | Simulation analysis to study the effects of single-sided and cross-ventilation on the thermal comfort of a naturally ventilated hostel operational building.<br><br>(Gupta, D., and Khare, V. R., 2021) | Using CFD simulation tool *Cradle scSTREAM*. | Drop of 2.0 to 2.5°C in air temperature through night ventilation.<br><br>Cross ventilation increases the air velocity by up to 0.5 m/s | Analysis of alternative ventilation strategies, such as the modelling of the solar chimney, design of the windcatcher, and detailed analysis of various climates. |
| [19] | To compare mixed flow ventilation system and displacement ventilation system by analyzing parameters such as air temperature and velocity distribution in occupied spaces, draft effect.<br><br>(Chitaru, G., Berville, C., and Dogeanu, A. ,2018) | Heating, cooling, and humidity loads are taken using Romanian Standards. The ANSYS AIM module of Space Claim was used to prepare the virtual model.<br>A mathematical solver configuration and corresponding boundary values are entered to get the desired results. | Air velocity is in the range of 0.2 m/s to 0.25 m/s with an average temperature of approximately 22 °C in the Displacement Ventilation Case whereas<br>the air velocity ranges from 0.3 m/s to 0.35 m/s and the average temperature is around 25 o C in the mixing ventilation. | A study on different positions of inlets and their angle of introduction can be done. |
| [20] | Adaptive thermal comfort experiments | Different parameters were studied using | Higher air velocity reduces the discomfort due to | The study is limited to occupant's subjective |

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| | conducted in Mymensingh university classrooms in Bangladesh's hot and humid climate. (**Md. SarwarJahanTalukdar et al. 2020**) | instruments, Presto Hygro-Thermometer, and the Hold peak HP-866B. Thermal comfort survey based on occupants' votes. | humidity A drier environment is preferred by the students in the hot, humid summer season. | thermal comfort. Results are from one season an adaptive comfort model cannot be developed as it would require data for all seasons. |
| [21] | Study on the effect on air velocity, Humidity, and Air temperature due to single-sided and cross-ventilation method. (Omrani, S., Garcia-Hansen, V., Capra, B. R., and Drogemuller, R., 2017) | Using a 3D ultrasonic anemometer, two air velocity transducers, three 2D ultrasonic wind sensors, six thermometers, and one hygrometer air velocity, temperature, and relative humidity were analyzed. | 70% of the time within the comfort zone and 3 °C cooler in Cross ventilation than Single-sided ventilation | Measurements at different heights were not taken into account. Future scope in conduction of experiment at a different location. |
| [22] | A detailed review on the various wind-driven ventilation techniques with their properties, operation, and low rates (Naghman Khan, Yuehong Su, Saffa B. Riffat, 2008) | Research and study on existing knowledge | The systematic comparison is made among all the techniques based on their features, flow rates, and applications for easier understanding | Cost-based comparison is not done to determine the economically beneficial technique. |
| [23] | A review study to assess natural ventilation capabilities in order to provide resilience to thermal comfort from heat waves in warm climates and for high indoor air quality. (Ahmed, T., Kumar, P., and Mottet, L. , 2021) | Collection and analysis of existing literature. | Solar chimneys and wind catchers can offer around an 8 ◦C difference in temperature than outdoor temperatures in warm weather (>35 ◦C). | No study has been done to test these systems in an environment where the surrounding obstacles have an immediate effect on their functioning and also for future climate scenarios. |
| [24] | A review study of natural and hybrid ventilation inside a building. (Li, Y., and Heiselberg, P. , 2003) | Collection and analysis of existing literature. | CFD has the capacity to estimate detailed flows in every room or area of a complex building. Multi-zone models can be used to model entire building performance. | Further developments of multi-zone methods and enhancement of the loop equation method |

**Key findings from the literature review-**

- The larger the size of the inlet the better is the amount of airflow.
- The ventilation is increased when the inlet is on the windward side.
- Airflow
  - < 0.5 m/s- Goes unnoticed or feels pleasant
  - 0.25 m/s- 1 m/s -Adequate
  - 0.25 m/s-1 m/s-Recommended

- Temperature effects due to air velocities ranging 0.3-0.65 m/s were very small.
- The use of Night ventilation showed a drop in temperature of 2-2,5 °C.

- Up-Down folio window and Mid-Pivoted Multi-sash wind give better air velocity and air mass flow rate.
- The sliding window had the least flow of air inside the room i.e. had the least air-circulation in the room.
- The addition of a window has the potential of increasing the air velocity by 6 times and also the temperature decrease by 1.72%.

- The usage of air conditioning can be expected to be 70% less in Cross-Ventilation.
- In comparison with single-sided ventilation, there is an approximately 3°C potential cooling effect in the application of cross-ventilation.
- The use of windows & doors for Cross-Ventilation has the potential to decrease the room temperature by 1.5 °C.
- Cross ventilation can enhance air velocity upto 0.5 m/s.

- Internal airflow direction is mostly affected by the ventilation mode than the wind direction.

- While choosing WWR, Thermal comfort should be given more attention than the amount of illuminance it can provide.

- About 105% of the annual building energy can be saved by optimum orientation.
- The size of ventilation is inversely proportional to indoor temperature.

## V. RESULTS AND DISCUSSIONS

Most of the major parameters that affect the heat and ventilation of the building cannot be assigned a fixed value that is ideal for thermal comfort. They differ from place and place, for different seasons and sometimes also for different times of the day. Let us consider them one by one.

Window design and its orientation play a significant role in determining the airflow through the building. In cross ventilation when a larger opening faces north, it facilitates maximum airflow in the hot tropical region of Dubai (**Abdelsalam et al.,2015**). In the northern hemisphere, however, the largest window to the southern walls brings maximum heat into the building **(Aiman et al., 2018**). A case study in Australia showed that heat losses could be minimized about 3 times in the winter months if the window is orientated to the north instead of the south **(Aiman et al., 2018).** A CFD analysis carried out in an academic building in Spain showed a building with south and west opening inlet and north opening outlet is more efficient as it provides better performance and needs 13.1% less time to renovate air (**Miguel et al., 2015**). From these facts, it can be concluded that optimum window orientation depends on the location as the wind direction might vary immensely in different parts of the world. Hence it is improbable to determine the best orientation for the window if there is no knowledge of the location of the building.

The W**i**ndow-to-wall ratio is another determinant factor for thermal comfort. For inlet window with 50% and outlet with 30% gives the maximum cross ventilation (**Abdelsalam et al.,2015**). The highest thermal comfort is provided by the rectangular-shaped building with a staircase positioned in the middle of the house with a WWR of 20. WWR can change thermal comfort by 20-30% **(Shakila et al.,2020**). This ratio has a huge contribution to thermal comfort as it determines the amount of airflow into and outside the building. It can be generally assumed thatthe bigger the inlet better the airflow. However, it is also required to keep in mind that it should be reasonably big, or else it might lead to problems such as excessive heat and glare.A study in Jordon showed orientation of a building where long axis facing north/south which allows entry of winter sun's radiation is considered best orientation. It also facilitates reducing heat energy by 35%**.** Annual energy consumption is least when the building is oriented to the North direction followed by East, West, and then South **(Aiman et al.,2018).** North facing house with the typical design was cooler compared to the east oriented one when compared in Surabaya, Indonesia (**Wanda et al., 2006).** TheNorth orientation of the building is generally considered ideal. However, this might vary depending on factors like surrounding buildings or other external obstructions. It can be noted that building orientation to the sun position influences the indoor temperature majorly.

As for air velocity and temperature a study in Jaipur, India showed that cross ventilation application can increase the air velocity by 0.5m/s and night ventilation can lead to a drop of 2-2.5°C in temperature **(Durva,Vaibhavi, 2020)**. Chongqing, China showed night ventilation contributes to energy savings as it lowers the indoor temperature during the daytime thus decreasing the air conditioning usage. Up to 4 ventilations/hour at night results in a significant reduction in energy consumption while 5 or more shows a limited reduction **(Kechun et. El, 2012).** Night ventilation is one of the effective energy-saving strategies that can be adopted more widely.When comparing types of natural ventilation, it was found double ventilation provides 70% of thermal comfort hours while single-sided ventilation provided about 1% and single-sided exhibits 3-degree Celsius higher temperature in the building compared to cross-ventilation (**Sara et al).** There is a clear pattern that determines cross or double ventilation facilitates better ventilation in and out of the building when compared with single-sided ventilation. Hence it is widely adopted to achieve better thermal comfort and indoor air quality.

As for the approaches of analysis of heat and ventilation of a building, through the years different ones have been adopted and evolved. The earliest method adopted was the experimental method using instruments such as manual thermometer, humidity meter, or digital thermometer. (Wanda et al., 2006). This method is not preferred anymore as there is a major risk of human or instrumental error which might result in inaccurate results. Another commonly adopted method is the PMV/PPV method which involves taking the votes from the occupants of the building being analyzed, to get their opinion on thermal comfort in a given situation. This method is not considered very reliable as the result highly depends on the individual's opinion which could be subjective. Hence, it is not ideal to apply on large scale. The most advanced and highly adopted method in recent years is simulation analysis. To carry out HV analysis a CFD analysis is done with the help of different soft wares. Some of the soft wares used in the reviewed papers are **ANSYS AIM, Cradle scSTREAM, Star CCM+, DesignBuilder, FLUENT 6.2 Software**. This allows for many parameter inputs which can be entered in different combination to optimize the heat and ventilation of a building. It is also cost-effective and less time-consuming. There is lesser room for error here. Hence simulation method is a highly favored method for analyzing heat and ventilation of the building.

## VI. CONCLUSIONS

An intensive review of the literature contributed to furnish the importance of natural ventilation and different techniques that needs more attention while designing the envelope of the building.

A review of multiple studies based on Single-sided and Cross-ventilation methods has helped in deducing that selection of either can have a significant difference in the amount of airflow and the indoor room temperature which signifies the importance of the use of cross-ventilation over single-sided ventilation i.e., approximately 3-degree Celsius potential cooling effect and an increase air velocity by 0.5m/s.

Building's orientation affects the heat level as it determines the amount of sunlight and wind coming towards and away from the building which in turn affects the building's energy load.
For Northern Hemisphere

- North facing windows provide less daylight and are cooler compared to East orientation.
- East facing units reduce lighting energy consumption.
- South oriented units provide sufficient daylight with optimum effect on overall building energy.
- In a cooler climate, the larger windows should be in the southern walls.

For Southern Hemisphere

- North facing side receives the most daylight followed by East, West and South.
- Likewise, East and West face lose more heat than they gain in winter and gain excess heat during summer.

On choosing optimum WWR the effect on thermal comfort is given more preference than on the amount of illuminance it can provide through daylight. Decreasing WWR decreases the cooling load, provides higher thermal comfort. WWR can have an effect of 20-55% on the thermal comfort level of the building.

From the review, it is observed that different modern techniques such as wind catchers, wing jetter systems, turbine ventilators, etc. other than the traditional ones are being used for providing superior ventilation inside the buildings. But due to lack of awareness, implementation of these techniques is less observed even though there exists a huge potential in providing a relatively better amount of airflow and can also be used to minimize the building's energy load.

It is observed that the combined effect of orientation with other parameters affecting the thermal comfort and ventilation was not carried out in the studies conducted which could provide more useful results. The ventilation of a building can be affected by the presence of some external obstructions. More studies must thus be undertaken to investigate the degree of its impact. Studies based on different seasons and the effect of wind direction on a certain orientation could help in deciding the optimum building's orientation for proper ventilation inside the living spaces.

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