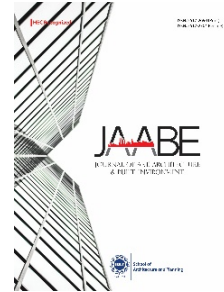
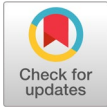



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# Ventilation System: A Tool for Energy Conservation in the Homes of Hyderabad, Pakistan

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## Abstract

Ventilation in buildings is very important for many reasons including human comfort, energy conservation, thermal comfort, indoor ventilation, and environmental hazards. Energy consumption is projected to grow by 3.7% by 2030, according to the National Energy Plan 2030. So, it has become imperative to understand the architectural variables that influence buildings' energy consumption and contribute to the reduction of the expected energy demand. Mostly due to rapid population growth, people have started moving to cities, resulting in the existing residential buildings to become congested. Wind catchers, courtyards, windows, atriums, and ducts are sources of natural ventilation. However, since people purchase already furnished homes, so they sometimes don't bother to have those features in their homes. The reason can be cost saving by builders, land costs, and use of artificial ventilation. Historically, the city of Hyderabad in Pakistan is known as the city of oriels, wind catchers, and old buildings with courtyards, although it does not look the same all over. This study focuses on natural ventilation to conserve energy and encourage the concept of a friendly indoor environment. Most of the ventilation features in general and in the homes of Hyderabad are discussed briefly with the help of a questionnaire survey, case studies, and unstructured interviews.

**Keywords:** cross-ventilation, energy conservation, Hyderabad, natural ventilation, thermal comfort

## Introduction

Ventilation is the vital presence of surrounding air in a confined space. and is, for the most part, used to control indoor air quality and dislodge indoor contaminations, although it can be utilized for Causes of moisture or dehumidification. Characteristic ventilation is the deliberately detached

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stream of sub-ethereal air working through arranged openings, for example, doors, windows, ventilators, wind catchers, channels, and courtyards. Common ventilation does not require a mechanical framework to move sub-flying air; it depends completely on uninvolved physical phenomena (Spentzou et al., [2013](#)).

Houses need to relax. They should attract natural air and remove stale air. Specialists prescribe that one portion of a home's air volume ought to be traded each hour. Ventilation becomes possible by opening the entryways and windows. In any case, the required ventilation should be provided without any mechanical framework. Satisfactory ventilation is essential since it ensures both the well-being of people and homes. It is expected to accomplish great indoor air quality (IAQ) May lead to loss of vitality in building (Cho et al., [2015](#)). Half and half or hybrid ventilation frameworks that utilize both characteristic ventilation and a mechanical framework, while changing the utilization of each framework as indicated by the season of the day or the period of the year, have drawn overall consideration (Heiselberg, [2002](#)).

The facade is the building component that provides the main thermal barrier through its design. It is the most vital factor for the assurance of warm solace, daylighting, and ventilation, as well as the measure of power required for the warming and cooling of the building. Window openings are crucial parameters to examine the adequacy of wind-driven cross-ventilation in homes. Therefore, natural ventilation can save the energy consumed by heating, mechanical ventilation, and air conditioning systems in a building if it provides acceptable indoor air quality and thermal comfort levels (Driss et al., [2015](#)). Ventilation altogether generates quite a few vital human reactions. Low ventilation rates may bring about expanded convergence of indoor created toxins, which might be related to debilitated building disorder side effects, comfort (saw air quality), wellbeing impacts (irritation, diseases, asthma, hypersensitivity), and efficiency. Accordingly, ventilation prerequisites attract significant consideration in building controls. Ventilation standards tend to cluster around typical values for recommended ventilation rates, and rates higher than  $0.3 \text{ h}^{-1}$  have been adopted in several countries. By and by, ventilation is frequently poor, which brings about high centralizations of toxins, thus imposing dangers to wellbeing (Dimitroulopoulou, [2012](#)). Thus, research on air flow remains vital due to the fact that an excellent air flow implies better productivity and

health of the occupants of buildings and also promotes energy efficiency.

### **Environmental Impacts, Materials, and Strategies for Ventilation**

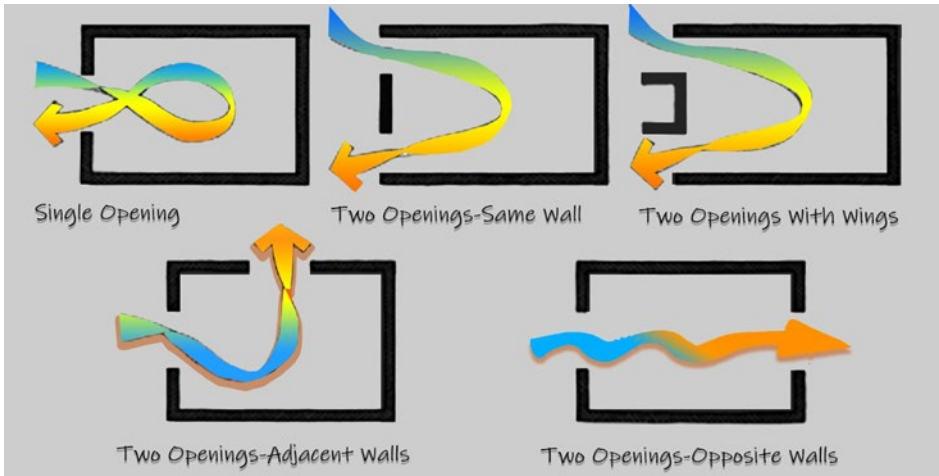
The inclusion of natural ventilation in houses can be achieved by using the following sources:

- a) **Windows/Doors/Ventilator/Oriels/Ducts:** The solutions for effective wind-driven ventilation design include proper building orientation and massing, as well as the appropriate sizing and placement of openings according to atmospheric conditions. With the specific end goal to boost wind ventilation, the weight distinction between the windward (channel) and leeward (outlet) needs to be augmented. In all cases, high pressure occurs on the windward side of a building, while low pressure occurs on the leeward side. (Philokyprou & Michael, [2016](#)).
- b) **Window/Opening Type:** Openings don't have to be confined to windows. There might also be doors, louvers, or ventilation grills and ducts. The choice of openings needs to consider the room and how it would be used, as well as privacy and natural lighting requirements. Not all types of openings are equal when it comes to ventilation.
- c) **Cross-ventilation:** While providing ventilation openings, channels and shops improve the way air finishes the building. Windows or vents placed on opposite sides of a building allow natural breezes to pass through the structure. Cross ventilation is generally the most effective form of wind-driven ventilation.

It is paramount not to put openings precisely opposite each other in space. While this gives powerful and operative ventilation, it can make a few sections of the room cooled and ventilated at the expense of others. Placing openings opposite, but not exactly aligned with, each other promotes air circulation within the building, improving the distribution of fresh and outdoor air.

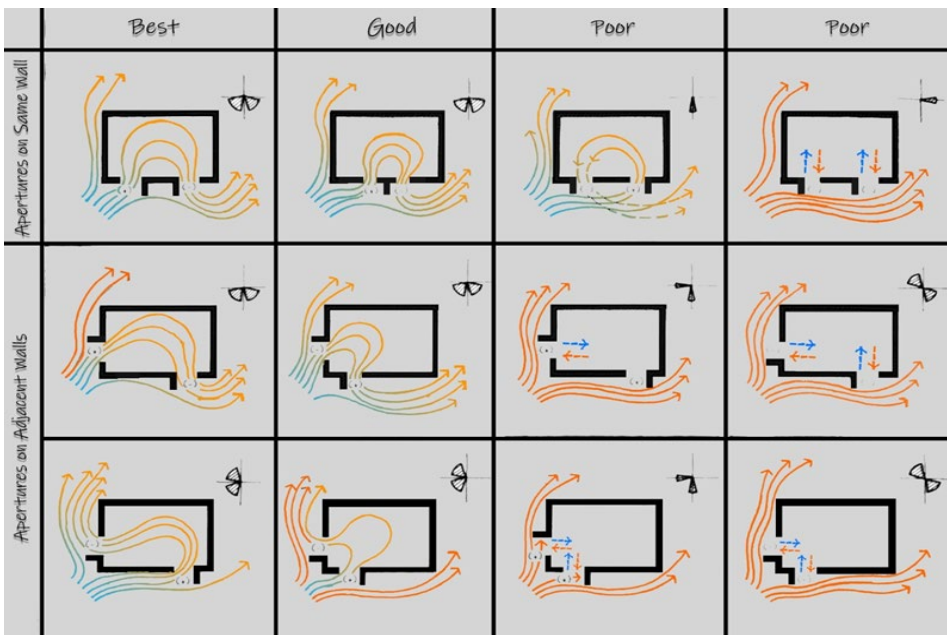
- d) **Wing Walls:** Wing walls extend outward alongside a window so that even a gentle breeze against the wall creates a high-pressure zone on one side and a low-pressure zone on the other. The resulting pressure difference drives outdoor air in through one open window and out through the adjacent one. Wing walls are particularly effective in locations with low outdoor wind speed and variable wind direction.

**Figure 1**  
*Cross-ventilation*



Source: (Brown et al., [2001](#))

**Figure 2**  
*Different Wing Walls with Better and Worse Effectiveness, on the Same Wall and Adjacent Walls*



Source: (Brown et al., [2001](#)).

- e) **Wind Catchers:** The wind catcher is an energy free natural ventilation system that combines the benefits of both top-down and isolated stack ventilation. The system consists of four external louver banks, which prevent the entry of rain and are protected internally by a tri-layer weather barrier. The simple yet effective design of the system provides outdoor air during the day as well as nighttime cooling. Due to the adaptability of the breeze catcher, the framework can be custom fitted to suit the necessities of any region (Spentzou et al., [2013](#)).
- f) **Courtyards:** Courtyards, in general, form a fundamental element of the Architectural language throughout the history of many regions. The patio, particularly the focal yard, is one of the bland methodologies accessible to designers and architects to give more vitality to proficient and naturally appropriate structures. The inner patio boosts the collaboration between the building and the open-air condition, bringing the outside environment into the core of the building (Givoni, [1969](#)).

### **Energy and Environment Performance of Ventilation**

Since energy consumption has become a serious concern these days, research on the concept of energy efficiency has gained significant traction (Givoni, [1969](#)). Residential and commercial buildings are designed mostly to use artificial means of lighting, which results in excessive utilization of energy and also has an impact on the heating and cooling loads requirements of respective buildings. Approximately, 25-40% of total energy is utilized in artificial lighting (Krarti, [2020](#)). Literature reveals substantial opportunities for efficiency gains in buildings by incorporating ventilation into buildings as a daylight-enhancing model or technique. The minimization of space for conditioning (heating or cooling) and lighting loads can also be achieved. To address these issues, all the necessary aspects of ventilation (orientation, size, shape, proportion, height, glazing, shading, ratio and thermal mass of walls) need to be designed properly (Aldawoud, [2008](#)).

### **Natural Ventilation Strategies**

Natural ventilation strategies are essential to architectural design, particularly to enhance thermal comfort and indoor air quality. These design methods utilize the nature of air movement to create the desired effects. However, the successful use of natural ventilation in a structure depends upon various design variables such as window-to-wall ratio, orientation, as

well as the design of operable openings. Research shows that the traditional form of a structure like the Penang Malay house in Penang Malaysia is the most effective combination of design principles for improving the quality of the internal air through reduced temperature and humidity within the structure, as opposed to the external environment (Hassan & Ramli, [2010](#)).

Vernacular architecture has been adapted to each local climate and manages temperature and humidity with natural ventilation to maintain comfort without artificial systems. This has been demonstrated in works such as those by (Heidari et al., [2017](#)). There are, however, further challenges in how these traditional methods can be integrated into modern architecture, with more extensive studies required across varied urban settings, as identified by Ramezani and Reza ([2022](#)), and Thravalou et al. ([2023](#)).

Though extensive work has been carried out in the area of vernacular architecture, there is a lack of relevant studies regarding the traditional architectural measures of the Javanese that contribute towards natural ventilation in rural and urban areas. There is an obvious lack of understanding regarding the adaptation of the traditional Javanese vernacular architecture towards a variety of environments. Thus, this problem needs further investigation. This particular study fulfils this need as it deals specifically with Javanese vernacular architecture that has been represented inadequately in previous scientific work.

### **Hyderabad as the “Wind City”**

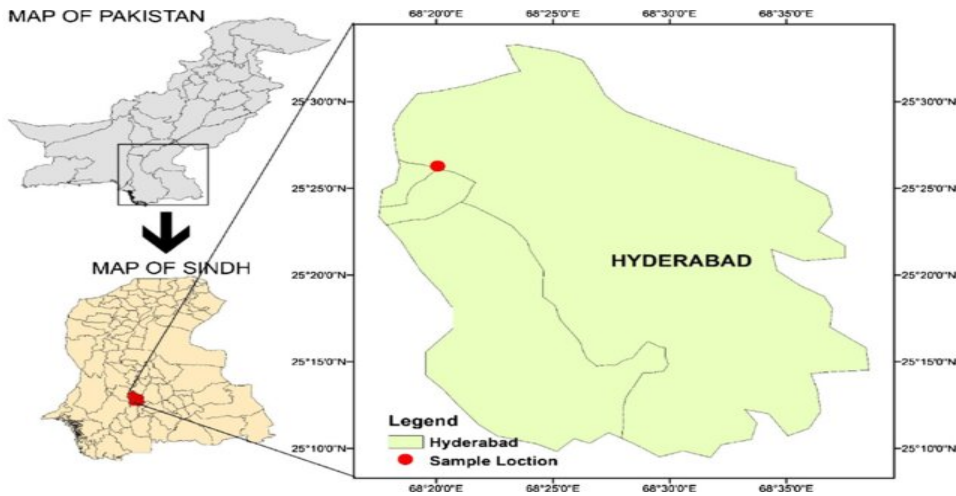
Hyderabad, a city in the Sindh province of Pakistan, is one of the oldest planned urban centers in South Asia. It was established by Mian Ghulam Shah Kalhoro in 1768, when he moved the capital from Khudabad to Hyderabad because of its strategic location on a hill made of limestone close to River Indus. The city was later to become one of the prominent political, social, and commercial hubs of Sindh under the rule of the Talpur Mirs.

Hyderabad is locally referred to as the “Wind City” due to its consistent and strong natural airflow, particularly during the summer months. Its elevated terrain and proximity to the Indus River corridor create pressure differentials that promote continuous cross-ventilation across the urban fabric (Givoni, [1998](#); Koenigshberger et al., [2010](#)). Historically, this natural wind flow was intentionally harnessed in traditional architecture through high ceilings and thick masonry walls, multiple openings such as jharokas

and ventilators, internal courtyards (angan) facilitating stack ventilation, and street alignments oriented to channel prevailing winds (Fathy, 1985). These passive design strategies significantly reduced indoor temperatures and enhanced thermal comfort long before the advent of mechanical cooling systems, demonstrating a climate-responsive approach to urban and architectural design (Olgay, 2015).

### Figure 3

*Location Map of Hyderabad, Sindh, Pakistan (Study Area)*



*Note.* Figure modified from geographical maps of Hyderabad district by ResearchGate in the year 2025.

The combination that makes Hyderabad a suitable subject for the current study includes its architectural and climatic conditions, as well as the impact that the changing demands of urbanization, specifically the shift from a traditional ventilation approach to a mechanically dominated approach, enforce.

## Methodology

This research used the mixed method approach to investigate natural ventilation, an effective means of energy conservation in the residential structures of Hyderabad, Pakistan. For this purpose, the methodology was directed to incorporate theoretical concepts with empirical research in order to formulate an overall analysis of ventilation practices, perceptions, and energy savings. This research initially commenced with an in-depth analysis

of the literature encompassing the national and global aspects of natural ventilation, indoor air quality, thermal comfort, and energy saving within residential buildings. Peer-reviewed journals, textbooks, and research reports were scrutinized to gather information about the significant architectural parameters that influence natural ventilation, such as orientation, facade designs, scale, positioning, courtyard designs, wind towers, and ducts (Givoni, [1992](#); Heiselberg, [2002](#); Spentzou, [2013](#)).

This literature provided an analytical framework for the research which, in turn, assisted in the selection of parameters in the context of Hyderabad. Additionally, unstructured interviews were held with professionals in the area of architecture, designing, and environmental studies to incorporate the analysis into the literature for contextuality. The discussion offered valuable technical knowledge about the current residential structures being designed, reduced application of passive designs, and the significant shift to the usage of mechanical designs for ventilation. Expert feedback also helped to identify additional socioeconomic and regulatory factors influencing ventilation design that were not sufficiently addressed in previous studies (Cho et al., [2015](#)). The qualitative information obtained through interviews was used to refine the research variables and improve the relevance of the survey instrument.

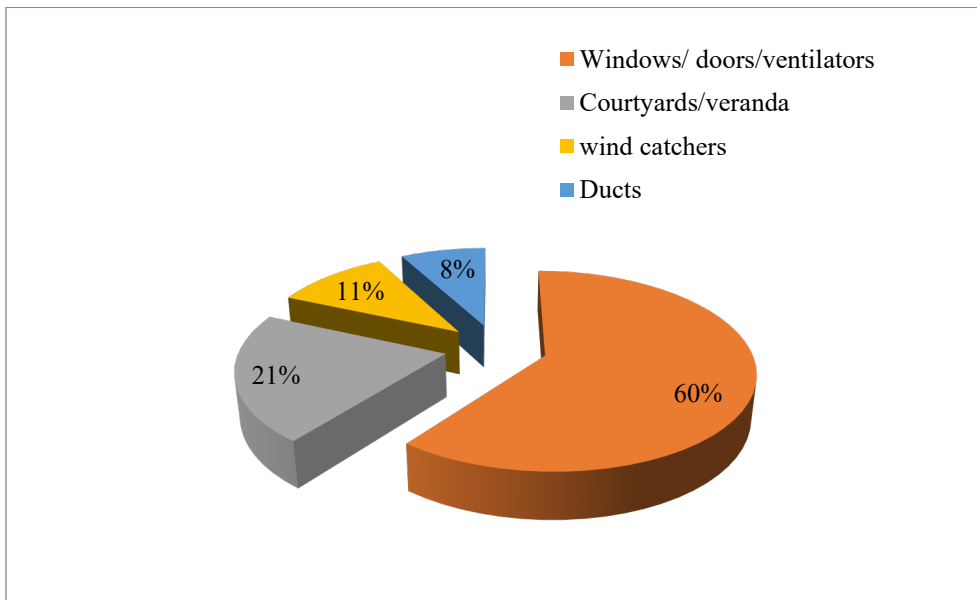
A structured questionnaire was prepared based on the collective insights generated through literature review and expert consultations for collecting primary information from the residents of Hyderabad. The questionnaire emphasized the existence of natural ventilation elements in residential structures, their health and comfort advantages, energy conserving capabilities, and factors responsible for ignoring natural ventilation in modern residential structures. Online and hard copies of the questionnaire were dispatched for information gathering in order to encourage more people from diverse residential structures, including lower and taller buildings, unanimously without any restriction or obligation. All the respondents were allowed freedom to participate in the questionnaire survey without revealing their identities throughout the information collection process. The final information was analyzed through quantitative methods, that is, through percentage analysis and ranking, to assess the significance of diverse ventilation elements. Statistical analysis was done using the Statistical Package for Social Sciences (SPSS). The results were organized and presented in tabular and graphical formats using Microsoft Excel. The

integration of literature review, expert interviews, and questionnaire-based survey enabled data triangulation, thereby enhancing the validity and reliability of the findings (Creswell & Creswell, [2017](#); Dimitroulopoulou, [2012](#)).

## Results

Several features that contribute to the reduction in energy use and pollution were analyzed in terms of percentages and rank techniques using the SPSS software. The analyzed data is presented below using tables made in MS Excel software.

**Figure 4**  
*Energy Saving Features*

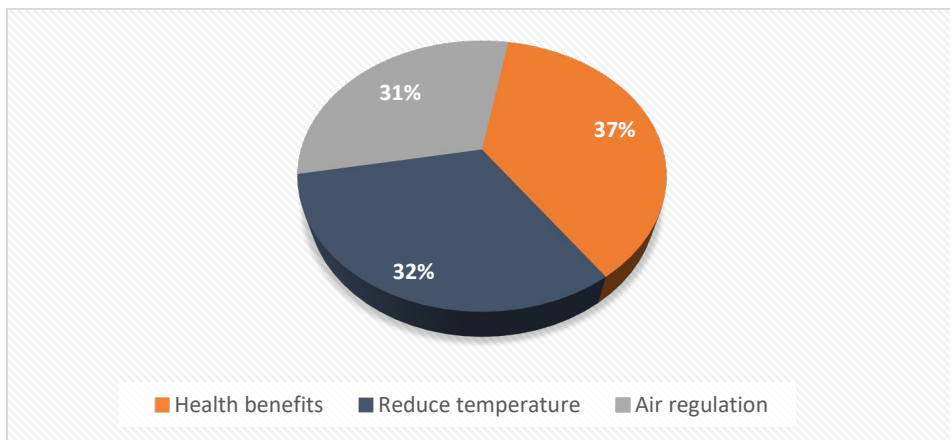


**Table 1**  
*Energy Saving Features*

Energy Saving Features	Score	Rank
Windows/ doors/ventilators	60.53%	1
Courtyards/veranda	21.05%	2
wind catchers	10.53%	3
Ducts	7.89%	4

Table 1 shows the findings concerning the energy saving characteristics. The questionnaire included items regarding energy saving features, for instance, windows, doors, ventilators, courtyards, and ducts. The respondents were asked to rank the feature they think is the most important and effectively used in their respective homes. A rating scale was applied, ranging from 1 to 4. With a maximum percentage of 60.53%, windows, doors, and ventilators were ranked as the most important features by the respondents to conserve energy in households in Hyderabad. Courtyard and verandah were counted as the second most important features (21.05%) to conserve energy. The third-ranked feature was the wind catcher (10.53%). The fourth-ranked feature was ducts (7.89%). Mostly, this feature is present in high-rise buildings to maintain ventilation and light.

**Figure 5**  
*Benefits of Ventilation*



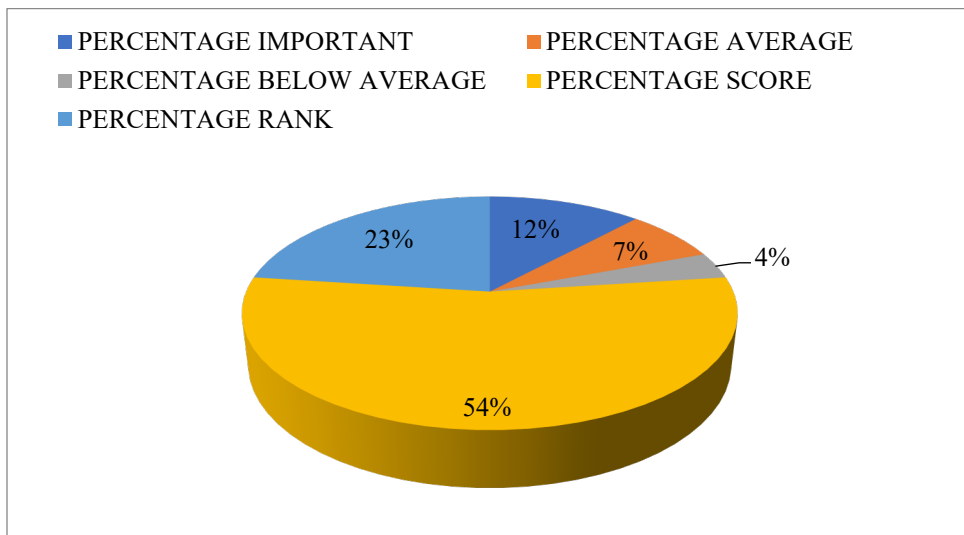
**Table 2**  
*Benefits of Ventilation*

Benefits of Ventilation	Percentage			Score	Rank
	Important	Average	Below Average		
Health benefits	39.29%	35.71%	25.00%	2.14	1
Reduce temperature	33.33%	27.78%	38.89%	1.97	2
Air regulation	32.14%	28.57%	39.29%	1.97	2

The benefits of home ventilation, which significantly contribute to energy conservation, are countless. A survey was carried out based on the questionnaire regarding the advantages of natural ventilation of homes which received an excellent response from the public. The top benefit was related to health with a score of 2.14. Suffocation is reduced by natural ventilation which improves the health. In the second position with a score of 1.97, ventilation reduces temperature and improves air regulation by the respondents.

**Figure 6**

*Reasons for the Absence of Ventilation in Modern Buildings*



**Table 3**

*Reasons for Not Having Ventilation in Modern Buildings*

Reasons for Not Having Ventilation in Modern Buildings	Percentage			Score	Rank
	Important	Average	Below Average		
Construction of vertical buildings	52.00%	32.00%	16.00%	2.36	1
Modern living style	27.27%	31.82%	40.91%	1.86	3
Artificial means of ventilation	35.71%	21.43%	42.86%	1.93	2

The reasons for the lack of natural ventilation in houses were ranked on a scale, with 1 indicating the most important reason and 3 representing a below average reason for not having natural ventilation in the houses. As land cost is increasing day by day, so vertical construction of buildings has increased with a score of 2.36, it holds the highest rank. The second main reason for not having natural ventilation is that artificial means of ventilation are used in homes with a score of 1.93. The third main reason is the rapid increase in the cost of construction with the score of 1.86.

### Discussion

The results proved natural ventilation to be an extremely effective and accepted technique for energy saving in residential buildings in Hyderabad, Pakistan. Among the vast number of ventilation techniques, windows, doors, and ventilators stood out to be the most significant for energy saving, thus highlighting their effectiveness, adaptability, and applicability for residential buildings. The application of courtyards and verandahs, being an old practice for residential buildings, took the next position, thus marking their reduced application in residential buildings in the current scenario, owing to land constraints along with vertical expansion. Wind catchers and ducts stood at a relatively lower position, thus marking the absence of awareness, adaptability, or applicability of these techniques in residential buildings. The findings also showed that the key significance of natural ventilation is related to health enhancement, thereby indicating that the respondents understood the significance of adequate ventilation and its role in preventing suffocation and improving indoor air quality. The significance of room temperature reduction, as one of the most important advantages, is augmented by the significance of ventilation in lessening reliance on cooling systems in order to cool homes. Moreover, this study establishes vertical building type as the primary cause of inadequate natural ventilation, followed by reliance on artificial ventilation systems and adoption of modern lifestyle patterns.

The outcomes reveal that the factors surrounding natural ventilation play an important role in energy saving and indoor environments in residential structures in the city of Hyderabad, Pakistan. The dominance of windows, doors, and ventilators regarding energy saving reflects the use of conventional and convenient opening systems found in earlier studies, including their effectiveness in wind-driven ventilation and indoor environments (Brown et al., [2001](#); Givoni, [1969](#)). The dominance of

courtyards and verandahs in earlier and more traditional residential buildings in the city, though ranking second, reveals their diminished usage in modern residential settings owing to space considerations. The low ranking of wind catchers and ducts indicates less usage of conventional design-oriented ventilation systems, especially in high-rise structures. The reinforcing aspect of health is the most important element in ventilation which supports the established relationship between sufficient ventilation, indoor air pollution, and occupant health conditions (Dimitroulopoulou, [2012](#)). Moreover, the importance and dominance of vertical building structures and artificial systems in ventilation act as important factors and barriers which identify the influence of urbanization and modern life conditions that undermine the passive systems.

### **Recommendations**

Based on the observations made in this research, it is advisable to use natural ventilation methods in the initial design phase of residential structures with the aim of maximizing energy efficiency and environments. While designing residential buildings, architects and planners should emphasize the strategic location and dimensioning of windows, doors, and ventilators to ensure effective cross-ventilation, even while designing compact and vertically built residential structures. Common passive design techniques including courtyards, verandahs, and wind catchers can be reinvented according to new residential designs to reduce the space constraints. Construction rules and development control norms should emphasize and propagate the necessity for minimum ventilation standards and passive designs in order to limit the overreliance on mechanical ventilation systems. Also, the conceptualization of awareness initiatives is imperative to educate residents and housing developers about the advantages of health and energy efficiency due to natural ventilation techniques. Future research should focus on developing innovative ventilation solutions for high-rise residential buildings that combine traditional principles with modern construction technologies.

### **Conclusion**

This study explored the role of natural ventilation as an important and sustainable means of energy conservation in residential structures in the city of Hyderabad, which has historically been the result of appropriate climate-responsive architecture. The discussion underlines the importance of proper

ventilation which, aside from enhancing the quality of air and reducing the indoor temperature, has the ability to reduce the use of energy-driven air-conditioning units. The analysis established the fact that windows, doors, and ventilators, which constitute the conventional means of ventilation, still remain the most effective and commonly used means of conserving energy. While, the use of courtyard and wind tower, which until recently were an important part of the architecture of the city of Hyderabad, has been progressively decreasing as the area becomes more urbanized. The analysis established the fact that health factors continue to remain the “most important benefit of natural ventilation” and play a significant role in developing healthy interiors. On the other hand, the growing application of artificial ventilation systems indicates an accelerated need to disregard climate-responsive architecture, thereby implying the danger of unsustainability in terms of energy. To conclude, it is asserted that the need for the reintegration of the traditional means of ventilation in the present residential architecture to achieve energy efficiency, comfort, and sustainability, as well as adapting traditional passive strategies to modern housing typologies, can play a decisive role in addressing current and future energy challenges in rapidly urbanizing cities such as Hyderabad.

#### **Author Contribution**

**Sabeen:** Conceptualization, Methodology, Writing – original draft, methodology, data analysis. **Hina Marvi:** writing-review & editing. **Sania Rehman Memon:** writing-review & editing. **Ira Kazi:** writing-review & editing. **Mehwish Soomro:** writing-review & editing.

#### **Conflict of Interest**

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

#### **Data Availability Statement**

Data supporting the findings of this study will be made available by the corresponding author upon request.

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The authors did not use any type of generative artificial intelligence software for this research.

## **References**

Aldawoud, A. (2008). Thermal performance of courtyard buildings. *Energy and Buildings*, 40(5), 906–910.

<https://doi.org/10.1016/j.enbuild.2007.07.007>

- Brown, G. Z., DeKay, M., & Sun, W. (2001). *Light: Architectural design strategies*. Wiley & Sons.
- Cho, W., Song, D., Hwang, S., & Yun, S. (2015). Energy-efficient ventilation with air-cleaning mode and demand control in a multi-residential building. *Energy and Buildings*, 90, 6–14. <https://doi.org/10.1016/j.enbuild.2015.01.002>
- Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications.
- DeKay, M., & Brown, G. Z. (2013). *Sun, wind, and light: Architectural design strategies*. Wiley & Sons.
- Dimitroulopoulou, C. (2012). Ventilation in European dwellings: A review. *Building and Environment*, 47, 109–125. <https://doi.org/10.1016/j.buildenv.2011.07.016>
- Driss, S., Driss, Z., & Kammoun, I. K. (2015). Numerical simulation and wind tunnel experiments on wind-induced natural ventilation in isolated building with patio. *Energy*, 90, 917–925. <https://doi.org/10.1016/j.energy.2015.07.128>
- Eiraji, J., & Namdar, S. A. (2011). Sustainable systems in Iranian traditional architecture. *Procedia Engineering*, 21, 553–559. <https://doi.org/10.1016/j.proeng.2011.11.2050>
- Fathy, H. (1985). *Natural energy and vernacular architecture: Principles and examples with reference to hot arid climates*. University of Chicago Press.
- Givoni, B. (1969). *Man, climate and architecture*. Elsevier.
- Givoni, B. (1992). Comfort, climate analysis and building design guidelines. *Energy and Buildings*, 18(1), 11–23. [https://doi.org/10.1016/0378-7788\(92\)90047-K](https://doi.org/10.1016/0378-7788(92)90047-K)
- Givoni, B. (1998). *Climate considerations in building and urban design*. John Wiley & Sons.
- Hassan, A. S. (2004). *Issues in sustainable development of architecture in Malaysia*. Penerbit Universiti Sains Malaysia.

- Hassan, A. S., & Ramli, M. (2010). Natural ventilation of indoor air temperature: A case study of the traditional Malay house in Penang. *American Journal of Engineering and Applied Sciences*, 3(3), 521–528. <https://doi.org/10.3844/ajeassp.2010.521.528>
- Heidari, A., Sahebzadeh, S., & Dalvand, Z. (2017). Natural ventilation in vernacular architecture of Sistan, Iran: Classification and CFD study of compound rooms. *Sustainability*, 9(6), Article e1048. <https://doi.org/10.3390/su9061048>
- Heiselberg, P. (2002). *Principles of hybrid ventilation*. Aalborg University. [https://iea-ebc.org/Data/publications/EBC\\_Annex\\_35\\_Principles\\_of\\_H\\_V.pdf](https://iea-ebc.org/Data/publications/EBC_Annex_35_Principles_of_H_V.pdf)
- Koenigsberger, O. H., Ingersoll, T. G., Mayhew, A., & Szokolay, S. V. (2010). *Manual of tropical housing and building: Climatic design*. Universities Press.
- Krarti, M. (2020). *Energy audit of building systems: An engineering approach*. CRC Press.
- Muhaisen, A. S., & Gadi, M. B. (2005). Mathematical model for calculating the shaded and sunlit areas in a circular courtyard geometry. *Building and Environment*, 40(12), 1619–1625. <https://doi.org/10.1016/j.buildenv.2004.12.018>
- Muqoffa, M., Suyitno, Yaningsih, I., Rachmanto, R. A., Himawan, K., Caroko, N., & Basuki. (2025). Exploring natural ventilation strategies in Javanese vernacular houses for sustainable design. *Journal of Asian Architecture and Building Engineering*, 24(6), 4985–5004. <https://doi.org/10.1080/13467581.2024.2439348>
- Olgay, V. (2015). *Design with climate: Bioclimatic approach to architectural regionalism*. Princeton University Press.
- Oliver, P. (2007). *Built to meet needs: Cultural issues in vernacular architecture*. Routledge.
- Philokyrou, M., & Michael, A. (2016). Social and environmental aspects of courtyards in Cyprus vernacular architecture. *Serbian Architectural Journal*, 8(1), 75–90. <https://doi.org/10.5937/SAJ1601075P>
- Ramezani, H., & Reza, E. (2022). The consequence of combining indigenous techniques with flexible design to reduce energy

consumption in residential buildings for future architecture. *Sustainability*, 14(21), Article e13958. <https://doi.org/10.3390/su142113958>

Spentzou, E., Cook, M., & Emmitt, S. (2013). *Enhancing indoor comfort in existing apartment buildings in Athens using natural ventilation* [Paper presentation]. Proceedings of Building Simulation 2013, Chambéry, France. <https://doi.org/10.26868/25222708.2013.1233>

Thralvalou, S., Michael, A., Neophytou, M., & Philokyprou, M. (2023). The ventilation capacity of earthen vernacular buildings with timber projections (sachnisi) in dense urban canyons: Findings from a field study in the Mediterranean. *IOP Conference Series: Earth and Environmental Science*, 1196(1), Article e012089. <https://doi.org/10.1088/1755-1315/1196/1/012089>