KPU International Journal of Engineering & Technology
Volume 4, Issue2, Sep. 2024
e-ISSN:2790-0819, p-ISSN:2790-0800

Date Received: 2024-09-11
Date Accepted: 2024-09-28
Date Published: 2024-09-30

Assessment of the appropriate natural ventilation methods for Residential buildings: A study in the context of Kabul City

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Abstract

Natural ventilation is an effective passive strategy for cooling and ventilating indoor air and improving the air quality of the building.
This research aims to identify the appropriate method for natural ventilation in residential buildings in the unique climatic conditions of Kabul city.
The researcher focuses on implementing natural ventilation methods and strategies such as Cross-ventilation, one-sided ventilation, and stack ventilation in buildings. Although a comprehensive review of articles, and case studies from different countries on natural ventilation compare the strategies and elements of natural ventilation in qualitative and quantitative methods the study evaluates the effectiveness of several ventilation strategies in the Kabul context.
The finding shows that natural cross-ventilation from the north side and northwest in the building shape consider planting a seasonal tree from the north side to bring the fresh and filtered air from the window into the building for better ventilation and optimize the energy efficiency in the residential building and wind tower (wind catchers) and stuck effect in courtyard housing is a suitable option for Kabul city.
In conclusion, the assessment of natural ventilation's impact on energy consumption showed that it has significant energy savings compared to mechanical ventilation systems. By employing appropriate natural ventilation strategies, buildings saw their reliance on artificial cooling decrease, resulting in lower energy consumption and decreased operational costs. This finding proves the potential of natural ventilation as an applicable solution to reduce energy demand and provide the best indoor air quality in residential buildings in Kabul context.

Keywords: Natural ventilation, energy efficiency, cross-ventilation, wind towers (wind catchers), Indoor Air Quality (IAQ)

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1. Introduction

In recent years, the weather in Kabul has been hot, dry, and dusty during the summer and cold during the winter.
The temperature can range from 24 to 93 degrees Fahrenheit, and it has recorded a low of 14 degrees [1].
The importance of ventilation in buildings lies in its ability to improve indoor air quality, remove air pollution, and create a comfortable environment that enhances quality of life.
Several ventilation systems are observed in the buildings as below:

1. A natural ventilation system
2. Mechanical ventilation system
3. Hybrid ventilation system

Natural ventilation is used in buildings as a passive strategy to bring fresh air into the building and exhaust stale air from the building by creating openings, wind catchers, windows, etc.
Mechanical ventilation system: this system works as part of mechanic vehicles such as fans, and ductwork as an active strategy from supply and exhaust air to the building.
Hybrid ventilation system (mixed ventilation system): this system combines mechanical and natural strategies for ventilating and optimizes the building's efficiency.
This research focuses on analyzing natural ventilation strategies, which are very important for the indoor climate of buildings and consume less energy. It suggests the most suitable option based on these conditions for Kabul city.
The integration of natural ventilation strategies in green architecture has gained significant attention in recent years due to its potential to enhance sustainability and energy efficiency It is found that buildings consume about 40% of total world energy [2].
Natural ventilation is an effective passive strategy for cooling and ventilating indoor air and improving the air quality of the building. It involves three principles.
1. One-sided ventilation 2. Cross ventilation 3. Stack ventilation

1. **One-side ventilation:** in this method, one side opening or window will be conducted and fresh air comes into the room and circulates the airflow by the changes of pressure differences that drive the airflow.
2. **Cross ventilation (cross flow):** In this method, the openings are located on opposite sides of the room fresh Air enters through one side of the room, while stale air comes out from the other side of the opening It takes advantage of wind pressures differences and utilizes the airflow created by prevailing winds.
3. **Stack ventilation (chimney effect):** this method is available for the temperature difference between indoor and outdoor air, fresh air enters from the lower level opening while stale air is expelled through a higher level opening located at the top of the building and it is important for building with vertical spaces such as atriums, staircase, etc.

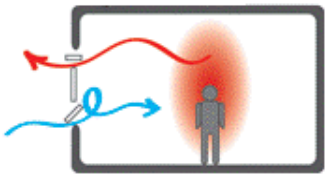


Fig. 1. One-side ventilation [12]

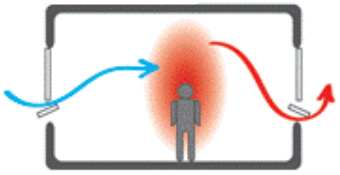


Fig. 2. Cross ventilation [12]

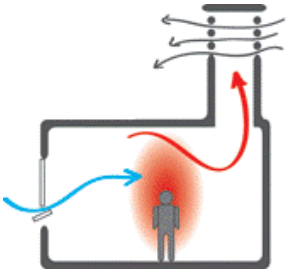


Fig. 3. Stack ventilation [12]

In Kabul, the challenges of indoor air quality, thermal comfort, and energy efficiency can be addressed through the use of appropriate natural ventilation strategies.

Indoor air quality (IAQ) is a critical factor in the health and well-being of building occupants, particularly in residential buildings where people spend a significant amount of time, Poor IAQ can contribute to a range of health problems, including respiratory illnesses, allergies, and asthma, and can hurt cognitive function and productivity [3].
Kabul's unique climate can help buildings with natural ventilation perform better.

2. Objectives

This research aims to evaluate the most appropriate ventilation solution in Kabul City and compare it to other studies on ventilation strategies and methods.
To evaluate the impact of these techniques on indoor air quality, thermal comfort, and energy efficiency, while also considering the unique climatic conditions and building typologies prevalent in Kabul.
In addition, to evaluate the current state of indoor air quality (IAQ) and energy use in buildings in Kabul City, obtaining a comprehensive understanding of the current conditions and recognizing the need for more effective ventilation strategies.
To examine the architectural concepts that influence the efficiency of natural ventilation strategies and methods in Kabul City, such as building orientation, placement of the building, shape, and design of the building, landscaping, and appropriate building elements (sun breakers, shading devices, the shutter of windows and facade design and wind catchers.
In short, the objective is to thoroughly evaluate suitable natural ventilation methods and strategies for residential buildings in Kabul City, considering the site context, climate, rules, and potential advantages.
The findings of this study will assist architects, designers, and policymakers who are engaged in green architecture projects in Kabul.

3. Literature Review

This study analyzes the research on natural ventilation methods in green architecture, with a special emphasis on how they can be applied in Kabul City's climate conditions.
This review is directed toward studies, articles, and case studies that examine diverse aspects of natural ventilation from various countries.

A case study about wind catchers in the Yazd city of Iran describes three typologies planned in this city [4].

1. Wind catchers located in the back of the hall connect the hall and courtyard and extend through the symmetry axis.
2. Wind catchers located at the corner of the yard attached to the hall through the medium of an aquarium space that is not directly related.
3. The wind catcher is located at the northern corners of a hall.

Windcatcher (wind tower): positioned at the top of the building and separated from two parts of shaft top shaft receives the fresh air into the lower shaft and the lower shaft distributes the air to the building.

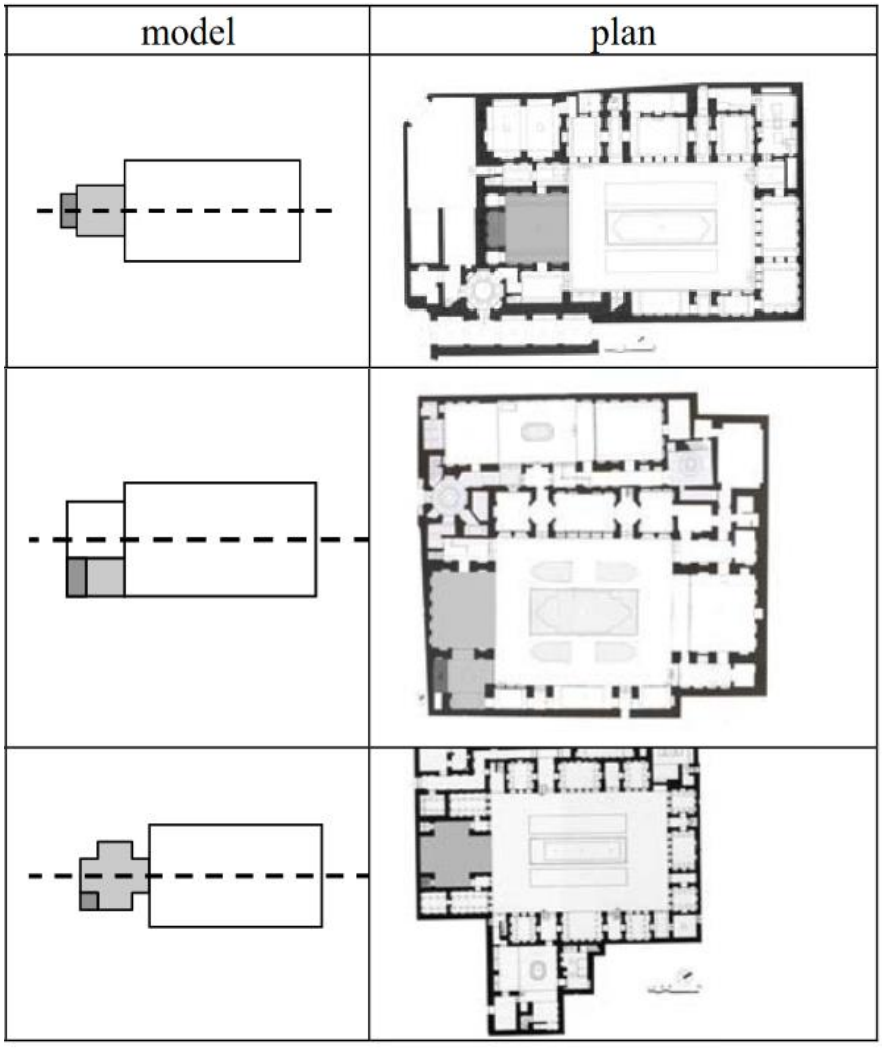


Fig. 4. Three kind of Typology model [13]

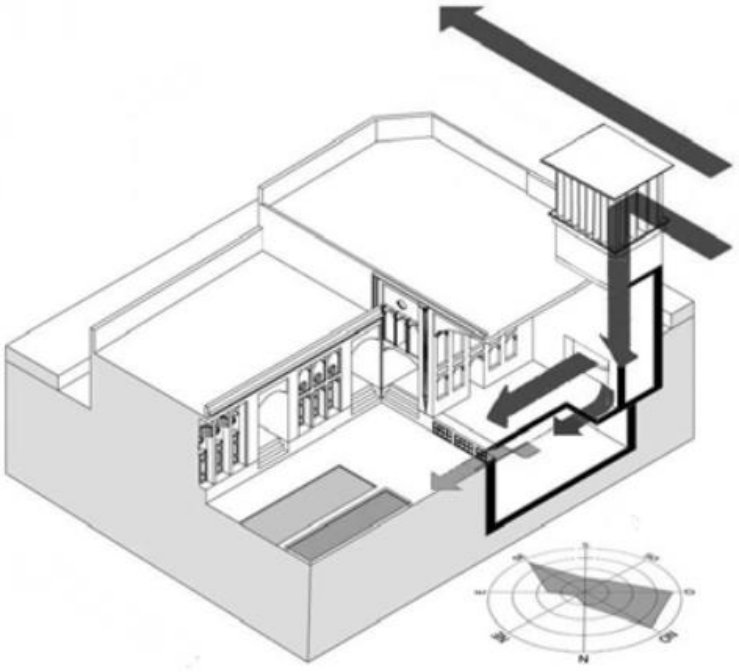


Fig. 5. Function of wind tower with high wind speed [13]

This research evaluates this system into current climatic conditions suitable if we consider the mixed method ventilation on the top of the building.
Wind towers are considered fans that require energy from the solar panel because in Kabul the weather is not all day and hours are windy so it is recommended to supply fresh air into the building from the top and exhaust the pollution and stale air from inside of the building through wind tower during the day.
Also, the researcher emphasizes considering these types of wind catchers in low-rise residential buildings with suitable orientation and well-considered courtyard housing.
Courtyard housing is the housing type used by 95% of people in Afghanistan [5].
A case study of 3 types of Afghan residential buildings and courtyard housing in Kabul city shows that Morphology in a building from the perspective of architecture determines the shape, form, and opening and plays a crucial role in energy demand, the comparison of three buildings' morphology in Kabul city confirmed that the building morphology could decrease energy demand by up to 44% [6].
Energy consumption is influenced by the form and shape of buildings or their morphology. However, the orientation of the site, window placement, sizes, and locations should be taken into account according to the wind flow in Kabul, which usually rises from the north and northwest.

To keep the natural cross-ventilation from the north side and northwest in the building shape considered planting a seasonal tree from the north side to bring the fresh and filtered air from the window into the building for better ventilation and optimize the energy efficiency in the residential building and courtyard housing is the most suitable option in affordable housing in Kabul condition. in Figure 8, 9

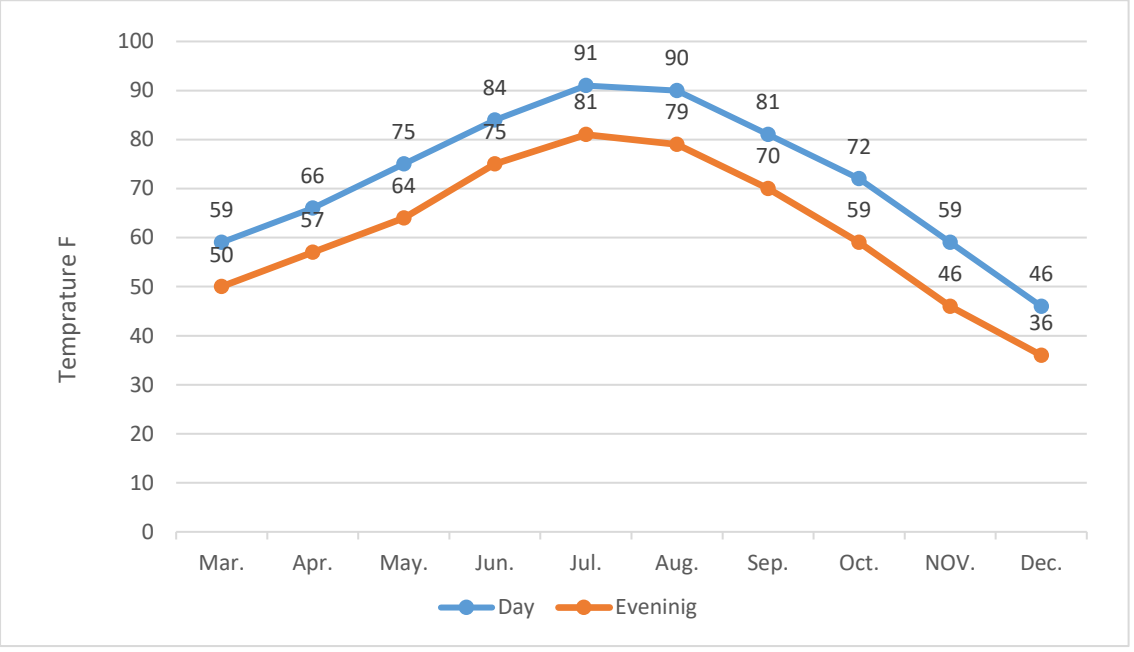


Fig. 6. Average day and night temperature graph in Kabul for one year [14]

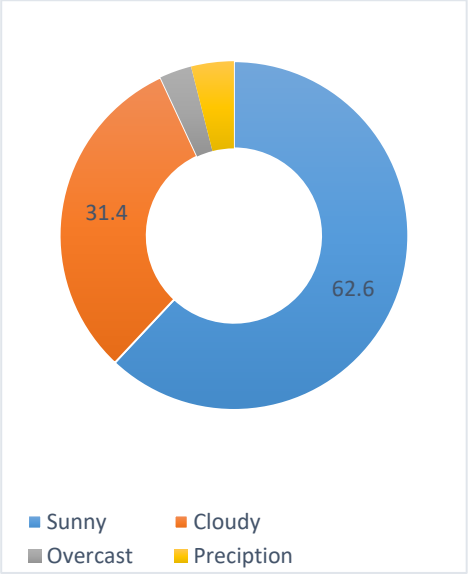


Fig. 7. Weather characteristics Chance of precipitation during the year

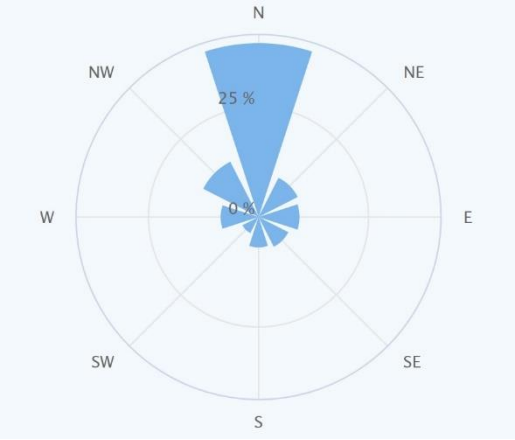


Fig. 8. Wind direction graph in Kabul [14]

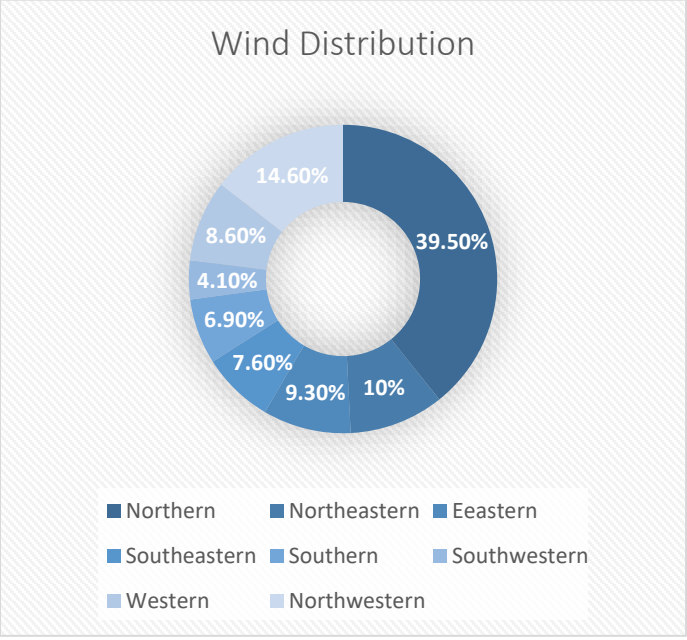


Fig. 9. Wind Distribution graph in Kabul using average values according to our data (Source Authors)

There are two usable factors in natural ventilation in Kabul City in residential buildings.

1. The interior spaces and main rooms are located on the best side of the building to receive sunlight heating during the winter and ventilate the air through a cross-ventilation system or one-sided ventilation.
2. The windows need to be designed in such a way that they can receive fresh air from the positive windward direction and expel air from the opposite direction as it flows. Figure 10

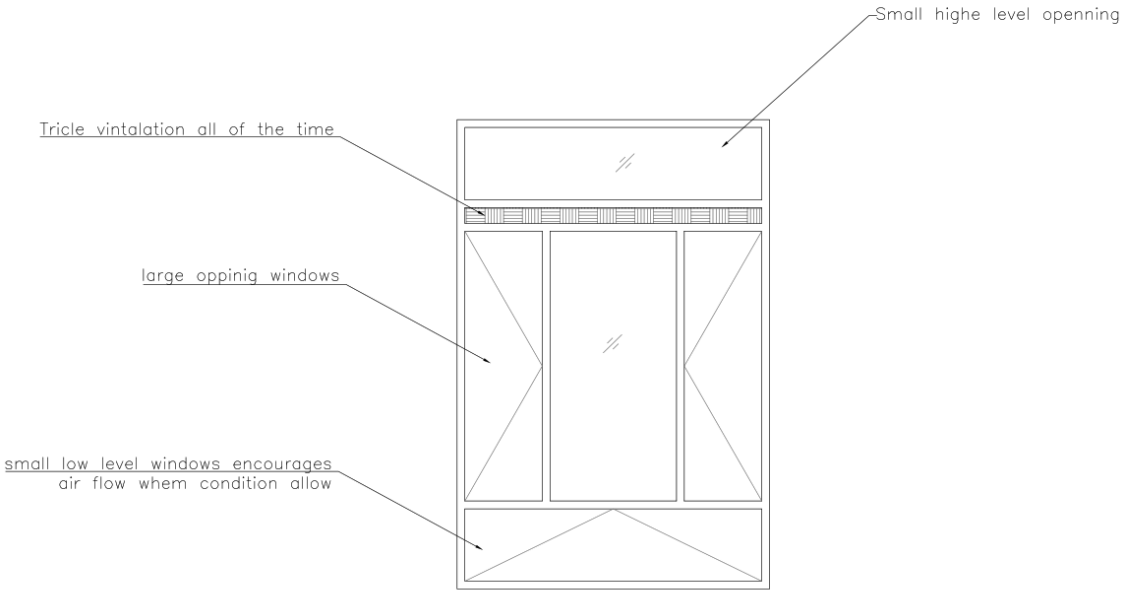


Fig. 10. The window design (Source Authors)

- In high winds, small amounts of ventilation can be achieved through small high-level windows.
- Trickle ventilators are advisable to use during cold weather, high winds, and when other windows are shut for safety reasons.
- Large central windows are ideal for the still and hot summer weather.
- To avoid papers from flying, small windows located at bench height for all-round ventilation may have to be closed in high winds.

High-rise residential buildings encounter difficulties in incorporating natural ventilation, according to a case study conducted in Kuje, Nigeria.
Despite their limitations, verandahs, balconies, and terraces offer a good opportunity to connect outdoor and indoor spaces.

A case study in high rise building in Berlin City the headquarters of GSW shows that the stack and cross-ventilation are considered through the double facade when wind flows from the east façade to exhaust from thermal flow into the west façade through as stack effect in ventilation cavity [7].

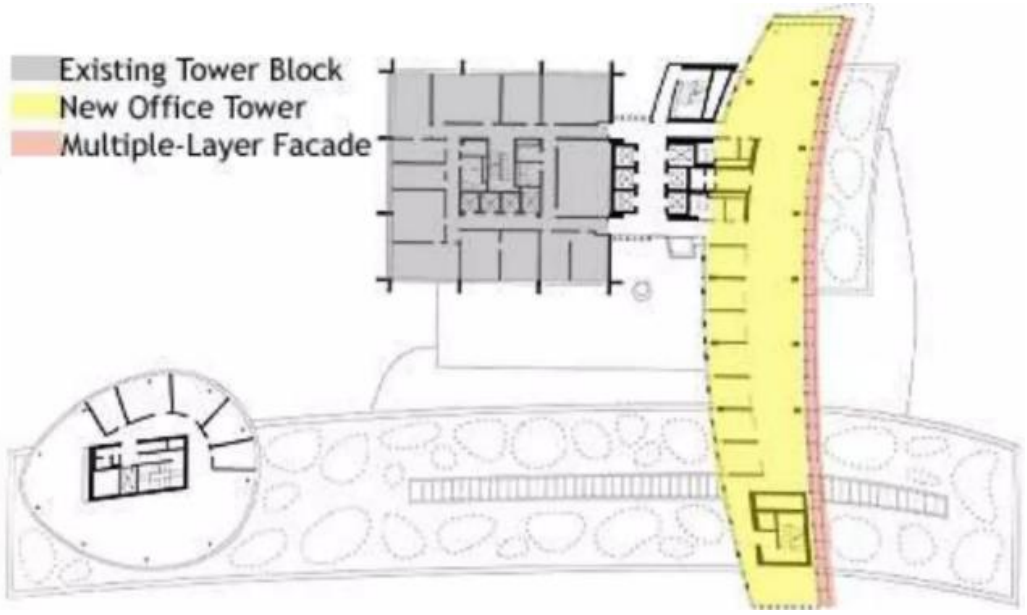


Fig. 11. Headquarter GSW Plan [7]

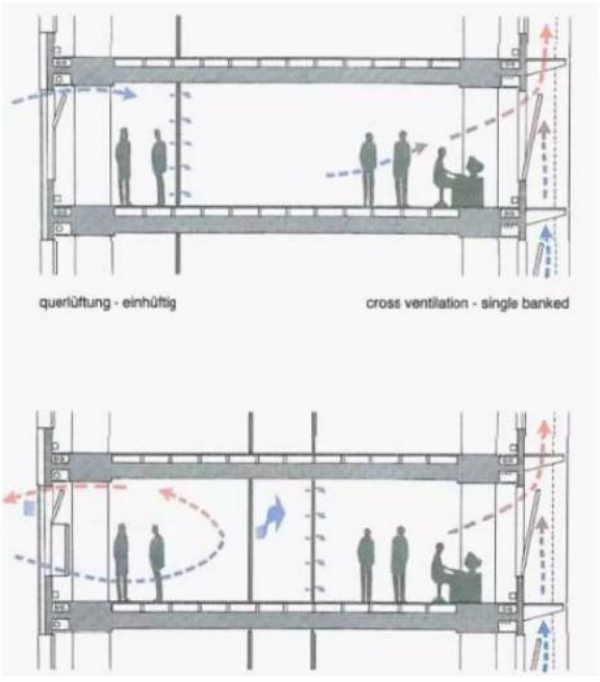


Fig. 12. Ventilation air flow [7]

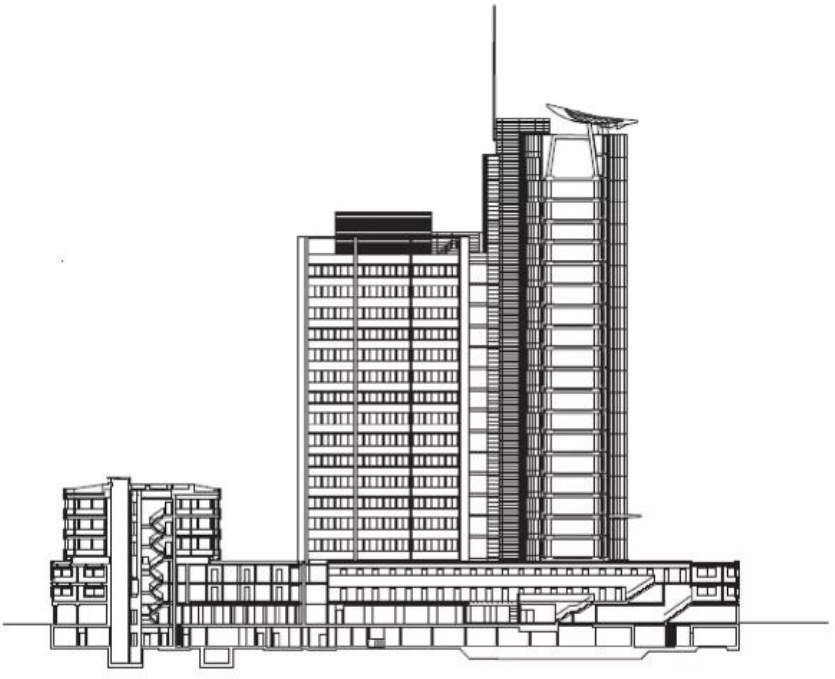


Fig. 13. Headquarters GSW section [7]

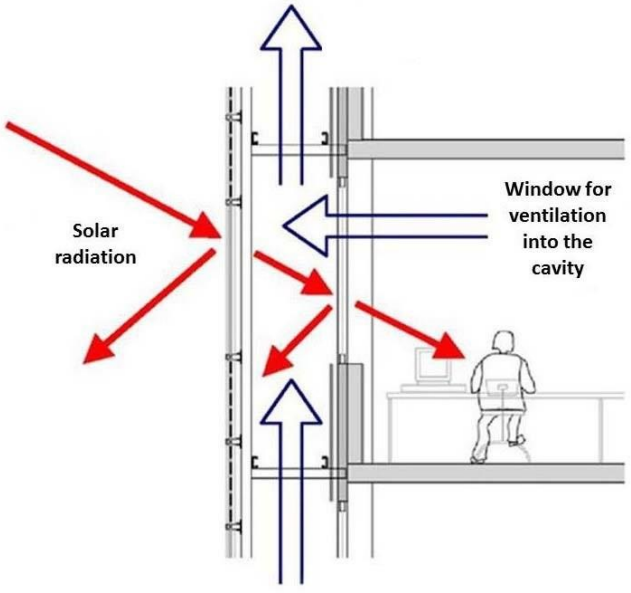


Fig. 14. Ventilation Cavity [12]

Researchers are suggesting cross-ventilation in high-rise buildings in light of the current situation in Kabul city.

To create and replicate a hybrid ventilation system for a high-rise building that utilizes stack ventilation.

4. Knowledge Gap

In this study, the challenge is to implement natural ventilation strategies in residential buildings in Kabul to guarantee indoor air quality and energy consumption efficiency.
The study will explore the effectiveness of different natural ventilation methodologies such as cross-ventilation, stack ventilation, and wind catchers for improved air quality, thermal comfort, and energy reduction due to mechanical ventilation in a dusty environment with extreme temperature variations in Kabul.
This research is intended to specify the most appropriate ventilation solutions that can be implemented in architectural practices in Kabul, to promote a healthier and sustainable living environment. The results from this study will guide architects, designers, and decision-makers during the construction and renovation of residential buildings in Kabul.

5. Methodology

This research is to evaluate the appropriate method for natural ventilation in climatic conditions of Kabul city, it is important in a building that ventilates naturally to reduce energy consumption, and it's better for affordable and contemporary housing in Kabul city.
The approach is centered around examining articles on natural ventilation topics, and journal articles, and analyzing the fundamentals of natural ventilation and its components in buildings.
By comparing case studies from different cities and comparing principles and methods, it is possible to evaluate and select the appropriate method based on the approach of quality and quantity.
The climate conditions in Kabul City are thoroughly analyzed. Climatic data, such as temperature ranges, wind patterns, wind rose analysis, and seasonal variations, is derived from local weather stations.
Qualitative and quantitative analysis is performed on secondary data, interviews, climatic analysis, literature review findings, and case study information. Quantitative analysis is statistical analysis while qualitative analysis is the identification of common themes, patterns, and key insights from the data to Identify relevant factors such as energy usage, indoor air quality conditions, and occupant comfort levels.
A comprehensive evaluation is being carried out to evaluate the effectiveness and suitability of various natural ventilation strategies within Kabul City. Various aspects such as energy efficiency, user comfort, indoor air quality, and architectural feasibility are taken into account. The comparison of these methods involves analyzing their performance, and comparing them to specific climatic conditions and architectural constraints of Kabul City, through the use of cross-ventilation, stack ventilation, and wind catchers.

Briefly, this approach merges data collection, climate analysis, literature review, case studies, data analysis, comparative assessment, and recommendations to evaluate the suitable natural ventilation methods for green architecture in Kabul City. The topic can be evaluated thoroughly and strongly by utilizing secondary data sources and qualitative and quantitative analysis techniques.

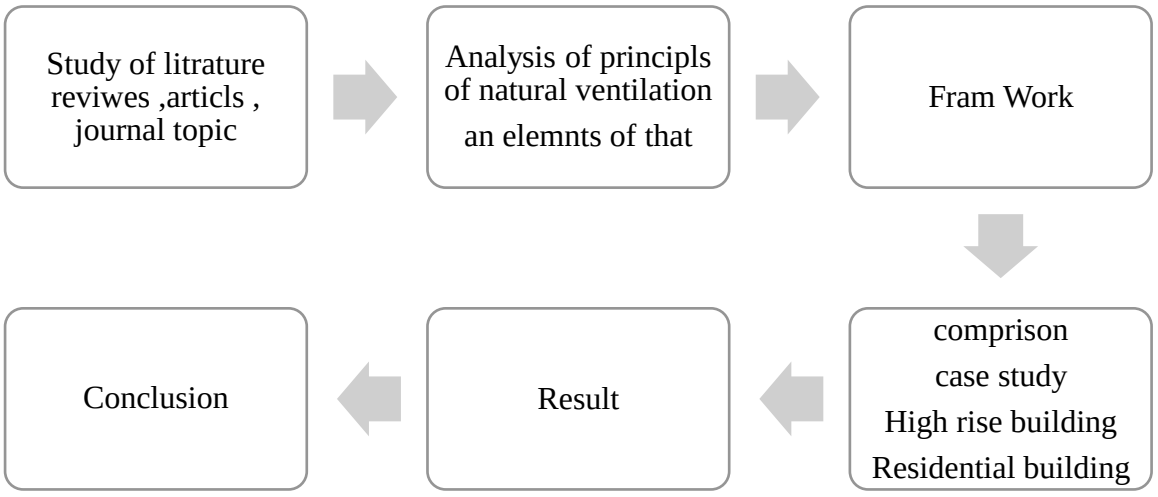


Fig. 15. Methodology workflow

6. Results

The data analysis identified several ideas and trends regarding natural ventilation methods in Kabul City.

7. Key findings include:

- Natural ventilation strategies in green architecture projects are becoming more recognized by architects and designers. Passive ventilation techniques that take advantage of wind and stack effects are preferred for airflow promotion. Integrating natural ventilation with other sustainable design elements, like shading devices sun breakers, and appropriate building elements, is now becoming a favorable approach.
- Energy consumption is influenced by buildings' form and shape or morphology. However, the site's orientation, window placement, sizes, and locations should be considered according to the wind flow in Kabul, which usually rises from the north and northwest.
- To keep the natural cross-ventilation from the north side and northwest in the building shape consider planting a seasonal tree from the north side to bring the fresh and filtered air from the window into the building for better ventilation and

optimize the energy efficiency in the residential building and courtyard housing is a most suitable option in affordable housing in Kabul condition.

- The researcher examines to evaluates this system into current climatic conditions suitable if we consider the mixed method ventilation on the top of the building.
- The use of wind towers as fans requires energy from solar panels in Kabul because the weather in Kabul is not always windy. So it is recommended to supply fresh air into the building from the top and exhaust the pollution and stale air from inside of the building through the wind tower during the day.

- Comparative analysis of ventilation strategies determined variations in their performance and suitability for Kabul City. Cross-ventilation was found to be highly well organized in buildings with more openings, permitting for good airflow circulation. The use of stack effect ventilation, particularly in taller buildings, showcased efficient vertical air movement. Even though wind catchers are less widely used, they have shown potential in harnessing overcoming winds for natural ventilation. The success and suitability of each strategy were influenced by factors like building design, site orientation, morphology, shape, window placement, and overcoming wind patterns.

- The assessment of natural ventilation's impact on energy consumption picked that it has significant energy savings when compared to mechanical ventilation systems. By employing appropriate natural ventilation methods, buildings saw their reliance on artificial cooling decrease, resulting in lower energy consumption and decreased operational costs. This finding proves the potential of natural ventilation as an applicable solution to reduce energy demand in Kabul City's buildings.

- The study obviously that natural ventilation had a crucial impact on enhancing indoor air quality. Buildings that have effective natural ventilation strategies showed better air exchange rates, reduced pollutant concentration, and enhanced indoor air quality. Natural ventilation is a key factor in creating healthier indoor environments for users according to this finding.

- The correlation between appropriate natural ventilation methods and users' comfort was found through data analysis. By using natural ventilation systems that were well-designed, buildings were able to improve thermal comfort, decrease humidity levels, and enhance air movement, leading to increased satisfaction among occupants overall. This finding stresses the importance of taking into account users' comfort when designing and implementing natural ventilation strategies.

According to the data analysis, the use of the correct natural ventilation methods has a significant impact on energy consumption, indoor air quality, and user comfort in Kabul City.

As the findings impact, toilsome natural ventilation strategies are needed to create durable, comfortable, and healthy built environments in green architecture projects.

8. Conclusion

In conclusion, the researcher determined the appropriate natural ventilation for the unique climates of Kabul, the wind towers (wind catchers +fan on the top) for low-rise residential buildings in the courtyard housing, and medium and high residential buildings the cross ventilation is considered when the orientation of building and morphology of that and window placement is important to be taken in the best site preparation.

- Energy consumption is influenced by buildings' form and shape or morphology. However, the site's orientation, window placement, sizes, and locations should be considered according to the wind flow in Kabul, which usually rises from the north and northwest.
- To keep the natural cross-ventilation from the north side and northwest in the building shape consider planting a seasonal tree from the north side to bring the fresh and filtered air from the window into the building for better ventilation and optimize the energy efficiency in the residential building and courtyard housing is a most suitable option in affordable housing in Kabul condition.

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Architect Ahmad Jamal Jahid born in 1991 in Kabul, Afghanistan, is a Senior Architect with significant experience in both public and national development sectors. He earned his Bachelor of Science in Architecture from Kabul University in 2014 and he is currently studying Master's program in Architecture at Kabul Polytechnic University. Ahmad Jamal has worked as a Senior Architect at the Ministry of Urban Development from April 2015 to 2020 and has been serving in the same capacity at the National Development Corporation (NDC) in Kabul since 2020. His professional and academic focus is on sustainable architecture, with a particular interest in passive cooling and natural ventilation strategies.



Architect Ahmed Masih Safi joined the engineering faculty of Kabul Polytechnic University in 2017 and graduated from Kabul Polytechnic University with a bachelor's degree in 2021. He is currently a master's student in architecture at Kabul Polytechnic University. His research area is the architecture of ancient buildings, building physics, sustainable architecture, and Islamic architecture.



Saleh Mohammad Yari received an M.Sc. degree in Civil and Industrial Construction from Kabul Polytechnic University in 1985. Presently, he is working as a Professor in the Department of Architecture, at Kabul Polytechnic University, Kabul Afghanistan. His areas of research include Searching and Establishment of Afghanistan's National Architecture Characteristics in Contemporary Architecture.