Windphil Poetic in Architecture: Energy Efficient Strategies in Modern Buildings of Iran

Sepideh Samadzadehyazdi, Mohammad Javad Khalili, Sarvenaz Samadzadehyazdi, Mohammad Javad Mahdavinejad

Abstract**—**The term 'Windphil Architecture' refers to the building that facilitates natural ventilation by architectural elements. Natural ventilation uses the natural forces of wind pressure and stacks effect to direct the movement of air through buildings. Natural ventilation is increasingly being used in contemporary buildings to minimize the consumption of non-renewable energy and it is an effective way to improve indoor air quality. The main objective of this paper is to identify the strategies of using natural ventilation in Iranian modern buildings. In this regard, the research method is 'descriptive-analytical' that is based on comparative techniques. To simulate wind flow in the interior spaces of case studies, FLUENT software has been used. Research achievements show that it is possible to use natural ventilation to create a thermally comfortable indoor environment. The natural ventilation strategies could be classified into two groups of environmental characteristics such as public space structure, and architectural characteristics including building form and orientation, openings, central courtyards, wind catchers, roof, wall wings, semi-open spaces and the heat capacity of materials. Having investigated modern buildings of Iran, innovative elements like wind catchers and wall wings are less used than the traditional architecture. Instead, passive ventilation strategies have been more considered in the building design as for the roof structure and openings.

Keywords**—**Natural ventilation strategies, wind catchers, wind flow, Iranian modern buildings.

I. Introduction

PRESERVING environment is the most important issue of today's world in which human being has to reduce energy consumption. As it is clear, worldwide around 40% of energy is consumed in buildings [1]. The depletion of energy resources and the risk of climate change are demanding for a sustainable development path based on renewable sources of energy and energy efficiency [2]. Sustainability involves a lot of conceptions and considerations, but one of the most important ones among all is the tolerance of ecological pressure in buildings. In sustainability term, the most important thing is to build energy efficient and non-toxic buildings and to eliminate the use of non-renewable resources [3]. Good energy efficiency buildings provide better environments for people living in them as well as reducing the impact on the natural environment [3]. On the other hand, the basic philosophy of sustainable design lies upon the evaluation of climatic influence and the optimization of building environmental performance. As a result, it can play a significant role in reducing energy consumption of buildings without compromising modern living standards [4]. Today, the environmental comfort of people in a building depends on adaptation with climatic factors such as wind, and sun [5]. Complex geometry [6], [7], sophisticated detailing [8], [9] and endogenous energy efficient strategies [10], [11] in architecture and planning made good opportunity for future architecture [12]. Therefore, by using sustainable design and considering wind as one of the main climatic elements, we would be able to go further steps in preserving the environment [13], [14] and minimizing energy consumption which is a nowadays discussion.

The term "Windphil architecture" refers to the buildings that facilitate the natural ventilation and the use of the renewable energy of the wind through the architectural vocabulary (designs of site, plan and detail), thus eventually cut the building energy consumption and improve the built environment. In this regard, foundations of many Iranian modern buildings have been derived from the nature and its great deal of energy (sunlight, water, wind and soil). Studying these buildings could be a proper source for investigating their solutions for adaptation with climate conditions and reducing energy consumption.

II. Literature Review

A. A Review on the History of Natural Ventilation in Iran

The wind catcher system is one of the green features for providing natural ventilation. This system has been employed in buildings in the Middle East for more than three thousand years. Wind catchers, "Baud-Geers" in Persian, are the main component of the traditional buildings in the hot regions of Iran. A Baud-Geer is a tower linked to a building that uses wind to provide natural ventilation and passive cooling [15]. This passive renewable strategy offers the opportunity to improve the ambient comfort conditions in building whilst reducing the energy consumption of air-conditioning systems.

Fig. 1 Baud-Geers in Dolataabad garden of Yazd

Wind catcher is a tall structure located on the roof of a building with the height of 5 to 33 meters. The wind catcher tower is divided by diagonal walls, which create four separate air walls facing four different directions. It is worth

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mentioning that some wind catchers like the one in “Dolatabad” garden of Yazd are of great height with the form of octagonal to receive the most flow of wind from different directions (Fig. 1). Wind catchers have shuttered to keep out unwanted incoming wind. In dry climates, they also have a means of evaporating water to cool the incoming air. They relate with the moisturizing elements such as: 1) pool, 2) garden, 3) trees, 4) basement walls, 5) Payab and compensate the shortage of ground moisture. There are actually two kinds of main functions about wind catchers.

The way that a wind catcher works is mainly based on taking the fresh air into the building and sending the hot and polluted air out or "the suction functions" perhaps it is not so necessary to explain that when the wind hits against the walls of internal blades of the wind catcher it necessarily falls down, but it is necessary to refer to this point that the other holes of the wind catcher turning back to the wind direction, give the hot and polluted air into the wind and so work like a ventilation and a sucked machine (Fig. 2).

The function of this kind of a wind catcher is actually performed according to this fact that when the wind hits an obstacle, and since the density of the air is thick on the side of the wind direction, there is a positive pressure, but a negative pressure on the other side. Therefore, when the ventilation is open on the sided of the wind, there will be a positive pressure to a negative pressure [16]. In the wind catchers, according to this principal, the opening facing the wind takes the air into the porch and the air in the porch with its negative pressure on the opening back of the wind is drawn out.

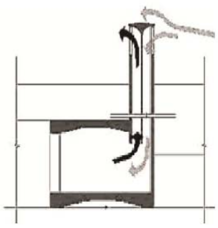


Fig. 2 Traction and suction in wind catcher

Fig. 3 Khishkhan in Dolatabad garden of Yazd

The structure of these systems is traditionally based on the experience of architects as well as the dignity, wealth and social position of the house owner. Indeed, they are different in the height of tower, cross-section of the air passages, placement and the number of openings as well as placement of the tower with respect to the structure it cools [17]. “Khishkhan” is the other element of the traditional buildings of Iran which facilitates ventilation as a dome. It is an oculus in the middle of the ceiling of the room of “Hozkhane’ which is located in the northern part of the building. This room has a pool and is usually used in the summer. This oculus used to be covered by moist mat, earthenware and thorny bushes which cooled the entering breeze (Fig. 3).

B. Natural Ventilation

Any building, even with all windows and doors shut, has a degree of ventilation [18]. Natural ventilation uses the natural forces of wind pressure and stacks effect to aid and directs the movement of air through buildings. The two fundamental principles of natural ventilation could be mentioned as stack effect and wind driven ventilation. Stack effect is caused by temperature differences between the inside and outside spaces of buildings. When the temperature of inside the building is greater than the outside, warm indoor air will rise and exit thus being replaced by cooler, denser air from below. The stack effect is dominant during periods of low wind speed and reduces in summer when temperature differences are minimal [19]. On the other hand, differences in wind pressure along the facade and between indoor and outdoor temperatures create a natural air exchange between indoor and outdoor air. The ventilation rate is affected by the strength and direction of these forces and the resistance of the flow path [20]. Wind incident on a building face will produce a positive pressure on the windward side and a relative negative pressure on the leeward side. This pressure difference as well as the pressure differences inside the building will drive airflow [19].

Natural ventilation is apparently the simplest and cheapest option to cool the building, it is also the most difficult to control, since the driving forces, and thus the air flow rates, vary constantly with the weather.

C. Natural Ventilation Strategies

Natural ventilation could be affected by public space structure, building form, orientation, and architectural elements as openings, courtyard, wind catchers, roof, wall wings, semi-open spaces and the heat capacity of materials (Fig. 4).

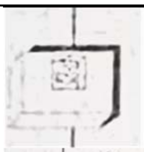
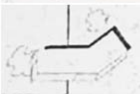
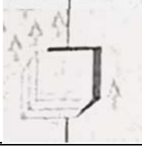
1. Public Space Structure

Street networks should be shaped with an organic hierarchical order, which is as a result of temperature, humidity, orientation to wind flow, the earth’s natural topography, possession and socio-economical characteristics [21]. For instance, “Shushtareno” is one of the contemporary residential complexes designed according to the climatic conditions of the city of Shushtar in the southern part of Iran. Passages are exposed to dominant winds from north and northern west. Besides, alleys with low width and high buildings provide the essential shadow with the cool breeze for spending warm seasons (Fig. 5).

2. Building Form

The shape of a building influences ventilation by its height, influencing stack effect ventilation, and its shape in relation to the prevailing wind speed and direction which affects wind-induced ventilation [21]. Selecting the suitable form, thermal loss in arid climates would be minimized and passive ventilation in humid climates would be maximized (Table I).

TABLE I
THE SUITABLE SHAPES OF BUILDINGS IN DIFFERENT CLIMATES

Climate	Form	Ratio (width to length)
Hot-arid		1/3
Hot-humid		1/7
Mild-humid		1/6
Cold		1/1

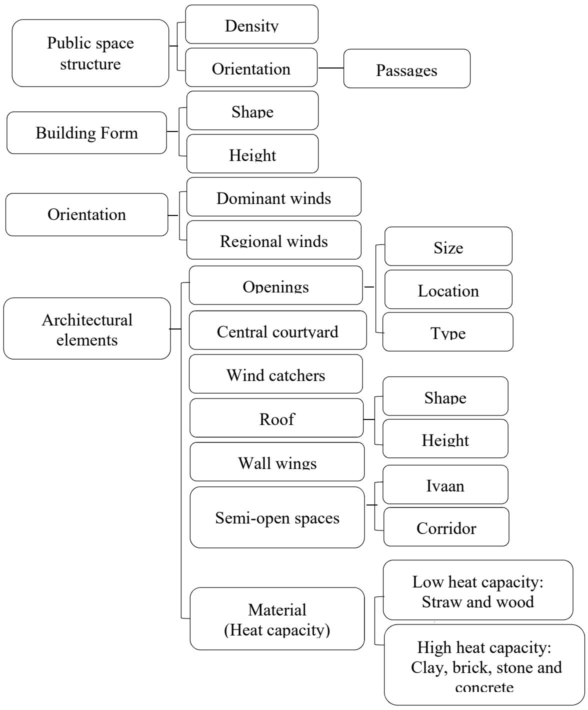


Fig. 4 Natural ventilation strategies

Fig. 5 Shadow with cool breeze in Shushtareno complex

3. Orientation

Orientation of a building could increase natural ventilation in hot and humid cities and reduce the heat loss in the cold ones [22]. Despite of dominant winds, one of the most significant climatic factors that affect the ventilation's condition especially in hot and humid cities is the regional winds [23]. Regional winds are produced because of the difference in atmospheric pressure, uneven distribution of solar radiation and the differences in the air density [24]. Hence, by the correct orientation of buildings, there would be a great deal of regional wind flow inside them.

4. Openings

Openings are usually enough to cool the buildings. Although use of an opening for ventilation of a space seems to be very simple, the flow that occurs is rather complicated. The amount of air going through the openings depends on several items such as size, type, and location of the openings [25].

Generally, the inlet and outlet size should be about the same, since the amount of ventilation is mainly a function of the smaller opening. However, if one opening is smaller, it should usually be the inlet because that maximizes the velocity of the indoor airstream, and it is the velocity that has the greatest effect on comfort. The inlet opening not only determines the velocity, but also determines the air flow pattern in the room. The location of the outlet, on the other hand, has little effect on the air velocity and flow pattern [26].

The location of openings could have an effect on wind circulation inside the building. If inlet openings are located in positive pressure zones and outlet openings are located in negative pressure zones, it provides the best conditions for maximum air movement through the building [27]. On the other hand, cross ventilation could be so effective because air is both pushed and pulled through the building by a positive pressure on the windward side and by a negative pressure on the leeward side [26]. When the single openings are on opposite sides of an interior space and the air movement is perpendicular to the inlet opening, the main airflow travels from inlet opening to outlet opening. The remainder of the interior space receives no significant air movement. When air movement is skewed to the inlet opening, but the inlet and outlet openings are in alignment with the exterior direction of the air movement, the flow of air will pass through the interior space in a narrow stream. When the air movement is perpendicular to the inlet opening and the outlet opening is in an adjacent wall, the flow of air will circulate throughout the entire interior space (Fig. 6) [27].

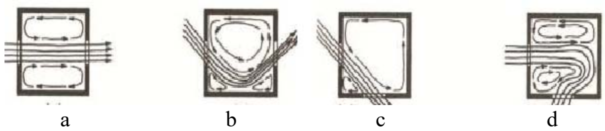


Fig. 6 The effect of opening location on the wind flow (a) Air movement is perpendicular to the inlet opening and is aligned with both openings. (b) Air movement is oblique to aligned inlet and outlet openings. (c) Air movement is skewed to the inlet opening, but the inlet and outlet openings are in alignment with the exterior direction of the air movement. (d) Air movement is perpendicular to the inlet opening and the outlet openings in an adjacent wall

High openings are also important for night-flush cooling where air must pass over the structure of the building. It is often advantageous to place windows high on a wall where they are too high to reach for direct manual operation (Fig. 7) [8].

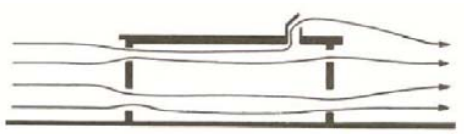


Fig. 7 High opening vent the hot air collecting near the ceiling

5. Central Courtyard

The existence of the central courtyard in internal heart of a building is considered as a useful passive system that is in a way that can easily make better use of the wind flow. In each space with opening windows toward the central courtyard and toward alleys, transverse ventilation would be created which can reduce the intensity of heat and damp [28].

In the hot and humid areas, the high closeness of the central courtyard makes the open space act like a ventilator for indoor spaces, which makes the air exited and tall walls make the courtyard stay in shadows (Fig. 8).

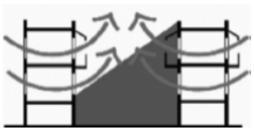


Fig. 8 The role of central courtyard in making wind draft

6. Wind Catchers

The stack effect of the wind catcher can be followed in contemporary buildings to help vertical ventilation. In this context, there could be a channel on the reverse side of inlet openings, in which air can flow. Getting sun's radiation on its walls, the channel makes the inside air warm and it moves upward. This warm air can get out of the channel through the holes located in the highest part of the channel. Consequently, the indoor hot air rises in the building and the vertical ventilation occurs [29].

Some wind catchers have a means of evaporating water to cool the incoming air. Some of them have porous jugs of water at their base, while others use fountains or trickling water. Whenever the humidity is low, evaporating cooling is very effective. The results are best if the evaporation occurs indoors or in the incoming air stream. If the air coming through the inlet opening gets rather humid, evaporating cooling and ventilation will simultaneously occur and thermal comfort requirements can be met. In public buildings which usually involve courtyards or atria, evaporating cooling is effective. Evaporative cooling of courtyards and atria is especially effective when the courtyard or atria is the main source of air for the building (Fig. 9) [26].

7. Roof

The form of the skyline in urban spaces is compatible with the use of wind flow. The form and the height of building roofs could have impacts on passive ventilation and heat loss (Fig. 10).

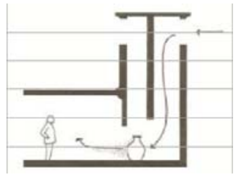


Fig. 9 Cooling the incoming air by evaporating system

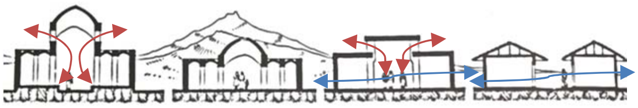


Fig. 10 Traditional forms of roof in Iranian architecture (a) Hot-arid climate, (b) Cold climate, (c) Hot-humid climate (d) Mild-humid climate

In hot and humid areas located near sea, rooftops used to be a place for sleeping at summer nights. The enhancement of the building's height and the usage of the rooftop as the last surface of the building would have provided the maximum use of the wind draft. Since the sun shines near the seashore daily, the earth's surface will become warmer than the sea and as a result, the air next to the earth's surface will elevate and substitute with the cool breeze of the sea. At night, the earth's surface will lose its heat, and the sea water is warmer than the earth. Therefore, the warm air will elevate from the sea and the cross-current will move to the sea from the earth [30]. This cool breeze is sensible from the shore, and because of its distinct direction, it can easily be used for ventilation of the building.

8. Wall Wings

Fig. 11 The effect of wing walls on the wind flow (a) Wing walls can significantly increase ventilation through windows on the same wall. (b) Poor ventilation result from wing walls placed on the same side of each window or when two wings are used on each window

Using wing walls can help the building to develop positive and negative pressure. A wing wall is usually used to aid single sided ventilation on windward facing windows. The objective is to explicitly induce positive and negative pressures on either side of two protrusions emanating from the window, thus enhancing the flow rate on an already handicapped single sided system cites results claiming that, when wing walls are used, the average air velocity in the room is 40% of the outside incident wind velocity limitation appears to be architectural integration and more specifically their use may tend to block sunlight. One way around this could be to use materials of a transparent nature which could doubly act to

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enhance and/or direct sunlight into the building. There is currently little research on the topic, perhaps due to the limited single sided target although they could be adapted anywhere where distinct and opposing pressures are needed (Fig. 11) [8].

9. Semi-Open Spaces

Semi-open spaces that are toward the dominant wind, have important impacts on infiltration of wind inside the building. The two roles of these spaces are as follows: the first one is that they are located in front of the closed space to avoid from the intense solar radiation; the second role is that they can reduce the wall's temperature because of the made shadow on the outside surface [31]. Indeed, the combination of semi-open spaces induces the airflow upward upstairs through semi-open corridors. Semi-open corridors act like a chimney and bring out the heat inside the house trough suction. Openings, which are toward outside the buildings, will strengthen this system [32].

10. The Heat Capacity of Materials

Wind flow could reduce the temperature of low heat capacity materials like wood but does not have much influence on high heat capacity ones like clay, brick, stone and concrete. Therefore, different materials could be used in different climates according to the average temperature and wind flow. In humid climates, the usage of materials with low heat capacity, which do not accumulate heat, is better and more useful. Thus, wood is the best material in these regions mainly because the day's heat accumulates on the woods surface and it will perish by the cool breeze of the nights. As a result, woods are used in making sunshades, doors and windows. On the contrary, in arid climates, materials with high heat capacity do not easily lose heat by wind flow and are helpful to reduce the temperature fluctuations.

III. Research Methodology

This paper explores the strategies of using natural ventilation as a passive cooling system in Iranian modern buildings. Research method applied here is "descriptive-analytical" which is based on comparative techniques. To evaluate the speed of the wind flow, the interior spaces of case studies have been simulated by FLUENT software.

To achieve the paper objective, literature review and survey studies were performed to collect data. A comprehensive literature review was con-ducted by focusing on the strategies of passive ventilation in contemporary buildings. A field survey was conducted to evaluate the design characteristics of eight valuable modern buildings in four types of climates in Iran. Four climatic zones were identified in Iran based on the Köppen climate classification, as follows: A, hot–humid climate; B, hot–arid climate; C, mild–humid climate; and D, cold climate (Fig. 12) [33].

Eight modern buildings from the four climates of Iran have been investigated using the field measurement method, and among all, one of them is presented in detail.

IV. Field Investigation: Contemporary architecture of Iran

Criterion 1: Imperial Bank of Persia

The imperial bank of Persia was a British bank that operated as the state bank and bank of issue in Iran between 1889 and 1929. It was established in 1885 with a concession from the Persian government to Baron Julius De Reuter a German-Jewish banker and businessman who later became a British subject. The bank was the first modern bank in Iran and thus is of historical value (Fig. 13) [34]. This building is located in the city of Tehran which has hot-arid climate.

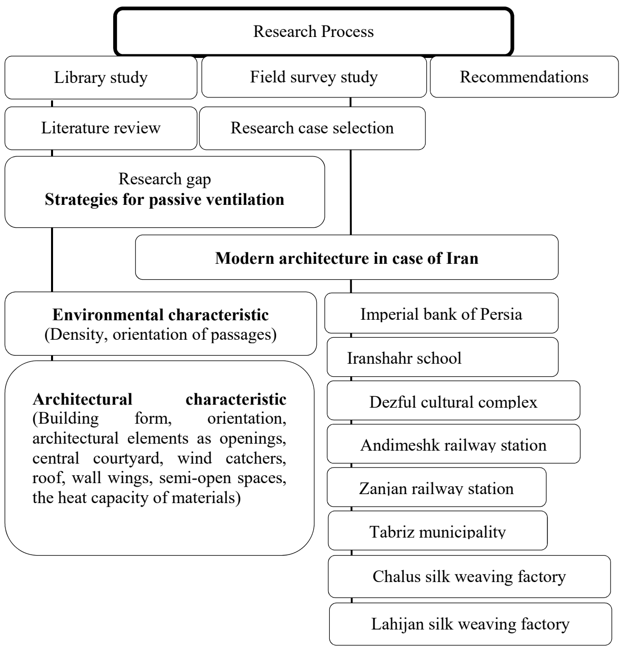
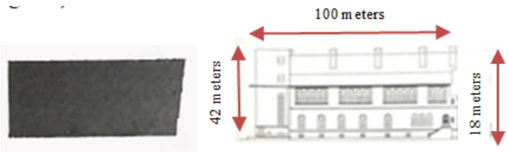


Fig. 12 The research methodology

Fig. 13 Imperial bank of Persia

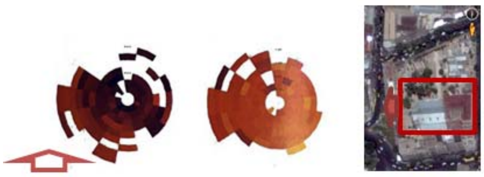
As it was mentioned, the form of the building could be evaluated according to the shape and height of it. The shape of the building is trapezius. The ratio of width to length is almost 1/3 which is the suitable ratio in hot and arid climate to reduce the heat loss. Indeed, the building is of great height (almost 18 meters) to facilitate the convection flow. Therefore, the warm weather easily goes up and exists through wind catchers and cool weather substitutes to provide thermal comfort for the users (Fig. 14).



a b

Fig. 14 The shape and the height of the imperial bank (a) The ratio almost equals to 1/3 that is suitable for hot-arid climate (b) High ceiling (almost 18 meters) suitable for the convection flow

As the dominant wind flow of the region is from the west, the orientation of the building is towards the west too. Therefore, the desirable wind flow enters the building through the wind catchers in the summer (Fig. 15).



a b c

Fig. 15 The wind direction and the building orientation (a) The direction of the wind flow in fall and winter, (b) The direction of the wind flow in spring and summer, (c) The orientation of the building towards the west

Wind catchers are the main elements for the passive ventilation in this building. Ten wind catchers are located at the top of the roof in a double linear structure. To adjust the temperature of the incoming air according to the thermal comfort temperature, a mechanical system is installed. Therefore, in warm seasons, the cooling system cools the incoming air and in cold seasons, the heating system warms it.

The two factors which influence the wind flow inside the building are the number of the wind catchers and their location. As it is tested, when all the wind catchers are open, the speed of the wind flow in the central corridor is twice faster than the time just one wind catcher is open (Fig. 16). The function of the wind catchers depends on their location towards the wind flow which results in the positive or the negative pressure. Therefore, the wind catchers with positive pressure takes the cool air in and those with negative pressure takes the warm air out.

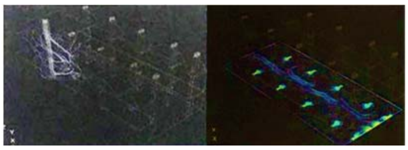


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Fig. 16 Path lines colored by velocity magnitude (m/s) (a) The wind flow when only one wind catcher is open, (b) The wind flow when all the wind catchers are open

Façade openings are located symmetrically in the northern and southern parts of the building (Fig. 17). When the roof is heated, the warm weather will exit through the wind catchers and the cool weather coming in through the facade openings will substitute it. Therefore, the desirable wind will be flowing at the height of 120-150 cm from the floor where the workers will feel comfortable.

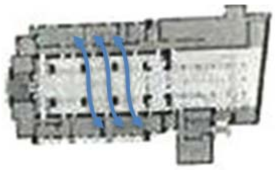


Fig. 17 Openings located symmetrically in the plan

The material used in the façade is brick which is of high capacity and is suitable for hot-arid climate to reduce the temperature fluctuations by the wind flow (Fig. 18).

Fig. 18 The material of brick in the façade

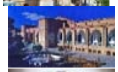
V. Analysis Results of Field Investigation

In this section, the results of investigation of the eight Iranian modern buildings will be presented (Table II and Fig. 19)

Natural ventilation strategies could be classified into two groups of environmental characteristics and architectural characteristics. Environmental characteristics include public space structure and the orientation of passages towards dominant and regional wind flows, while architectural characteristics include building form and orientation, openings, central courtyards, wind catchers, roof, wall wings, semi-open spaces and the heat capacity of materials.

Analysis results of field investigation show that, in Iranian modern buildings, natural ventilation design strategies like roof structure and openings are considered more than the innovative elements like wind catchers and wall wings. Wind catchers play a significant role in natural ventilation as in the traditional buildings. Of course, to adjust the temperature of the incoming air to thermal comfort in different seasons, installing a mechanical system is essential. Having investigated buildings in the four major climates of Iran, natural ventilation is achieved in humid climates through openings and ceiling height where air flow is desirable, while in arid climates, natural ventilation is achieved through wind catchers combined with evaporating system, where air flow should be controlled.

TABLE II
THE ADAPTATION OF BUILDINGS TO THE CLIMATE IN CASE OF PASSIVE VENTILATION

Climate	The building	Picture	Form	Orientation	Openings	Central courtyard	Wind catchers	Roof	Wall wings	Semi-open spaces	Material
Hot-arid	Imperial bank of Persia		+	+	+	–	+	+	–	–	+
	Iranshahr school		–	+	+	+	–	+	+	+	+
Hot-humid	Dezful cultural coplex		+	–	+	+	+	+	–	+	–
	Andimeshk railway station		+	+	+	–	–	+	–	+	–
Cold	Zanjan railway station		–	+	–	–	–	–	–	–	+
	Tabriz municipality		–	–	–	–	–	+	–	–	+
Mild-humid	Chalus silk weaving factory		+	–	+	–	–	+	–	–	–
	Lahijan silk weaving factory		+	+	+	–	–	+	–	–	–

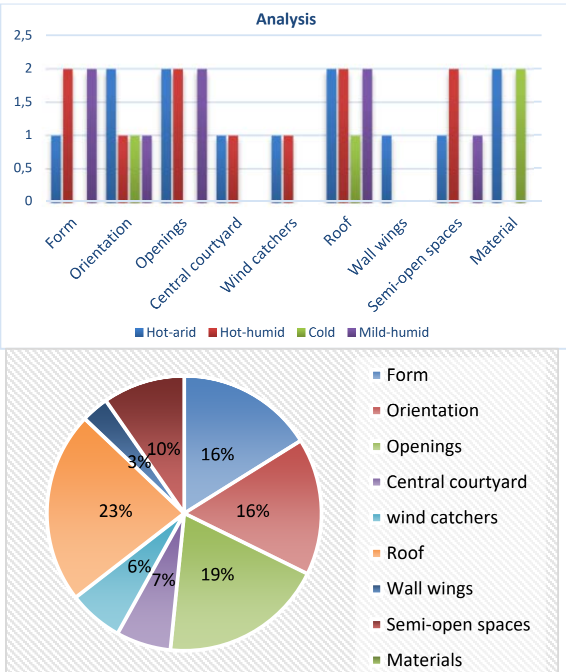


Fig. 19 Analysis results of field investigation

VI. CONCLUSION

Research achievements show that natural ventilation strategies could create thermal comfort in modern buildings. Natural ventilation uses the natural force of wind pressure and stacks effect to direct the movement of air through buildings. The two fundamental principles of natural ventilation are stack effect and wind driven ventilation. Natural ventilation strategies could be classified into two groups of environmental characteristics and architectural characteristics. To adjust the temperature of the incoming air through wind catchers, installing a mechanical system could be helpful.

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