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Study on Vernacular Architecture Patterns to Improve Natural Ventilation Estimating in Humid Subtropical Climate

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Abstract

Wind ventilation is an efficient design strategy for the natural cooling system (NCS) in humid climates. The building forms can generate different pressures and temperatures to induce natural ventilation. This study has been carried out in Rasht city, Iran in 2017. The method was performed using a computational fluid dynamic (CFD) approach simulation to study variance between the proposed and the actual results of a design. The goal of the study is to assist architects to design optimum building form for natural ventilation. Hence, the purpose of this study was to investigate the effect of the form on natural ventilation. On this basis, wind flow simulation was performed using Design Builder Version 4.5. In this paper, the present usage of natural ventilation of rural residential buildings in Rasht area the application of this methodology. Initially, wind simulation was carried out based on actual building specifications. Then the proposed L-shaped extension was added to the building. The results showed that if the rectangular form is turned into an L shape, it can offer a better flow pattern for wind in all rooms, but the speed will be reduced.

Keywords: Vernacular Architecture; Natural Ventilation; Humid Subtropical Climate; Abrishami House; Wind Cooling System.

1. Introduction

Many countries and governments are seeking to increase the use of renewable energies such as solar, wind, biomass and geothermal resources due to concerns related to fossil fuels, such as limited reserves and environmental impacts like climate change and increasing demand for electricity [1-3]. During the last two decades, the interest in natural ventilation in buildings has been reawakened because of the increasing awareness on emission of greenhouse gases and the need for an efficient passive ventilation system as a part of green building architecture. In this regard, ventilation having appropriate size would be appeared as a way to save energy [4-6]. One of the most important functions in architecture is housing. Because people spend most of their time at home, so the building should be designed in such way that initially provide thermal comfort for habitants [7].

Natural ventilation has been widely used in buildings due to the great potential for energy conservation and indoor air quality (IAQ) promotion [8, 9]. Also, the fundamental purpose of buildings is to provide a comfortable living environment protected from the extremes of climate. In this regard vernacular buildings evolved gradually to meet environmental, socioeconomic, and sociocultural factors of the society to meet the changing lifestyle over a period of time. These buildings have obtained deep harmonization with site surrounding and have imposed minimal environmental impacts. According to ASHRAE Standard 55 (2013), thermal comfort is the condition in which the mind expresses satisfaction with the thermal environment and is assessed by subjective evaluation [10]. The main factors that influence

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thermal comfort are those determining heat gain and loss, namely metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity [11].

Today, sustainable architecture as a way of architectural design which is based on environmental aspects, is a specific style of design in which architects and designers try to pay more attention to it. Architects in Iran, as a vast country having different climatic zones and regions, had to use this way of design in Iranian traditional architecture from a long time ago to solve environmental problems in architecture and have a specific system for each region. However, it seems that vernacular architecture of Iran shows signs of sustainability in architecture. The Gilan's pattern architecture has been studied as an example of the harmony and combination of nature with environment as a result of various climatic, social, economic, cultural factors that have the greatest impact on the climate and environment around them [12-15]. Rasht city, the capital of Gilan province, was selected as the study area with humid subtropical climate located in northern of Iran. According to weather data, it was observed that this area has a high humidity. Therefore, natural ventilation can be proposed as a solution to solve this problem design [16].

In this research, a part of the vernacular architecture of Rasht has been studied from wind and natural ventilation viewpoint as a cooling system. The research hypothesis is that the form of building seems to affect the natural ventilation and wind behavior in the residential building. On this basis, the Abrishami house in Rasht was evaluated as a pilot case. Initially, wind simulation was carried out based on actual building specifications. Then the proposed L-shaped extension was added to the building. The purpose of this study was to investigate the effect of the form on natural ventilation.

2. Literature review

Numerous studies have been conducted on passive design strategies (PDS) in term of using wind ventilation in order to improve the thermal comfort in buildings as a cooling passive system (CPS). Baghaei Daemei et al. (2016) conducted a study about the effect of opening and the design of residential interior partitions on the amount of natural ventilation. On this basis, four plans proposed for cross ventilation and three plans proposed for single-side ventilation were evaluated. The results of this research include the proportions of zones and design consideration for using the air flows and ventilation inside the building. In this regard, wind simulation was performed using CFD model [16]. Allocca et al. (2003) studied single-sided natural ventilation by using a computational fluid dynamics (CFD) model along with analytical and empirical models. This investigation also studied the effects of opposing buoyancy and wind forces [17]. de Dear and Brager (2002) in their paper summarized this earlier adaptive comfort research and presented some of its findings for naturally ventilated buildings, and discussed the process of getting the ACS incorporated into Standard 55. In this study, suggested ways for ACS could be used for the design, operation, evaluation of buildings and research applications. Moreover, GIS mapping techniques have been used to examine the energy-savings potential of the ACS on a regional scale across the US. Finally, the related new directions have been discussed for researchers and practitioners involved in the design of buildings and their environmental control systems [11]. Raja et al. (2001) field study was done to investigate the thermal comfort of workers in natural ventilated office buildings in Oxford and Aberdeen, UK through applying the information about use of building controls [18]. The results make it possible to predict the effect of temperature on the ventilation rate in naturally ventilated buildings.

Furthermore, some studies were carried out by other researchers on natural ventilation with passive design strategies for other reasons. The methodology and case study of Guo et al. (2015) was done to optimize the building's natural ventilation through CFD wind environment simulation from three aspects, i.e. site planning, building shape and building envelope. The goal was to offer some ideas in order to address the mismatching and poor synergy between architectural design and technological analysis [19]. Wang et al, (2007) conducted a study about facade designs for naturally ventilated residential buildings in Singapore in order to optimize facade designs for better indoor thermal comfort and energy saving. The results showed that optimum facade designs and thermal comfort indices are summarized for naturally ventilated residential buildings in Singapore [20]. Stavrakakis et al. (2012) have described a novel approach to provide computational method in order to optimize window design for thermal comfort in naturally ventilated buildings. The methodology is demonstrated by means of a prototype case which corresponds to a single-room, rural-type building. Results showed that the proposed methodology provides the optimal window designs corresponding to the best objective variables for both single and several activity levels [21].

Ranjbar et al. (2010) conducted a study about descriptive - analytical method and data collection with field survey pursuits climatic design initiatives according to wind flow in old Bushehr. Results show that urban spaces of Bushehr have been formed in a hierarchical climatic design according to regional wind [22]. Also, Mahmoudi and Pourmousa (2010) have found similar results on the air flow around the building in the Golsar District in Rasht. They have investigated the air curtain outside and inside of the building, resulting in the use of air from the air flow [23]. Sokhandan Sorkhabi and Khanmohammadi (2015) also found similar results in a research done to find a new solution for improving cooling and ventilation function of some parts of exterior walls in the buildings, like sunshades which are provided as a architectural passive design. In this research, first step was to study some specifications such as winds and find the unfavorable factors that affect architectural design of buildings in North Arasbaran. Second step was to make the green channels that can direct the wind in a suitable direction for cooling and ventilation uses. Direction of green channel should be in harmony with prevailing wind. The results show economic performance and efficiency of designed system through tests, local experiences and observations in Arasbaran [24].

In addition, Iravani et al. (2016) conducted a study about the role of wind and its influence on residential architecture. Climatic changes are concluded to be a predominant factor in the creation of new styles within recent periods. By reviewing the evolution of buildings, recommendations were proposed for modern architecture [25]. Kubota and Hooi Chyee (2016) have found similar results on potential of using passive cooling techniques for Malaysian modern houses aiming to reduce air–conditioning usage. A full–scale field experiment was carried out to reveal the detailed indoor thermal environment for various ventilation strategies. Night ventilation was found to be the best one over daytime ventilation, full–day ventilation and no ventilation options in terms of air temperature reductions during the day and night. Several other potential passive cooling techniques are also proposed for achieving acceptable thermal comfort in modern Malaysian houses [3]. Generally, several studies have been conducted to compare and verify the performance of different wind and flow models for natural ventilation (Table 1).

Table 1. Summary of studies from other researchers

Author(s)	Year	Ventilation type	Short description
Dascalaki et al.	1996	Single-side	In this paper, single sided ventilation experiments were carried out in a full scale outdoor Test Cell facility [26].
Gan	2000	Single-side	This paper introduces the effective depth of fresh air distribution in rooms with single-sided natural ventilation. A numerical method for the determination of the effective depth is described [27].
Allocca et al.	2003	Single-side	This investigation studied single-sided natural ventilation by using a computational fluid dynamics (CFD) model, together with analytical and empirical models [17].
Favarolo and Manz	2005	Single-side	As part of an investigation into the night-time cooling of commercial buildings by single-sided natural ventilation through open windows, a computational fluid dynamics study was performed to analyze the impact on the airflow rate of the dimensions and position of a large rectangular opening [28].
Larsen and Heiselberg	2008	Single-side	In this work, full-scale wind tunnel experiments have been made with the aim of making a new expression for calculation of the airflow rate in single-sided natural ventilation [29].
Caciolo et al.	2011	Single-side	In this paper, the flow field and the air change rate generated by a simple configuration of natural ventilation, namely single-sided ventilation, are examined experimentally [30].
Mochida et al.	2005	Cross vent.	This paper investigates methods for controlling airflow in and around a building in order to improve indoor thermal comfort by utilizing cross-ventilation [31].
Stavrakakis et al.	2008	Cross vent.	In this study, natural cross-ventilation with openings at non-symmetrical locations is examined experimentally in a test chamber and numerically using advanced computational fluid dynamics techniques [32].
Hughes and Abdul Ghani	2010	Stack vent.	This paper investigates the effect of altering the external angle of the Wind vent louvres against the internal pressure and velocity within the device and the microclimate velocity [33].
Gładyszewska-Fiedoruk and Gajewski	2012	Stack vent.	The present article deals with effects of wind on the stack ventilation performance in an average kindergarten in Bialystok (Central Europe) [34].
Ali Elmualim	2006	Wind catcher	This paper discusses experimental and theoretical investigations and Computational Fluid Dynamics (CFD) modelling considerations to evaluate the performance of a square section wind catcher system connected to the top of a test room for the purpose of natural ventilation [35].
Naghman Khan et al.	2008	Wind catcher	This paper reviews miscellaneous wind driven ventilation designs with respect to traditional means such as wind towers and more modern techniques including turbine ventilators and wind catchers [36].
Montazeri et al.	2010	Wind catcher	Additional experimental tests and computational fluid dynamics simulation of the wind catcher in the wind tunnel were also conducted in order to assess the accuracy of measurement procedures and the uncertainty of experimental results. This article also represents a semi-empirical approach in which experimental data were used for a detailed analytic model, in order to provide an accurate estimate of the performance of wind catchers [37].
Hedayat et al.	2017	Wind catcher	In this study a long-term whole year monitoring campaign on an existing full scale four sided wind catcher in Yazd was carried out in 2014–2015. Three prevailing wind directions were identified and the measured on-site wind speeds were used to estimate the wind induced natural ventilation potential of the tower [38].
Montazeri and Montazeri	2018	Wind catcher	This paper, presents a detailed evaluation of the impact of the outlet openings on the ventilation performance of a single-zone isolated building with a wind catcher. The evaluation is based on three ventilation performance indicators induced airflow rate, age of air, and air change efficiency [39].
Kolokotroni and Aronis	1999	Night purge	This paper investigates the applicability of night ventilation in air-conditioned office buildings. A thermal and ventilation simulation model, together with suitable weather data were used to examine the potential for energy savings and/or improved internal comfort conditions by applying night ventilation cooling [40].
Kolokotroni et al.	2006	Night purge	This paper investigates the effect that increased air temperature due to the London heat island has on the effectiveness of stack night ventilation strategies for office buildings. Stack ventilation was investigated as the most suitable night ventilation strategy because this is largely independent of wind variations affected by local urban morphology [41].

Moreover, many studies conducted about using natural ventilation in recent years. For example Jomehzadeh et al. [42] in their investigation focused on the IAQ and thermal comfort aspects in the UK using CFD and experimental techniques. Elshafei et al. [43] conducted experimental and simulation studies for evaluating the effects of natural cooling on the thermal comfort indoor residential buildings. Some of the results in the Muhsin et al. [44] studied the provision of the void to enhance natural ventilation performance in the living units of multi-storey housing. The methods employed by the research are field measurement and computer simulation using computational fluid dynamic software. Omrani et al. [45] proposed a process model for the better integration and evaluation of natural ventilation design into the overall building design process for multi-storey buildings. Also, Schulze et al. [46] studied aims to compare the overall energetic efficiency and comfort provision of controlled natural ventilation in energy efficient offices and in the non-refurbished building stock with the related mechanically ventilated reference. The goal is to determine the energy savings for modern offices with low heating demand and higher summer cooling loads compared to existing office buildings, where heating loads dominate. Landsman et al. [47] conducted study addressed to describe the performance, in terms of indoor environmental conditions, of three buildings from both the U.S. and India that use night ventilation as their primary cooling method.

3. Research methodology

The software package used for the design of a naturally ventilated building is Design Builder using the Energy Plus simulation engine, since it is one of the efficient software tools which can model realistic Natural Ventilation air flows with less effort and is also considered excellent for early stage building design [48]. This study proposes to provide the building form of Abrishami house to scientifically analyze the wind behavior with CFD approach. For this reason, a comparison was made between two recommendation plans in Rasht using CFD modeling operation conducted by Design Builder v4.5 Software. This software uses Energy plus Simulation engine. Air flow modeling was implemented based on ASHRAE international standard. Moreover, Meteonorm Software and EPW file format were applied to access climate information of Rasht. The applied research methodology was based on library studies and analysis methodology was based on CFD simulation results. Boundary conditions are defined for all walls and openings (Table 2). The maximum cell aspect ratio (MCAR) is set below 50 to control accuracy of grid (CAG). K-epsilon model was developed for the analysis of turbulent flow model algorithm. It should be noted that the results of all simulations converge with together. Figure 1 shows the CFD grid statics.

Table 2. CFD boundary details

Description	Data
Inside surface temperature (C)	20
Inside surface window temperature (C)	10
Average zone air temperature (C)	22
Incoming air temperature (C)	20
Calculation options data	
Turbulence model	K-e
Discretization scheme	Upwind
Iterations	5000
Surface heat transfer	Calculated

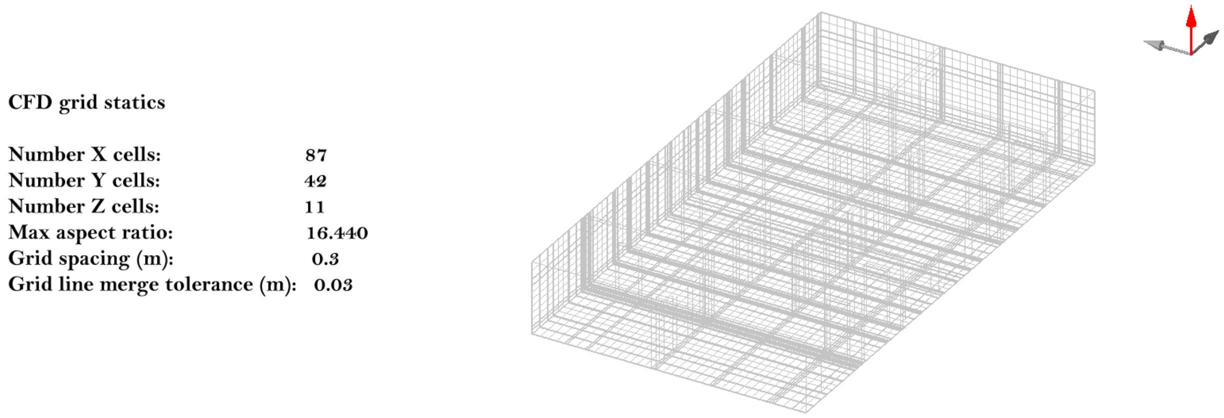


Figure 1. CFD grid statics

If fact, the steps of the research were such that, at first whether data was collected from Meteonorm. This data imported to the Design Builder Software as an EPW format. Also, the 3D modeling of the existing case was also conducted in the Design Builder and then, CFD simulation was done on it. In the next step, the proposed building forms were evaluated for the research hypothesis.

4. Theoretical Framework

4.1. Wind Ventilation and Strategies

The keys for good wind ventilation design include the building orientation and massing, dimensions and the places of openings located appropriately based on the climate circumstances. In order to maximize wind ventilation, the pressure difference between the windward (inlet) and leeward (outlet) sides to be maximized. Almost in all cases, high pressures occur on the windward side of a building while low pressures happen on the leeward side. The local climate may have strong prevailing winds in a certain direction, or light variable breezes, or may have very different wind conditions at different times. Often, a great deal of adjustability by occupants is required. It should be consulted climate data for wind rose diagrams. The local climate may also have very hot times during the day or year while other times are quite cold (particularly desert regions). In summer, wind is usually used to supply as much fresh air as possible while in winter, wind ventilation is normally reduced to levels sufficient only to remove excess moisture and pollutants [49].

Different weather requires different architectural responses and it is one of the factors affecting human life, comfort and climatic conditions [50]. Natural ventilation is often an element in what is typically referred to as “green” or “sustainable” architecture. This category of architecture has an immensely wide span, ranging from ultra-high-tech solutions to very low-tech and passive solutions. The majority of the “green,” “low energy” or “sustainable” buildings seem to be located in one of the two categories, and not so much in between. This study should provide an opportunity to find out whether there are building designs that fill the gap between the two extremes [51]. We use three essential aspects of natural ventilation to describe and classify various concepts. The first aspect is the natural force utilized to drive the ventilation. The driving force can be wind, buoyancy or a combination of both. The second aspect is the ventilation principle used to exploit the natural driving forces to ventilate a space. This can be done by single-sided ventilation, cross ventilation, or stack ventilation.

In the first aspect, windows can only be opened on one side of the room. The amount of fresh air coming into the room is limited by single-sided ventilation. It is recommended that the depth of the room should not exceed 2.5 times the clear height of the room and that the space is not used for meeting rooms, classrooms or similar [16, 27]. This type of natural ventilation has a weak performance. In the second aspect, windows located in two or more facades can create cross-ventilation of the room. The ventilation is powered primarily by the wind, which creates differences in wind pressure on the facades in which the window openings are located. As a principle rule, cross-ventilation can be used effectively when the depth of the room is up to 5 times the clear height of the room [32, 52]. This method provides a good natural ventilation performance. The third aspect is the characteristic ventilation element used to realize natural ventilation. Stack-ventilation occurs when there is a height difference between windows, between facade and roof opening. This type of ventilation is primarily driven by warm air rising to the top creating a pressure difference (Bernoulli principles) which drives the ventilation. The best effect is obtained when the openings for Natural Ventilation are placed so that the wind pressure contributes to an increase in the driving pressure [32, 53, 54].

4.2. Site, Massing, and Orientation for Wind Ventilation

The building geometry i.e. form, height and size of a structure plays a significant role for using the wind cooling [55]. Wind is one of the most important parameters for the passive design buildings (PDB). Commonly, the design of the envelope and building orientation with architectural considerations has a significant role in reducing and increasing the flow of wind [56]. Wind provides natural ventilation and usually cools buildings and habitants because it accelerates the rate of heat transfer. Wind speed and direction is changed throughout the day and year, and are not as universally predictable parameter.

Natural ventilation, also called passive ventilation, uses outside natural air movement and pressure differences to both passively cool and ventilate a building. Natural ventilation is important because it can provide and move fresh air without fans. For warm and hot climates, it can help meet a building's cooling loads without using mechanical air conditioning systems. This can be a large fraction of a building's total energy efficiency. To measure the effectiveness of ventilation, both the volume and speed of the airflow can be measured [52, 56, 57]. The volume of the airflow is important since it dictates the rate at which stale air can be replaced by fresh air as well as determines how much heat the space gains or losses as a result. The volume of airflow due to wind as Equation 1.

$$Q_{wind} = K \times A \times V \tag{1}$$

Referring to ASHRAE 55 for thermal comfort guidelines regarding air speeds for interior spaces, the standard suggests that air speeds appropriate for indoor environments do not exceed 0.2 m/s or 0.447 mph. ASHRAE also accounts for elevated air speeds that will increase the acceptable temperature. The maximum allowable elevated airspeed is 1.5 m/s or 3.579 mph. Massing and orientation are two important design factors to consider passive cooling, specifically, natural ventilation. As a general rule in passive cooling, the buildings will encourage natural ventilation and utilize prevailing winds, cross ventilation, and stack effect. Thinner buildings increase the ratio of surface area to volume. This will make utilizing natural ventilation for passive cooling easy [58-60].Conversely, a deep floor plan will make natural ventilation difficult - especially getting air into the core of the building - and may require mechanical ventilation. Tall buildings also increase the effectiveness of natural ventilation, because wind speeds are faster at greater heights. This improves not only cross ventilation but also stack effect ventilation. Generally, orienting the building so that its shorter axis aligns with prevailing winds will provide the most wind ventilation, while orienting it perpendicular to prevailing winds will provide the least passive ventilation. Passive solar building design can be described as the utilization of the sun's energy together with local climate characteristics and selected building materials to directly maintain thermally comfortable conditions within a built-environment [61].

4.3. Apertures for Cooling (Opening Shape, Size and Types)

The simple act of opening a window can often provide immediate cooling effects. But how do the size and placement of that window impact the effect you feel? Window design and ventilation louver design greatly affects passive cooling potential, specifically natural ventilation. Be sure to visit the wind, stack, and purge ventilation pages to learn more about more specific opening strategies. Opening shape matters and can influence airflow effectiveness. Long horizontal strip windows can ventilate a space more evenly. Tall windows with openings at top and bottom can use convection as well as outside breezes to pull hot air out the top of the room while supplying cool air at the bottom. Window or louver size can affect both the amount of air and its speed. For an adequate amount of air, one rule of thumb states that the area of operable windows or louvers should be 20% or more of the floor area, with the area of inlet openings roughly matching the area of outlets. Windows that only open halfway, such as double-hung and sliding windows, are only half as effective for ventilation as they are for daylight. Some casement windows and Jalousie windows, however, can open so wide that effectively their entire area is useful for ventilation [62, 65].

5. Case Study

5.1. Rasht Climate Indicators

Rasht is the capital of Gilan province on the northern front of Iran. Because of high humidity, temperature fluctuations in the day and night are low, and usually the summer will be somewhat wetter than in the winter. Another feature of the climate in Rasht is the equal distribution of rain during the year. In Rasht, the month of August is the hottest month while February is the coldest month of the year. The highest summer temperatures are +36°C scale and the lowest in winter is +3°C scale. According to the statistics published by the Meteorological Organization, the average rainfall is 135 days and the daily precipitation is 10 mm or more. The average relative humidity recorded from 2007 to 2017 was 80.9%. The wind speed is rising in the summer, rising again in the autumn. Establishment of high buildings in the Direction of wind flow is non-scientific; because it prevents the flow of air within the city. The average annual wind speed in Rasht is 1.7 m/s. Geographical information and climatic parameters of Rasht are shown in Table 3. Moreover, Figure 2 shows the temperature range and sun chart for Rasht.

Table 3. The geographical positions and climatic parameters during 2007-2017

Station	Latitude (°)	Longitude (°)	WMO	ASHRAE climate zone	Mean Temp. (°C)	Max mean Temp. (°C)	Wind speed (m/s)	Rainfall (mm)
Rasht	37.25 N	49.6 E	407190	3B	16.2	22.4	1.7	1314

(a) (b)

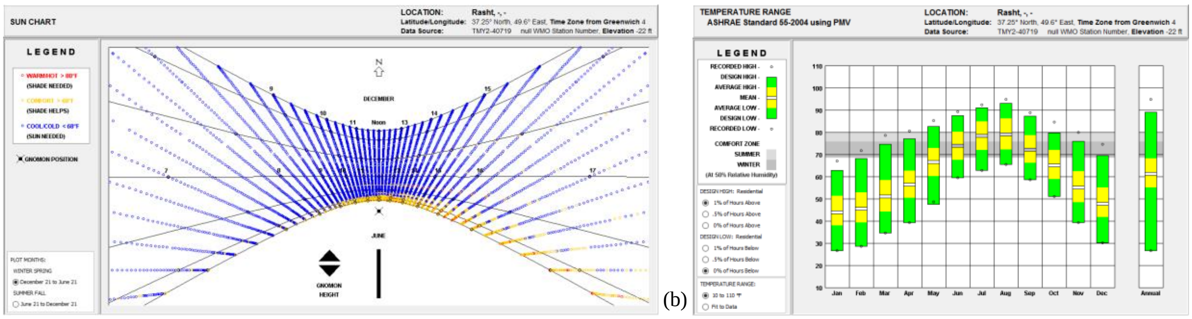


Figure 2. (a) Temperature range; (b) and Sun chart for Rasht (Outputs plotted as Climate Consultant Software)

Wind is one of the vector qualities with two features: direction and speed. If the temperature of air and ground is the same in all parts, there was no reason to move air and produce wind. The main cause is difference between different parts of the Earth's temperature which is emerged due to the angle of inclination of the earth relative to the sun [16]. The Statistical information of wind during the last five years is shown in Table 4.

Table 4. Statistical information of wind

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Year 1-12
Dominant wind direction	◄	◄	◄	◄	◄	▼	▼	▼	▼	◄	◄	◄	◄
Wind probability > = 4 Beaufort (%)	10	6	6	4	3	2	2	1	1	5	4	3	3
Average Wind speed (kts)	6	6	6	6	6	6	6	6	5	6	5	5	5

Wind direction in the direction from which the wind blows. To determine the wind direction, a page named wind rose was prepared. Then wind rose in 2017 along with its annual positions are demonstrated in Figure 3.

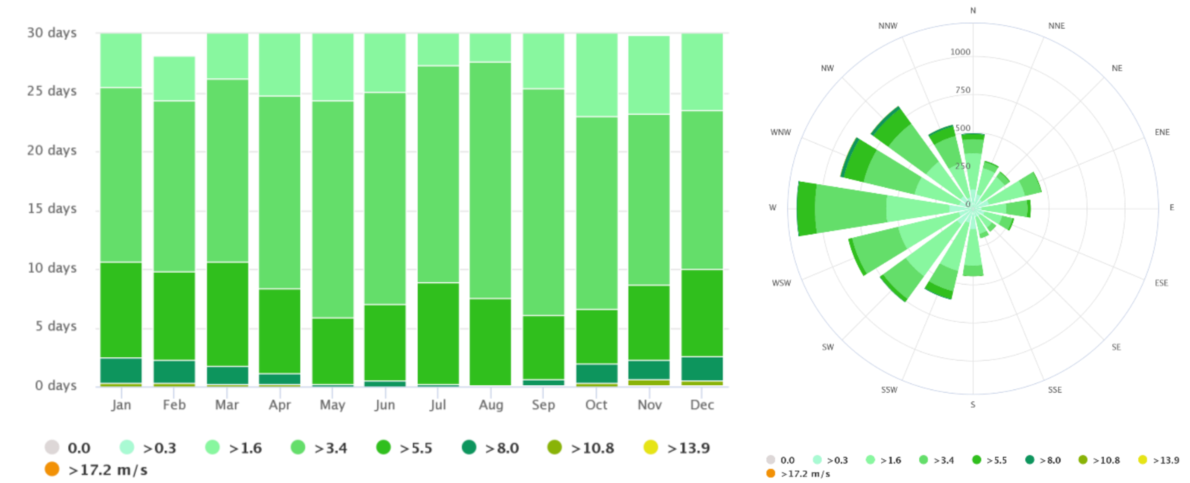


Figure 3. Wind speed and wind rose for Rasht

According to Figure 3, wind rose diagram shows how many days within one month can be expected to reach certain wind speeds for Rasht. The wind rose for Rasht shows how many hours per year the wind blows from the indicated direction.

5.2. Abrishami House

This house is located on the southeastern side of the Seyghalan square and at the end of the Shaeri alley with the position of 37.280695° N and 49.594558° E. The area of the enclosure and the building about 2000 m^2 and the basement area is 650 m^2. The main building has two floors and each floor has 8 spaces. The height of the first floor is 3m and the height of the second floor is 3.44m. Figure 4 shows the location of Abrishami house in the map.

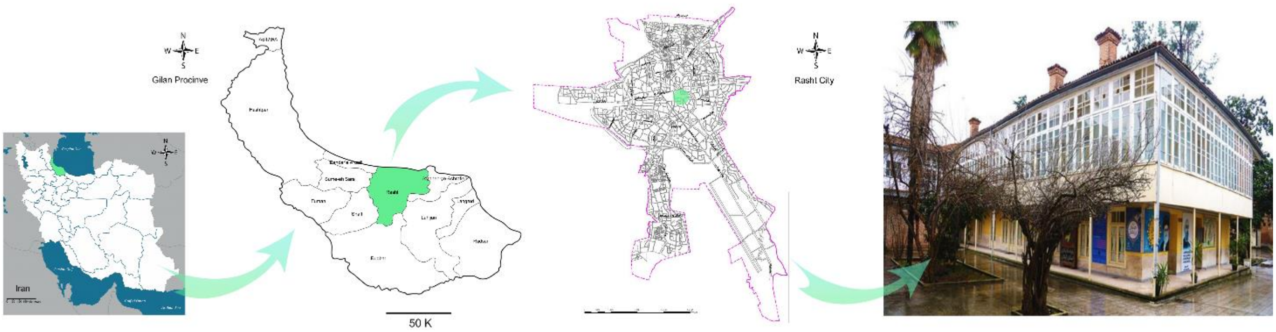


Figure 4. Case study location in map

In the following, the ground floor main plan and southeast elevation can be observed in Figure 5. Dimensions in plan and facade are matched with actual specifications on exited building. Extra information on openings proportions can also be extracted from Table 5.

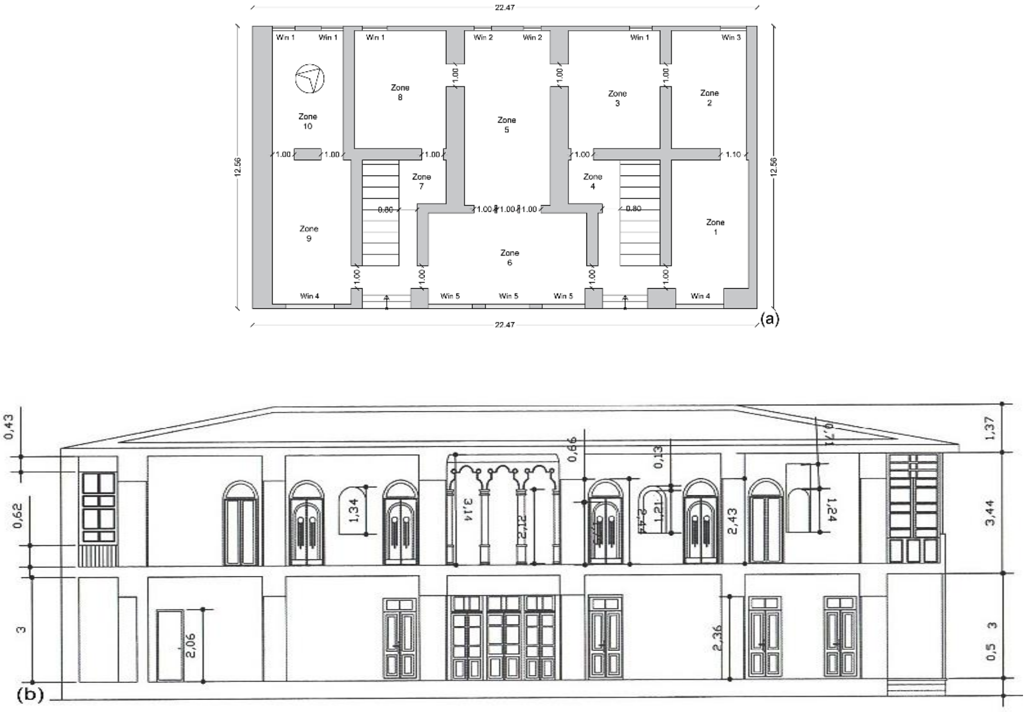


Figure 5. Abrishami house main plan (ground floor) and elevation (southeast)

Table 5. Openings dimension

	Win 1	Win 2	Win 3	Win 4	Win 5
Width	100 cm	80 cm	115 cm	215 cm	190 cm
Height	160 cm	160 cm	160 cm	160 cm	160 cm
O.K.B	50 cm	50 cm	50 cm	50 cm	50 cm

Also, Figure 6 shows two proposed plans that have an L-shaped section added to the northwest and southwest faces.

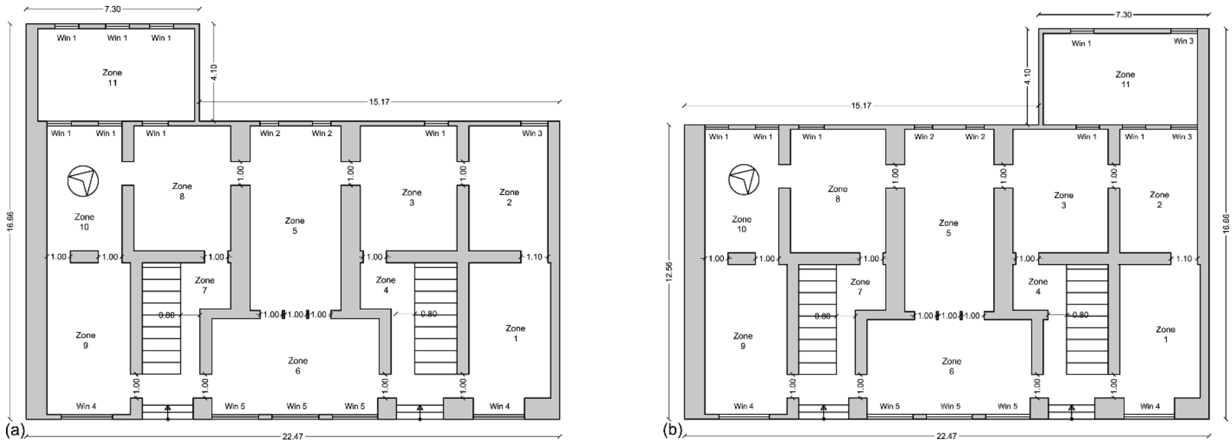


Figure 6. The proposed plan for Abrishami house

6. Results and Discussion

6.1. Evaluation in Real Condition

This simulation is done only on the ground floor because the wind speed in urban environment is low near the ground or at the pedestrian level. For this purpose, the proposed plans for the ground floor are intended to bring the natural air flows conditioning to the highest level at near the ground. Indeed, this paper investigates the impact of cross-ventilation using integration into the building. Based in Rasht weather statistics reported during 10 years, the prevailing wind speed has was 9.8 m/s and the average wind speed is 1.7 m/s. Therefore, due to fluctuations in speed, the average wind velocity was considered as 5 m/s. Simulations were initially performed on the ground floor plan with actual building specifications. Figure 7 shows the information obtained from the stimulation of the first step.

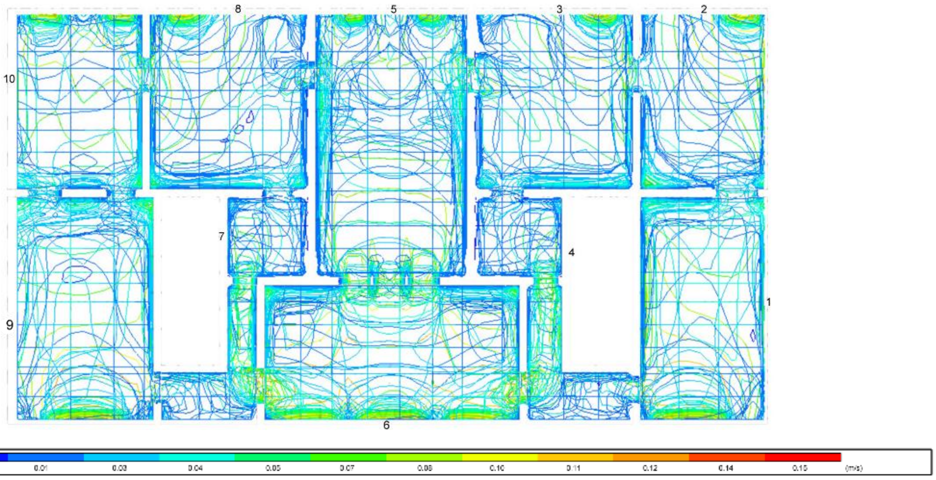


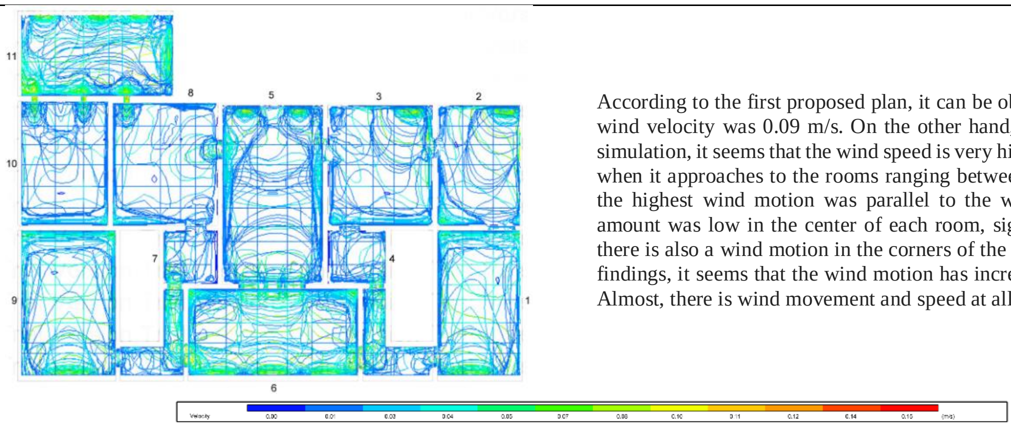
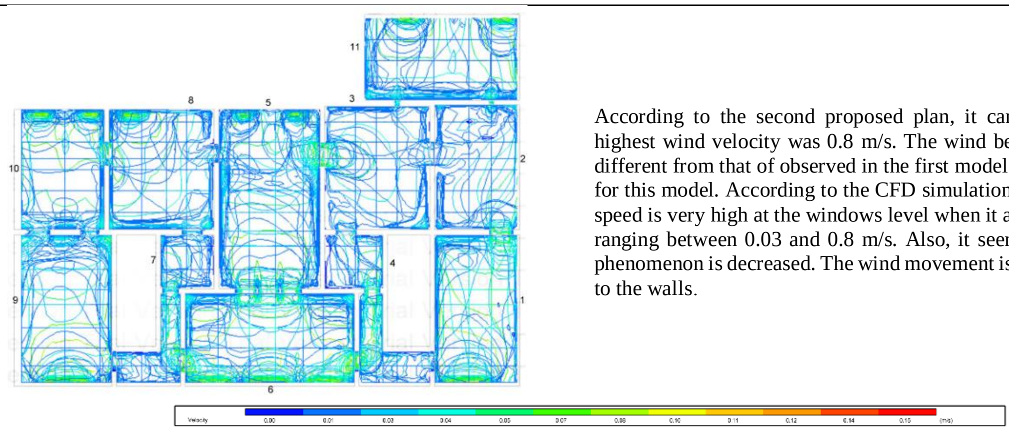
Figure 7. The Current wind speed and flows in first step (ground floor plan)

From the Figure 7, it can be observed that the highest wind speed was 0.16 m/s. On the other hand, according to the CFD simulation, the wind speed at the entrance to the rooms seems to be high at the windows level so that it ranges between 0.12 and 0.16 m/s. The highest wind flow rate was parallel to the wall surface, and this amount was far lower in the center of each zone. In addition, there is also a wind motion in the corners of the zone.

6.2. Design Recommendation Based on CFD Simulations

In the first proposed plan, a room was added to the main plan. In this case, the plan is reformed from the of the rectangle shape to L one (Table 6). The reason for suggesting this form was also to increase the wall surface against the wind [54]. When wind hits the face of the building (in this paper 45°), the flow is divaricated and diverted into several streams so that the orientation and number depend on the angle of wind incidence relative to building edges and the "flatness" of the upwind building surface as well.

Table 6. Proposed plans based on mail plan

First proposed plan	**Description**
	According to the first proposed plan, it can be observed that the highest wind velocity was 0.09 m/s. On the other hand, according to the CFD simulation, it seems that the wind speed is very high at the windows level when it approaches to the rooms ranging between 0.3 to 0.9 m/s. Also, the highest wind motion was parallel to the wall surfaces while this amount was low in the center of each room, significantly. In addition, there is also a wind motion in the corners of the room. According to the findings, it seems that the wind motion has increased within the rooms. Almost, there is wind movement and speed at all levels of the room.
Second proposed plan	Description
	According to the second proposed plan, it can be observed that the highest wind velocity was 0.8 m/s. The wind behavior in this model is different from that of observed in the first model. There is no clear order for this model. According to the CFD simulation, it seems that the wind speed is very high at the windows level when it approaches to the rooms ranging between 0.03 and 0.8 m/s. Also, it seems the wind turbulence phenomenon is decreased. The wind movement is more visible in parallel to the walls.

6.3. Wind Behavior in Ground Floor Plan

- Zone 1: The wind speed is almost uniform throughout the room. When it approaches the other openings (door), it has a higher velocity (suction). Also wind speed in the corners is more than it in the centre of zones compared to other points.
- Zone 2: The wind speed in this room varies from 0.01 to 0.05 m/s. From the corner of the room toward the upper section, it has a turbulent motion with speed of 0.08 m/s.
- Zone 3: The wind speed in this room varies from 0.01 to 0.04 m/s. It has higher values in the corners of the room and wall surfaces as well as when it is exiting the room equalled to 0.05 m/s.
- Zone 4: The wind speed in this room is distributed uniformly due to low area of this room. The wind speed is varied from 0.01 to 0.04 m/s. This value reaches to 0.05 m/s in suction conditions.
- Zone 5: It seems the wind has travelled 2.3 meters when it entered the room due to extensive shape of space. In top section during depletion from 3 openings, the wind us almost static. The wind speed is observed between 0.01 to 0.07 m/s. This value reaches to 0.08 m/s in suction conditions on wall surfaces.
- Zone 6: This room has a higher wind speed due to the high number of openings, with a maximum and minimum values of 0.01 to 0.12 m/s. It has the lowest amount in the centre of the room and the highest value in the corners and suction condition areas. The two corridors connecting zones 4 and 7 to zone 6 experienced large suction and had a speed of 0.08 to 0.10 m / s. Zone 7: The low area of the room had distributed the wind throughout all surfaces uniformly;. The wind speed ranges from 0.01 to 0.03, this amount is approaching to 0.05 m/s in suction condition.
- Zone 8: The wind speed in this room is varied between 0.01 and 0.04 m/s; in the corners and wall surfaces as well as when the wind exits the room, the wind is faster, equalled to 0.05 m/s.
- Zone 9: Due to the rectangular shape of this room, it can be stated that the wind has travelled approximately 40 percent of the room's length at a speed of 0.11 m/s and the lowest wind speed is 0.01 m/s.
- Zone 10: It seems that the wind has the least movement in this room compared to other rooms. The wind speed in this room is ranged between 0.01 and 0.05 m/s.

6.4. Wind Behavior in First Proposed Plan

- Zone 1: The wind speed in this room is ranged between 0.01 and 0.08 m/s. The wind movement is visible throughout the room and there is also air circulation in the middle section of the room. The wind has higher speed in the corner of the room. The wind speed is even. On the other hand, it seems there is a turbulent motion in the centre of the room.
- Zone 2: The average wind speed in this room is about 0.06 m/s. The wind has a low velocity in the opening region of the room (door) while its speed has increased in corners and centre of the room.
- Zone 3: In this room, since there are several openings, the wind movement is almost uniform and its speed is ranged between 0.02 to 0.09 m/s. The wind speed has increased in the corners and in parallel with the rooms.
- Zone 4: This room has low area compared to other rooms. The lower corridor was able to enter the required speed and motion due to its extension. The lowest wind speed is 0.04 m/s.
- Zone 5: There is the symmetry of wind phenomenon in this room. This is because the room has the same openings in each direction. The average wind speed is about 0.07 m/s.
- Zone 6: In Zone 6, due to its extension and presence of multiple openings, it was observed that there is a good wind speed and symmetry of the wind has occurred. The average wind speed in this room is about 0.05 m/s.
- Zone 7: The wind flow can be observed in all parts of the room due to its small area. The wind speed here is between 0.02 and 0.05 m/s, and it has high suction when it enters to the inside.
- Zone 8: This room has a low wind motion compared to other rooms. Only in the entrance part of the room, the higher velocity ranged from 0.02 to 0.05 was observed due to the pressure differences. In addition, the wind has a smaller motion in the centre of the room.
- Zone 9: The average wind speed in this room is about 0.07 m/s. The wind speed is increased in parallel with the walls, and proper wind speed is also seen in the centre of the room.
- Zone 10: Zone 10 has lower wind speed and wind movement than other rooms like to Zone 8. The average speed of the wind is about 0.04 m/s. The wind speed has increased in parallel to the walls.

- Zone 11: This room has the highest speed and wind motion compared to other rooms. It is observed that there is a wind motion in the whole room. The average wind speed here is about 0.08 m/s.

6.5. Wind Behavior in Second Proposed Plan

- Zone 1: The average wind speed in this room is 0.04 m/s. The wind motion is observed in the corners and it has the highest velocity when the wind enters the room through the opening.
- Zone 2: It seem that in this room, the wind motion is very slow and linear, and it has less speed than other rooms. But it has proper movement due to presence of opening on each side.
- Zone 3: The wind speed in this room is slightly higher than room 2 and the wind is faster when it enters room due to pressure differences. The average wind speed is 0.03 m/s.
- Zone 4: The wind moves throughout this room due to its low area. Also, it has suitable speed inside the room due to its bottom corridor and suction as well as pressure.
- Zone 5: Because there are a multiple openings in this room, the wind motion around the entire room can be observed. There are also turbulence phenomena in the front section of the room in parallel with the rooms.
- Zone 6: The room has suitable for wind speeds and proper wind motion throughout the room due to its aspects. The wind speed at the entrance and exit on the opening surfaces is greater and equalled to 0.07 m/s.
- Zone 7: The behaviour of the wind in this room is like Zone 4. Only the type of winding is slightly different and the wind moves throughout the room.
- Zone 8: The speed and motion of the wind dropped in this room again. The wind motion has been lowered in the lower part of the room while wind motion is faster in the upper part due to openings.
- Zone 9: In this room, the speed and motion of the wind are parallel to the walls. There is almost little wind in the centre of the room. The wind motion is more in the upper part of the room than the other parts.
- Zone 10: The wind behaviour in this room is like Zone 9. The average wind speed here is about 0.04 m/s.
- Zone 11: In this room, there is very little wind motion in the middle section of the room, and the speed and movement are just opposite of the openings. Especially at the lower wall surface. The average wind speed is about 0.05 m/s.

7. Conclusion

By studying literature, it was found out that the traditional vernacular architecture has taught us the best way of sustainable architecture and ecologically sensitive adaptation, using passive features ranging from building orientation and form, appropriately sized and oriented openings linked with vertical forms, the benefits of local materials and mass for night cooling, and the relationship of buildings in context to ensure effective air flows. Also similar result of CFD simulation shows that the natural ventilation and building form have a logical connection. Further, with regard to conducted simulation, it was observed that in all three cases, how shape can affects the shape and velocity of the wind flow inside the building. In general, the wind speed was higher in the original building than both proposed plans. Similarly, the phenomenon of wind turbulence has been less observed in the original plan. In the first proposed plan, by adding a form to the building in the southwest side, the velocity and pattern of wind flow are better than the second proposed form. Also, in the first proposed plan, in all rooms, the wind was non-uniformly repeated while this phenomenon was not seen in the second plan. It is worth to note that in the first proposed plan, compared to the second proposed form, there may be wind whirled in all parts of the room, but its velocity is lower compared to the second form. The results of this study showed that if the rectangular form is turned into an L shape, it can offer a better flow pattern for wind in all rooms, but the speed will be reduced. One reasons may be that the addition of a room may result to divide the amount of wind in each room and reduce its speed. So it could either reduce the number of rooms or use openings in other walls. Since the use of wind as a passive cooling system is very important in wet climates, it is suggested that more studies should be done on this issue in future researches.

8. Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this manuscript.

9. Nomenclature

IAQ	Indoor Air Quality	Q_{wind}	Airflow volumetric rate (m^3/h)
A	Opening area, of smaller opening (m^2)	K	Coefficient of effectiveness
E	East	N	North

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