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Analysis of Wind Behavior in Natural Ventilation and Reduction of Energy Consumption in Residential Building Based on Vernacular Architecture: A Case Study of Effects of Dimensions and Layout of Opening on Natural Ventilation in Amol City, Iran

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ABSTRACT

The increased average of non-renewable energy consumption in the residential sector and not using the passive techniques, which are often based on the vernacular architecture concepts and principles and climate, have led to energy waste and increased costs. Due to humidity and excessive heat in summer at noon, Amol exceeds the thermal comfort and needs natural ventilation. The current study aims to study the effect of dimensions and layout of the opening on the natural ventilation and reduction of energy consumption. First, reviewing the research background, natural ventilation was determined as the main component of the building design in this climate, and the operational principles of the stated component were extracted using Climate Consultant. Among the operational principles, the value of the opening area was determined as the main criterion of the climate design using the AHP method. With simulating a one-story residential building with an area of 75 square meters in Amol's climate in Envi-Met software and inputting climate information obtained from Climate Consultant analysis in Envi-met, the wind direction was north and north-western. The building understudy was simulated in Design Builder software. By comparing the window to surface percentage ratio and annual energy consumption, the ratio of 30% with the minimum energy consumption equivalent to 6839.87 kwh was considered the criterion for studying the opening effect. Windows of the residential building were considered as three parts to study the effect of the opening dimensions. In northern and southern sides where one-third of the window was closed, the minimum energy consumption value as the total of thermal and cooling loads was 7298.93 kwh, indicating the effects of the dimensions of the opening in the natural ventilation of the building in the humid and moderate climate.

Keywords: Natural Ventilation, Vernacular Architecture, Thermal Comfort, Simulating Energy Consumption, Opening.

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1. INTRODUCTION

With increased energy prices from 1970 to 1980 in most parts of the world, engineers intended to build energy-efficient houses (Ghiasi, Golkar, & Hajizadeh, 2015, p. 25). The average energy consumption in the residential sector in Iran is more than 40% of the total energy consumption of this country, which is more than the global average energy consumption in the residential sector. This value is also approximately ten times more than the advanced countries in energy, such as the United States of America and some European countries (Zakeri, Gorji, & Hosseinzadeh, 2014, p. 2). Enhancing the energy efficiency of the buildings could reduce the annual consumption in the residential sector and decrease the energy costs of the households. There are two general approaches for optimal energy consumption: passive and active techniques. The passive techniques include simpler and non-mechanical approaches. However, active techniques require more advanced technologies. Some of the passive approaches require active participation, such as opening and closing the windows or creating ventilation, while some of the fully active approaches (such as photovoltaic planes or automated lighting control) do not need human intervention (Rahnama, 2017, p. 43).

The increased average of non-renewable energy consumption in the residential sector and not using the passive techniques, which are usually based on principles and concepts of the vernacular architecture and climate, led to energy waste and increased costs. Thus, the research question is to what extent is the effect of opening dimensions on building surfaces influential in energy saving in buildings in a moderate and humid climate? The current research was conducted based on this question. Using a maximum number of the opening in two sides of the building that are windward and leeward leads to ventilation and saving in energy consumption, was the research hypothesis.

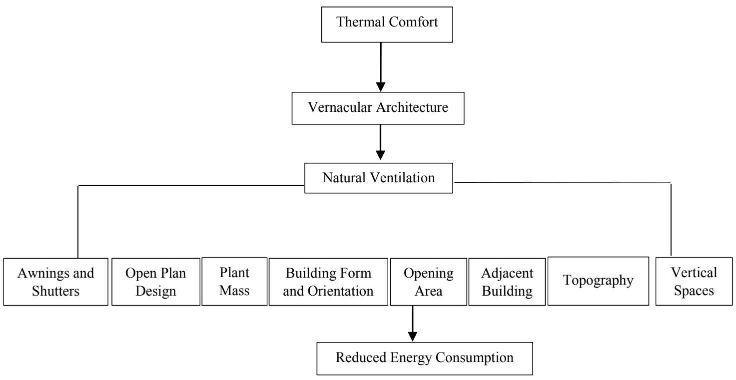


Fig. 1. Reducing Energy Consumption through Thermal Comfort

2. LITERATURE REVIEW

Environmental comfort is one of the essential components of the human-built environments; because for living and dwelling, the house must enjoy attributes and advantages to make the dwelling and living desirable and comfortable. According to the research, the criteria of the environmental comfort are as follows: 1) thermal comfort, including the components: weather, thermal control, air quality and pollutants, natural and artificial ventilation, space capacity; 2) visual comfort; light and color quality and density, spaces with windows, privacy with the possibility to have a view to the surrounding, close contact with nature; 3) audio comfort; noise and sound insulation requirements, location, and spatial density (Taher Tolou Del & Aminifar, 2016, p. 5).

2.1. Thermal Comfort

Thermal comfort has different meanings. ASHRAE considers thermal comfort the mental conditions that express the people's satisfaction level with the temperature of the environment (Hejazizadeh & Karbalaei Dori, 2015, p. 46). Thermal comfort in an environment depends on the balance between the human and the thermal environment. When people state about feeling warm or hot, they assess the amount of heat energy they gave from the body to the environment and the quality of the air. The main factors in these assessments are temperature, relative humidity, airflow, and air quality. The research background shows that in recent years, extensive studies have been done on evaluating thermal comfort around the world (Pourdihimi, 2011, p. 68). In this regard, a paper in Lahijan Azad University evaluated the reduction of energy consumption in a residential building according to the optimal orientation and percentage of openings in Anzali by placing the building at zero angle and rotations of 10 degrees clockwise in each analysis up to 360-degree rotation. Then, it examined the optimal area of the window to the facade of the building from zero to 100% ratio of openings to the facade. Finally, the results of the energy consumption of the heating and cooling, and lighting were recorded, indicating the desirability of the window area of 50% in the northern facade and 60% in the southern façade (Rasti & Roshan, 2017, p. 91).

2.2. Climate and Site

Mazandaran province, with an area of 23756.4 square meters, is approximately 1.46 km out of the total area of Iran. Amol County is the middle district of Mazandaran province with an area of 2910.1 square kilometers, which has 12% of the total area of the province. Geographically, the Amol region consists of three climate zones of plains, foothills, and mountainous. In the plain region, the temperature difference is low at night and day and seasons of the year. However, in the mountainous region, as the altitude increases, the weather becomes cold (Mahmoudi pati, Nikpoor, & Mahmoudi, 2016, p. 5).

2.3. Characteristics of the Vernacular Architecture in the Moderate and Humid Regions

These regions, which include the coasts of the Caspian Sea and the northern hillsides of Alborz Mountain, generally have the following characteristics:
1. In extremely humid areas near the coast, houses are built on wooden foundations to protect the building from excessive moisture. However, in the foothills where the humidity is less, the houses are usually built on stone and mud foundations as the crawl space.
2. The wide and covered porches were built around the rooms to protect them from the rain. These spaces are used to work and rest and sometimes store crops in many months of the year.
3. Most buildings were constructed using materials with minimum thermal capacity. In the case of using heavy construction materials, their thickness is kept to a minimum (it is better to use light materials in these regions. When the daily temperature fluctuation is less, the heat storage does not make sense. Also, the heavy materials significantly reduce ventilation and circulation, which is one of the necessities in this region.
4. Natural ventilation and circulation are used in all buildings of these regions. Generally, the open and extensive plans and their physical forms are mostly geometrical long and narrow shapes. To maximum use of the wind flows in creating the natural ventilation inside the room, the orientation of the building was determined based on the direction of the sea breezes. In regions where the intense and long-term winds blow, the windward parts of the building are fully closed. Also, the buildings were organized as decentralized and scattered in the complex due to the abundance of water and the possibility of access to it anywhere.
5. Due to the heavy rainfall in these regions, the roofs have steep slopes (Kasmaei, 2012, p. 80).

3. RESEARCH METHOD

First, the components affecting the natural ventilation of the building in the moderate and humid climate presented in Table 1 were obtained by the library and document studies. Then, using the survey method, a researcher-made questionnaire containing the stated components was distributed among 15 professors in architecture and energy departments to determine the most influential component in natural ventilation. The main component was extracted using the Analytic Hierarchy Process method. Then, the climate data of the region, the comfort zone, and the critical conditions were analyzed using the EPW file in Climate Consultant software. By inputting the climatic information extracted from the Climate Consultant in the Climate Information section of Envi-Met software, a residential building with an area of 75 square meters in Amol city, on the 22nd of June 2018, the wind speed and direction around the residential building in Envi-met software were simulated. In the following, the energy consumption was analyzed in different situations by simulating the stated building in Design Builder software, considering the best layout of the opening and the results of Envi-met and its lot coverage. Finally, the obtained results were presented in a table. Table 2 shows the results of the analysis of the experts' questionnaire in AHP software.

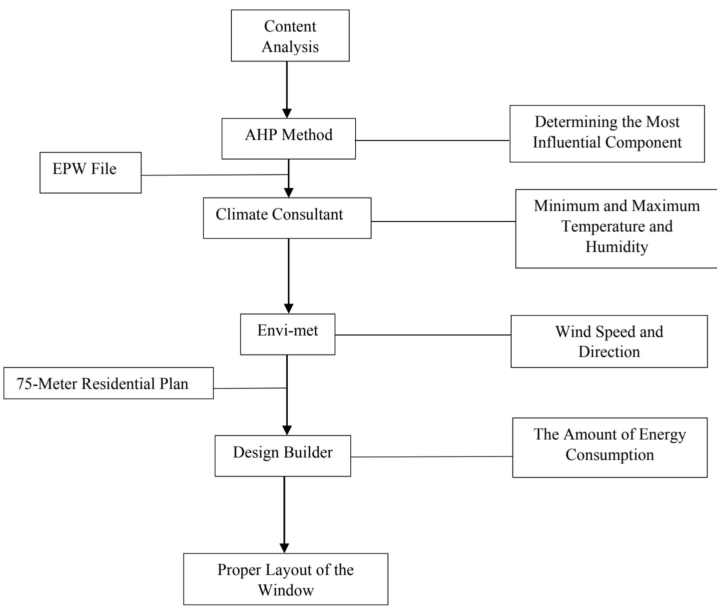
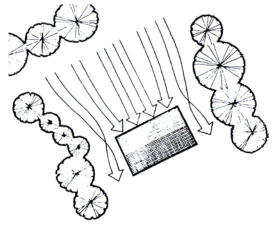
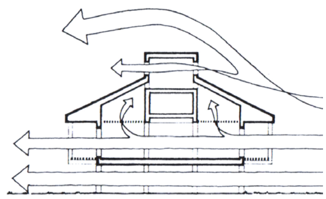
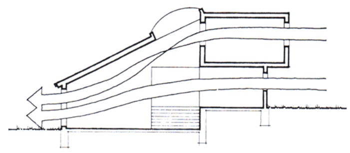
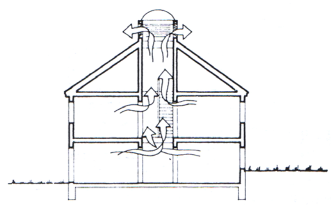
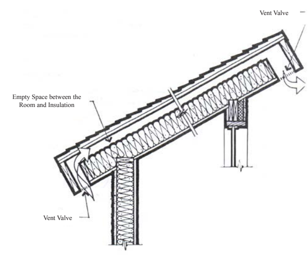
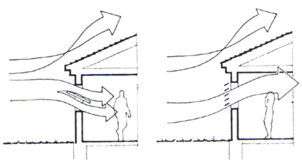
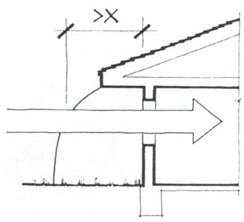
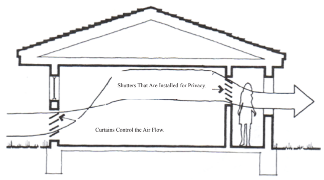


Fig. 2. Scrutinizing Research

Table 1. Effective Components in Natural Ventilation (Summer)

Row	Executive Principles	Images of Executive Principles
1	Using Topography, Adjacent Buildings, and Plants to Use the Summer Breeze More	
2	Shaping and Orienting the Building for the Maximum Use of the Summer Breeze	
3	Designing an Open Plan to Use the Natural Ventilation	
4	Creating Vertical Space for Natural Ventilation and Using a Roof Ventilator for the Vertical Ventilation of the Air.	
5	Using Cavity Wall and Roof for the Ventilation Inside the Building.	
6	Doors and Windows Should Be Installed in a Direction So that Summer Breezes Can Enter Easily.	
7	Additional Walls, Projections, and Shutters Must Be Used to Direct the Summer Winds Inside the Building.	
8	Using Shutter to Control the Flow of the Air Ventilation.	

(Ghobadian & Feiz Mahdavi, 2013, p. 12)

According to Table 2, an opening area with the maximum air circulation index was determined as the most influential factor in the natural ventilation among the components. To this end, the location of the window and its effect on the natural ventilation were studied. The most important factor in creating influential ventilation conditions is that the openings must be windward and leeward. The conducted studies and experiments in recent two decades show that the best ventilation occurs when the wind direction to the window is oblique. In cases where the wind blows obliquely to the window surface, increasing the size of the window increases the speed of the air inside the room; If the leeward window is larger than the windward window, the maximum and average indoor airflow velocity will be greatly increased (Foroughian & Taheri ShahrAyini, 2015, p. 4).

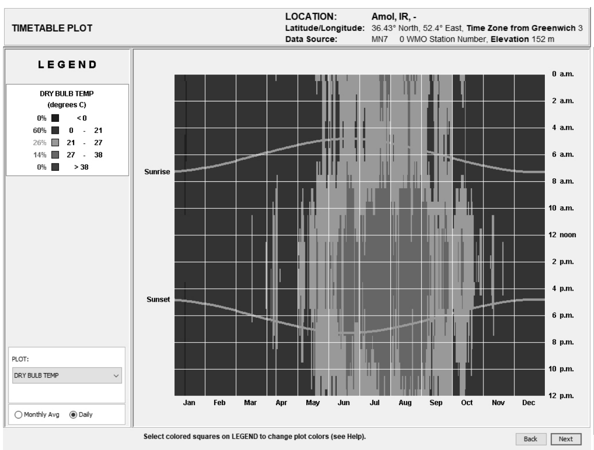
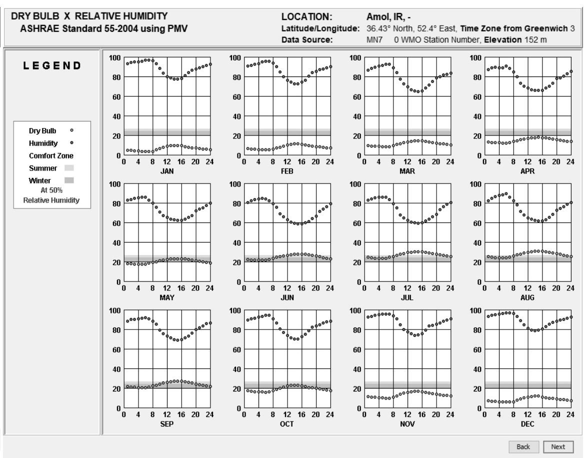
Table 2. The Weight of the Influential Components on the Natural Ventilation

Row	Influential Components in Natural Ventilation	Air Circulation Index (0.6)	Decreased Humidity Index (0.4)	Final Average (0.5)	Unification
1	Using Topography	0.105837	0.027473	0.066655	0.133309
2	Adjacent Buildings	0.046016	0.041758	0.043887	0.087774
3	Plant Mass	0.044099	0.042308	0.043203	0.086406
4	Shaping and Orienting the Building	0.043445	0.041209	0.041772	0.083543
5	Opening Area	0.176394	0.023626	0.10001	0.200021
6	Vertical Spaces for Ventilation	0.00882	0.054396	0.031608	0.063215
7	Designing Open Plan	0.070558	0.03022	0.050389	0.100778
8	Shade and Shutter	0.062257	0.035714	0.048986	0.097971

3.1. Climate Consultant Outputs

In recent years, various software was developed to simulate and statistical calculation of the climate information. Climate Consultant is to analyze the climate information of the region. To obtain the wind direction in the study region and analyze the opening area in the software after importing the EPW file of Amol city with coordinates (Latitude / Longitude: 36.43 North, 52.4 East-Time Zone From Greenwich 3), station number 0 WMO, and 152 meters elevation above sea level for ten years from 2006 to 2016, Table 3 was obtained, including the diagram of isothermal points and the diagram of relative humidity and dry-bulb temperature, to analyze climatic conditions and prepare input information to Envi-met software.

Table 3. Climate Information Obtained From Climate Consultant Software

Isothermal Diagram	Diagram of Relative Humidity and Dry-Bulb Temperature
	
According to the isothermal diagram, from the later June to the mid-September, the temperature was in the range of 27-48 centigrade degrees from 8 A.M. to 6 P.M. indicating the temperature higher than the comfort zone, and it needs cooling.	Studying the maximum temperature and minimum temperature shows that air temperature is high from June to mid-September. Also, studying these months in the relative humidity diagram and dry-bulb temperature diagram, the humidity in these months is higher than 65% between 6 A.M. and 12 P.M. which exceeds the comfort zone and makes it difficult to breathe while it is essential to have the ventilation and cooling system when human is working.

3.2. Analyzing the Output of Envi-Met Software

To study the wind behavior and effect on the building using simulation in Envi-met software, the wind speed and direction were investigated in the study area. This software is applied to simulate the cross interactions of the surface, plant, air, and interior urban environments and analyzing the thermal comfort regime in micro scales. Table 4 shows the minimum and maximum temperature and humidity extracted from the relative humidity and isothermal diagrams presented in Table 3.

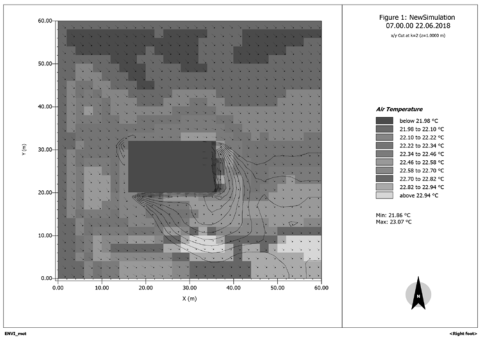
Table 4. Temperature and Humidity Information Inputted to Envi-Met Software

Temperature	Minimum		Maximum	
	06:00 A.M.	20.2	14:00 P.M.	27
Humidity	**Minimum**		**Maximum**	
	14:00 P.M.	69	06:00 A.M.	88

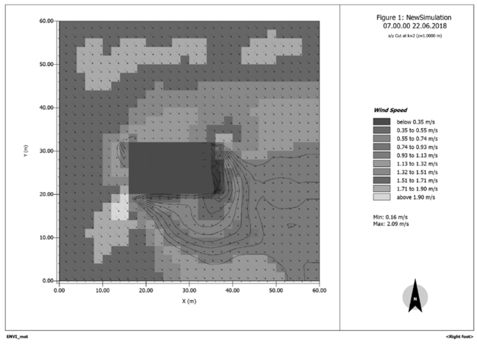
By simulating the one-story residential building with 75 square meter area in Envi-met and considering the environmental conditions of the study area, Vegetation: Betula Pendula, grass 25 cm Avar Dense and Soil and surface: Loamy soil, Asphalt road, on 22nd of June, the obtained analyzes were investigated to study the wind direction and speed accurately.

Table 5. Analyzes Obtained From Envi-Met Software

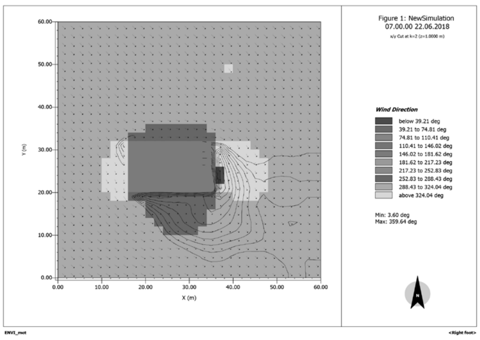
Analyzes Dated June 22, 2018



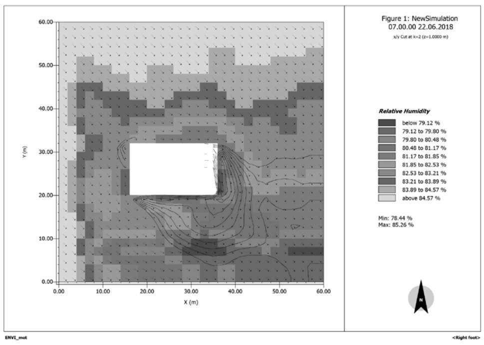
Analysis of Temperature
Minimum Temperature: 21.86 Centigrade Degree
Maximum Temperature: 23.07 Centigrade Degree



Analysis of Wind Speed
Minimum Speed: 0.16 M/S
Maximum Speed: 2.09 M/2



Analysis of Wind Direction
Prevailing Wind Direction: 288.69 Degrees To 324. 28 Degree



Analysis of the Relative Humidity
Minimum Relative Humidity: 78.44%
Maximum Relative Humidity: 85.26%

Analyses were obtained at 1-meter height from the ground in a 24-hours simulation on June 22, 2018. The wind direction is from north and northwest to the southeast, according to the analysis of the wind direction in Table 5. Considering the table of the principles of climate design in the moderate and humid region, a building with an area of 75 square meters was designed in Design-Builder based on the wind direction and speed.

3.3. Analysis of Opening Area in Design Builder

The validity of the Energy Plus software, which is the simulating engine of the Design builder, has been confirmed based on the Bestest and ASHRAE-14 standards. Airflow Network Modeling of the Energy plus Software was validated by comparing modeling results with a large series of high-quality laboratory measurements by the Oak Ridge National Laboratory and the Building Science Lab at the Florida Building Energy Lab. The separated zones in the software included two bedrooms, one bathroom and toilet, a living room, and a kitchen with furniture. The image of the plan understudy was presented in Figure 3. Since the height of the furniture is equal to the okb of the windows, it does not obstacle the air circulation in the interior space.

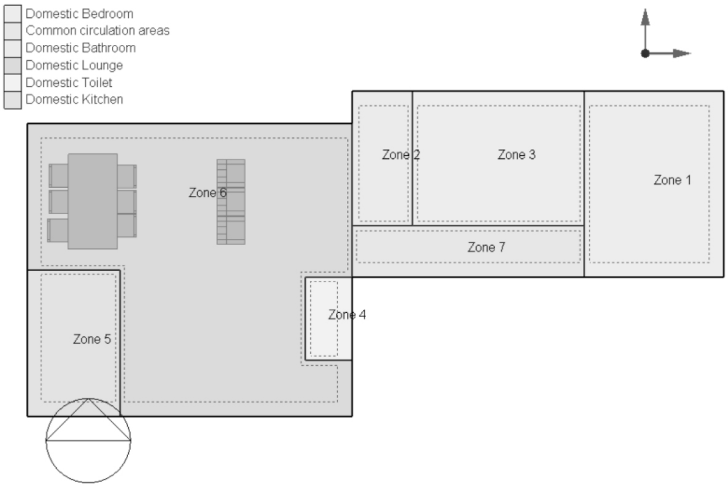


Fig. 3. The Analyzed Plan in Design Builder

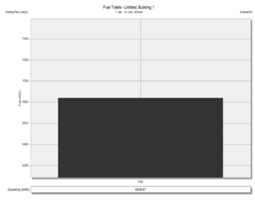
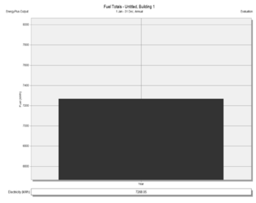
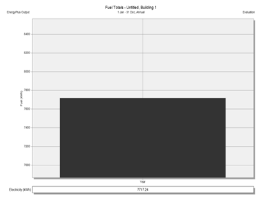
The input information in the software was presented in Table 6, considering the climate conditions of the region and the comfort terms for conducting simulation.

Table 6. Information of the Activity, Opening, Light, Mechanical Facilities, and Construction in Design Builder

	Activity	
Activity Pattern	Residential Spaces	
Environmental Control	Heating	20
	Heating Set Back	25.7
	Cooling	21.5
	Cooling Set Back	29
	Construction	
Airtightness	Constant Rate	0.7
	Opening	
Glazing Template	Dbl Clr 6mm/6mm Air	
Dimensions	Window to Wall (%)	30
	Window Height (M)	1.5
	Sill Height	0.8
Airflow Control Windows	Max Flowrate(M3/S-M)	0.008
	Lighting	
Lighting Template	Florescent Compact	
	Hvac	
Hvac Template	Split No Fresh Air	
Natural Ventilation	Outside Air Definition By Zone	

According to the research background, the window to wall ratio of 30-70 % for the moderate and humid climate is the best option for ventilation (Sohrabi, Ghadimi, & Haji Mollaali, 2018, p. 28). First, by comparing the three samples, the effect of increasing the window to wall ratio on the total fuel consumption was determined by simulating the stated building. In this case study, the more this ratio, the more the amount of fuel consumption. Also, the ratio with the minimum fuel consumption was considered a criterion to study the opening area. The dimensions of the opening must be in a way that the window has three parts. Also, five modes in the north-northwest and southern sides of the building were analyzed, and values of energy consumption were presented in the following tables. Five modes are as follows: all parts of the window are closed, one-third of the window is closed in two sides, two-thirds of the window is closed in two sides, one-third in the northern facade, two thirds in southern façade are closed, two-thirds is closed in the northern facade, and one-third is closed in the southern facade.

Table 7. Analyzing the Amount of Fuel Consumption in Design Builder

Fuels Totals			
Window/ Wall Ratio Percentage	30	40	50
Analysis Graph			
Fuel Consumption Amount	6839.87 Electricity (kwh)	7268.05 Electricity (kwh)	7717.24 electricity (kwh)

According to Table 8, the minimum amount of the energy consumption for cooling was in one-third of the windows to be closed in the first row, indicating the effect of the natural ventilation in reducing the cooling load in the building. On some days, due to the changes in the daily temperature and open windows and natural ventilation, it is required to study the thermal load through software analysis, which is conducted annually.

Table 8. The Consumption Amount of Cooling Load

Row	Modes of Opening	Separating Load Based on the Night and Day		Cooling Load (Kwh)
1	The Window is Fully Closed.	Day	3622.01	5587.69
		Night	1955.68	
2	Two-Third of the Windows Are Closed.	Day	3186.97	4903.02
		Night	1716.05	
3	One-Third of Windows Are Closed.	Day	2777.91	4273.7
		Night	1495.79	
4	One-Third of a Window in the Northern Façade and Two-Third of the Window in the Southern Façade Are Closed.	Day	2971.05	4570.84
		Night	1599.79	
5	Two-Third of the Window in the Northern Façade and One-Third of the Window in the Southern Façade Are Closed.	Day	2988.82	4598.18
		Night	1609.36	

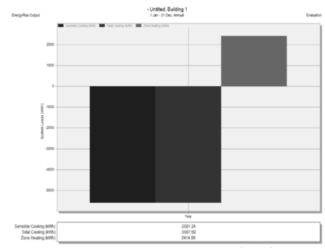
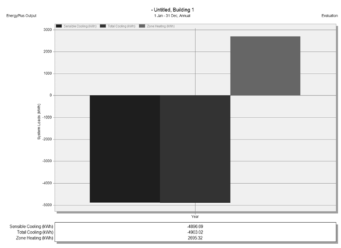
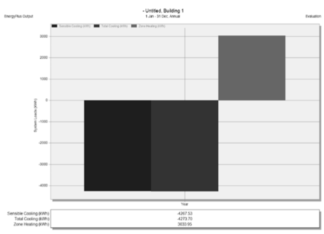
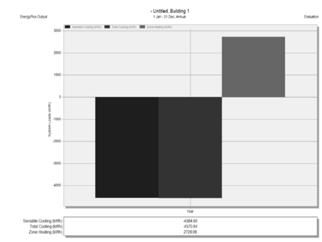
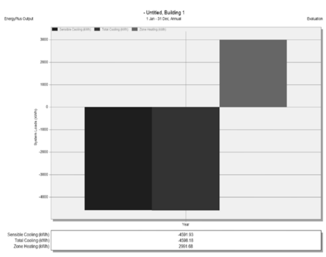
In Table 9, the minimum value of the heating energy consumption is when the window is fully closed. Total heating and cooling energy consumption were also analyzed for the conclusion.

Table 9. Amount of the Heating Energy Consumption

Row	Modes of Opening	Separating Load Based on the Night and Day		Cooling Load (Kwh)
1	The Window is Fully Closed.	Day	1569.16	2414.09
		Night	844.93	
2	Two-Third of the Windows Are Closed.	Day	1751.96	2695.32
		Night	943.36	
3	One-Third of Windows Are Closed.	Day	1972.07	3033.95
		Night	1061.88	
4	One-Third of the Window in the Northern Façade and Two-Third of the Window in the Southern Façade Are Closed.	Day	1773.26	2728.09
		Night	954.83	
5	Two-Third of the Window in the Northern Façade and One-Third of the Window in the Southern Façade Are Closed.	Day	1944.60	22991.68
		Night	1047.08	

In Table 10, the minimum amount of energy consumption was when one-third of the windows are closed, considering the total energy consumption for heating and cooling.

Table 10. Total of Energy Consumption of Heating and Cooling

Row	Modes of Opening	Total Heating and Cooling Load (kwh)	Analysis
1	The Window is Fully Closed.	8001.78	
2	Two-Third of the Windows Are Closed.	7598.34	
3	One-Third of Windows Are Closed.	7298.93	
4	One-Third of the Window in the Northern Façade and Two-Third of the Window in the Southern Façade Are Closed.	7307.65	
5	Two-Third of the Window in the Northern Façade and One-Third of the Window in the Southern Façade Are Closed.	7589.86	

4. DISCUSSION AND CONCLUSION

Since the opening area was determined as one of the most important factors affecting the natural ventilation, window layout and its effect in the natural ventilation was studied. The most significant fact in creating effective and practical ventilation is when parts of the opening are leeward and windward on two sides. The effect of the size of the room windows on the ventilation conditions inside it largely depends on the presence or absence of air circulation in the room. The air circulation by the wind is created in the room when each of its windward and leeward walls has an open opening. In some cases, when the wind obliquely blows on the window surface, the increase in the window size increases the airflow speed in the room. If the leeward window is larger than the windward window, the maximum and average speed of the interior airflow will be significantly increased. As software analyses showed, by increasing the window to wall ratio, the cooling energy consumption increases. It indicates that increasing the window area leads to increasing solar energy, especially in the summer. This amount of solar energy absorption also leads to higher cooling energy consumption. By analyzing the wind speed and direction of the region, it was revealed that the prevailing wind blow was from the north and northwest fronts. By considering the wind direction, the window to wall ratio with three indicators of 30%, 40%, and 50% was compared. It was proven that the higher the ratio of window area to the wall, the higher the fuel consumption. Considering 30% window to wall ratio, as the lowest fuel consumption equivalent to 6839.87 kwh, and the opening to be three-parts, the effect of opening on reducing energy consumption was analyzed and compared in five different modes in the north and northwest fronts, as air entrance, and southern front, as air exit. As a result, if one-third of the windows are closed, and two-third are considered opened, due to the proper layout of the building and windows, it will have the lowest cooling and heating load equivalent to 7298.93 kwh. This result indicates the effect of natural ventilation on reducing energy consumption.

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