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Research Paper

Investigating the Effect of Building Volume Porosity on Energy Consumption of High-rise Residential Complexes in Tehran

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Abstract
In recent years, optimizing the energy consumption of buildings has become one of the important environmental and economic goals in sustainable architecture and urban planning. A group of factors affecting the energy consumption of buildings is their physical characteristics and form. In this regard, in the present research, the effect of volumetric porosity in high-rise buildings on their energy consumption has been investigated. The purpose of this research is to explain the correlation between the volumetric porosity of a building, as an independent variable, and its cooling and heating load, as a dependent variable, in a high-rise residential complex in Tehran. In this regard, first, a modular-generative model has been created in the Grasshopper plugin of Rhino software, which can create a porosity of 0 to 50% parametrically. Then, the cooling and heating load of each of the produced models in the city of Tehran and on the June 21 (summer solstice) and December 21 (winter solstice) were calculated using the Honeybee plugin, with standard settings. The data obtained from the simulation were entered into the SPSS software environment and the correlation test of the percentage of volume porosity and energy consumption was performed on the two aforementioned dates in Tehran. In order to validate the research method, this process was performed in 3 other climatic zones of Iran and the findings were compared with other studies in this field. The results of this research showed that the increase in porosity, assuming the number of modules is kept constant (the total volume of the building remains constant) and the site coverage ratio - as is common and inevitable in high-rise buildings - have a significant positive correlation with increased energy consumption in high-rise residential buildings in Tehran.

Keywords: *Energy consumption, Porosity, High-rise Residential complexes, an Algorithmic method, Modular generative model, Multi-parameter energy simulation.*

1. INTRODUCTION

Energy is one of the most important aspects of industrial and economic development in the world (Anvari-Moghaddam et al., 2019), and its excessive consumption, not only increases the energy supply crisis in the world but also causes environmental pollution (Shahhosseini & Aflatounian, 2016). Considering that buildings are one of the biggest sources of energy loss; reducing energy consumption in them, especially in residential complexes, with the aim of preserving the environment and reducing related problems, is a concern that attention is increasing nowadays (Shahhosseini & Aflatounian, 2016) (Davarian et al., 2016). Furthermore, energy production systems in the future must be equipped to provide sustainable, affordable and renewable energy according to the needs of consumers (Anvari-moghaddam et al., 2019). For this reason, paying attention to building technologies for energy saving is really important (Rahmani et al., 2017). These technologies, in addition to reducing energy consumption, create suitable and ideal conditions according to the needs of the building's residents (Vahidian & Nejati, 2016). One of the correct approaches to achieve this goal is to optimize the building's energy consumption in the early stages of design, which leads to the construction of buildings

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with high energy efficiency (Gassar et al., 2021). In general, the early stages of building design are the most appropriate time to optimize energy consumption, because the most correct building optimization decisions can be made, and the maximum potential of buildings for high energy efficiency and carbon reduction can be used (Negendahl, 2015). Examples of important factors in building energy consumption that are considered in the early stages of design are the geometry of buildings and their physical characteristics, including form, height, and façade (Rafieian et al., 2011; Shareef, 2021).

One of the physical characteristics affecting the amount of energy consumption, which has been less discussed in the studies conducted in this regard, is the volumetric porosity of buildings. Porosity can be caused by the sinking of the volume of the building in order to create a balcony in the walls (Saadatjoo et al., 2019). Or, as in the modular building technique, the volume can be obtained by removing cells on several fronts (Javanroodi et al., 2021). Porosity, for whatever purpose or in any way can have an effect on the cooling and heating load of the building (Javanroodi et al., 2019) by shading and reducing the energy received by the walls (Saligheh & Saadatjoo, 2020), changes in the way of natural ventilation and air flow (Saadatjoo et al., 2019, Javanroodi et al., 2021, Javanroodi et al., 2020), and changing of the surface to volume ratio. For this reason, in this research, the volumetric porosity of the building as one of the important physical characteristics of the building has been investigated in order to achieve its correlation with the consumption of cooling and heating systems in high-rise residential buildings in Tehran (due to the increasing population, construction, and the need for heating energy[1] supply).

2. BACKGROUND AND THEORETICAL FRAMEWORK OF THE RESEARCH

Due to the importance of reducing energy consumption and the effect of physical characteristics of the buildings and urban morphology on energy efficiency, in recent years, many researchers have studied these indicators to achieve the optimal solution in design. In this part, we will review the results of previous research related to the above topic. Numerous studies, focusing on urban density contexts, have addressed the high-density environmental consequences from different perspectives such as the relationship between different forms of buildings and local layouts in high urban density for ventilation (Allard et al., 2010), availability of daylight (Cheung & Chung, 2005), thermal comfort (Wong et al., 2002), and urban weather (Wong et al., 2010). According to the research by Afsour et al., the density of horizontal housing compared to vertical cases can be better for energy efficiency in hot climates (Asfour & Alshawaf, 2015). According to a study by Salvati et al., the effect of urban compaction will reduce the annual energy demand in the urban context with a Mediterranean climate (Salvati et al., 2017). Mohajeri et al. also concluded that due to the increases in compaction, the annual solar radiation on the walls will decrease (Mohajeri et al., 2016). Song et al., by examining urban morphology, found that, in general, the ratio of dimensions and height of the buildings, the ratio of floor area, and the coefficient of shape, are the parameters affecting heating energy use intensity (EUI) (Song et al., 2020). Shareef also found that altitude variation reduces the cooling load in the UAE climate by applying this variation along the short axis of the urban block relative to the long axis (Shareef, 2021). According to Quan et al., energy consumption decreases with increasing Floor Area Ration (FAR) of buildings in the urban context, before reaching a certain turning point, and then this relationship is reversed. Also, building shapes and factors such as weather affect the energy consumption of the buildings (Quan et al., 2014). Okeil also compared the urban form and energy efficiency in two conventional forms and a proposed-energy efficient form on the urban block scale. His research showed that compared to the linear and block urban form, RSB or residential solar block leads to an increase in winter solar radiation at a latitude of 48 degrees, which allows to achieve the maximum potential of passive use of solar energy in buildings (Okeil, 2010).

In addition to the characteristics related to the layout of the building, several studies have been conducted on the formal characteristics. Javanroodi et al. achieved an optimization framework, called efficient form-finder (EEF), which is an extended version of Building Modular Cells (BMC) to reduce the demand for cooling, heating, and thermal discomfort time (TDT) in high-rise office buildings in Tehran. In their study, courtyard forms are the optimal solution, especially for heating demand. Also, most of the empty cells of the form have occurred on the western side of the produced compounds (Javanroodi et al., 2019). In a study by

[1] According to Koppen Climate Classification, Tehran is located in BSk (cold semi-arid) climate. Therefore, there is a need to use a heating system in the building at most times of the year to reach a comfortable temperature in the buildings.

Saadatjoo et al., the effect of balcony distribution pattern as porosity (model: Unit-Relocation (U-RL), Row-Relocation (R-RL), and Combined-Relocation (CO-RL) and solid blocks) was investigated on the natural ventilation performance of mid-rise buildings in hot and humid climates. The results showed that porous residential blocks are more efficient up to 64% in natural ventilation performance. Also, the U-RL model has a better performance due to the indoor air speed, and when the air flow inside the balcony is considered, the R-RL and CO-RL models have a good performance (Saadatjoo et al., 2019). Saligheh and Saadatjoo also examined shading, reduction of received radiant energy, and balcony depth. According to the result, the U-RL model has the best and the R-RL model has the worst behavior for shading and received radiant energy. Also, the depth of the balcony affects only the distribution pattern of the CO-RL balcony (Saligheh & Saadatjoo, 2020). A summary of the research background results is given in Table 1.

Based on the above studies, density (Asfour & Alshawaf, 2015; Salvati et al., 2017; Mohajeri et al., 2016), urban morphology and geometry of buildings in the urban block (Shareef, 2021; Song et al., 2020; Quan et al., 2014 Okeil, 2010), porosity pattern and distribution of balconies (Saligheh & Saadatjoo, 2020) (Javanroodi et al., 2019) in the volume of the building and other similar factors have a significant impact on energy efficiency, solar energy, air flow, and in general, factors affecting the energy efficiency of the building. However, there is no research that specifically deals with volumetric porosity in buildings, especially high-rise buildings. On the other hand, as can be seen from the study of research background, the effect of porosity on cooling and heating loads is a function of changes in surface area-to-volume ratio, shading on volume, and other factors that determine different optimal porosity ratios in different climatic conditions. This also needs to achieve a method that can be used to easily calculate this optimal value in different climatic zones. Thus, the present research produces an algorithmic method by maintaining the site coverage ratio and the total volume of the building, the porosity can be changed parametrically and the optimal value in each zone can be calculated by simulating cooling and heating load. This algorithmic model can be generalized and applied in all climatic situations because of parametric capability. In the research, this model has been used to determine the correlation between the porosity and the cooling and heating load of a high-rise building in Tehran.

Accordingly, the independent variables of the research include the Vp and dimensions of the building. The Vp is adjusted between 0 and 50% by removing the space modules in the volume and moving them to a height. The dimensions of the building can be changed from at least 3 Mw and Ml and 10 Mh, to the desired amount of use, which is limited to minimum values in this research. The dependent variables of the research are Cl and Hl. The Cl is the rate of heat that must be removed from the environment (buildings) so that the environment is in the desired range in terms of temperature and humidity and remains in that state (Garmasardco, 2017). Hl is the amount of energy given to a building to control and maintain temperatures at a comfortable level. The characteristics of these variables are written according to Table 2.

Table 1. Summary of Research Background Results

Subject	Authors	Title	Result
Density and Compression	Omar S. Asfour, Ebtesam S. Alshawaf	Effect of housing density on the energy efficiency of buildings located in hot climates; 2015	Horizontal housing density can work better in energy efficiency in hot climates than vertical ones.
	Agnese Salvati, Helena Coch, Michele Morganti	Effects of urban compactness on the building energy performance in Mediterranean climate; 2017	The increase in urban compactness determines a decrease in the annual energy demand in the urban context.
	Nahid Mohajeri, Govinda Upadhyay, Agust Gudmundsson, Dan Assouline, Jerome Keampf, Jean-Louis Scartezzini	Effects of urban compactness on solar energy potential; 2016	With increasing compactness, the annual solar irradiation decreases.

Subject	Authors	Title	Result
Urban morphology	Shiyi Song, Hong Leng, Han Xu, Ran Guo, Yan Zhao	Impact of Urban Morphology and Climate on Heating Energy Consumption of Buildings in Severe Cold Regions; 2020	aspect ratio and building height accounted for almost 50% of the overall impact on heating demand. floor area ratio and shape factor are also energy-related urban morphological parameters.
	Sundus Shareef	The impact of urban morphology and building's height diversity on energy consumption at urban scale. The case study of Dubai; 2021	the implementation of the height diversity resulted in reducing the cooling load is higher when applying this diversity along the short axis of the urban block compared to the long axis.
	Steven Jige Quan, Athana assions Economou, Thomas Grasl, Perry Pei-Ju Yang	computing energy performance of building density, shape and topology in urban context; 2014	the energy consumption decreases with increasing FAR before FAR reaches a specific turning point, and then the relationship reverses. Even with the same FAR, building shapes and different climates, etc. can become different energy consumption.
	Ahmad Okeil	A holistic approach to energy efficient building forms; 2010	Compared to both the linear urban form and the block urban form, the RSB results in increased winter solar radiation. This allows the maximum potential of passive utilization of solar energy in buildings to be reached.
Form finding	Kavan Javanroodi, Vahid M. Nik, Mohammadjavad Mahdavinejad	A novel design-based optimization framework for enhancing the energy efficiency of high-rise office buildings in urban areas; 2020	By adopting EEF framework, cooling and heating demand and TDT of high-rise office buildings can be reduced. Courtyard and semi-courtyard forms were the most frequent forms of optimal solutions in all the urban areas; particularly in terms of heating demand. And the highest number of empty cells occurred on western side of generated combinations.
	Paria Saadatjoo, Mohammadjavad Mahdavinejad, Afsaneh Zarkesh	Porosity Rendering in High-Performance Architecture: Wind-Driven Natural Ventilation and Porosity Distribution Patterns; 2019	porous residential blocks are effective in enhancing the natural ventilation performance up to 64 percent compared to the solid models. Considering the interior air velocity, wind-phil buildings with U-RL distribution patterns have the best performance compared to others.
	Elham Saligheh, Paria Saadatjoo	Impact of Building Porosity on Self-Shading and Absorbed Solar Heat Reduction in Hot and Humid Regions;2019	Checkered porous models have the best and row worst behavior in terms of shading and received radiant energy. The depth of the balcony, except for the pattern of the composite terrace, has no visible change in the amount of shading surface.

Table 2. Research Variables

Variables			Range of changes	Unit	Abbreviation
Independent	Volume porosity		0-50	%	Vp
	Dimensions	Width	+3 (in this research, 3)	Module	Mw
		length	+3 (in this research, 3)	Module	Ml
		Height	+10 (in this research, 10)	Module	Mh
Dependent	Cooling load		-	kWh/m2	Cl
	Heating load		-	kWh/m2	Hl

3. METHODS

This research has been done in four main stages:

A. Building a productive model, including:

1. Proposing a parametric generative model to produce volumes with different porosity percentages;
2. Production of a basic model for the city of Tehran;
3. Production of secondary models, with different porosity, based on the generative model.

B. Energy consumption simulation, including:

Computing Cl and Hl of secondary models;

C. Research findings

D. Correlation test between Vp rate and its Cl and Hl

The research steps are shown in Figure 1. Each of these steps is performed as follows:

A. Parametric Generator Model:

In the first step, to achieve different percentages of Vp, a parametric generative model that can be controlled by the operator is needed to be able to produce the values of the independent variables, according to their values and intervals of variation in compliance with Table 3. This productive model was proposed and built based on a modular structure. Each cell was defined as equivalent to a minimum space. In this parametric model, the user can define the number of spatial modules in the width, length, and height of the building and determine their porosity from 0 to 50%. In the present research, after producing a modular generative model, a sample of a high-rise building with a width and length of 3 modules and a height of 10 modules was produced. In this model, subtracting and adding each modulus causes a change of 2% in the porosity of the set.

Each module has dimensions equivalent to 3 * 3 * 3 meters, which is considered according to the standard floor-to-floor height, and in order to reduce the effect of proportions, its width and length are also equivalent to 3 meters in height. Porosity was created by random reducing of some of these volume-forming modules (proportional to the required porosity). The removal of each module has led to its addition to the height so that the overall volume of the building (Total floor area) does not change. Table 3 shows some examples of volumes with different porosity percentages.

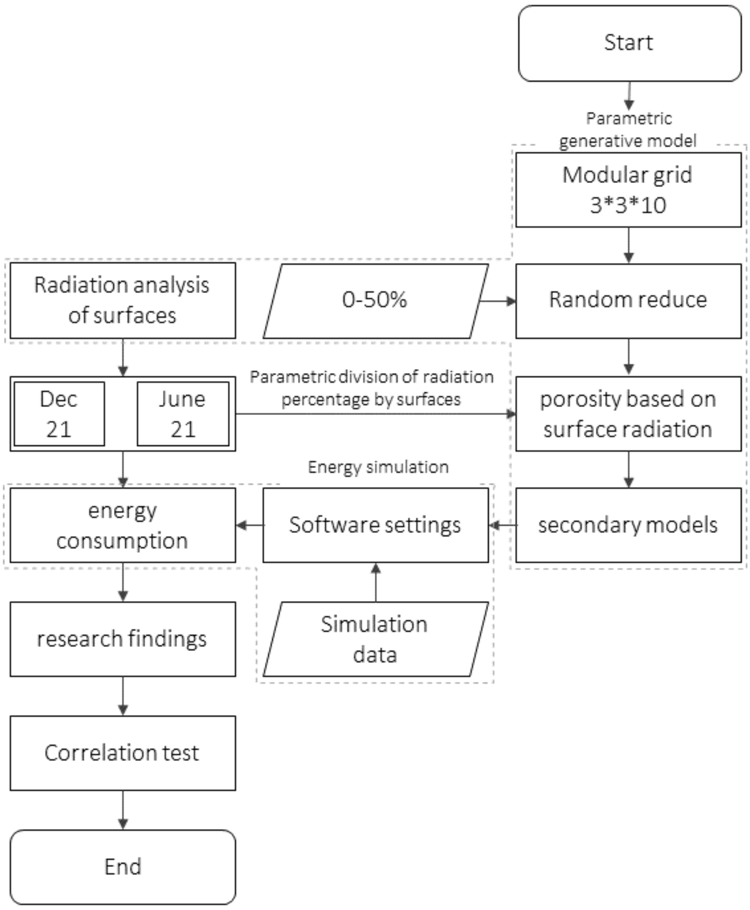
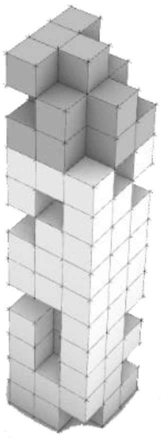
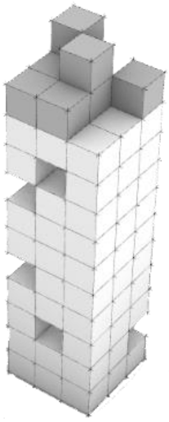
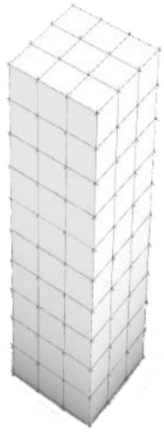
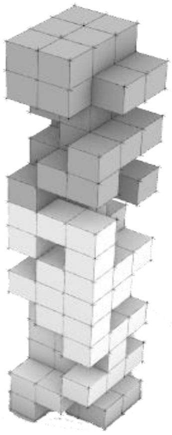
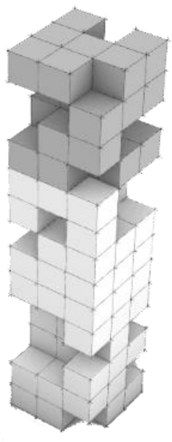


Fig 1. The Flowchart of the Research Stages

Table 3. Secondary Models

20% Vp	10% Vp	Generative Model
		
50% Vp	40% Vp	30% Vp
		

The examples of a porous module model are innumerable, based on the percentage of module deletions and the number of cases of their random reduction in the software. The table above shows only 5 examples of these cases. The process for doing this step, which is encoded in the Grasshopper plugin in Rhino software is shown in the form of a flowchart in Figure 2. The reason for using this plugin is the possibility of algorithmic design with the 3D presentation of the obtained models in Rhino software, and the possibility of connecting with other required plugins, including weather data and energy consumption calculations plugins (grasshopper3d.com).

Due to the base model that receives different amounts of radiation on its surfaces, and also with the removal of each module ell in each surface, the depth and shape of the shadow will be different. Therefore, the effect of each module in the Cl and Hl of the whole set varies according to its position in the volume. Thus, the random module removal algorithm must be normalized in such a way that the distribution of the deleted modules is commensurate with their role in the Cl and Hl of the complex; otherwise, the findings will not be reliable. For this purpose, according to Figure 3, the radiation of Tehran on the surfaces of the productive model was calculated on summer solstice and winter solstice and the percentage of radiation on the volumes constituting the volume was obtained. In this regard, the number of deleted modules of the parametric generator model according to the percentage of porosity given to the algorithm, based on the percentage of radiation in Tehran on the surfaces of the generative model was considered. For this purpose, the percentage of radiation received was parametrically divided by the number of modular columns around the volume, which is 8 in this research. Accordingly, the number of modules removed in each view (and each column of modules) will be proportional to the percentage of radiation on that column on the desired date. For example, according to the December 21 radiation analysis, the south side (column 4) receives 24.1875% of the sun's radiation. Accordingly, 24.1875% of the number of deleted modules in the Vp algorithm should be removed from the south side.

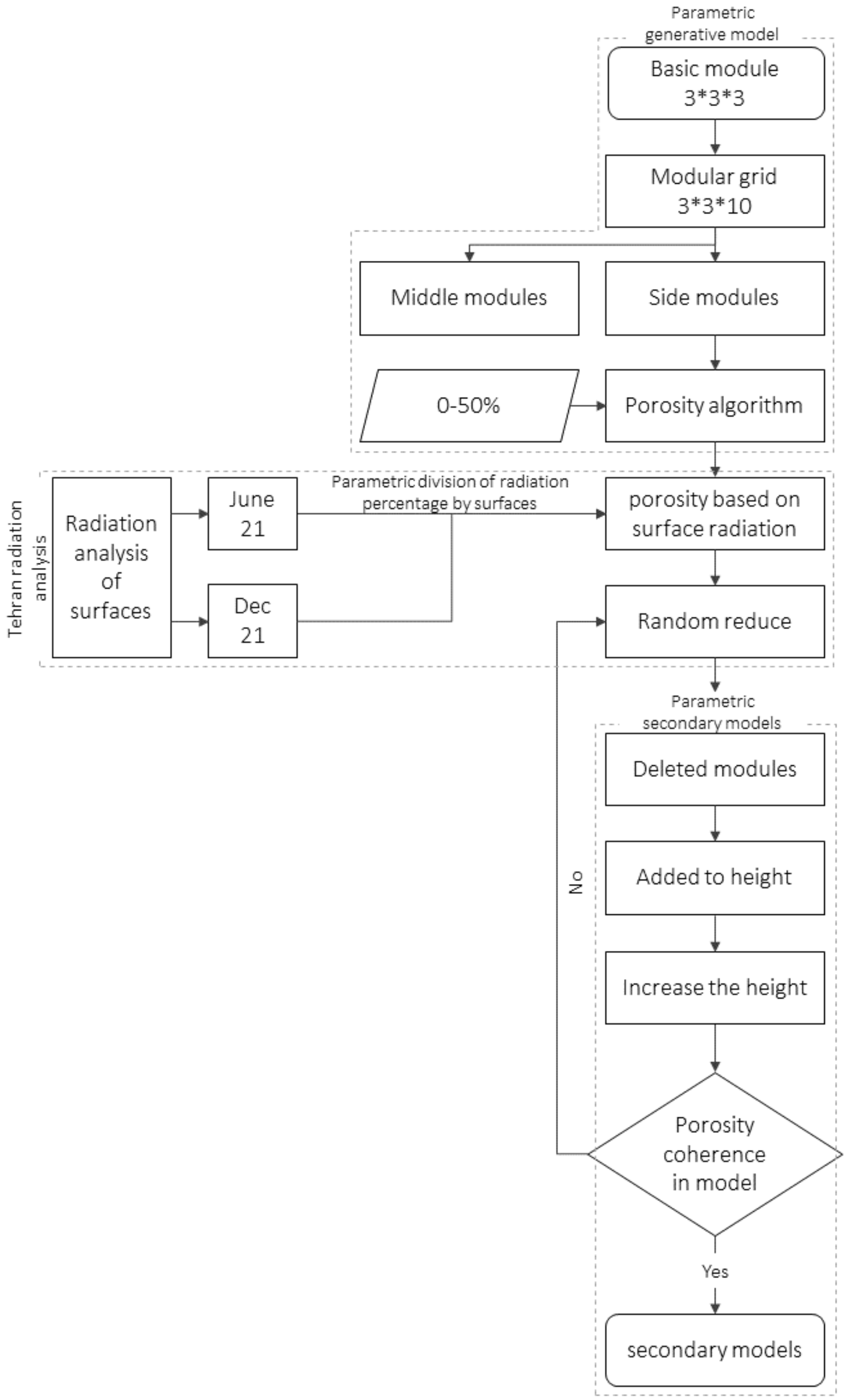


Fig 2. Flowchart of Parametric Model Formation

According to the algorithm, the modular models produced with the same porosity percentage are different from each other due to the difference in the percentage of radiation received by the surfaces in each of the mentioned dates. Table 4 shows some examples of porous volumes formed based on radiation analysis.

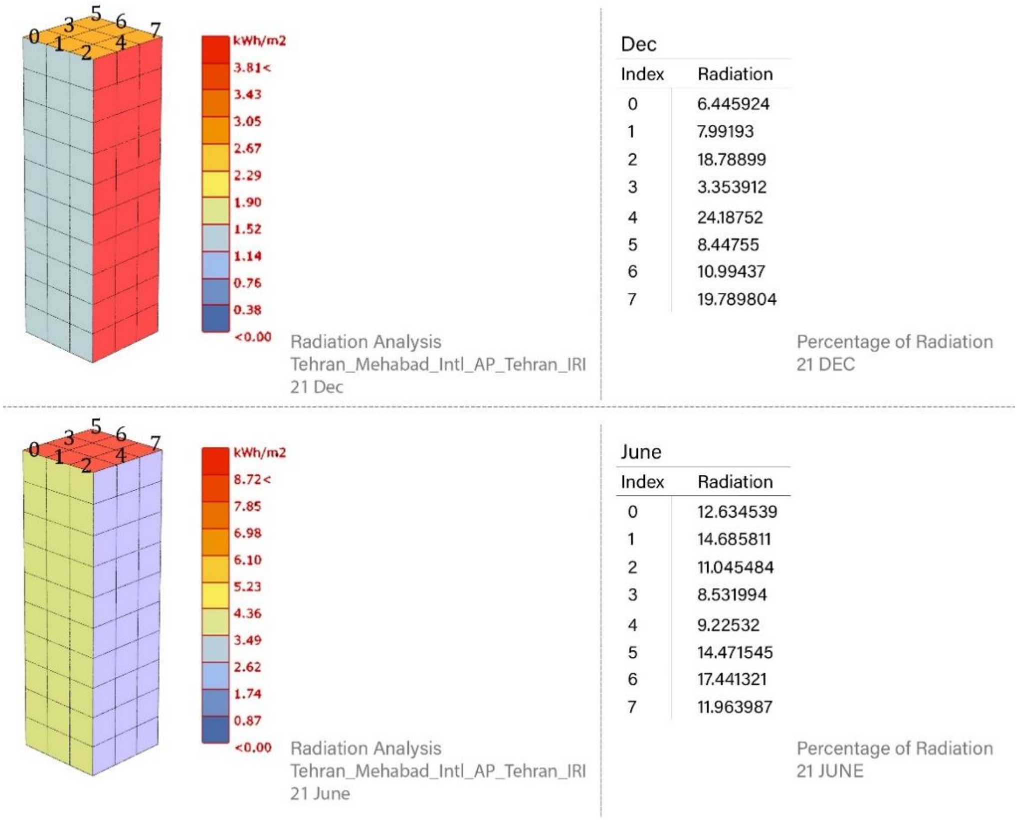
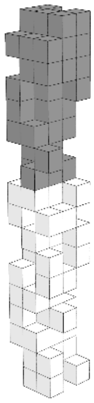
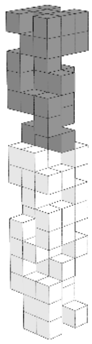
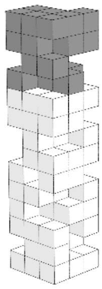
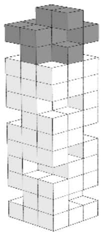
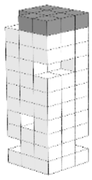
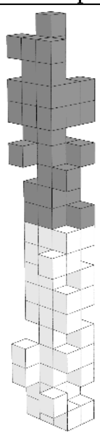
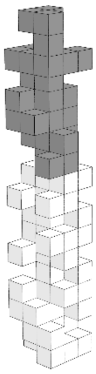
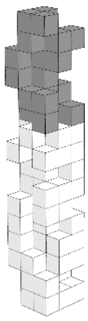
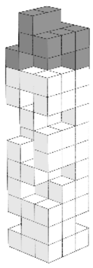
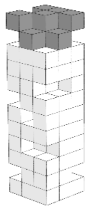


Fig 3. Tehran Radiation Analysis on the Surfaces of the Generative Model on June 21 and Dec 21

Table 4. Secondary Models Based on Tehran Radiation Analysis

	50% Vp	40% Vp	30% Vp	20% Vp	10% Vp
June 21					
	50% Vp	40% Vp	30% Vp	20% Vp	10% Vp
December 21					

The models of volumes formed in this step are numerous due to the percentage of porosity, the cases of accidental removal of modules in the software, and the difference in the percentage of radiation received by the surfaces. Table 4 shows only 5 examples of these volumes and their differences in the two dates mentioned. Finally, 10 models of the layouts produced on June 21, and 10 models of the layouts produced on December 21, were chosen based on porosity of 0 to 50%, with 5% intervals. Then, the next step was performed.

B. Energy Consumption Simulation:

The Honeybee plugin in the Grasshopper plugin in the Rhino software was used for energy consumption simulation in the generative model and secondary models. This plugin uses the Energy Plus engine to calculate the Cl and Hl. The simulation settings, including scheduling, materials, HVAC systems, etc., were performed according to Table 5. In the next step, based on these settings, the energy simulation process for the generative model and 20 secondary models produced in the previous step was performed on the mentioned days (based on Tehran weather data).

The above settings were given to the path of the energy simulation algorithm according to the existing standards. In order to carefully examine the consumption of cooling and heating systems and the lack of effect of the results from other side factors, the lighting and natural ventilation system was turned off. The steps of energy consumption simulation are performed according to Figure 4.

C. Results of Energy Consumption Simulations:

According to Table 6, the simulation data show that the maximum Hl is 0.5971 kWh/m2 at 45% porosity and the lowest is 0.2623 kWh/m2 at 0% porosity. The difference between the minimum and maximum Hl is 0.3348 kWh/m2 and the maximum Hl is 127.64% more than the minimum value. Also, the maximum Cl is 0.5590 kWh/m2 in 50% porosity and the lowest is 0.2855 kWh/m2 in 0% porosity. The difference between the minimum and maximum Cl is 0.2735 kWh/m2 and the maximum Cl is 95.80% more than the minimum value.

D. Correlation Test Between Variables:

In this step, the correlation test between the independent variable, the percentage of Vp and the dependent variable (Cl and Hl) was performed, due to the data obtained from the simulation of the models. The correlation chart between the percentage of Vp and energy consumption of the cooling system on June 21 and the heating system on December 21 in Tehran is shown in Figure 5. In this chart, the horizontal axis indicates the percentage of Vp and the vertical axis represents the amount of energy consumption in kWh/m^2. The linear and increasing slope shows the effect of porosity on energy consumption in the aforementioned 2 dates.

Table 5. Algorithm Input Settings

Properties	Setting	Explanation
Available building program	Midrise Apartment: Apartment	
Number of people per square meter	0.028	
Lighting Schedules	Off	No effect of other factors on the simulation results
Natural ventilation Schedules	Off	
Cooling setpoint	26	degrees Celsius
Cooling setback	32	
Heating setpoint	20	
Heating setback	13	
R-Value (external wall)	1.77	m^2.k/w
R-Value (floors)	1.42	
R-Value (ground floor)	0.6	
R-Value (roof)	1.55	
HVAC system	Thermostat only	

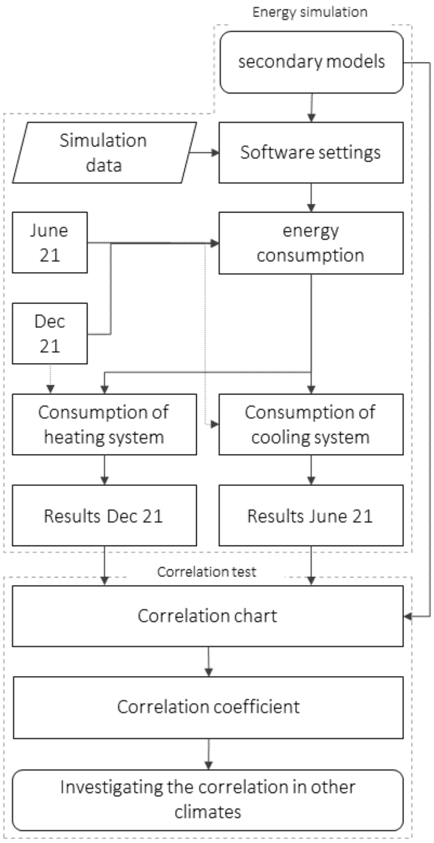


Fig 4. Flowchart of Energy Simulation Steps

Table 6. Research Findings

Percentage of porosity	Heating consumption (kWh/m2)	Cooling consumption (kWh/m2)
0	0.2623	0.2855
5	0.3151	0.3288
10	0.4122	0.3699
15	0.4127	0.3797
20	0.4594	0.3959
25	0.5065	0.4370
30	0.5948	0.4630
35	0.5829	0.4832
40	0.6214	0.5463
45	0.6236	0.5506
50	0.5971	0.5590

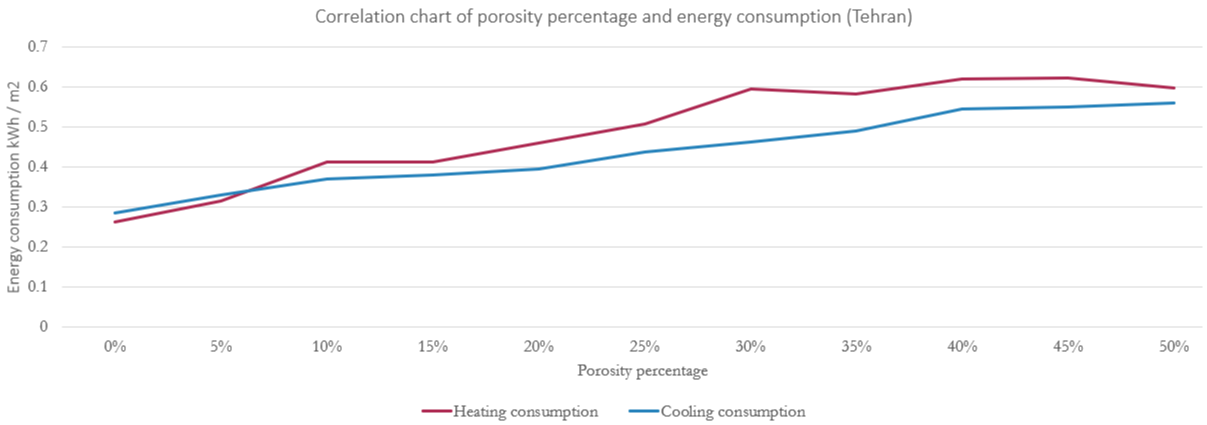


Fig 5. Correlation Chart of Porosity Percentage and Consumption of Cooling (June 21) and Heating (December 21) in Tehran

The above chart shows a positive correlation between Vp and the total Cl and Hl. According to the chart, in general, increasing porosity during the year increases energy consumption in Tehran. The reason for this is the increase in surface area-to-volume ratio and, consequently, the increase in heat exchange and loss, especially in the cold seasons of the year. In hot seasons, although the increase in surface area-to-volume ratio leads to increased shading, there is more need for HVAC systems to maintain thermal comfort, due to the increase of walls in the vicinity with the external environment and more heat exchange.

According to Table 7, the Pearson correlation coefficient (in the range of -1 to +1) was obtained. The results calculated in SPSS software show a strong correlation coefficient between the independent variable and the dependent variables. Due to the fact that the correlation is performed at a level less than 0.01, the assumption that the correlation coefficient is zero will be rejected. Accordingly, the correlation coefficient of Vp with Hl is 0.951 and with Cl is 0.990.

3.1. Ability to Generalize the Method

In this step, energy simulation was performed in 3 other cities with different climates, including Yazd (hot and dry climate), Bandar Abbas (hot and humid climate), and Ramsar (temperate and humid), to ensure the generalizability of the method in other climates. Finally, the correlation chart of independent and dependent variables in the mentioned cities was analyzed briefly on June 21 (summer solstice) and December 21 (winter solstice) to ensure the accuracy of the extracted results. According to Table 8, the correlation chart of the percentage of Vp and the consumption of the cooling system was obtained on June 21 in the cities of Yazd, Ramsar, and Bandar Abbas. To ensure the results, the difference between the consumption of the cooling system and the required consumption of the cooling system of the above cities in June, which was extracted from the Ladybug plugin in the Grasshopper plugin of Rhino software, were compared. The analysis of the following correlation chart shows that the increase in porosity leads to an increase in the consumption of the cooling system on June 21, due to the increase in heat exchange and loss and the increase in levels in the vicinity of sunlight in hot cities. The reason for the greater need for a cooling system in Bandar Abbas is the decrease in the value of shading and its lower impact on cooling at lower latitudes. Also, the increase in porosity in the city of Ramsar before reaching a certain turning point, due to the increase in surface area-to-volume ratio, blow and air conditioning in temperate and humid climates helps to slightly reduce energy consumption. In general, due to the low need for cooling in Ramsar, increasing porosity won't have much effect on the energy consumption of the cooling system.

According to Table 8, the correlation chart of Vp percentage and heating system consumption was obtained on December 21 in Yazd, Ramsar, and Bandar Abbas. The obtained results were compared with the required consumption of the heating system of the above cities in December. According to the analysis, the increase in porosity in the city of Yazd, due to the increase in heat exchange and the prevention of receiving sufficient sunlight, led to an increase in energy consumption on December 21. In order to increase porosity, the consumption of the heating system in the city of Ramsar has increased significantly due to the lack of sufficient solar radiation and the entry of cold air into the building. Also, the energy consumption of the Bandar Abbas heating system, due to the low need for heating, has not had a great impact on energy consumption.

Table 7. Correlation Coefficient Obtained from SPSS Software

		Vp %	Hl	Cl
Vp %	Pearson Correlation	1	0.951**	0.990**
	Sig. (2-tailed)		.000	.000
	N	11	11	11
Hl	Pearson Correlation	0.951**	1	0.962**
	Sig. (2-tailed)	.000		.000
	N	11	11	11
Cl	Pearson Correlation	0.990**	0.962**	1
	Sig. (2-tailed)	.000	.000	
	N	11	11	11

** Correlation is significant at the 0.01 level (2-tailed)

Table 8. Correlation Chart of Porosity Percentage and Cooling Consumption of 21 June and Required Consumption of Cooling in Yazd, Bandar Abbas, and Ramsar Cities in June

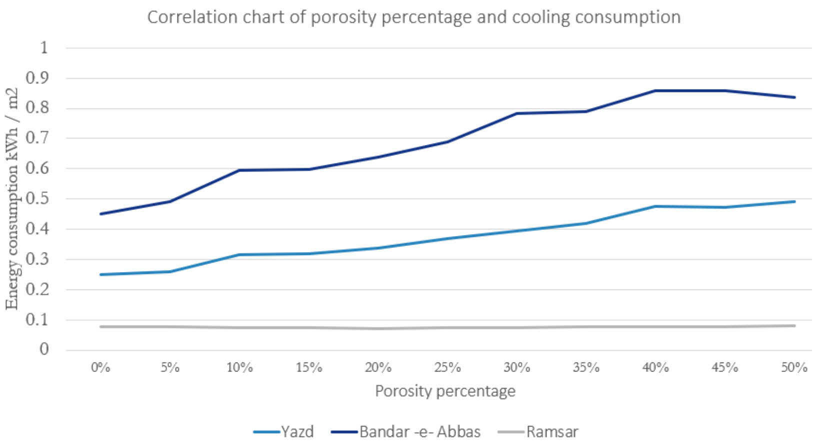
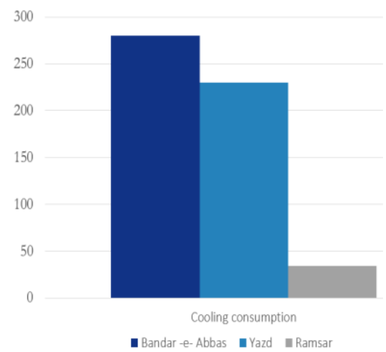
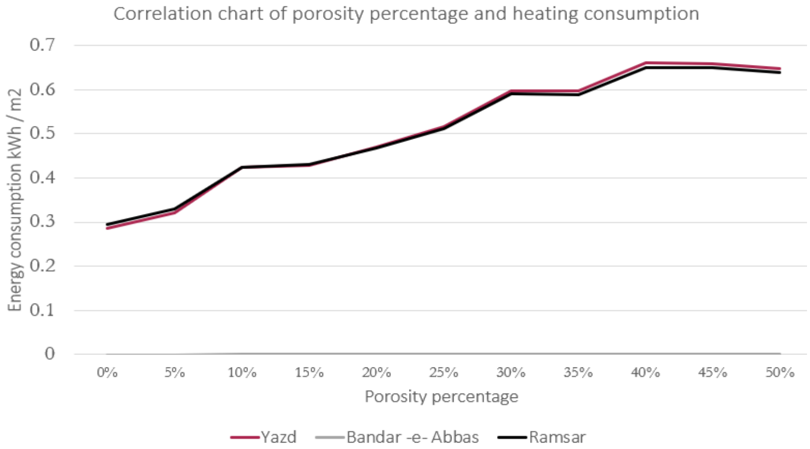
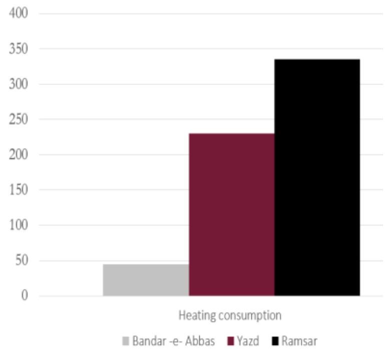
21 Correlation chart of porosity percentage and cooling consumption on June	Consumption required for the cooling in June
	

Table 9. Correlation Chart of Porosity Percentage and Heating Consumption of 21 December and Required Consumption of Heating in Yazd, Bandar Abbas, and Ramsar Cities in December

Correlation chart of porosity percentage and Heating consumption on December 21	Consumption required for the heating in December
	

The generalizability of the research method was evaluated by analyzing the correlation charts of the relationships of independent and dependent variables in 3 different climates from Tehran on June 21 and December 21. According to the logical results, based on Köppen climate recommendations, the written algorithm can be generalized to other global climates.

4. DISCUSSION AND CONCLUSION

Nowadays, the high consumption of non-renewable energy, especially in big cities, where the demand is doubled due to the large population, is one of the crises that has affected the environment. According to the background and theoretical framework of the research, optimizing the volume and shape of the building in the early stages of project design and decision-making has a significant impact on saving energy consumption. For this purpose, the aim of this research is to investigate the correlation diagram and the optimal porosity of the building volume in order to achieve the optimal energy consumption of the cooling and heating system in high-rise buildings in Tehran. In this regard, by examining and comparing the previously proposed methods in similar studies, it was considered to provide a parametric module generative model. The reason for this choice is the use of algorithmic design and the extraction of secondary models with the help of artificial intelligence, along with the 3D presentation of the obtained models, also their quantitative results, in the fastest possible way. The mentioned secondary models with porosity of 0-50% were extracted by obtaining the porosity algorithm based on the amount of radiation received by Tehran city on the surfaces of the generative model on 2 dates, one day in the winter solstice and one day in the summer solstice. This algorithm was written in such a way that the radiation percentage of each wall has a direct relationship with the percentage of module removal in the same wall. Also, the removal of each module leads to its addition to the height and maintains the overall volume of the building (total floor area). In order to achieve the correlation test, the consumption of the cooling system of 10 samples of the secondary models on June 1st, and the consumption of the heating system of 10 samples of the secondary models on Dec 1st, along with the energy consumption of the generative model were obtained on each of the 2 mentioned dates. Based on the simulation results of energy consumption in part C, the correlation chart of porosity percentage and cooling and heating system consumption, also their correlation coefficient, was extracted. The results showed that the percentage of porosity has a strong and positive correlation with both utility systems in Tehran. The correlation coefficient of the percentage of porosity with the heating system is 0.951 and with the cooling system is 0.990. Moreover, the energy consumption of the secondary model with maximum porosity is 127.64% more than the secondary model with minimum porosity in the heating system and 95.80% more in the cooling system. Based on this, the increase in porosity leads to an increase in the consumption of the cooling and heating system due to the increase in the ratio of surface to volume and due to that, an increase in heat exchange and loss in Tehran. For this reason, the reduction of energy consumption in Tehran requires as little porosity as possible (zero or close to zero percent) in high-rise buildings, construction within a specific height range, and a reduction of the surface-to-volume ratio.

In this research, the effect of air flow entering the building, daylight, and also the effect of the urban context around the building on the consumption of utility systems have not been considered. The reason for this limitation is the detailed examination of the cooling and heating system consumption, as well as the examination of a comprehensive model for a specific climate. Conclusion and achieving a more accurate percentage for a specific project requires considering the above indicators. Moreover, there is a need to investigate the optimization methods of parametric porosity models in future studies; in order to consider other architectural characteristics, including the spatial quality of the building and the use of porous building design. Optimization of porosity models based on climatic conditions may be accompanied by other limitations in the design department; This will require further investigation based on future results.

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