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The Effect of Building Blocks Layout on Indoor Thermal Comfort and Energy Consumption of Buildings in the Humid Subtropical Climate of The Caspian Coast

Zahra Sorayaei, Raheleh Rostami *, Fatemeh Mozaffari Ghadikolaei

Department of Architecture, Faculty of Engineering, Sari Branch, Islamic Azad University , Sari, Iran

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Abstract

Cities use a lot of energy sources and they form more than 70 percent of global carbon emissions. It is very important to measure the relationship between urban form and energy consumption. The form of different building blocks in the city can create different microclimates and subsequently affect the thermal comfort and energy performance of each building. Building blocks form includes different variables. The purpose of the research was to predict the effect of the layout pattern of building blocks on the thermal conditions of the building and the annual energy consumption of the building. The general pattern of building block layout (discrete, linear, centripetal) and its characteristics, including length, depth and direction, were considered as independent variables of the research and the annual energy consumption of the building as a dependent variable. The thermal conditions in the building are based on the PMV thermal index as a mediating variable. This research is a quantitative study that includes a literature review and research and software analysis. Accordingly, the samples of building block layouts based on typical patterns in the study area located in the CFA climate were simulated using DesignBuilder software and the results were compared with each other results. Energy consumption results have shown a direct relationship with the thermal conditions of the building. The layout patterns of the building block in the form of a medium-depth centripetal (annual energy consumption: 52718.5 wh/m^2) and a short-length linear (annual energy consumption: 54127 wh/m^2) can be considered as favorable options in terms of annual energy consumption. Also, changing the direction of building blocks with a linear form causes a significant change in energy consumption (It increases by 10.7% compared to the short linear pattern), and in the discrete pattern, considering designing strategy like insulation for external walls are important to prevent heat loss.

***Keywords* :** Thermal comfort; Energy consumption; Building blocks layout; DesignBuilder; PMV index

1. Introduction

Currently, 50% of the world's population lives in urban areas, which will grow to about 70% by 2050 (Huang and Li, 2017). The rapid and increasing growth of urbanization and the subsequent increase in the population of cities have had various consequences in various fields. Among the most important of these consequences, we can mention the increase in consumption and demand for energy resources (Sanaiyan et al., 2014). So that 75% of the world's energy is approximately consumed in cities (Huang and Li, 2017). The increase in consumption and demand for fossil energy sources can be considered from two aspects: One is the limited energy sources and the other is the environmental pollution caused by the consumption of fossil fuels. A large part of the world's energy is consumed for environmental compliance and creating thermal comfort conditions in building (US Energy Information Administration, 2017). Since people's expectations of environment comfort level have increased, the need for cooling and heating of buildings increases, and failure to adopt a suitable approach can result in heavy costs. (Lang and Moleski, 2010) (Zinzi and Carnielo, 2017).

The energy performance of buildings depends on five factors: climate, system efficiency, residents' behavior, building design, urban form (Sanaieian et al., 2014). Most studies by architects in this field have investigated more on the scale of building design and strategies such as green building, which can consume up to 30% less energy than conventional buildings (Zuo and Yu zhao, 2013) as well as zero energy buildings where the annual energy consumption of this building is equal to the annual energy production of that building using renewable energies (D'Agostinoa and Mazzarella, 2019) and passive buildings that need to consume little energy and its annual energy consumption should be less than 15 kwh/m^2 (Mihaiy et al., 2017) all had grown significantly. On a larger scale than a single building, several studies have been done by urban designers to investigate the effect of urban form on thermal conditions of urban environments. In fact, most of the researches on thermal comfort and energy consumption, urban designers have focused on the open space and architects on the interior space and individual buildings, and finally it causes contradictions in design (Taleghani et al., 2013). Building groups affect the amount of solar radiation on building cover, as well as the microclimate and air flow pattern around the building (M.Galal, 2020). Therefore, it is not enough to focus only on individual buildings, but it is important to expand the analysis to groups of buildings or urban form. The internal thermal behavior of buildings changes when they

* Corresponding Author Email Address: raheleh.rostami@gmail.com

are placed in the building blocks (Taleghani et al., 2013). Among the influencing elements of urban form on building energy performance are the type and dimensions and size of building, density (including the physical compactness of building units), layout of buildings (including the street direction and configuration of buildings) and surface permeability and green space and other factors that affect the efficiency of thermal and cooling system of building (Ko, 2013).

Identifying and measuring the relationship between urban form and energy consumption is very important (Shuja, 2020) and it is necessary to conduct additional studies and plan this issue as one of the important axes of urban planning in the country (Mir Moqtadai, 2014). Based on the global attention growth to this issue, optimizing and saving consumption is also vital in Iran, according to the statistics and figures of fuel consumption to achieve thermal comfort. In Iran, energy consumption in the building sector is 40.6% of the total energy consumption, while in developed countries, this amount is 33% (Zomorodian and Nasrollahi, 2013). In recent years, studies have been done on the relationship between city morphology and energy consumption in Iran, but most of them have focused on macro level (national or sectoral) and micro level (building scale) and there is little information about energy consumption metabolisms at intermediate level (inter-building scale) of our country's cities. Mazandaran is ranked after the province of Tehran in the annual average household electricity consumption rate of 2680 kWh and is one of the high-consumption the provinces (Ministry of Energy, 2021). Considering the high population concentration of Babol compared to other cities of Mazandaran, as well as the service-commercial performance in this city, it has increased the construction process. Babol is the leader in terms of the intensity of urban development, and on the other hand, due to the lack of guiding criteria in urban plans in the field of construction based on the issue of climate and building energy and the trend of construction based on the construction market, it causes little attention to the climate and native architectural components in the city. Research is needed to understand the effects of urban form variables on micro-urban climate and ultimately its relationship with building architecture to provide operational principles for city professionals and policymakers. In this research, an attempt is made to analyze the effect of building blocks layout based on the parametric method, on the internal thermal Comfort of building and the amount of energy consumption of the building in the Babol, especially the street spaces of the city center. Finally, the attempt is achieved the optimal layout of the building block in the urban space by paying attention to its effect on the external environment as well as the thermal environment inside the building to create thermal comfort along with optimizing energy consumption.

2.Theoretical Framework

2.1. background research

The population increase and improper expansion of cities have had many destructive effects on urban environments. It has caused temperature and climate changes, especially in residential areas (Rezaee Rad et al., 2021). For example, in the metropolitan areas of Sydney, the urban heat island causes the temperature rise up to 6 ℃, which leads to an increase in the cooling requirement of the building by 3 times (Santamouris et al., 2001). Also, in Athens, the average temperature increase due to the heat island has been up to 10℃, which leads to an increase in the cooling load up to 2 times and it has increased the electricity consumption up to three times (Santamouris et al., 2018). In fact, urban buildings create a climate that affects human comfort, air quality, and energy consumption (Gobaks and Kolokotsa, 2017). The random and careless design of urban blocks creates unpleasant conditions (Rezaei Rad et al., 2021). In this section, studies that have been proposed at scales beyond the building scale, are discussed. Investigating the effect of building block form parameters on thermal conditions inside the building and in the next step to investigate its effect on energy consumption are discussed in these studies.

Air flow is one of the important variables of thermal comfort. Checking the air flow inside the building without considering the effect of the neighbor buildings on wind pressure coefficient cannot be useful for understanding the natural ventilation process (Azizi and Javanmardi, 2017). Sanaiyan on his reviewing research has introduced the ratio of building height to street width, the buildings layout and the buildings orientation in relation to the prevailing wind direction as important parameters for improving the wind flow (Sanaiyan et al, 2014). Adach et al (2020) on his research evaluated two building layout models, the linear model (SQ-STR) and the staggered model (ST-STR), along with openings placement in two different places using numerical simulation method, with investigating the effect of building layout pattern and the location of openings on the amount and speed of internal natural ventilation. Finally, they concluded that the staggered model (ST-STR) where the openings are in the direction of wind flow, the ventilation increases about 2 times. Azizi and Javanmardi (2017) investigated the effect of urban block forms on natural ventilation patterns using computational fluid dynamics (CFD) analysis. The results have shown that the height of the urban block and the width of side building passages were two factors that had the greatest effect on a difference in wind pressure and so, increasing the natural ventilation potential.

Solar radiation is one of the important component of weather and it is very important for human thermal comfort inside and outside the house. Urban density, buildings orientation, buildings' and streets' outlines (ratio of building height to street width and buildings' layout) have the greatest effect on the building's access to sunlight (Sanaiyan et al, 2014). Rode et al. have evaluated the amount of heating energy demand in relation to the parameters of density, surface-to-volume , height ratio and occupancy level of the building in different building patterns in Paris, London, Berlin and Istanbul. The results demonstrated that heating energy efficiency can be achieved through the creation of little buildings, compact blocks or high-rise buildings (Rode and et al., 2014). Nedro has investigated the effect of parameters such as decoration, geometry and roads' orientation on shading conditions and access to solar energy in urban valleys in both contemporary and ancient Greece contexts. He points out that these parameters can strongly affect the microclimate conditions of urban valleys such as air temperature and surface temperature (Andreou, 2014).

The effect of building block form on thermal conditions and building energy consumption are among the studies that are focused in this field. Taleghani et al., in their research (2013), compared three types of urban block layout, including single building, linear building and the central yard at three different heights in terms of annual heating and lighting energy demand and summer thermal comfort hours in The Netherlands. The results showed that individual houses have the highest amount of daylight and therefore the least need for lighting energy, and the shape of the central yard in all three heights has the least need for heating energy, and it leads to higher improved performance of summer thermal comfort and energy efficiency due to the external surface reduction exposed to the external environment. In another research (2014), Taleghani has investigated the different orientations of linear and individual models and their effect on thermal comfort. It is difficult to distinguish between north-south and east-west forms in a single pattern because they receive equal amounts of radiation and are equally exposed to wind. But the thermal behavior is different among the north-south and east-west forms in the linear pattern. The N-S orientation has cooler thermal conditions. In another research (2014), Taleghani investigated the effect of different variables of yard block form (orientation, dimensions, roof and floor covering) on the internal thermal performance of building in summer and Netherlands. The results showed that the hottest model is related to the model that receives the most solar radiation, therefore, the forms with the most block elongation and in the north-south direction have the worst thermal conditions (with 90% of uncomfortable cases). The longest NW-SE and NE-SW rotations also have a high percentage of discomfort hours (74% and 85%, respectively). Of course, the thermal conditions are slightly better due to the prevailing wind in the Netherlands (Southwest) in the NW-SE orientation among the rotating forms. Blocks with East-West extension create the best internal thermal conditions. Also, a reduction (14%) in number hours of discomfort occurs when the roof and yard are covered with vegetation. Mangan et al. (2020) modeled building forms that are in terms of plan type (square or rectangular), building height (3 m, 5 m, 10 m or 15 m), H/W ratio (0.50, 1.00 or 2.00) were different and they investigated them in two types of urban layout (single, strip) and four types of orientation (0°C, 45°C, 90°C or 135°C) to evaluate the impact of urban form on energy consumption in temperate climate regions. The results show that building height and H/W ratio play more important role on building energy performance than orientation. Heating, lighting and total energy consumption (heating + cooling + lighting) decreased with the increase of building height or the number of floors, and cooling energy consumption increases with the decrease of H/W ratio (increasing solar radiation and solar portion). Hong and Lee (2017) investigated the effect of street geometry and green space on cooling energy consumption in the hot and humid climate of Taiwan. The results show that the ratio of height to street width has the greatest impact on the building energy consumption, and after this parameter, the street direction and the green space density are effective. The deeper the valley of the street (more H/W), the lower the energy consumption due to more shading, and in the case of low H/W, due to the lack of shading effects, street orientation and vegetation have a more obvious effect on energy consumption.

From the research carried out in Iran, Mortezaei et al.(2016) modeled 25 patterns of residential fabric in SepahanShahr with DesignBuilder software and the amount of primary energy for heating, cooling and lighting per year were investigated in their paper. The findings indicate that there is a strong correlation between the consumption of primary energy and layout plan indicators, mass location, building form, building height, level of passages and open spaces, and there is a moderate correlation between primary energy consumption and block proportions index. Based on these results, common row patterns and square patterns are the most efficient and inefficient pattern of the new residential fabric, respectively. Mehdizadeh and Nasrollahi (2012) compared six types of common building blocks in Tehran in terms of energy consumption in their study. The results have shown that, the amount of radiation from east and west on the building (east and west windows of the building) in summer and, the open space between the buildings and how the building is placed on the site in winter have the greatest impact on energy performance. Finally, linear models are the best option in terms of heating and cooling energy consumption, and central yard buildings are the best option for access to daylight. Moradkhani et al. (2018) examined the effect of different layout patterns of building blocks, at the neighborhood scale and in the city of Sanandaj, a linear pattern with dense building masses (with a minimum amount of mass exposed to air) due to receiving more radiation and heat transfer loss, introduced as an efficient model in terms of total annual energy consumption.

Given to a difference of climatic regions, each climatic region requires its own special design solutions (Taleghani et al., 2013). Other research to analyze the effect of microclimate on interior thermal conditions and new strategies at the inter-building scale should be considered to improve energy efficiency in different locations and climatic conditions (Kobiax, 2017). The study focus on Caspian climate region, as well as Babol, as a leading city in terms of the intensity of urban development because of the research weakness in the field of urban climate of these regions.

2.2. Energy consumption

Currently, 50% of the world's population lives in urban areas, which will grow to about 70% by 2050 (Allgrini et al., 2012). These regions consume approximately 75% of the world's energy (Haung and Li, 2017). Today, the concern about energy consumption is increasing and the unsuitable use of energy and raw materials causes irreparable damage, such as environmental destruction, destruction of fossil energy sources, economic and psychological problems, and finally, it causes the deprivation of human comfort and health (Sanaiyan et al., 2014). Iran is one of the rich countries in the field of fossil energy, and at the same time, it is one of the excessive consumers of energy (Haj Malek et al., 2017). In Iran, energy consumption in the building sector is 40.6% of the total energy consumption, while in developed countries, this amount is 33% (Zomorodian and Nasrollahi, 2013). The energy consumption performance of buildings depends on five factors: weather, building design, urban form, systems' efficiency, residents' behavior (Sanaiyan et al., 2014) and energy consumption including heating, cooling, hot water consumption, lighting, baking and other cases that a large part of the world's energy is consumed for environmental compliance and creating thermal comfort conditions in the building (Energy Information Management Organization of America, 2017). Therefore, in the current research, the criterion for measuring the efficient model is the amount of heating and cooling energy consumption for the thermal comfort of the interior space.

2.3. Thermal comfort

Thermal comfort is a characteristic in the environment that people prefer neither lower nor colder temperatures (Lai et al., 2018 and Standard Ashri, 2017). Thermal comfort in the building is the main factor for the health and productivity of users from the environment (Ramponi et al., 2015). In forming thermal comfort conditions, four environmental variables have an important role, like air temperature, average radiation temperature, air humidity, air flow, and human-related variables such as the amount of activity, the type of cover (Hejazi and Karbalaei, 2016). Thermal comfort and its establishment is one of the most important criteria in building design, and not paying attention to it, increases the use of energy resources (Hamze Nejad, 2021). Thermal comfort can be evaluated in different ways. The PMV model is superior among known thermal comfort models. The PMV is an index for predicting the average heat ratings of people, which has a range between -3 and +3 according to the ASHRAE standard. These numbers represent the thermal sensation people feel in similar environmental conditions inside the space (Standard Eshri, 2017).

2.4. Urban form

The urban form is the spatial pattern of the large, stationary and permanent physical elements of the city (Seif al-Dini et al., 2013). Of course, the views are different according to the studies and it is not possible to give a precise definition of the urban form (Azizi et al., 2021). So, the urban form is defined according to its type of use (Alipourkohi et al., 2021). This means that the indexes and components that are used to evaluate the urban form are appropriate to the research goal. Urban form variables can have a significant effect on microclimate such as solar radiation, air temperature, wind speed and thermal comfort and therefore energy consumption. (Zebardast, 2021). The research goal is to investigate the effect of the changing layout of buildings on the internal thermal building conditions and the amount of energy consumption.

3. Research Methodology

This research includes parts of library study, and software analysis, respectively, to develop a theoretical framework and categorize repetitive forms to model and analyze the energy and thermal comfort of categorized forms. Based on the research literature, the effect of the building block form pattern on the thermal conditions of the building and its result affects the amount of energy consumption in the building. Accordingly, in this study, the general pattern of building block layout (discrete, linear, centripetal) and its characteristics, including length, depth, direction, were considered as independent variables of the research. The annual energy consumption of the building was considered as dependent variable. The thermal conditions in the building are based on the PMV thermal index as a mediating variable in the effect of the different layout patterns on the energy consumption of the building. Accordingly, the samples of building block layouts based on typical patterns in the study area located in the humid subtropical climate of Caspian Coast (CFA in Koppen climate classification) will be simulated using DesignBuilder software and the results were compared with each other. Identification of types of building layout through aerial photographs and calculation of area, ratio of length to width and orientation of land is done by GIS software.

Research objectives: 1- Predicting the effect of the layout of building blocks on the thermal conditions of the building, 2- Predicting the impact of the layout of building blocks on the annual energy consumption caused by changes in the thermal conditions of the building.

Research questions: In the humid subtropical climate of Caspian, which building block layout provides the most favorable annual energy consumption due to thermal conditions in the building.

4. Study Area

4. 1. Babol city climate

Using the psychrometric chart, it is possible to determine that the city in question is in the comfort zone during several hours of the year, and in which zones comfort conditions can be reached using passive methods, and in which zones mechanical devices can be used for cooling and heating. According to this diagram, the city of Babol is in the comfort zone in 810 hours of the year, and 29.5% of the hours of the year require heating equipment and 18.7% of the hours of the year require cooling equipment (Fig. 1).

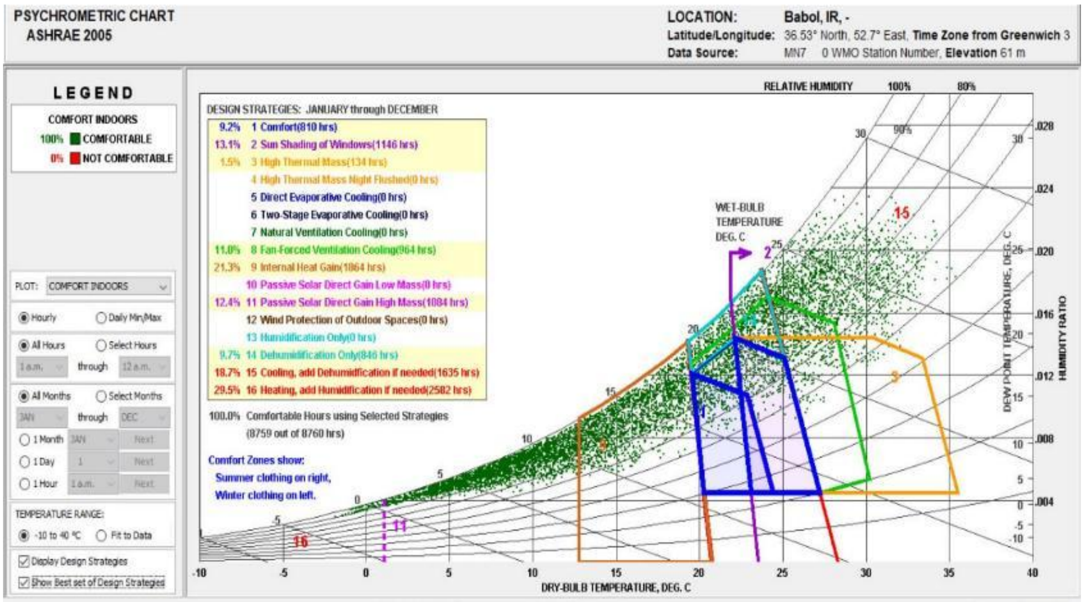


Fig. 1. Psychometric diagram of Babol

4.2. Study samples

After a comprehensive examination of building blocks' morphology on Babol, different species were extracted and a parametric study was performed on the existing common species to completely cover the layouts of building blocks on Babol in the study and finally the optimal solution is provided. In this regard, the urban spaces that have a specific discipline are considered. The dominant form is linear (Figure A) and is continuous in the space of urban streets. Also, the presence of a pattern in the square form (Figure B) among the building blocks of old residential neighborhoods indicates the original pattern of urban design in this city, which needs to be investigated.

In this research, 8 common patterns of street spaces in the city with different layouts have been selected to investigate the energy consumption and buildings' interior thermal comfort. These patterns are:

1. Linear patterns (Fig. 2) which include: short linear pattern, street medium linear pattern, long linear pattern, a northeast-southwest linear pattern.
2. A Centripetal Tendency Patterns (Fig. 3) which include: shallow centripetal pattern, medium deep centripetal pattern, deep centripetal pattern.
3. Discrete pattern (Image No. 4.)

(4) (3) (2) (1)

Fig. 2. (1) Short linear pattern, (2) medium linear pattern, (3) long linear pattern, (4) a northeast-southwest linear pattern

(3) (2) (1)

Fig. 3. (1) Shallow centripetal pattern, (2) medium-depth centripetal pattern, (3) deep centripetal pattern

Fig. 4. Discrete pattern

4. Simulation process and analysis of the energy consumption and thermal comfort of study samples 8

common patterns of Babol are modeled by Design Builder software and analyzed in terms of thermal comfort and energy consumption in this simulator. PMV index is used to check thermal comfort conditions. In all the examined models, the height, occupation level, proportion, materials and the presence of people are the same. In different layouts, the target building (middle building of each model) is analyzed in terms of thermal comfort conditions and energy consumption.

Table 1
The characteristics of the building

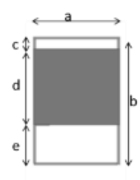
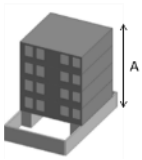
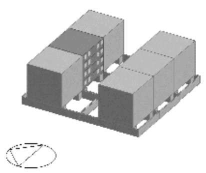
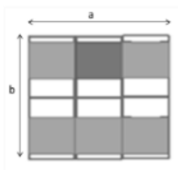
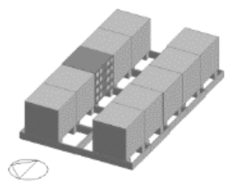
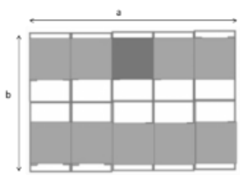
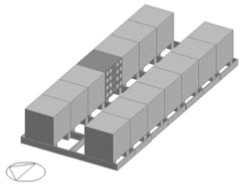
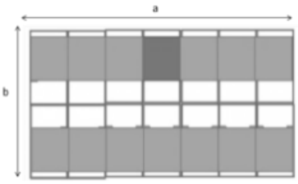
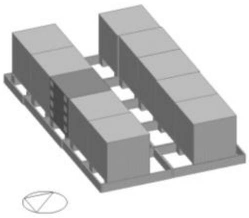
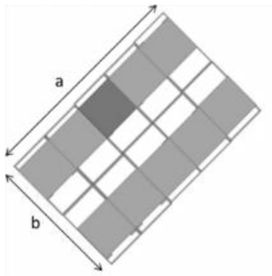
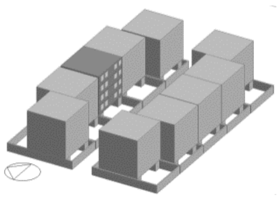
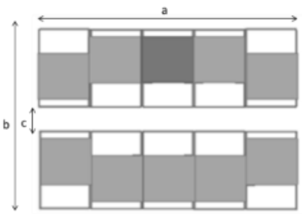
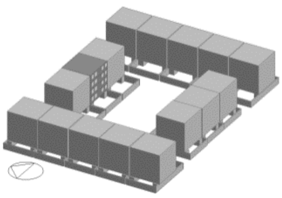
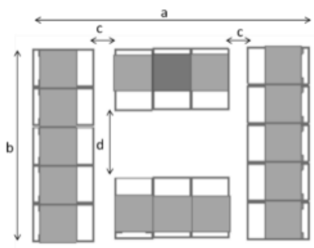
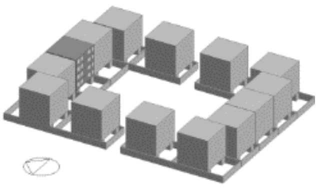
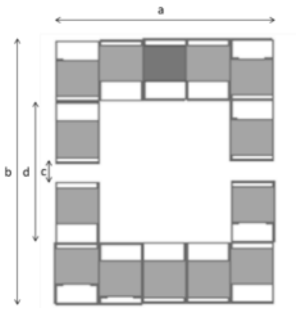
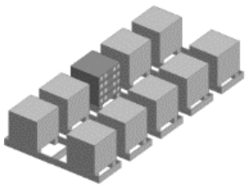
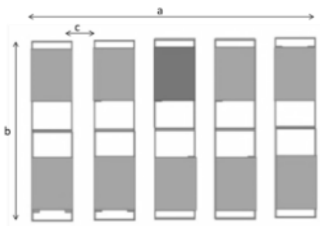
Building	Floor area	Dimension and sizes (m)	U-value W/(m^2/K)	Window to wall %
 	60%	A= 14.5 a= 12.5 b= 20 c= 2 d= 12 e= 6	external wall: 0.92 inner wall: 2.41 Ceiling between floors: 1.18 Flat roof: 0.93	30

Table 2
Specification of building block layout patterns

Typical layout pattern			Dimensions and sizes of building block(m)	Orientation	Percentage of building mass to block area
	Perspective	Plan			
short linear pattern			a= 37.5 b= 40	E-W, O^{O}	60%
medium linear pattern			a= 62.5 b= 40	E-W, O^{O}	60%

long linear pattern			a= 87.5 b= 40	E-W, O^{O}	60%
northeast-southwest linear pattern			a= 62.5 b= 40	NE-SW,135^{O}	60%
shallow centripetal pattern			a= 62.5 b= 46 c= 6	E-W, O^{O}	51%
medium-depth centripetal pattern			a= 89.5 b= 62.5 c= 6 d= 22.5	E-W, O^{O}	43%
deep centripetal pattern			a= 62.5 b= 86 c= 6 d= 46	E-W, O^{O}	40%
Discrete pattern			a= 86.5 b= 40 c= 6	E-W, O^{O}	44%

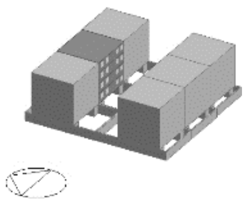
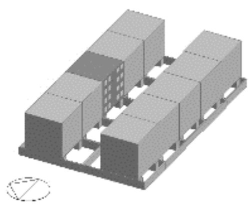
5. Simulation Results

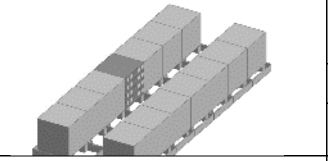
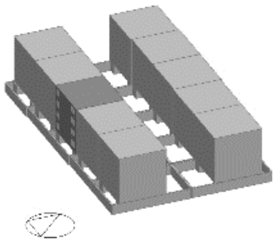
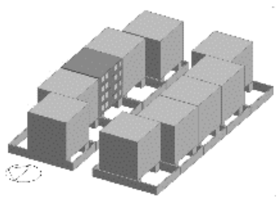
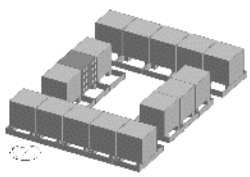
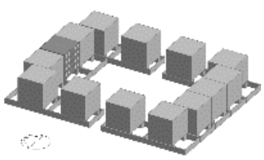
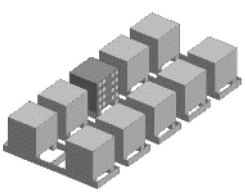
PMV index. Eight layout patterns of different building blocks have been simulated in the Babol's climate conditions and the consumption of heating and cooling energy and total energy as well as their PMV index have been calculated (Table 3.)

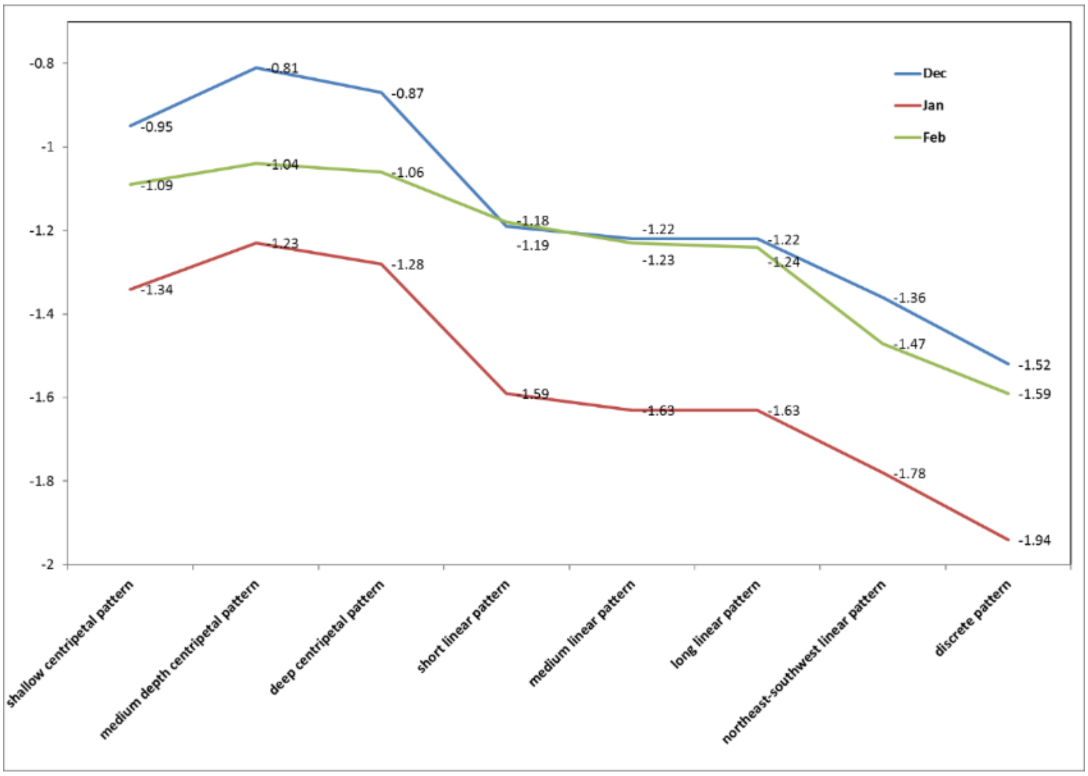
The range of PMV index in the discrete pattern is between -1.94 to -1.52 in the cold three months of the year and between +1.72 to +2.72 in the hot three months. This pattern has the greatest distance from the neutral axis of the PMV index in the cold three months of the year and the least distance from the neutral state of the PMV index in the three hot months. Among the samples of the linear pattern, as the length of the block decreases, the monthly average PMV increases, and in the short linear pattern, the range of the PMV index in the three cold months of the year is between -1.59 to -1.18 and the three warm months are between +1.98 to +2.98. This pattern has the greatest distance from the neutral axis of the PMV index in the hot three months of the year and the least distance from the neutral state of the PMV index in the cold three months, compared to other linear patterns (East-West). It can be seen that in both seasons, the amount of PMV in centripetal patterns is higher than in linear patterns. In the centripetal pattern with medium-depth, the range of PMV index in the three cold months of the year is between -1.23 and -0.81 and the three hot months are between +2.96 and +1.96. In the linear pattern with a northeast-southwest direction, the PMV index ranges between -1.78 and -1.36 in the cold three months of the year and between +3.17 and +2.41 in the three warm months. In the linear pattern with a northeast-southwest direction, it has the highest amount of PMV in the hot season and the lowest amount of PMV in the cold season after the discrete pattern.

Energy consumption. The centripetal patterns have the lowest total energy consumption during a year (average annual total energy consumption in the shallow centripetal pattern: 53114.89 wh/m^2, medium deep centripetal pattern: 52718.57 wh/m^2, deep centripetal: 52854.23 wh/m^2). Linear patterns (east-west) have the lowest annual energy consumption after centripetal patterns. The consumption of cooling and heating energy in a linear pattern with a northeast-southwest orientation is 31668.3 wh/m^2 and 9958.83 wh/m^2, respectively. In the separate pattern with 26982.22 wh/m^2, the amount of cooling energy consumption is a little lower than other patterns, but it has the highest amount of heating energy and total energy consumption throughout the year.

Table 3
Annual heating, cooling and total energy consumption with PMV index for three cold and warm months of the year

<table>
<tr><th colspan="2">Typical layout pattern</th><th colspan="6">Annual energy consumption(wh/m^2)</th></tr>
<tr><td rowspan="6">short linear pattern</td><td rowspan="6"></td><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">8483.38</td><td colspan="2">27998.64</td><td colspan="2">54127.07</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-1.19</td><td>-1.59</td><td>-1.18</td><td>1.9</td><td>2.54</td><td>2.88</td></tr>
<tr><td rowspan="7">medium linear pattern</td><td rowspan="7"></td><td colspan="6">Annual energy consumption(wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">8735.16</td><td colspan="2">27730.23</td><td colspan="2">54616.48</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-1.22</td><td>-1.63</td><td>-1.23</td><td>1.88</td><td>2.52</td><td>2.86</td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td colspan="6">Annual energy consumption(wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">8770.54</td><td colspan="2">27679.88</td><td colspan="2">54650.48</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
</table>

<table>
<tr><td rowspan="3">long linear pattern</td><td rowspan="3"></td><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-1.22</td><td>-1.63</td><td>-1.24</td><td>1.87</td><td>2.51</td><td>2.85</td></tr>
<tr><td rowspan="7">northeast-southwest linear pattern</td><td rowspan="7"></td><td colspan="6">Annual energy consumption(wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">9958.83</td><td colspan="2">31668.3</td><td colspan="2">59853.13</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-1.36</td><td>-1.78</td><td>-1.47</td><td>2.41</td><td>3.06</td><td>3.17</td></tr>
<tr><td rowspan="7">shallow centripetal pattern</td><td rowspan="7"></td><td colspan="6">Annual energy consumption(wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">7049.54</td><td colspan="2">28772.42</td><td colspan="2">53114.89</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-0.95</td><td>-1.34</td><td>-1.09</td><td>1.89</td><td>2.53</td><td>2.88</td></tr>
<tr><td rowspan="7">medium-depth centripetal pattern</td><td rowspan="7"></td><td colspan="6">Average Annual energy consumption(wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">6215.71</td><td colspan="2">28842.96</td><td colspan="2">52718.57</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-0.81</td><td>-1.23</td><td>-1.04</td><td>1.96</td><td>2.62</td><td>2.96</td></tr>
<tr><td rowspan="7">deep centripetal pattern</td><td rowspan="7"></td><td colspan="6">Average energy consumption (wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">6807.93</td><td colspan="2">28824.33</td><td colspan="2">52854.23</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-0.87</td><td>-1.28</td><td>-1.06</td><td>1.98</td><td>2.62</td><td>2.96</td></tr>
<tr><td rowspan="7">Discrete pattern</td><td rowspan="7"></td><td colspan="6">Annual energy consumption(wh/m^2)</td></tr>
<tr><td colspan="2">Heating</td><td colspan="2">Cooling</td><td colspan="2">Total (Heating+ Cooling +lighting)</td></tr>
<tr><td colspan="2">16363.62</td><td colspan="2">26982.22</td><td colspan="2">61011.32</td></tr>
<tr><td colspan="6">Average monthly PMV index</td></tr>
<tr><td colspan="3">Average monthly PMV index in the cold months of the year</td><td colspan="3">Average monthly PMV index in the hot months of the year</td></tr>
<tr><td>Dec</td><td>Jan</td><td>Feb</td><td>Jun</td><td>Jul</td><td>Aug</td></tr>
<tr><td>-1.52</td><td>-1.94</td><td>-1.59</td><td>1.72</td><td>2.39</td><td>2.72</td></tr>
</table>



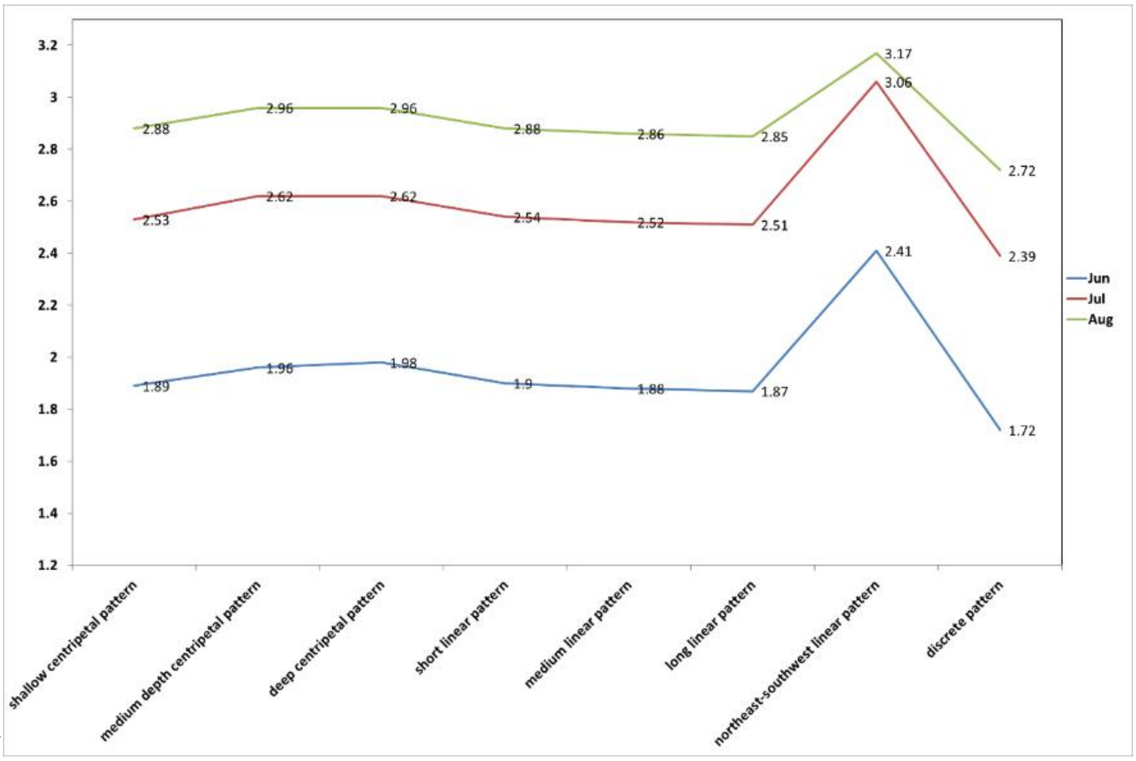


Fig. 5. Comparison of comfort conditions of models based on PMV index

6. Results and Discussions

The purpose of this research is 1- to predict the effect of the layout of building blocks on the thermal conditions of the building 2- to predict the effect of the layout of building blocks on the annual energy consumption caused by changes in the thermal conditions of the building. Accordingly, the obtained results are examined in two parts ،the effect of the layout pattern of building blocks on the thermal conditions of the building and the effect of the layout pattern of building blocks on the energy consumption inside the building، and finally a summary is presented .

6.1. The effect of changes in the layout pattern of building blocks on the thermal conditions of the building based on the PMV index

Comparison of the thermal comfort conditions of models based on PMV index

The monthly average PMV index in form patterns in hot and cold season of the year is presented on Fig. 5.

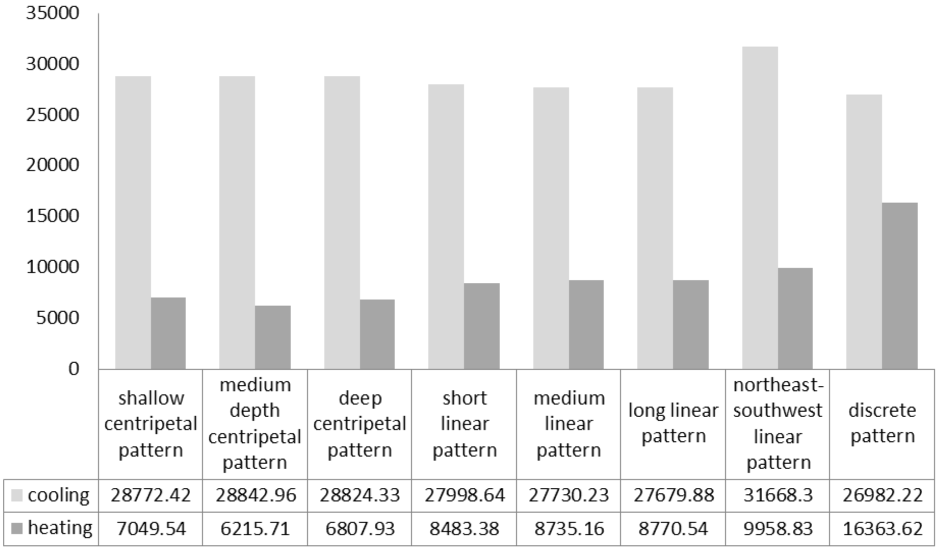
- It can be seen that in both seasons, the amount of PMV in centripetal patterns is higher than PMV in linear patterns. The reason for this is the greater distance between the walls and the possibility of receiving more radiation.
- The medium-depth centripetal pattern receives more radiation from the east and west angles due to its wider form and the spacing of the side walls, and the monthly average PMV in it is slightly higher than other centripetal samples (average PMV in the three cold months of the year: -1).
- Among linear pattern samples, as the length of the block decreases, the possibility of receiving radiation increases and the monthly average PMV increases. (Short linear pattern with average PMV of the three cold month of the year: 1.32 and three warm months: 2.44 and long linear pattern, average PMV of the three cold months of the year: -1.36 and three warm months: 2.41).
- The linear pattern with a northeast-southwest direction has the highest PMV in the hot season, and the lowest PMV after the discrete pattern in the cold season. This pattern receives the most radiation in the summer when the range of sun's movement is wider. But as the path of sun is shortened in winter, it receives the least amount of radiation (The average of the three cold months: -1.53 and the average PMV of the warm month: 2.88). Taleghani (2014) also presented similar results that the change of direction in building blocks with a linear form causes a change in thermal conditions.

Among all the examined patterns, the discrete pattern has the lowest PMV in hot season and also the lowest PMV in cold season. This model has the coldest conditions compared to other models due to all the windows being open and heat loss. (The average of the three cold months: -1.6 and the average PMV of the warm month: 2.2).

6.2. The effect of changes in the layout pattern of building blocks on building energy consumption

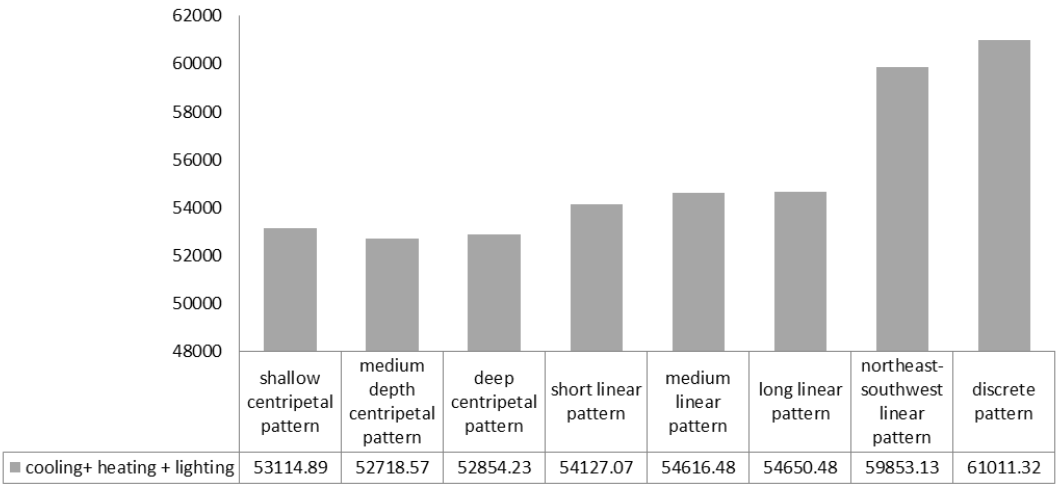
The average cooling and heating energy consumption of form models throughout the year is presented on Fig. 6 and the total energy consumption of form models throughout the year is presented on Fig7.

- In general, energy consumption shows a direct relationship with thermal building conditions.
- Centripetal patterns have the lowest total energy consumption during a year, because these patterns receive more radiation in winter and require less energy consumption. (The annual average amount of total energy consumption in the shallow centripetal model : 53114.89 wh/m^2, medium-deep centripetal: 52718.57 wh/m^2, deep centripetal: 52854.23 wh/m^2). Similar to the paper of Mangan et al. (2020), to evaluate the impact of urban form on energy consumption in temperate climate regions, building block forms that have the most solar gain, heating, lighting and total energy consumption were reduced.
- In linear patterns, as the length decreases and more radiation is received, heating energy consumption decreases in the cold season.
- Linear patterns (east-west) have the lowest annual energy consumption after centripetal patterns. As the length decreases in the linear patterns, due to receiving more radiation, the consumption of heating energy and total energy decreases and in (the consumption of heating energy, short linear patterns: 8483.38 wh/m^2, medium linear patterns: 8735.16 wh/m^2, long linear patterns: 8770.54 wh/m^2). The obtained results support the results of the studies of Moradkhani et al. (2018) and Sanyeayan et al (2013).
- The linear pattern with a northeast-southwest orientation, the consumption of cooling and heating energy and the total energy, is more than the linear examples of east-west, throughout the year (the consumption of cooling energy, 31668.3 wh/m^2, heating energy, 9958.83 wh/m^2).
- In the discrete model, the cooling energy consumption is a little lower than other models, but the heating energy consumption in this model is very high due to the transfer of heat to outside of building due to the opening of all the windows, and as a result, this model consumes the most energy throughout the year. (Annual cooling energy consumption, 26982.22 wh/m^2, annual heating energy consumption, 16363.62 wh/m^2, and total energy consumption, 61011.32 wh/m^2). Sanyayan et al. (2014) and Taleghani (2014) also presented similar results and the highest amount of total energy consumption was reported in the discrete model.



	shallow centripetal pattern	medium depth centripetal pattern	deep centripetal pattern	short linear pattern	medium linear pattern	long linear pattern	northeast-southwest linear pattern	discrete pattern
cooling	28772.42	28842.96	28824.33	27998.64	27730.23	27679.88	31668.3	26982.22
heating	7049.54	6215.71	6807.93	8483.38	8735.16	8770.54	9958.83	16363.62

Fig. 6. Comparison of cooling and heating energy consumption of all models (wh/m^2)



	shallow centripetal pattern	medium depth centripetal pattern	deep centripetal pattern	short linear pattern	medium linear pattern	long linear pattern	northeast-southwest linear pattern	discrete pattern
cooling+ heating + lighting	53114.89	52718.57	52854.23	54127.07	54616.48	54650.48	59853.13	61011.32

Fig. 7. Comparison of total energy consumption of all models (wh/m^2)

7. Conclusion

According to the research literature, the building block layout patterns affect on the thermal conditions of the building and consequently on the amount of energy consumption in the building. Based on this, in this study, the general pattern of building block layout (discrete, linear, centripetal) and its characteristics, including length, depth, direction, were considered as independent variables of the research. The annual energy consumption of the building was considered as a dependent variable. The thermal conditions in the building are based on the PMV thermal index as a mediating variable in the effect of the different layout pattern on the energy consumption of the building. The purpose of the research was to predict the effect of the layout pattern of building blocks on the thermal conditions of the building and to predict the effect of the layout pattern of building blocks on the annual energy consumption caused by changes in the thermal conditions of the building. Accordingly, the samples of building blocks layou based on typical patterns in the study area located in the mild and humid climate of the Humid Subtropical Climate of Caspian Coast (CFA) were simulated using Design Builder software and the results were compared with each other .

Based on the results, by receiving more radiation throughout the year due to the layout design pattern of building blocks will lead to increase in the PMV thermal index in the building. centripetal patterns have warmer thermal conditions than linear patterns due to the possibility of receiving more radiation. Among the samples with a medium-depth centripetal pattern, has the highest monthly average PMV due to the spacing between the side walls(average PMV in the three cold months of the year: -1, average PMV in the three cold months of the year: 2.4). Among the linear patterns, solar radiation intake and monthly average PMV increase as the block length decreases.

Energy consumption in the hot and cold seasons shows a direct relationship with the thermal conditions of the building. The centripetal patterns have the hottest thermal conditions throughout the year, and as a result, will lead to the lowest heating energy and the highest cooling energy requirement. The medium-depth centripetal pattern has the lowest amount of heating energy and the highest amount of cooling energy compared to other centripetal patterns with 28842.96 wh/m2. It also has the lowest amount of total energy consumption compared to all patterns with 52718.57 wh/m2. Among the linear patterns, the short linear pattern with 8483.38 wh/m2 has the lowest amount of heating energy consumption after the centripetal patterns and the highest amount of cooling energy consumption compared to other linear patterns (east-west) with 279498.6 wh/m2 and finally, it has the lowest amount of total energy after the centripetal pattern with 54127.0 wh/m2.

In general, the layout patterns of the building blocks, which provide the possibility of receiving more radiation throughout the year, are evaluated favorably in terms of energy consumption. Receiving more radiation, although it causes an increase in the consumption of cooling energy in the hot season, but its effect on reducing the consumption of heating energy in the cold season has been more significant and makes a difference in the annual energy consumption. This confirms the findings of some previous studies.

Based on the results, the layout patterns of the building block in the form of medium-depth centripetal pattern (annual energy consumption: 52718.57) and a short-length linear (annual energy consumption: 54127.07) can be considered as favorable options in terms of annual energy consumption. Also, the results regarding with linear and discrete patterns as dominant patterns in the northern cities of Iran indicate that the change of direction in building blocks with a linear form causes a significant change in energy consumption(It increases by 10.7% compared to the short linear pattern), and in the discrete pattern, considering designing strategy like insulation for external walls are important to prevent heat loss. It is suggested to investigate the impact of other urban form variables from the point of view of thermal conditions and energy consumption of buildings in future researches.

This research has investigated the effect of the building blocks layout pattern on energy consumption and thermal conditions. This has been done based on parametric analysis through modeling using Design Builder software. The results show a direct relationship between the energy consumption of building and system’s thermal conditions. In general, the building blocks layout patterns, which provide the possibility of receiving more radiation throughout the year, are evaluated favorably in terms of energy consumption. Receiving more radiation, although it causes an increase in the consumption of cooling energy in hot season, but its effect on reducing the consumption of heating energy in cold season has been more significant and makes difference in annual energy consumption.

Based on the results, the building blocks layout patterns in the form of centripetal and linear with short length can be considered as favorable options in terms of annual energy consumption. Also, the results regarding linear and discrete patterns as dominant patterns in the northern cities of Iran indicate that the change of direction in building blocks with a linear form causes a significant change in energy consumption, and in the discrete pattern, considering designing strategy like insulation for external walls are important to prevent heat loss.

Limitations and suggestions for future studies:

This research deals with the parametric analysis of the effect of the layout pattern on the thermal conditions and energy consumption of the building using computer modeling (Design Builder software). The limitation of the research is the changes in the micro-climate variables of the open space outside the buildings due to the changes in the layout of the building blocks, and another limitation of this research is the experimental examination of the results in real conditions.

For future studies, it is suggested to model the conditions inside the building in interaction with the modeling of the climatic conditions outside the building. Also, beyond computer modeling, the results of the effect of layout pattern on thermal conditions and energy consumption should be investigated in experimental studies in real conditions.

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