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The Effect of Building Aspect Ratio on the Energy Performance of Dormitory Buildings in Cold and Semi-Arid Climates of Iran

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ABSTRACT

This study investigates the effect of building aspect ratio on energy efficiency in the cold and semi-arid climate of Shiraz and proposes its optimal value for designing student dormitories in this city. A number of building models with different aspect ratios were developed and evaluated in two stages, using dynamic simulation tools. In the first stage, the models are characterized by larger windows at south and north facades while in the second, all facades were given an equal value of window to wall ratio (WWR). The results indicate that the optimal aspect ratio of a building can be different, when the WWR of each façade is changed. This has to be taken into account when proposing an ideal envelope design for buildings in certain climates and conditions.

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THE EFFECT OF BUILDING ASPECT RATIO ON THE ENERGY PERFORMANCE OF DORMITORY BUILDINGS IN COLD AND SEMI-ARID CLIMATES OF IRAN

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Abstract

This study investigates the effect of building aspect ratio on energy efficiency in the cold and semi-arid climate of Shiraz and proposes its optimal value for designing student dormitories in this city. A number of building models with different aspect ratios were developed and evaluated in two stages, using dynamic simulation tools. In the first stage, the models are characterized by larger windows at south and north facades while in the second, all facades were given an equal value of window to wall ratio (WWR). The results indicate that the optimal aspect ratio of a building can be different, when the WWR of each façade is changed. This has to be taken into account when proposing an ideal envelope design for buildings in certain climates and conditions.

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1. Introduction

The building envelope is the barrier that separates the interior environment from external conditions, providing thermal comfort for occupants. On the other hand, it can act as an obstacle to the entrance of daylight and solar radiation when needed. Thus, it can have both negative and positive effects on the energy requirements of a building and has to be carefully designed in order to reach high levels of efficiency.

Beside energy efficiency, building envelope design has to consider many other issues such as aesthetics and economic constraints. Thus, not only finding the optimal design that leads to least consumptions matters, but it is also important to know the extent of this influence. It will then be possible for the designer to reach a balance between energy performance and other design issues.

Different aspects of the design of the building envelope such as its shape and compactness and their effects on energy efficiency have been investigated in several previous studies [1-8]. It is

generally accepted that Rectangular shape is the optimal building shape for an energy efficient design [9]. On the other hand, finding the optimal rectangle with the ideal width to length ratio, also known as aspect ratio [10] is another objective in design optimization of buildings [10-12].

The aspect ratio of a building, affects its level of compactness and thus the amount of heat loss and gain [11]. An aspect ratio near 1:1 belongs to near-square shapes, which are more compact compared to elongated shapes with higher aspect ratios.

On the other hand, “the aspect ratio of a building along with its orientation, define the percentage of the facade exposed at each cardinal point” [13], which means it also affects how the building receives solar radiation.

Previous studies suggest that compact shapes are preferred in cold climates [1, 4], and the ideal aspect ratio in such places ranges from 1.3 to 1.5 [8]. In a comprehensive study, McKeen and Fung [11] investigated the effect of aspect ratio on energy requirements of multi-unit residential buildings in Canada and

confirmed that the 1.3 to 1.5 range is ideal in different cities of this country.

Inanici and demirbilek [12] also performed a similar study for different cities of turkey and suggested the aspect ratios of 1.2:1 and 2:1 for cold and warm climates of this country respectively, indicating that a more elongated shape performs better in climates with higher outdoor temperature. This is in line with the findings of Depecker et al. [1] and Albatici and Passerini [4], who observed that more compactness, does not necessarily lead to less heating energy demand in warm climates.

The present study, aims to test the findings of previous studies in the climatic conditions of Shiraz city. It investigates the optimal building aspect ratio as a part of a larger project, which aims to optimize the design of student dormitories in this city. The investigated models are thus, representatives of the current design and construction practices in these buildings.

The buildings used as reference, have less glazed surfaces on their east and west facades compared to the south and north ones. Such design can affect the optimal aspect ratio and the results cannot be used for buildings with equal WWR in all facades. In order to test different design alternatives and provide the ideal aspect ratio for each one, both types of façade design and their optimal elongations are investigated.

2. Research Methods

This study uses the parametric method to investigate the effect of aspect ratio on the energy requirements of buildings and provide its optimal value for student dormitories in Shiraz, Iran. Several Building models with different aspect ratios ranging from 1:1 to 4:1 were designed. Different characteristics of the models such as the plan design, and construction properties are selected based

on the current conditions of the built dormitories in Shiraz university campus.

The energy requirements of the models are tested in two stages. In the first stage, the west and east facades have a lower WWR than the north and south ones. In the second stage, the WWR of all facades were set to 20%.

In each stage, thermal performance of the models are analyzed using DesignBuilder dynamic simulation software tool [14]. The simulations are then followed by analytical comparisons of the effect of aspect ratio on the heating and cooling energy requirements.

2.1. Design of the models

The current condition of the dormitories of Shiraz University campus were first studied and the newest building was chosen to serve as the base case for simulations. Typical plan of this building presents a central corridor with bedrooms and other spaces on both sides of the corridor (see Fig. 1).

As can be seen in Fig. 1, there are several recesses in different facades of the building. These recesses increase the total surface area of the external envelope, resulting in an increased heat loss. As the aim of this study is to reach the ideal envelope configuration, the models are designed without these recesses and present the optimal rectangular shape.

Six rectangular models with aspect ratios ranging from 1:1 to 4:1 were developed in DesignBuilder simulation software tool. Table 1 compares the surface area of different facades of these models.

The models consist of four floors, all having a plan design similar to the plan presented in Fig. 1. Each floor has a gross internal area of 518.5 m² and includes 14 bedrooms each occupied by four adult individuals, a central corridor, a kitchen

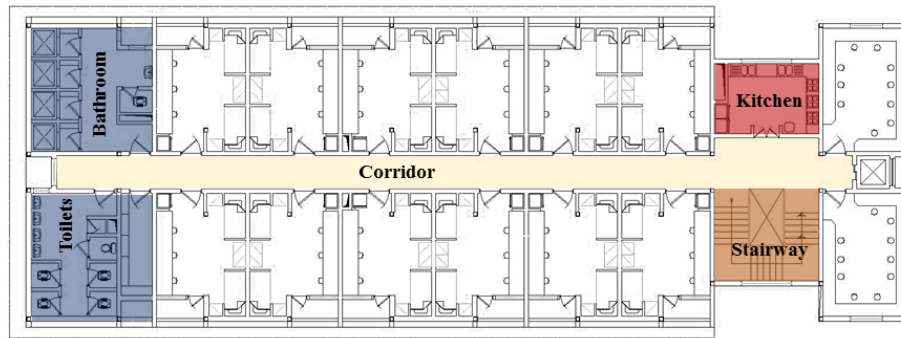
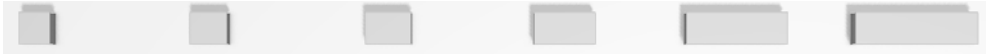


Fig.1. typical floor plan of the base case dormitory [15]

Table 1. surface areas of different façades of the models

						
Aspect Ratio	1:1	1.2:1	1.5:1	2:1	3.3:1	4:1
South/North façade surface area (m ²)	311.8	340.89	380.29	438.18	569.23	616.93
East/West façade surface area (m ²)	311.8	285.15	255.8	222.4	172.05	159.19
envelope surface area (m ²)	2330.18	2334.8	2355.72	2406.8	2573.44	2646.15

and a stairway. Fig. 2 shows the internal zoning for the extreme models with aspect ratios of 1:1 and 4:1.

The building is used throughout the year and all spaces except the stairways use an HVAC system to provide thermal comfort for occupants. Table 1 presents different characteristics of the HVAC system and internal gains from lighting and appliances.

WWR of the south and north façades were set to 20% in both stages of the study. In the first stage, the only windows on west and east façades were located on the external wall of the central corridor and had an area equal to 20% of this wall. In the second stage however, the WWR of the

east and west façades were set to 20 % as well (see Fig. 3).

3. Analysis & Results

3.1. Results for the models with low WWR in their east and west façades

The annual heating and cooling energy consumptions were calculated for models with aspect ratios ranging from 1:1 to 4:1. As shown in Fig. 4, for the cooling energy requirements, the square shape with the aspect ratio 1:1, resulted in the least energy need, and as the aspect ratio increased, the cooling energy consumption increased continuously.

The difference in the cooling

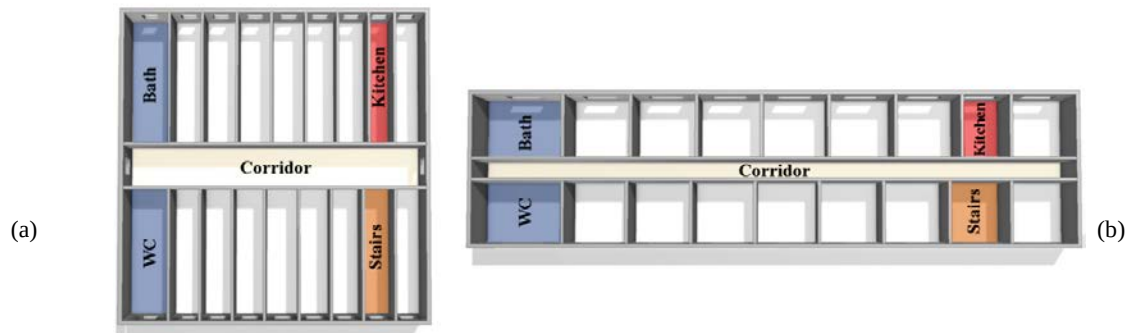


Fig. 2. Internal zoning of the models with different aspect ratios. (a) 1:1 and (b) 4:1.

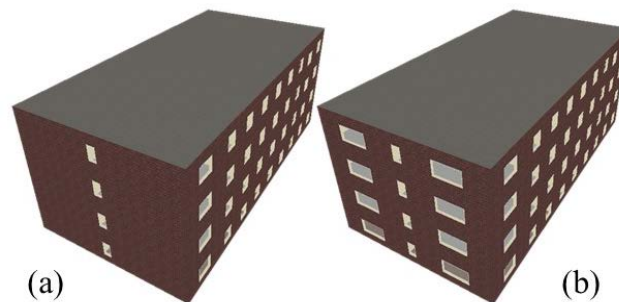


Fig 3. Example of façade designs in the firsts and second stage of the study. (a) first stage, (b) second stage.

Table 2. Model simulation parameters

Internal Gains from	Bedrooms: 8.90
Appliances (W/m ²)	Kitchen: 40.00
	Corridor: 0.00
	Bathroom: 1.60
	Toilets: 4.00
Lighting Gains (W/m ²)	Corridor 5.80
	Other spaces 3.36
Cooling system	Season: May 1 to September 30
	Set point temperature: 26°C
	Cop: 4.6
	Fuel: Electricity
Heating system	September 1 to May 31
	Set point temperature: 20C
	Cop: 0.8
	Fuel: natural gas
Supply ventilation (L/S per person)	Bedrooms: 2.5
	Bathroom and toilet: 12
	Kitchen: 10
	Corridor: 0.3 (L/S per m ²)

Table 3. Construction properties

component	Construction	U-value (W/m ² K)
External wall	Concrete + insulation + lime stone	0.78
Roof	Light and dense Concrete (2 layers) + concrete blocks + insulation	0.56
Slab on grade	Light and dense concrete (2 layers) + Ceramic	1.47
Window glazing	Double glazed (3mm), air filled (13 mm)	2.71 (SHGH = 0.764)
Window frame	PVC	1.8

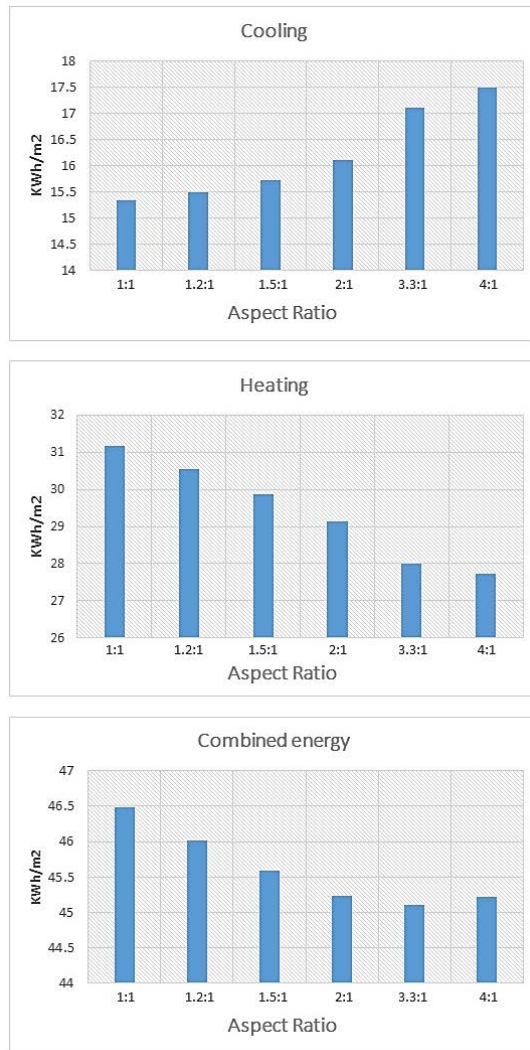


Fig.4. Annual cooling, heating and combined energy consumptions (KWh/m²) of the models with different aspect ratios.

energy consumption of the models with the best and worst performances is 12.3%.

On the other hand, the least heating energy consumption belongs to the most elongated shape with the aspect ratio 4:1. Strong solar radiation in Shiraz along with higher south façade areas in models with higher aspect ratios has resulted in a decrease in their heating energy consumption.

The difference in heating energy consumption of the models with the best and worst performances is 10.9%.

The most efficient aspect ratio is evidently one, which utilizes the least total energy.

The combined energy consumption, which quantifies the total heating and cooling consumption, is thus used to compare the efficiency of the models.

As can be seen in Fig. 4, the combined energy consumption is generally lower in models with more elongated shapes than the compact ones and the most efficient aspect ratio is 3.3:1.

The difference in combined energy consumption of the models with the best and worst performances is only 3%. This is a result of the fact that elongation has shown contrary effects on heating and cooling energy needs.

3.2. Results for the models with 20% WWR in all their facades

In the next stage of the study, all models were redesigned to have 20% WWR on all facades and their heating and cooling energy consumptions were recalculated. The results are shown in Fig. 5.

The least cooling energy consumption belongs to the model with the aspect ratio 1.5:1. When all the facades have an equal WWR, increasing the aspect ratio from 1:1 to 1.5:1 reduces the cooling energy consumption. This is likely the result of reduction in the west and east façade areas, which unlike the first stage will significantly reduce the window area in these facades.

However, increasing the aspect ratio above 1.5:1 will result in higher energy consumptions, which means that the reduction in solar radiation received, can no longer make up for the increase in heat gain due to larger external envelopes (see table 1). The difference in cooling energy need in models with the most efficient aspect ratio and the least efficient one is 4.5 %.

On the other hand, the heating energy consumption still decreases, as the aspect

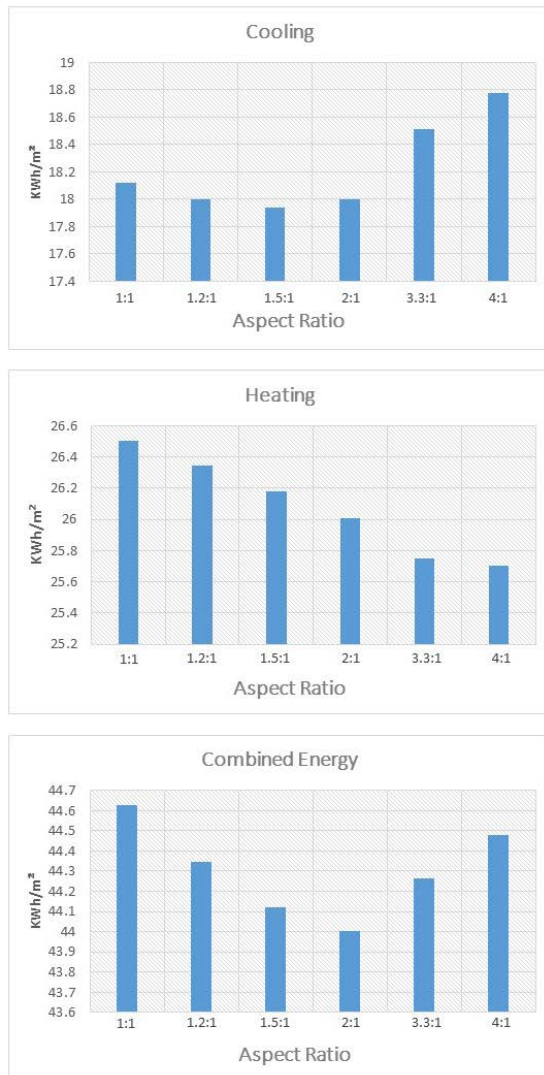


Fig.5. Annual cooling, heating and combined energy consumptions (KWh/m²) of the models with different aspect ratios.

ratio of the models increases, but the difference in heating energy need in models with the most efficient aspect ratio and the least efficient one is only 3% in this stage.

The combined energy consumptions of the models are also calculated and shown in Fig. 5. The combined energy consumption is lowest for the model with the aspect ratio 2:1 and highest for the square shaped model.

The results of this stage of the study is clearly different from the previous one, which shows that proposing one optimal

aspect ratio for all buildings in a certain climate, might be misleading in some cases. Further studies may be needed to test the effects of other design variables on optimal aspect ratio or test the findings of this study in other climates and conditions.

4. Discussion & Conclusion

This study investigated the effect of building aspect ratio on energy efficiency in the cold and semi-arid climate of Shiraz and proposed its optimal value for designing dormitories in this city. Two different façade designs were considered and the optimal aspect ratio was assessed for each one.

The aspect ratio of 3.3:1 was concluded to be optimal for buildings with small windows on their east and west facades while a less elongated shape with the aspect ratio of 2:1 was shown to perform better for buildings with an equal WWR in all facades. These findings show that the optimal aspect ratio of a building can be different when the WWR of each façade is changed.

5. References

- [1] Depecker, P., Menezo, C., Virgone, J., & Lepers, S. (2001). Design of buildings shape and energetic consumption. *Building and Environment*, 36(5), 627-635.
- [2] Wang, W., Rivard, H., & Zmeureanu, R. (2006). Floor shape optimization for green building design. *Advanced Engineering Informatics*, 20(4), 363-378.
- [3] AlAnzi, A., Seo, D., & Krarti, M. (2009). Impact of building shape on thermal performance of office buildings in Kuwait. *Energy Conversion and Management*, 50(3), 822-828.
- [4] Albatici, R., & Passerini, F. (2011). Bioclimatic design of buildings considering heating requirements in Italian climatic conditions. A simplified approach. *Building and Environment*, 46(8), 1624-1631.
- [5] Tuhus-Dubrow, D., & Krarti, M. (2010). Genetic-algorithm based approach

to optimize building envelope design for residential buildings. *Building and environment*, 45(7), 1574-1581.

[6] Bichiou, Y., & Krarti, M. (2011). Optimization of envelope and HVAC systems selection for residential buildings. *Energy and Buildings*, 43(12), 3373-3382.

[7] Lin, H. (1981). Building plane, form and orientation for energy saving. *Journal of Architecture*, 4, 37-41.

[8] Hachem, C., Athienitis, A., & Fazio, P. (2011). Parametric investigation of geometric form effects on solar potential of housing units. *Solar Energy*, 85(9), 1864-1877.

[9] Hachem, C., Athienitis, A., & Fazio, P. (2012). Evaluation of energy supply and demand in solar neighborhood. *Energy and Buildings*, 49, 335-347.

[10] Inanici, M. N., & Demirbilek, F. N. (2000). Thermal performance optimization of building aspect ratio and south window size in five cities having different climatic characteristics of Turkey. *Building and Environment*, 35(1), 41-52.

[11] McKeen, P., & Fung, A. S. (2014). The effect of building aspect ratio on energy efficiency: A case study for multi-unit residential buildings in Canada. *Buildings*, 4(3), 336-354.

[12] Aksoy, U. T., & Inalli, M. (2006). Impacts of some building passive design parameters on heating demand for a cold region. *Building and Environment*, 41(12), 1742-1754.

[13] Pacheco, R., Ordóñez, J., & Martínez, G. (2012). Energy efficient design of building: A review. *Renewable and Sustainable Energy Reviews*, 16(6), 3559-3573.

[14] DesignBuilder Software Ltd. 2016. DesignBuilder Software, www.designbuildersoftware.co.uk/ [accessed 20.12.2016].

[15] *Typical Floor Plan*. (2017). DWG File. Archive of Shiraz University. Shiraz, Iran.