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Research Paper

Dormitory Courtyard Proportion and Orientation in Yazd / Iran on Energy Consumption

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Abstract

Courtyard geometry plays an important role in the amount of received solar radiation, also heating and cooling energy consumption of buildings. Considering this geometry for finding its proper proportion and orientation is significant to increase indoor thermal comfort, and as a result reduce the amount of energy consumption. This paper mainly focuses on a dormitory courtyard in Yazd and investigate the effects of it's different proportions and orientations on the dormitory energy demand to reduce energy consumption. A computer software (EnergyPlus) was utilized to conduct the survey on base model which was obtained from existing university student dormitories in Yazd in a hot-dry climate of Iran. The findings indicated that the proportions and orientations of the courtyard dormitories affect the cooling and heating loads. Also, the outcomes indicated that the use of university student's courtyard dormitory with the proportion of 3/7 (width to length) and the orientation along east-west axis has the lowest required cooling and heating loads and could reduce the total energy consumption by 3.4 % compared with the most inappropriate courtyards based on their proportion and orientation.

Keywords: *Courtyard dormitory, Geometry, Energy use, Hot-dry region.*

1. INTRODUCTION

Courtyard residence is one of the most common residences and has been applied by many people. Having been improved by trial and error processing [1]. In hot-dry climate, courtyard residences are the best form, for coping with difficult climatic conditions. The interior spaces are open to inner courtyards, and therefore courtyard buildings are protected from harsh conditions such as winds with sand and dust, severe winter and extreme heat of summer [2]. While courtyards organize the inner spaces, they also provide desirable environmental features [3]. Inner courtyards as the core of courtyard buildings increase the thermal interaction between the interior spaces and the exterior environment.

In desert climates, a courtyard as a passive solar system in sustainable design, provides indoor thermal comfort. Therefore, courtyard residences have an important role in energy use and reducing the amount of consumption [4]. In fact, the building is an energy consumer and courtyard is one of the important elements of architecture influencing the amount of heating and cooling and hence building energy efficient [5, 6].

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Courtyard residences are still the traditional residence of many Asian, North African, South American and European countries [7]. In Iran, many of the courtyard residence forms have been used from ancient civilizations to present day. One of the courtyard residences in Iran is university students' dormitories that are built to use the courtyard resentence benefits in cities like Yazd, Damghan, and Sabzevar.

The city of Yazd is located in a hot-dry climate in central Iran and is known as the capital of deserts. Yazd is one of the historical cities of Iran and old courtyard residences can be found in this city [8]. The city is located at the longitude of 54° 24' E and latitude of 31° 54' N.

1.1 Energy efficiency

Nowadays energy efficiency is converting to a preference for building producers as energy consumption has grown a severe matter and is converting to a crisis. The domestic building sectors consume an enormous amount of power, and the energy consumption model will likely grow distinctly shortly [9]. In consequence, there has been a global shift towards obtaining efficient design plans to lower the energy needs of buildings and promote further knowledge of the energy-conscious plan. Previous articles revealed excellent chances for developing energy efficiency in the buildings by joining courtyards toward buildings [1].

1.2. Solar radiation and thermal performance of courtyard buildings

At the plan step specific decisions should be made in order to construct a proper courtyard building, some feature should be optimized including: inner envelope's finishing, materials, orientation and proportions of the physical factors of the courtyard form which the last two are of the utmost importance and objectives of the current research. Proportioning and orienting the inner courtyard could lead to gaining sufficient solar radiation in winter and as a result heating up the building and in summer making ample shadings by passing or decreasing a noticeable portion of cooling load.

Solar radiation is one of the factors that affects the climate performance of the courtyard buildings [10]. Because the sun, which provides heat and light, is the most significant energy input to buildings, solar radiation factor must be considered in the design of the courtyard to supply thermal convenient [11].

The important principle of thermal comfort in summer is passive cooling through shading [12]. The inner proportion and orientation of courtyards have a great impact on the amount of the received solar radiation and shading statuses provided on the inner face of the courtyard and subsequently affect the heating and cooling loads required for buildings [5, 13]. The geometrical parameters (especially proportions and orientation), position and climatic status, the time of the year and the sun's path impact the operation of a courtyard. Courtyard residences with undesirable proportion or orientation of courtyard receive excessive solar radiation when shading is required, or they produce too much shading when solar radiation is needed [14, 15].

In a hot-dry region, it is pleasing to have constructions with the most external shaded surfaces in summer and the least in winter. The greater shading generated in summer, the less solar energy is obtained. The greater shading generated in summer, the less solar energy is obtained. Therefore, less cooling load is needed. In winter, the reverse is right when the collected solar light provides more energy to help warming up the construction and as a result, decreases total heating load.

Mohsen [16], [17] evaluated the solar radiation impacts of the physical parameters and geometry of the courtyard on the courtyard building facade. The changeability of the radiation, which was gotten by varying the courtyard parameters, was inspected. Muhaisen and Gadi [14] studied many researches on the courtyard shape. They particularly concentrate on impacts of courtyard shape on the sun-shade impact, and also on solar radiation gain-loss. The aim of the research conducted by them in 2006 is to provide enough radiation to gain the required heat by the building during winter and to decrease its cooling load during summer.

1.3. The geometrical factors of the courtyard form

The orientation and proportion of courtyards are proposed of the significant geometrical factors of a courtyard form [13]. Geometrical descriptors contribute to understanding the geometrical factors of the courtyard form that according to Mohsen include: "The ratio, R, of width, W, to length, L, represents the elongation of its design" [16]. This rate is shown in figure 1.

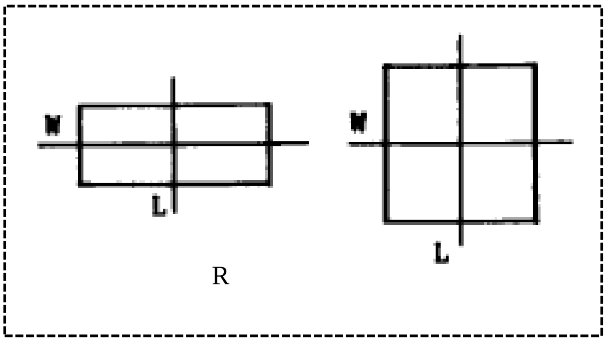

Fig. 1 R: the rate of width vs length (W/L)

1.4. Thermal comfort

Limit of thermal comfort directly affects the energy consumption of buildings [18]. Thermal convenient is expressed via ASHRAE Standard 55-2004 as "the status of mind which indicates satisfaction via the thermal environment" [19]. Since people have a similar feeling of thermal convenient in the same climate zone, specified limit of thermal comfort for each climate zone is necessary. Limit of thermal comfort in the city of Yazd was recognized by [18]. In this study, according to the climatic data and field observation and by corrected diagram of Olgyay, the thermal limit was determined for summer condition 21.8°-27° and for winter condition 20.4°-23°. Proposed limit of thermal comfort provides interior thermal comfort conditions and avoids unsustainable energy consumption.

This study goes further to understand what the appropriate geometrical parameters including the proportion and orientation of an inner rectangular courtyard are to decrease the courtyard dormitory need for cooling and heating loads in a hot-dry climate of Yazd.

2. METHODOLOGY

Different tests have been conducted to examine and assess the influence of solar radiation on energy consumption of buildings. There are 3 kinds of experimental approaches unusually utilized in the thermal performance of a building. They are real building measures, simulation investigations and the application of simple estimation techniques.

The benefits of utilizing a dynamic power simulation is that complicated thermal, and irradiative process among the courtyard building and the outdoor environment are expressed in the evaluation. Therefore, any plan shortcomings can be examined before finishing the plan.

2.1. Computer simulation tool

In this study, EnergyPlus software for its availability and reliability is employed. EnergyPlus is a significant energy simulation and energy analysis tool widely used in the building industry. EnergyPlus based on building features including physical structure, users, mechanical and electrical systems and also annual hourly weather data calculates cooling and heating loads to maintain a certain temperature or limit of thermal comfort in the building [20, 21]. "As EnergyPlus has been confirmed over the comparison Normal Approach of Test for the Evaluation of Building Energy Analysis Computer Programs BESTEST/ASHARE STD 140, it is reliable" [5].

All Courtyard model cases were modeled using SketchUp software and simulated using EnergyPlus. OpenStudio software is used as a user interface.

2.2. Courtyard design

For the aim of investigating what the appropriate geometrical parameters including orientation and proportion of inner rectangular courtyard are to decrease the heating and cooling use of university student's dormitory in a hot-dry climate of Yazd, one computer model was created in EnergyPlus.

Design requirements including schedules were considered for the simulation process. The area of students' courtyard dormitory is 3628.8 m^2 on three levels. Courtyard Adjacent spaces depth and floor-to-floor height are 9.6 and 3.5 m for each level respectively, which are common features in student courtyard dormitory in Iran. The internal environment of the adjacent spaces was modeled as fully conditioned. The technique utilized to evaluate infiltration for the spaces was air change/hour. Each space was supposed to have 0.25 air exchanges/hour.

A) Construction:

The roof and wall kinds were parameterized via the data in Table 1 for the simulation.

B) People:

Students' density in the dormitory was assumed to be 0.033 people/m2.

C) Artificial lighting:

The artificial lighting heat load was set to 3.49 W/m2.

D) Electric equipment:

The electric equipment heat load was set to 3.88 W/m2.

F) Glazing type and lighting:

The exterior window kind for the designs is double glazing (generic clear 4 mm- 0.9 W/mK) via an air cavity of 13 mm among the layers.

Table 1 Thermo physical building of the building case components

Building components	Materials (layers)	Thickness (cm)	Thermal conductivity (W/mk)	Density (Kg/m3)	Thermal capacity (J/kg K)
Ceiling	Terrazzo	2.5	2	2400	837
	Mortar	3	1.8	2240	900
	Light Weight Concrete	10	0.52	1500	900
	Ceiling Structure	30	1	427.75	1113.39
	Stucco	3	0.57	1300	837
Exterior Wall	Façade Brick	5	1	1850	900
	Rockwool	5	0.04	80	1170
	Porotherm Brick (20 cm)	20	0.5	731	790
	Stucco	3	0.57	1300	837
Floor	High Weight Concrete	10	0.52	1500	900
	Mortar	3	1.8	2240	900
	Terrazzo	2.5	2	2400	837
Interior Partition	Stucco	3	0.57	1300	837
	Porotherm Brick (10 cm)	10	0.52	783	790
	Stucco	3	0.57	1300	837
Roof	Terrazzo	2.5	2	2400	837
	Mortar	3	1.8	2240	900
	Tar layer	0.3	0.7	2100	836
	Mortar	3	1.8	2240	900
	Light Weight Concrete	10	0.52	1500	900
	Ceiling Structure	30	1	427.75	1113.39
	Stucco	3	0.57	1300	837

2.3. Weather data

Weather data in a TMY2 format for Yazd city of Iran was based on periods of record from 30 years. The ITMY (Iran Typical Meteorological Year) file for Yazd city was created using TmyCreator by Ebrahimpour [22] of the Building and Housing Research Center (BHRC) of Iran. This file was saved in the climate database and was used during the simulation. Furthermore, the heating and cooling thermostat settings were 20.4°C and 27°C respectively [23].

2.4. Variables and assumptions

The investigated courtyard dormitories are simple cubic forms that have different inner courtyards different inner courtyards each of which has a specific orientation and ratio of length to width.

The impact of varying the courtyard's proportion and orientation on the solar heat obtaining and so on the needed power to enhance thermal convenient was investigated via varying ratio (R) and orientation (O). The rate R is considered as the rate of the number of rooms in the rectangular courtyard width to the number of rooms in its length that shows the elongation of the form. Figure 2 shows all of the investigated values of ratios R. It varies between 1/9 and 5/5 in one room at each step. The orientation O angle of the courtyard form was altered from 0° (along with the north-south axis) to 90° (along with the east-west axis) in 7 steps as seen in figure 3. And also, the interior wall between rooms were considered.

The study was undertaken for nine months as an academic year (1th Jan to 20 Jun and 22 Sep to 31 Dec).

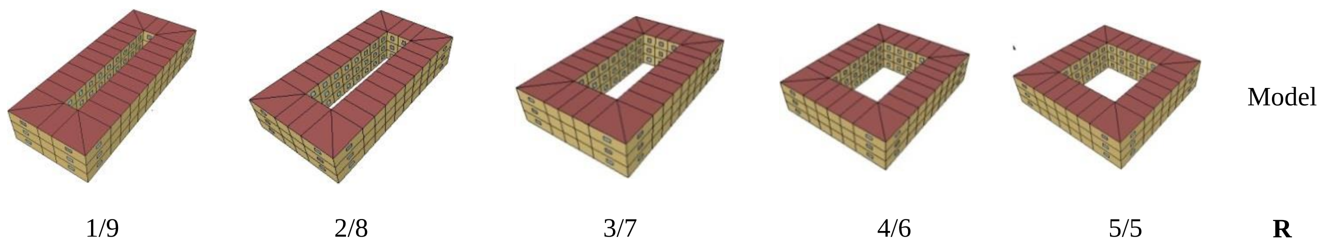

Fig. 2 Investigated values of ratios R of rectangular courtyard forms

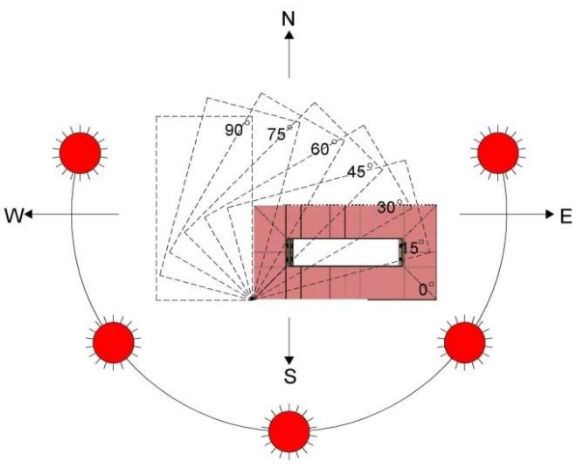

Fig. 3 Varying the orientation of the courtyard shape from 0° - 90° in 7 stages

3. RESULTS AND DISCUSSION

To find out the optimal courtyard dormitory with the minimum annual heating and cooling energy needed, R values ranging among 1/9, 2/8, 3/7, 4/6 and 5/5 and O values ranging between 0 and 90 were investigated. The investigated shapes have similar geometrical factors containing same roof zones, outer wall zones, courtyard inner envelope zones and interior volumes. The only geometrical parameters that change, in this case, is the courtyard elongation (R) and orientation (O).

Figure 4 shows the effect of having R changed on the required cooling loads. It could be noticed that, in summer the trend, with the form approaching a square (R=5/5), the cooling load is increased gradually. This confirms the result achieved in the previous study which showed that when the courtyard is less elongated, more irradiation is obtained, which has the result of increasing the building's heat gain and then the cooling load.

At ratios of R equal to 1/9 to 3/7, with increasing O angle, the cooling load increases dramatically. It would be, due to the East and West greater front of the building to sunlight. At ratios of R equal to 4/6 to 5/5, since the courtyard is oriented towards the square and there is the slight difference between the length and width of the courtyard, there is a slight difference in cooling energy use among the courtyard buildings with different O angles.

Depending on the size of eastern and western façades, different cooling loads between the courtyard buildings with different angles could be seen. As a ratio for R equal to 5/5, the angle of 45 degrees is the maximum amount of cooling load.

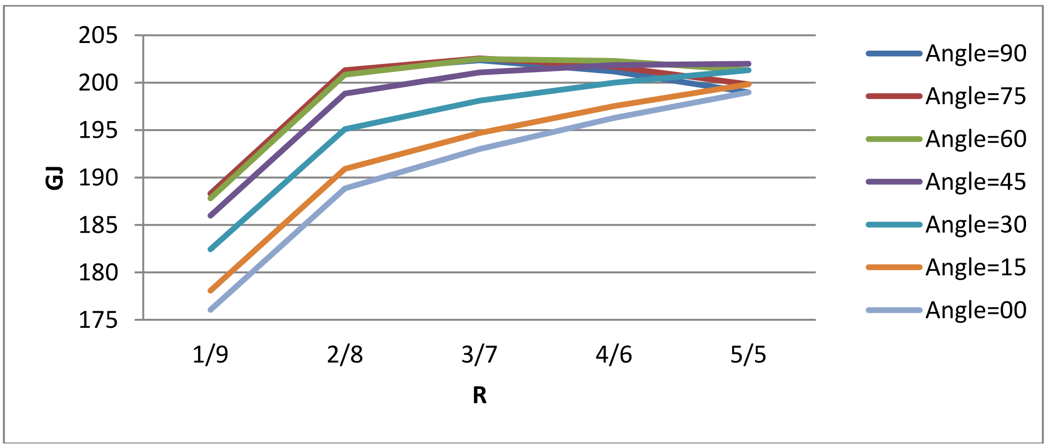

Fig. 4 Varying the courtyard ratios R on the annual needed cooling at the all values O

In winter, the figure 5 shows, the heating load decreases via the increase R. It is a logical result as a consequence of the improved radiation taken via the courtyard form when R approaches 5/5 (a square form). This confirms the result attained in the previous researches which presented when the courtyard is less elongated, more irradiation is achieved, so it causes increasing the building's heat gain and reducing heating energy consumption.

But, any reduction in R more than 3/7 has a minuscule impact on the needed heating load.

At R ratios equal to 1/9 to 3/7, with increasing O angle, the heating load increases dramatically. It would be, due to the less south front of building exposed to the south.

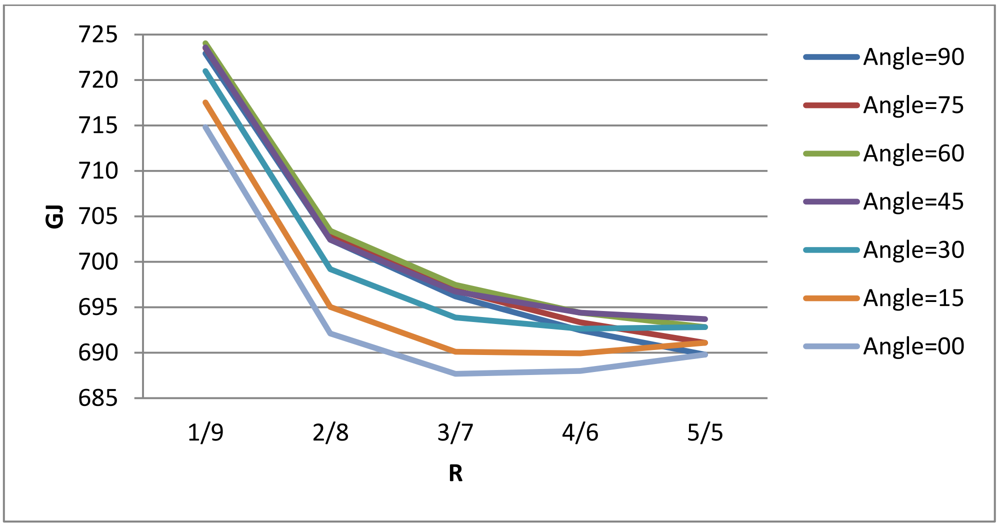

Fig. 5 Changing the courtyard ratios R on the annual required heating at the all values O

For the aim of understanding the optimum geometry of a courtyard dormitory according to minimum annual energy use, the cooling and heating loads were collected for each state and plotted into one chart, as seen in Figure 6. It can be realized that, at values of R equal to 1/9 to 3/7; the energy use decreases when the form approaches to a square shape. At this period, with reduction of O angle, the energy use, also decreases. Although, the rate of decreasing is more remarkable at small values of O angle (less than 45) and becomes smaller as O angle approaches to 90, at 3/7 to 5/5 R values, the energy use does not follow a particular order and it depends on the O angle.

The ideal ratios of a courtyard dormitory are described as those which ensure minimum energy use during the year for attaining comfort in the buildings. Therefore, a dormitory with an internal courtyard with R of 3/7 and angle of 0 is found as the ideal.

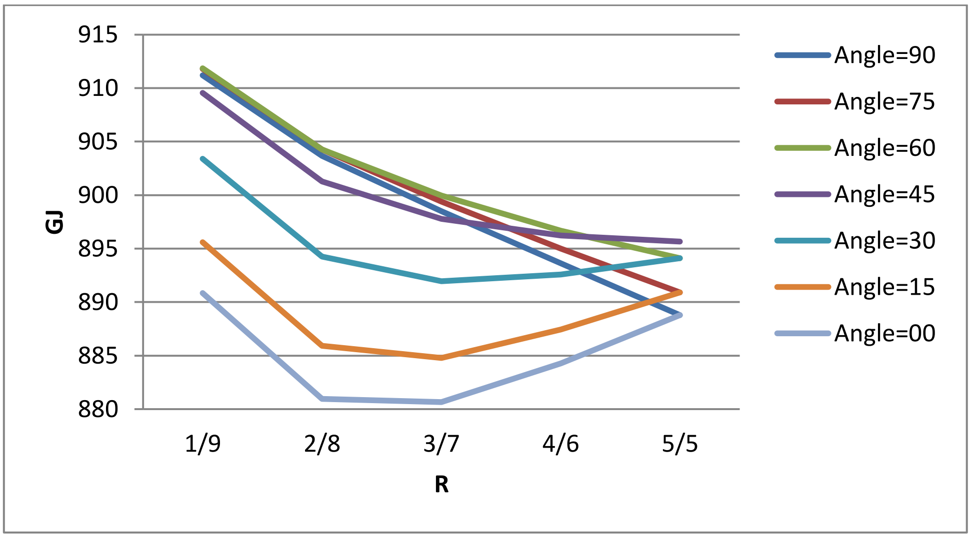

Fig. 6 Varying the courtyard rate R on the annual needed heating and cooling at the all values O.

4. CONCLUSION

The amount of sunlight shining on the faces of the courtyard buildings has a notable impact on the heat earnings and consequently on the necessary heating and cooling loads. The internal and external shady or exposed to sunlight surfaces of courtyard dormitory change through geometrical parameters of the courtyard form and alterations of the sun's location. Ignoring proper orientation and proportion of courtyard form can lead to high consumption of energy. Therefore, to reduce energy consumption adequate amounts of the shading and sunlight radiation must be considered.

It was found that, for the purpose of reducing the cooling load in summer, the longer courtyard forms, with the rotation angle of 0 were the most preferable. This is due to the reduced amount of received irradiation based on their forms in summers which results in low cooling energy use.

Also in winters, to reduce the heating load, the courtyard with an almost equal length and width with the rotation angle of 0 were the most preferable. Because, the courtyards with equal length and width receive more amount of irradiation in winters, which results in low heating energy use.

The results showed that the ideal ratios of a courtyard dormitory ensure minimum energy use during the year to reach thermal comfort in the courtyard dormitory. Therefore, an internal courtyard with R=3/7 and O=0° has the lowest total required heating and cooling loads. The maximum difference between the results of required cooling and heating loads in all the examined courtyard models is 13.08-5.03 % and between the results of total required energy is 3.42%. Since this study is limited to the proportions and orientations of courtyard dormitories on 3 levels of Yazd, further researches are needed.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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