



Effect of Different Proportions of Courtyard Buildings in Hot-Dry Climate on Energy Consumption (Case Study: Traditional Courtyard Houses of Kerman, Iran)

N. Tayari, M. Nikpour*

Department of Architecture, Bam Branch, Islamic Azad University, Bam, Iran

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ABSTRACT

One of the crucial issues in early stages of designing process of a building is a lack of architects' knowledge about the energy consumption in different forms of building with different proportions, especially in central courtyard forms. The purpose of this research is to investigate the effectiveness of the ratio of perimeter to the height of the courtyard (R1) and the ratio of width to length of the courtyard (R2) on energy consumption. In the first step of this research, different proportions of central courtyard with different R1 and R2 were simulated in DesignBuilder software. Then, multi linear regression was used to find out the effect of different proportions (R1 and R2) on energy consumption through SPSS software. Finally, the effect of R1 and R2 ratio on energy consumption was validated through investigating six existing central courtyard forms. The result demonstrated that the effective coefficient of the R1 and R2 ratio on energy consumption were -25.41 and 62.69 respectively. Findings of this research help architects to achieve relative acknowledge about the energy consumption of different proportions of the courtyard forms for creating more energy efficient forms.

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INTRODUCTION

Today, the excessive production of carbon by fossil fuel consumption in buildings is the main reason for climate changes [1]. Therefore, reducing energy exports may be one of the best alternative policy options to improve Iran's energy security and economic situation [2]. As part of the principles and practices of sustainable architecture, designers must define the architectural requirements of the building based on climatic conditions, environmental protection and reduction of energy consumption. Natural energy sources such as sunlight affect the thermal performance and lighting of buildings, depending on the characteristics of the building façade [3]. Renewable energy can be used to meet the energy needs. In addition, solar energy, as one of the sources of energy among renewable energies, plays an important role in meeting energy demands [4]. One of the main programs of the Iranian government is to reduce energy consumption in the residential buildings [5]. Although traditional Iranian

architecture is a very strong form based on climate considerations with development in construction techniques and changes in the life style and culture of people, traditional forms of buildings have been forgotten [6]. The most important buildings in Iranian traditional architecture, which are very detailed in response to climatic conditions, are houses [7]. Traditional Iranian houses reflect their needs, desires and the way to address these requirements [8].

One of the most prominent examples of this architecture against the climatic conditions is courtyards [9-11]. The main purposes of creating courtyard was cooling in hot region in the past [12]. Central yards have been adapted to the climate for 5,000 years, and a courtyard was an architectural feature that has been applied in houses [13]. There are different types of buildings with courtyards in Iran. Each of these buildings is named using the location of the rooms adjacent the courtyard; for example, U-shaped or L-shaped buildings and a central courtyard. Courtyards do not have fixed

*Corresponding Author Email: nikpour@iaubam.ac.ir (M. Nikpour)

plans. In most cases, the basic plans of residential courtyards are rectangular or square. Throughout history, the form of the courtyard has been developed to fulfill many aspects and functions to form new shapes of courtyards like L shape or U shape [14, 15].

There are very few benchmarks in the architecture that can provide protection, comfort, and safety in a building like the central courtyard [16]. There are numerous studies on courtyards in different types of buildings and climates [13, 17-20]. For example, Safarzadeh and Bahadori [21] studied on the courtyard affected by passive cooling and considered the effects of courtyard walls shading and other parameters like trees, a pool, and plants. They found that the examined features reduce the building's cooling energy needs. Some researchers have focused on the thermal features of the courtyards and their relationship with wind and solar radiation. The effects of those parameters have been investigated along with the orientation and courtyard geometric properties [15, 22-24].

Zakaria et al. [25] discussed a traditional shop house in Malaysia and its internal thermal environment that is affected by courtyards. The results of that research showed that the temperatures of indoor air in the master bedroom and the ground floor were lower than the outdoor air temperature during daytime. It means, during night-time, the temperatures of indoor air were higher than the outdoors. Amiriparyan and Kiani [26] have studied traditional houses in the specific period of Iran history. They believed that the central courtyard has been constantly active as a spatial homogenizer and organizer. Abdulkareem [27] focused on the courtyard's thermal comfort based on the courtyard's microclimates, to make a beneficial contribution to the contemporary architecture by showing its conditions and possibilities. Aldawoud [28] examined different factors such as climate, height, and glazing to find their effect on the performance of a courtyard. The results revealed that the thermal performance of courtyards are different due to various variable climate condition. In addition, in these types of buildings, the central courtyard helps light to penetrate the deep spaces of the house. Lights radiations are allowed to penetrate to spaces' depth to the house in central courtyard it also provides comfort and health for occupants [17]. The openings in the yard's wall are a good source of clean and favorable air for the residents of the building. These openings, by being inside and not in contact with the outside of the building, provide ventilation with less pollution.

The form of the central courtyard is a suitable form in climatic conditions, and in the central courtyard certain proportions of the form are responsive to climatic conditions.

The effective coefficient of different proportions of central courtyard form on amount of energy consumption per square meter has not been investigated in Hot and dry climate. In this paper, courtyard building forms in hot and

dry climates (Kerman province) have been investigated to extract the effect of R1 and R2 (ratio of perimeter to the height of the courtyard (R1) and the ratio of width to length of the courtyard (R2) on energy consumption

MATERIAL AND METHODS

Methodical consideration

In the past, many methods have been used in similar researches that included field measurement [29], scale models [30]. Nevertheless, the common method is computer simulation [31]. Computer simulation is a fast way to get acceptable results in most cases and this way you can save money and time [32]. Most of the time thermal analysis is considered as a computer program or manual calculation [33]. Using computer simulation act as an accurate method to test all the parameters. One of the most common simulations is the thermal simulation of buildings, which can be used to calculate the energy consumption of the building. The computer thermal simulation tools for modeling are very different in terms of method that they use to analyze [31].

Manioglu and Oral [34] used DesignBuilder as a simulator software to study the shape and dimensions of courtyards. Taleghani et al. [30] simulated their models for calculating heating and cooling in buildings with courtyards DesignBuilder. Tabesh and Sertyesilisik [35] also used DesignBuilder for measuring energy consumption in courtyard buildings. One of the most complete user interfaces of the Energy Plus for energy simulation is "DesignBuilder" software. Basic knowledge of DesignBuilder can be categorized into template components, material database, HVAC, natural ventilation, etc. In general, Energy Plus is a standalone simulation program that does not have a "user-friendly" graphical interface. DesignBuilder is added to the Energy Plus software calculation model and provides a convenient graphical interface. The simulation used by DesignBuilder is the most accurate simulation with dynamic parameters that include all energy calculations [36, 37].

The validation of DesignBuilder and energy plus software has been done in previous researches [37, 38]. Therefore this article used DesignBuilder software as an energy simulator.

Simulation

DesignBuilder as an interface for Energy Plus was used in order to measure the amount of energy usage per square meter in each model.

In this research, 100 courtyard models with different proportion modeled an simulated in DesignBuilder. Different proportion of models are created based on two ratio R1 and R2 which has been derived from a research done by Muhaisen and Gadi [31]. The ratio R1 is the perimeter (P) of the floor of the courtyard to height (H) of

the form that ranges from 1 to 10. With an increase in R1 level, the height of courtyard form decreases. The ratio of the width (W) to length (L) of the courtyard is R2 that varies between 0.1 and 1. As the amount of R2 increases, the width of the yard increases, and the shape of the yard changes from rectangle to square. The model with R1=0.1 and R2= 1 had 1-meter width and 10-meter length with a 22-meter height and perimeter. Figure 1 shows different models with different range of R1 and R2.

Weather data of the city of Kerman (latitude 29.48 and longitude 57.6 in a hot and dry region of Iran) was used for energy analysis in DesignBuilder. This weather data was obtained from airport meteorological synoptic station, which included dry bulb temperature and wet temperature, humidity, solar heat gain, etc.

Construction details for wall, roof and floor of all models are based on common materials which have been used in traditional houses in hot an dry climate.

Most of the materials used in these houses are clay, brick, thatch, and plaster. U-value of the floor, wall and roof are considered 1.463, 0.8, and 2.086 W/m²k, respectively in all models (Table 1).

The amount of energy consumption in each simulated model was measured per kWh/m², during the year.

Statistic

In order to estimate the effective coefficient of R1 and R2 on enrgy consumption for each one squre meter per year multiple linear regression has been used. Therefore, in phase two of the research energy consumption of all mod-

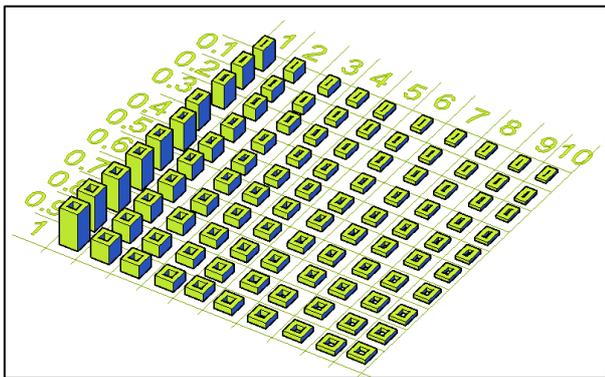


Figure 1. Overview of 100 models that simulated in DesignBuilder (Reference: Author)

Table 1. Construction details of all the models

Construction	Thickness	U-value surface to surface	R-value	U-value
Wall	0.34	0.926	1.25	0.8
Roof	0.22	2.946	0.479	2.086
Floor	0.2	2.112	0.684	1.463

els was entered in SPSS software. Multiple linear regression in SPSS software has used in “Shading simulation of the courtyard form in different climatic regions” and “Energy performance and thermal comfort of courtyard/atrium dwellings in the Netherlands in the light of climate change” (Equation 1) [30, 31]. Regression linear is a method that demonstrates how a dependent variable varies in relation to the independent variables. The advantage of the multi-linear regression approach is understanding the effect of variables on energy consumption [39]. For example, independent variables, R1 and R2, which affect the amount of energy consumption, were selected to develop the model using the results of regression models [40].

$$\text{Regression Equation: } Y = a + \beta_1 X_1 + \beta_2 X_2 + e \quad (1)$$

In this model, Y is the fitted value extracted from the coefficients table of SPSS and β1 and β2 are the estimations of the regression parameters [33].

In the last stage of this research, 6 houses in the Kerman city that had a central yard were selected for the case studies. After simulating these houses in DesignBuilder software, the amount of energy consumption in these houses was obtained. Amounts of energy consumption in these houses were analyzed according to the ratios of R1 and R2. Figure 2 shows the Process of research method step by step.

RESULTS AND DISCUSSION

Finding of the simulation

Table 2 reveals the amount of energy consumption per square meter in different model, as it can be seen in this table, with increasing R2, the ratio of width to length of courtyards, buildings consume more energy. Since incre-

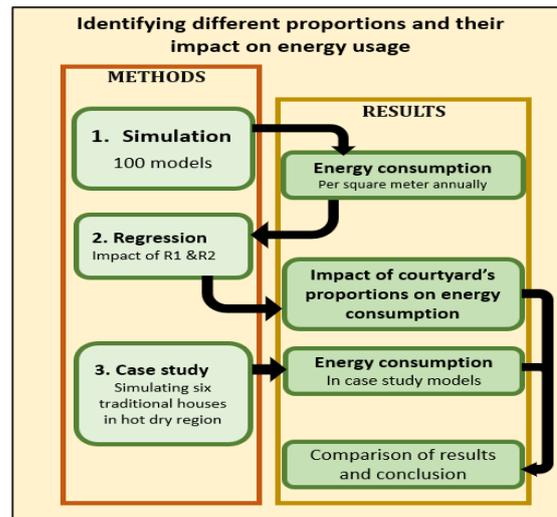


Figure 2. Process of research step by step, conceptual model

asing R2 causes more exposed area to the outdoor which leading to higher heat transfer through building envelop. Energy consumption decreases with increasing R1 which is the ratio of perimeter to the height.

The least energy demand belongs to a form with R1=10 and R2=0.1. This model is a narrow courtyard with minimum width and height. This shows that as the height of the building increases and the form of the yard becomes square, the amount of the outer shell of the building also increases. Therefore, the amount of energy consumption in these forms also increases due to the increase in heat conduction. Conversely, energy consumption is reduced in low-rise forms and rectangular courtyards with the least width. This increase and decrease in energy can be related to the high-energy consumption in hot seasons in this climate. As the yards become narrower, their amount of shading on the other envelops of the yard increases and this leads to a decrease in the reception of the solar heat energy.

Finding of the regression

The simulation results were transferred to SPSS to evaluate the effect of R1 and R2 on energy consumption. The multi-linear regression was used. The effectiveness and results of this step can be seen in Table 3.

Coefficient determination is used to specify the accuracy of the regression models. The coefficient of determination R2 (Table 2) indicates what percentage of changes in the dependent variable is explained by the independent variable. The value of R indicates a simple correlation between two variables and indicates the intensity of the correlation between the two variables.

Since the correlation coefficient (R= 0.786) and the determination coefficient (R-Squared= 0.617) as well as the "Adjusted coefficient" (Adjusted R-Squared= 0.609) have been calculated and these values are closer to 1, it seems that the regression model is appropriate. Moreover, the model shows a stronger relationship between the dependent and independent variables and it can be inferred that the model will be able to cover or express a higher percentage of changes in the dependent variable. R-square shows that nearly 62 percent of energy consumption was affected by the independent variables.

The coefficients table gives us information about the predictor variables. In Table 3, it can be seen that the constant value and the independent variable are both significant in the model. The Standard error of the table shows that the model can estimate the effectiveness of R1 more accurately than the R2. After verifying the significance of the value of the constant and independent variable, the Standardized Coefficients column represents the beta value.

According to the linear regression formula and the table provided, the effectiveness of each of ratio R1 ad R2 can be seen. The result demonstrated that the effective coefficients of the Variable R1 and R2 on energy consumption are -25.41 and 62.69, respectively. This means that

Table 2. Energy demand per square meter (kWh/m²) in 100 selected model

R2 (W/L)	R1 _(P/H)									
	1	2	3	4	5	6	7	8	9	10
0.1	468	339	298	280	269	262	257	254	251	249
0.2	491	350	306	285	273	265	260	256	253	251
0.3	514	362	313	290	277	268	262	258	255	253
0.4	537	373	320	295	281	271	265	261	257	254
0.5	560	384	327	300	285	275	268	263	259	256
0.6	584	396	335	305	289	278	270	265	261	258
0.7	607	407	342	311	293	281	273	267	263	259
0.8	630	418	349	316	297	284	276	269	265	261
0.9	652	430	357	321	301	288	278	272	267	263
1	675	441	364	327	305	291	281	274	269	265

Table 3. Including the effective coefficient of variables derived from SPSS

Model	Coefficients					
	Unstandardized Coefficients		Standardized Coefficients Beta	t	Sig.	
	B	Std. Error				
1	(Constant)	426.643	17.348		24.593	0.000
	R1	-25.414	2.092	-0.763	-12.146	0.000
	R2	62.698	20.923	0.188	2.997	0.003

with the addition of each unit of R1, the amount of energy consumption in the form with a courtyard by about 25 kWh per square meter, and with an increase in each unit of R2, approximately 62 kWh per square meter of energy consumption of the form will be increased.

Finding of the case studies

In the third phase of this research, 6 selected traditional houses were simulated. The sizes of the houses (Table 4) were carefully examined and their proportions were obtained according to the variable discussed in this article (R1 and R2). The houses were then simulated in DesignBuilder software to obtain their energy consumption per square meter per year.

All selected houses have a central courtyard and are very similar in terms of plan layout. Table 4 presents the

proportions of the yards and their effects on energy consumption per square meter of houses.

Table 5 shows the results of all the calculations from six courtyard building cases. Also Table 5 shows that the

Table 4. Proportion of six randomly selected traditional courtyard houses

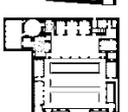
No.	← North	Total plan	Courtyard	Perimeter	Length	Width	Height	R2	R1
1		500	177	53.6	15	11.8	4.2	0.78	12.76
2		520.5	166.03	52.18	15.08	11.01	4.7	0.73	11.1
3		700	234	62	18	13	4.6	0.72	13.47
4		1340	428	83.04	22.72	18.8	4.7	0.82	17.66
5		753.5	224	60	16	14	5.2	0.85	11.53
6		477	108	42	12	9	4.5	0.75	9.33

Table 5. Comparison table of simulation results and the effect of factors on energy consumption

Houses	R2	R1	DesignBuilder Energy consumption (kWh/m ²)
Aminiyan	0.78	12.76	140.32
Lotfalizadeh	0.73	11.1	178.54
Movahedi	0.72	13.47	121.89
Tavakoli	0.82	17.66	83.92
Farokhzad	0.85	11.53	179.77
Nikandish	0.75	9.33	218.21

energy consumption per square meter in Tavakoli house is lower than other houses, which has the highest R1 ratio among all models. This finding can be proven by the simulation and regression results which stated that by increasing the R1 ratio, (which is the ratio of the perimeter to the height), the amount of energy consumption per square meter decreases.

The reason behind the difference in energy consumptions in any type of prediction can be the variety of courtyard forms and the depth of the roofed part of the buildings. The results obtained from DesignBuilder software show that R1 and R2 ratios have an effect on energy consumption, while this amount of impact is more pronounced and visible by the R1 factor. By referring to Table 5, it can be seen that the Tavakoli house has the highest R1 (the perimeter to the height ratio) among other models, but the amount of energy consumption per square meter in this house is less than other houses. According to the results of the Nikandish House, which has the lowest amount of R1, this result is more clearly proven. In the present study, the results show that energy consumption in courtyard form will be higher when the shape of courtyard is closer to the square. Regardless of the shape of courtyard (square or rectangle), energy consumption decreases while the height of courtyard decreases. Reducing the height of the yard's envelop and transforming the shape of courtyard from rectangle to square are two factors that cause reduction in energy consumption per square meter of the courtyard forms.

CONCLUSION

The amount of energy consumption in courtyard buildings was changed by changing the proportions of courtyard's models. Although the energy consumption is affected by different parameters, in this research the effectiveness of R1 (perimeter/height) and R2 (width/length) ratio of courtyards on energy consumption was investigated solely. Results of simulation in step one of this researches revealed that with increasing the variable R1, the amount of energy consumption decreased while the amount of energy consumption increased with increasing the value of R2. In order to evaluate the effect of each of these parameters, the results obtained from the simulations were analyzed using multi-linear regression in SPSS software. The regression results showed that the effectiveness of R1 and R2 on energy consumption is - 25.41 and 62.69. Findings of the optimum proportion of courtyard help architects in the early stage of the design process to have a comprehensive perspective to create more efficient courtyard building forms. More variables of courtyard building properties could be involved as effective parameters on energy consumption which need to be evaluated as further studies.

CONFLICT OF INTEREST

There is no conflict of interest.

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Persian Abstract

چکیده

یکی از مسائل مهم در مراحل اولیه طراحی ساختمان، عدم آگاهی معماران در مورد مصرف انرژی در شکل‌های مختلف ساختمان با نسبت‌های مختلف به ویژه در فرم حیاط مرکزی است. هدف از این تحقیق بررسی تأثیر نسبت محیط به ارتفاع فرم حیاط مرکزی (R1) و نسبت عرض به طول فرم حیاط مرکزی (R2) بر میزان مصرف انرژی است. در اولین گام این تحقیق، نسبت‌های مختلف فرم حیاط مرکزی که دارای R1 و R2 متفاوت هستند در نرم افزار دیزاین بیلدر شبیه‌سازی شد و از رگرسیون برای تعیین تأثیر نسبت‌های مختلف (R1 و R2) بر مصرف انرژی از طریق نرم افزار SPSS استفاده گردید. در نهایت، تأثیر نسبت R1 و R2 بر مصرف انرژی از طریق بررسی شش فرم حیاط مرکزی موجود ارزیابی و مورد تأیید قرار گرفت. نتایج نشان داد که ضریب تأثیر R1 و R2 بر مصرف انرژی به ترتیب ۲۵/۴۱- و ۶۲/۶۹ می‌باشد. یافته‌های این تحقیق به معماران کمک می‌کند تا اطلاعات اولیه در رابطه مصرف انرژی تناسبات مختلف فرم‌های حیاط مرکزی داشته باشند که به خلق فرم‌های کارآمدتر انرژی منجر گردد.