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Research Paper

Comparing the results of thermal simulation of rasoulian house in Yazd by design builder software, with experimental data

A. Eisabegloo[1], M. Haghshenas[2,*], A. Borzoui[3]

[1] *M.A. Graduate, Faculty of Architecture, Maziyar Institute for Higher Education, Noor, Mazandaran, Iran*
[2] *Guest Professor, Faculty of Art and Architecture, Islamic Azad University, Shiraz, Iran*
[3] *Assistant Professor, Faculty of Architecture, Maziyar Institute for Higher Education, Noor, Mazandaran, Iran*

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Abstract

Environmental problems caused by fossil fuel consumption, on the one hand, and the upcoming prospect of ending these fuels on the other, attracted much attention towards sustainable architecture. Traditional buildings can be seen as a sample of sustainability; as they have used strategies to cope with the environment, which have been developed over the years, providing users' comfort conditions for centuries. But before implementing these strategies in today buildings, we need to know the exact effect of their use; something that is regularly performed by an energy simulation software. Thus, first, we should know the ability of the software in modeling different design strategies, and secondly we should be certain of the validation of its results. This research aims to study the ability of DesignBuilder software (as one of the most applied software for building energy simulation) to model and simulate a complex traditional building. The accuracy of DesignBuilder thermal simulation results, in comparison with the experimental data is the main question of this study. To do this, Rasoulian house in Yazd (in hot and arid climate of Iran) was chosen as a case study and after simulating the entire building, the simulation results were compared with experimental measurement data. The results show that in most spaces, the experimental data were only 1–5°C different from the results of the simulation. Finally, the probable causes of these differences were analyzed and some suggestions were proposed to develop DesignBuilder, to be more applicable in simulating buildings of hot and arid climate.

Keywords: *Energy consumption, Thermal simulation, Rasoulian house, Hot and arid climate, Design builder software*.

1. INTRODUCTION

Today, the world of architecture is subjected to significant shifts in building design processes towards a more holistic point of view. Energy and fuel crisis on the one hand and environmental pollution and global warming on the other, has made human to rethink about their attitude about nature. Buildings are one of the world's major energy consumers; so their design has a significant impact on fossil fuel consumption and environmental changes. Building sector consumes about one-third of the total energy and two-thirds of the total electricity, even in the developed countries [1]. Similarly, in Iran, buildings account for over 40 percent of the total energy usage in the country [2]. The approximate annual primary energy consumption in residential buildings of Iran is about 450 kWh/m^2, which is more than twice the indexes in many other countries [3]. While buildings' construction and demolition process will produce contaminations inevitably, poor design or poor quality degree of buildings doubles the amount of pollutions. On the other hand, such an approach might lead to create undesirable areas of thermal comfort and the quality of the internal environment of building [4]. In order to have sustainable buildings, the amount of building's total energy requirements should be limited.

The maximum use of sustainable energy sources should be considered, and if we have no other choice but using fossil fuels, we have to use them as efficient and clean as possible. None of these can be obtained without proper architectural design of the buildings. In order to meet the desired quality and standard for the building, all these aspects should be considered at all stages of design and construction. A great number of factors should be considered while designing an energy-efficient building. This can be possible only by adopting a holistic approach; in which the number of effective factors is more than that to be kept in one's mind. So we have to apply software.

** Corresponding author: s.sabouri@tabrizu.ac.ir*
Tell: +989144009088; Fax: +982177240277

Hensen and others [5], show that today the amount of interfering factors on improving quality and efficiency of buildings have increased so it is very difficult to keep all of them in mind. That is because computer, has played an important role as a tool to help designers. Building simulation software is also a tool which can be used by architects and designers as an assistant. This software has kept their place as helpful tools, in the design and construction industry all over the world. Designers can avoid the occurrence of obvious errors in the design process, by using the results of computer simulations for modifying their earlier ideas. In the past few years, the usage of simulation software has become an inseparable part of the design process on the global scale, having a quarter–century of experience [6]. Now there is a question whether these software has enough accuracy for calculation of thermal energy in the buildings?

In order to answer this question, Rasoulian house in Yazd city was chosen, modeled, and simulated in DesignBuilder software. This house was chosen because its experimental studies had been done earlier [7]. In this study, temperatures in different parts of the building were measured for the warmest period of the year (June 10^{th} to July 4^{th}), three times a day (at 8:00 a.m., 14:00 p.m., and 20:00 p.m.). The whole building was simulated by DesignBuilder software and the results of simulation for this period were compared with experimental data.

2. LITERATURE REVIEW

The researches on the capabilities of the existing simulation devices are often general; rarely have there been studies on the desired capabilities in the domain of architecture. Ghiaee and colleagues in 2003, analyzed a variety of popular energy calculating software to find the best simulation software for architectural purposes, based on their ease of use. At the end of the research Ecotect and eQUEST were chosen as the most suitable software. It should be noted that in this paper DesignBuilder was only mentioned as a new software in the market and it was not analyzed or compared with the others [8]. Sadeghipour Roudsari also introduced some software and their effect on architectural design; however, his focus is more on the simulation of CFD in buildings [9]. Rallapalli in her Ph.D. thesis in 2010, compared the capabilities of eQUEST with EnergyPlus; in this study, eQUEST is introduced as an easy and fast software for simulation as well as the latter. The EnergyPlus software was suggested just for complex models, because modeling in this software is time-consuming. It is also noted that choosing a simulation software depends on the usage and the function of the program in satisfying the requirements of the user [10]. Baharvand and his colleagues in 2013, studied the validation and confirmation of the DesignBuilder software. The main focus of this study was on two critical factors: the speed of air and the weather temperature in interactive natural air–conditioning. The results of computational fluid dynamics (CFD) by DesignBuilder were compared with experimentally measured data. The result showed that DesignBuilder software can predict temperature and speed of the inside air with a high accuracy and can be used to evaluate interactive natural air–conditioning [11].

DesignBuilder software's ease of use is studied in other research, a group of architecture students were asked to simulate an existing educational building in Cambridge and compare their outputs with experimental measurements. The results showed that not only the students of design are capable of learning simulation, but also they learn the physics of the building in this process. The DesignBuilder also allows the students to build meaningful energy models which can be used in preliminary stages of designs and it is also indicated as a basic lesson that when the weather data of a particular region is not available, the weather data of the DesignBuilder software can be used and it is an economical option for team design [12]. Finally, Cardinale and his colleagues in 2013, carried out an experimental research on two types of Mediterranean vernacular building in southern Italy, to validate the numerical codes provided by DesignBuilder/EnergyPlus software. The results show that there were only 1–2 degrees centigrade difference between measured and calculated indoor temperature of these buildings [13]. However, this study was carried out in a hot and humid climate, and performing such study for a building in hot and dry climate (such as Yazd in Iran) is still needed.

3. STUDY AREA

3.1. Case Study Selection

Rasoulian house in Yazd is as one of the best examples of traditional architecture which different researches has been done on various parts of the house, such as investigating and analyzing wind tower in Fluent software, investigating spaces and architecture plans and materials used in different parts of the house. Regarding the purpose of present study, which was investigating the accuracy of DesignBuilder software in thermal calculations and comparing the software results with experimental measurements, Rasoulian house was chosen as a good case because an experimental study was done earlier and thermal conditions of different parts of it were available [7]. In this study, computer–connected sensors were used to measure and record temperature and relative humidity of different parts of this house, from June 10^{th} to July 4^{th} 2005. The results of this experimental study were used to validate the results of computer simulation for this house.

3.2. Software Selection

DesignBuilder software was used for modeling various aspects of building such as the physics of the building (materials), architecture, heating and cooling systems, lighting systems, etc.; and has the capability to model nearly all aspects of building; it can simulate the consumption of different types of energy in building as a dynamic model, including energy consumption for heating, cooling, lighting, appliances, domestic hot water, etc. Also this software can calculate the rate of lighting and it has the ability in modeling CFD. DesignBuilder software can calculate receiving, waste and energy consumption based on climatic conditions of building site precisely, by using climatic files of six major cities of Iran. Besides, this software has a good graphic user interface (GUI) and doesn't need any other software for modeling. Moreover, ease of use was another reason to choose *DesignBuilder* software.

3.3. The Simulation Process

First of all, a 3D model of the building was made using the *AutoCAD* software, and this model was imported to *DesignBuilder*. Different parts of the building were defined as thermal zones. The basement of this house was defined as a separate block. Also first floor was defined as 4 blocks, including summer and winter rooms (Figure 1), and western and eastern parts (Figure 2). In order to include thermal conditions of the courtyards in the simulation results, each of the two central courtyards of the house, were also defined as a separate block with one “Hole” in their roof. Each of the blocks was divided into different zones based on their thermal behavior (Figure 3).

The level of the building’s ground floor was higher than the courtyards; so the building’s ground floor level was considered as ±0.00 and the two courtyards were modeled at the underneath level. In this way, the underground parts of the house were spontaneously placed on the underside of ground level; therefore, it wasn’t necessary to use “Ground” icon of DesignBuilder to draw underground parts and any other available information such as plans, sections, elevations, height codes, and thickness were utilized for simulation.

Some of the underground parts of the house had walls with different heights, which “Boolean” order was used for modeling them. In order to simplify the existing difference in thicknesses of walls and pillars, the thickness of all the walls was considered 50 cm. Besides, the rest of the remained thicknesses and the arches and vaults in the building were considered as “thermal mass” and the number, which was obtained from calculating the thermal masses of each zone, was entered in “Construction / Internal Thermal Mass” section in the software.

Furthermore, in the section of yards’ Internal Thermal Mass, volume of thermal mass for the pool area was considered by using 10°C water in these parts.

Fig. 1 Winter room (left) and the summer room (right)

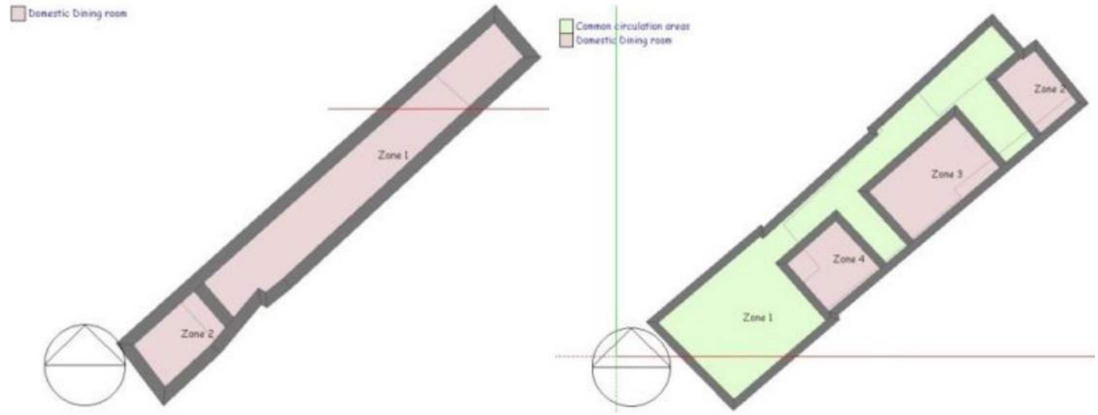


Fig. 2 Western corridor (left), and the eastern corridor (right)

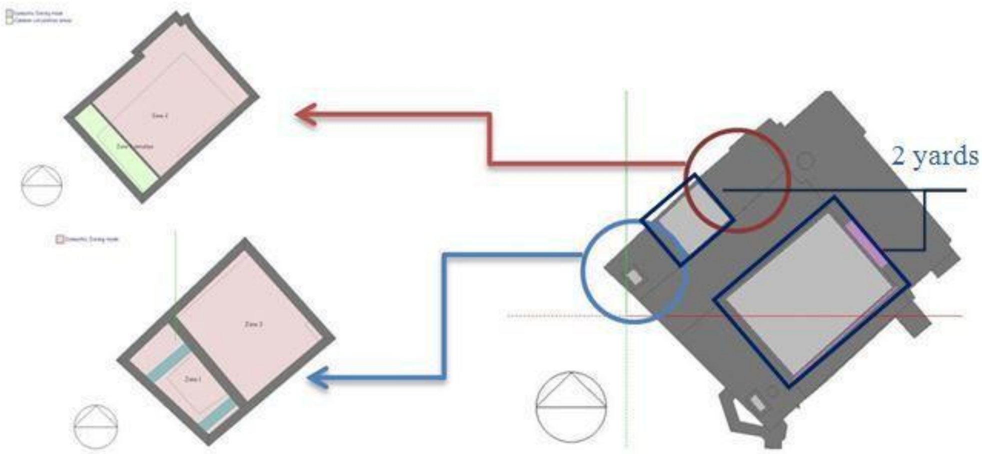


Fig. 3 Courtyards and other parts of the model

3.4. Calculation Factors of Thermal Mass in Each Zone

In order to calculate thermal mass for each zone, lateral zone area and thickness were considered based on the following method:

1– *Lateral zone area = [2 × surface length (walls)] × height (wall)*

2– Thickness and gender = 50 cm thermal thickness was considered for all the building's surfaces and materials, including walls and floor, except the two courtyards.

In order to have the most accuracy in the calculation results, the model had to be as simple as possible; so the cellar, which is actually stepped, was considered to have a flat floor without any stairs (the stairs of the cellar were not modelled) as can be seen in Figure 4.

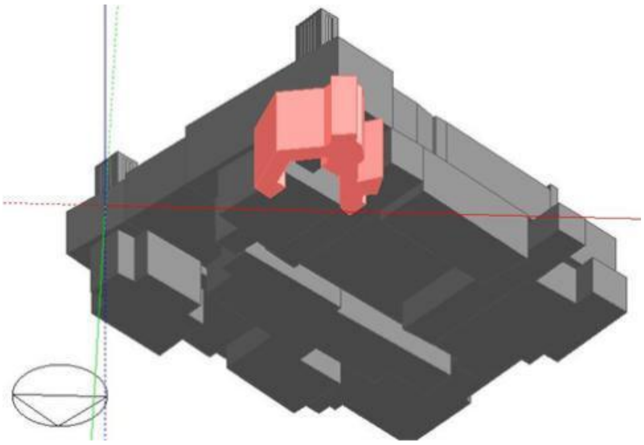


Fig. 4 cellar modification in the model

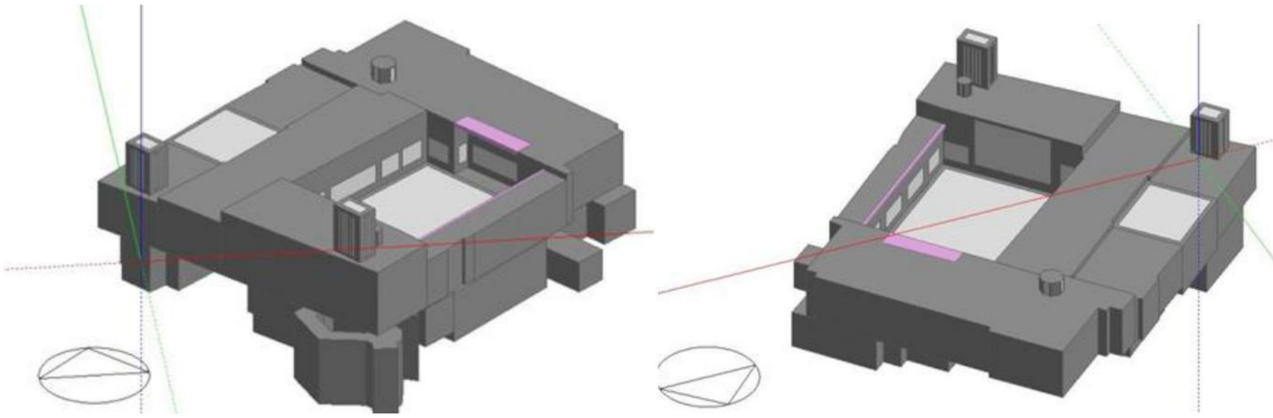


Fig. 5 different views from the model

Appropriate activities were considered for each zone; while the model did not have any HVAC or Lighting systems.

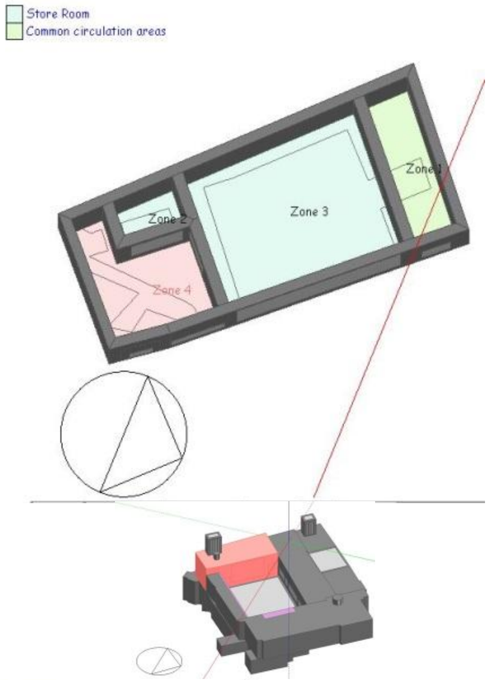
The amount of U–Value was considered 1.482 (W/m^2.K) for all the flooring and 1.328 (W/m^2.K) for all the walls in all zones. The amount of U–Value of the last roof was considered 0.390 (W/m^2.K) for Summer and winter rooms, western and eastern parts, corridors and reception, northern part and the summer room next to the outer yard; but the amount of U–Value for the basement was considered 1.384 (W/m^2.K). For the model's windows, there was not an exact choice for traditional windows in the software; so the "project glazing with 30% glazed" option, with "painted wooden frame" was the closest choice which could be chosen from the software's database.

Table 1 Thermal Mass and U–Values used in different parts of the model

Zone	Walls U–Value (W/m^2.K)	Final Roof U–Value (W/m^2.K)	Floor U–Value (W/m^2.K)
Summer and winter room, western and eastern parts, corridors and reception, northern part and the summer room (next to the courtyard)	1.328	0.390	1.482
Interior and exterior courtyards	1.328	–	1.482
Basement	1.328	1.384	1.482

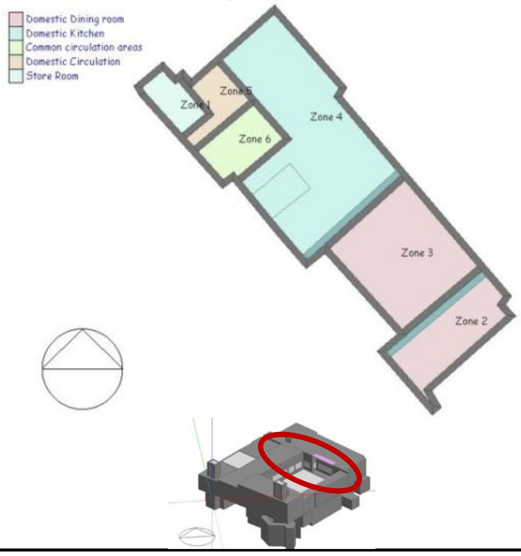
Summer room (zone 3) and Pergola (red colored part)

Zone	Thermal Mass (m^2)
Zone 1	132.24
Zone 2	4.18
Zone 3	332.69
Zone 4	101.62



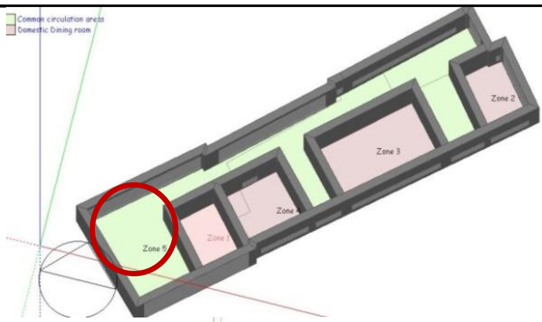
Winter room

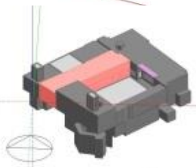
Zone	Thermal Mass (m^2)
Zone 1	56.90
Zone 2	158.18
Zone 3	97.87
Zone 4	480.24
Zone 5	99.01
Zone 6	6.00



Western part, corridors and reception (specified by the circle)

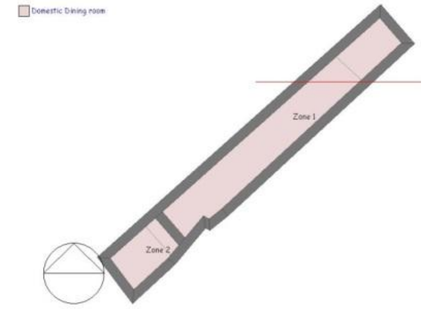
Zone	Thermal Mass (m^2)
Zone 1	65.12
Zone 2	125.18
Zone 3	75.11
Zone 4	87.63
Zone 5	806.88

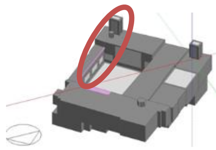




Eastern part

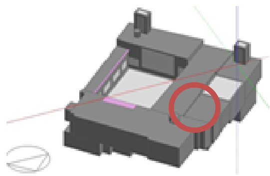
Zone	Thermal Mass (m^2)
Zone 1	193.76
Zone 2	50.30





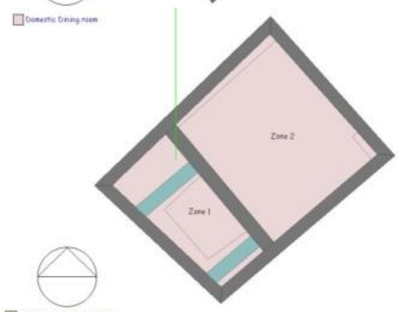
The northern part (next to the outer yard)

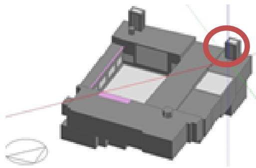
Zone	Thermal Mass (m^2)
Zone 1	53.85
Zone 2	193.55



Summer room next to the outer yard

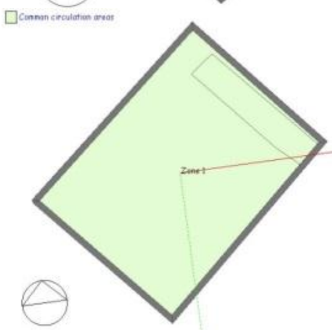
Zone	Thermal Mass (m^2)
Zone 1	113.79
Zone 2	113.79

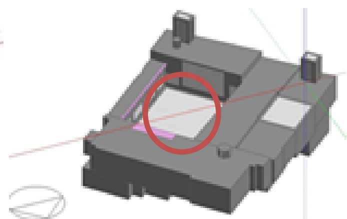


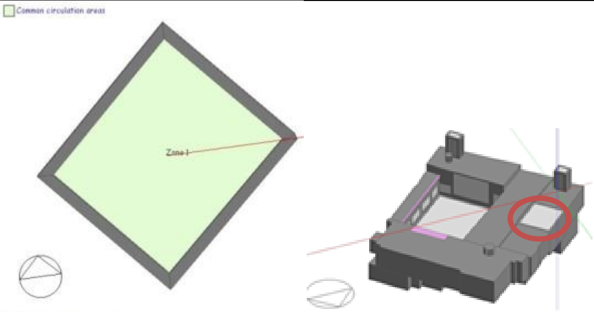
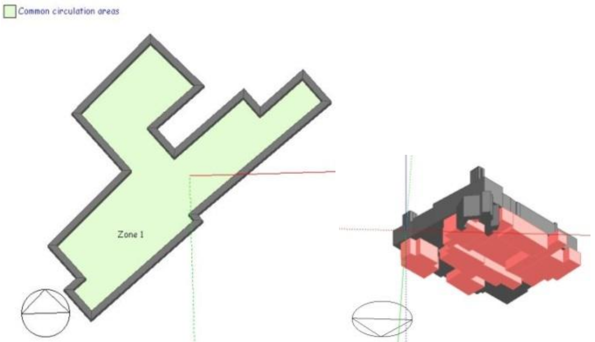
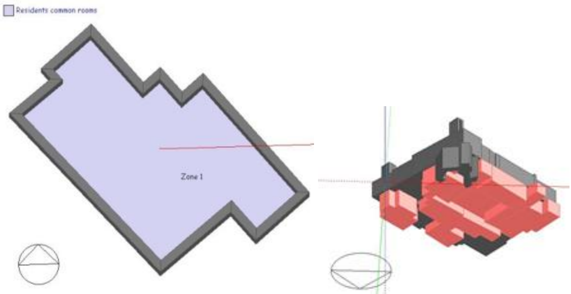
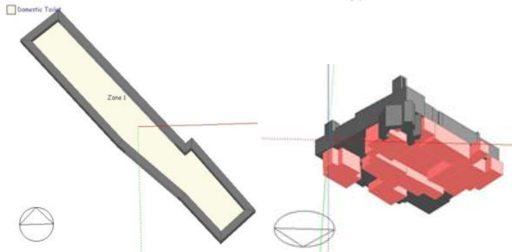
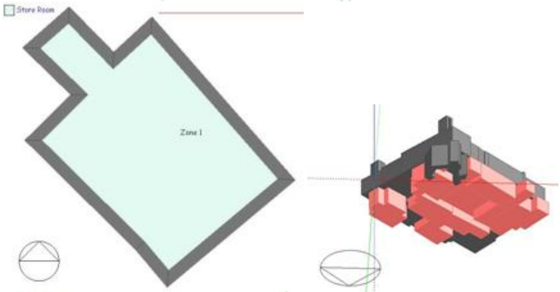
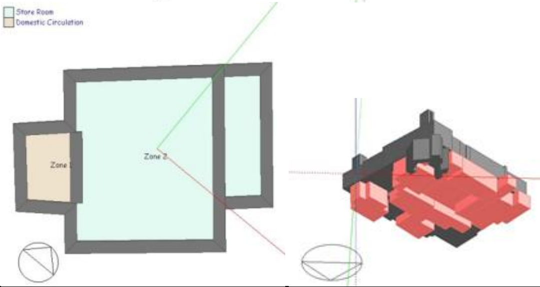


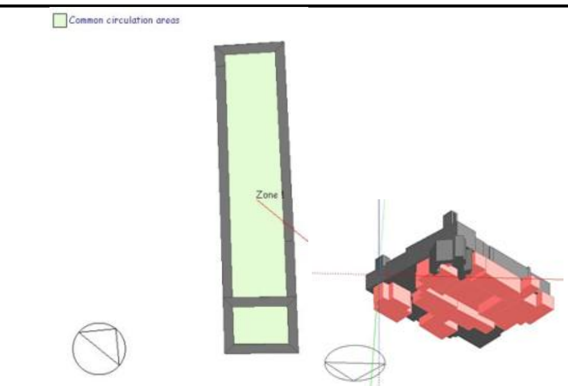
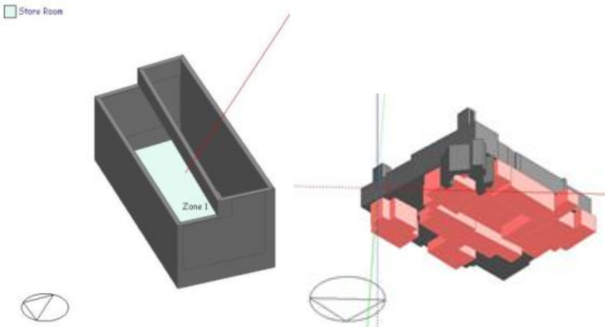
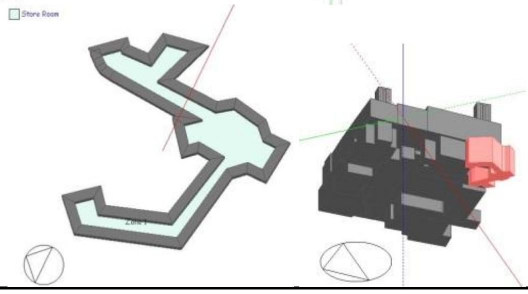
Interior yard

Zone	Thermal Mass (m^2)
Zone 1	103.41





Zone	Thermal Mass (m^2)	
Exterior yard		
Zone	Thermal Mass (m^2)	
Zone 1	7.60	
Basement		
Zone	Thermal Mass (m^2)	
Zone 1	207.91	
Basement		
Zone	Thermal Mass (m^2)	
Zone 1	48.60	
Basement		
Zone	Thermal Mass (m^2)	
Zone 1	72.19	
Basement		
Zone	Thermal Mass (m^2)	
Zone 1	259.04	
Basement		
Zone	Thermal Mass (m^2)	
Zone 1	0.00	
Zone 2	173.76	

Basement		
Zone	Thermal Mass (m^2)	
Zone 1	57.53	
Basement		
Zone	Thermal Mass (m^2)	
Zone 1	217.38	
Cellar		
Zone	Thermal Mass (m^2)	
Zone 1	2.59	

The amount of U–Value was considered 1.482 ($W/m^2.K$) for all the flooring and 1.328 ($W/m^2.K$) for all the walls in all zones. The amount of U–Value of the last roof was considered 0.390 ($W/m^2.K$) for Summer and winter rooms, western and eastern parts, corridors and reception, northern part and the summer room next to the outer yard; but the amount of U–Value for the basement was considered 1.384 ($W/m^2.K$). For the model's windows, there was not an exact choice for traditional windows in the software; so the "project glazing with 30% glazed" option, with "painted wooden frame" was the closest choice which could be chosen from the software's database.

4. RESULTS AND DISCUSSION

Simulation results are compared with experimental data in Table 2.

Table 2 Comparing the temperature of different parts of the house at different times of the warmest days of the year (June 10th to July 4th)

Spaces	Simulation Results			Experimental data [7]		
	8:00	14:00	20:00	8:00	14:00	20:00
Hall	32.2	33.2	31.9	35.6	38.8	34.3
Corridors	31.8	32.8	32.6	29.6	31.8	32.2
Pergola	32.2	33.2	31.9	31.8	35	34.1
Reception	26.7	26.8	26.9	28.9	27.1	29.6
Basement	24.7	25.5	25.6	27.9	27.6	27.2
Cellar	32.3	33.2	31.9	19.4	19.7	19.5
Outside	26.4	36.0	35.0	37.1	39.8	38.7

The first and most important reason of the differences between experimental measurements and the simulation data is the difference between default outside temperature estimated in the software and real temperature occurred. That was because the weather data file used by the software is made based on the average climatic data of recent years; but this average data isn't the same as actual data on a specific day and time. Also, the courtyard has its own microclimate which is different from the general climate of the city; so it was another reason why assumed results for the outside temperature were different from the measured experimental data. As it can be seen from table 2, outside temperature in the simulations (from the weather data file) was assumed 3 to 11 degrees lower than what has happened in the real conditions which has affected the calculated room temperatures.

Having mentioned in *Avatefi Nezhad* and partners' article, they used some strategies to improve wind tower's performance in a pergola room by connecting it to the cellar, during their experiment. In this case, pergola room's wind tower was connected to the cellar, by excavating a channel under it, so that the wind tower could be used as a stack chimney [7]. However, this issue was not considered in the simulation and the building was modeled based on the original conditions. Also, it should be mentioned that CFD analysis was not performed in this study, that is why the effect of wind tower has not completely considered.

The cellar's temperature had the most difference with experimental measurements (14-degrees centigrade approximately) mainly because DesignBuilder cannot calculate the effect of evaporative cooling, which is the most important cooling strategy in cellar space. Also, it can be caused by the procedure of software modeling. Because in reality, cellar can be connected or disconnected with the wind tower by a vent; however, in simulation method, tail–end of the wind tower towards cellar space is simulated regardless of any vents.

5. CONCLUSIONS

The results show the good ability of DesignBuilder software in modeling different strategies used even in a traditional complex building. The simulation results could give a good estimation of indoor thermal conditions for most of the spaces; but there are some problems in using this software for thermal modeling of traditional buildings in hot and arid climate. The most important deficiency of this software is that it is incapable of calculating the effect of evaporative cooling. Evaporation is one of the most used strategies to cool down the buildings in hot and arid climate. As a result, including this ability in DesignBuilder is strongly recommended to enhance its usage in different climates and countries.

CONFLICT OF INTEREST

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

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AUTHOR (S) BIOSKETCHES

Eisabegloo, A., *M.A. Graduate, Faculty of Architecture, Maziyar Institute for Higher Education, Noor, Mazandaran, Iran*
Email*: architectae@yahoo.com*

Haghshenas, M., *Guest Professor, Faculty of Art and Architecture, Islamic Azad University, Shiraz, Iran*
Email: *m.haghshenas@modares.ac.ir*

Borzoui, A., *Assistant Professor, Faculty of Architecture, Maziyar Institute for Higher Education, Noor, Mazandaran, Iran*
Email: *a.borzouei@maziar.ac.ir*

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