Iranian (Iranica) Journal of Energy & Environment
Journal Homepage: www.ijee.net
IJEE an official peer review journal of Babol Noshirvani University of Technology, ISSN:2079-2115

Investigating DesignBuilder Simulation Software's Validation in Term of Heat Gain through Field Measured Data of Adjacent Rooms of Courtyard House

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P A P E R I N F O

Paper history:
Received 07 August 2022
Accepted in revised form 09 September 2022

Keywords:
DesignBuilder
Field measurement
Heat gain
Simulation software

A B S T R A C T

New designing techniques have been used recently in design phases of buildings to adapt human thermal comfort. Due to wide range of energy consumption within a building, it is impossible to make a proper decision about the impact of different energy efficiency strategies without simulation tools. Architects need to understand the accuracy and precision of simulation software to use them as valuable tools to predict energy consumption. This research aims to investigate the validity of DesignBuilder simulation software by using the actual traditional house in terms of heat gain. In this study, the comparative method was used to determine the differences in heat gain in a traditional courtyard house in Kerman that was simulated using DesignBuilder software and measured experimentally. This study also reveals that the difference between simulation results and empirical measurement is not more than 10%. It can be concluded that DesignBuilder has enough validity to calculate the amount of heat gain in the rooms adjacent to courtyards.

doi: *10.5829/ijee.2023.14.01.01*

INTRODUCTION

In previous decade, energy consumption has increased for daily activities [1]. The building sector consumes more than 40% of the total energy consumption in developing countries. So, the best strategies and answers to reduce energy consumption in buildings have become more critical [2, 3]. This sector contributes a considerable share of global energy consumption and greenhouse gas (GHG) emissions worldwide [4].

One of the ultimate methods for investigating buildings' whole performance is computer simulation [5, 6]. Accurate predicting building performance can be done by using building energy simulation programs [7, 8]. Computer simulation is one of the top methods for holistically analyzing the entire performance of buildings [5]. This method can be used to simulate buildings with different climate conditions. Researchers have usually used similar methods to acquire outputs or data on the performance of buildings [9].

Previous studies have shown that several simulators have been designed to simulate various energy-saving applications [10]. Some tools have been designed to analyze buildings' energy and thermal conditions [11]. DesignBuilder software is one of the most specific programs for simulating building energy. Different types of validation can evaluate the performance of a building performance simulation tool. Empirical validation is one way to test the building simulation software [12]. One of the proper forms of validating energy software is to compare the results of actual values obtained from building to the results of simulations [13]. Validation refers to validating the results against a series of standard examinations. This validation procedure can range from simplistic procedures to verifying that programs produce results within practice ranges. However, dynamic calculation procedures have complex calculation algorithms and require a more complex validation process. A validation exercise exists in which experimental measurement is compared with

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Please cite this article as: N. Tayari, M. Nikpour, 2023. Investigating DesignBuilder Simulation Software's Validation in Term of Heat Gain through Field Measured Data of Adjacent Rooms of Courtyard House, Iranian (Iranica) Journal of Energy and Environment, 14(1), pp. 1-8. Doi: 10.5829/ijee.2023.14.01.01

mathematical results [14]. Validation of simulation software on building performance can be executed using three different methods.
1) Empirical method: this method is based on comparing the field measured data with the results of a simulation
2) Analytical method: this method involves comparing known analytical or numerical results with simulation results
3) Comparative method: this method is based on comparing different software's simulation results with each other [15].

This study has used the empirical method to compare the field measured data obtained from the traditional courtyard house in Kerman city with the results of a similar model simulated with DesignBuilder software. Empirical validation compares calculated or simulated results and monitoring data from an actual building. There is always uncertainty in empirical studies [12]. Some research showed that the primary reason for the dissimilarity between the actual and predicted energy consumption is the error in the weather data that was added to the simulation software. The research by Eskin and Turkmen Energy Plus software and its values were compared with actual samples in 24 hours. The difference was 9 and 1 percent, respectively [16].

Previous studies have shown that different tools have been developed to simulate energy consumption [17].

DesignBuilder has been validated in a study by Mustafaraj et al. [18]. Simulated results of a model university building compared with field measurement results. Similarly, Sun et al. [19] compared simulated and measured results of six university buildings in the USA. Another study by Baharvand et al. [20] compared the results of CFD simulations using DesignBuilder software with an actual situation simulated result.

This study aims to develop and validate simulation methodology and analyze the use of DesignBuilder to examine the performance of buildings. The results can be used in the early steps of design to improve the building's energy performance.

MATERIAL AND METHODS

Study area

According to the latitude 30.29 and longitude 57.06, Kerman province is located in the southeast of Iran and in the hot and dry region, which is the widest climate in Iran [21].

The Yazdanpanah's House, one of the old houses in Kerman, was selected for study and used to field measure and compare the results of software simulation to validate the DesignBuilder software.

The reason for choosing the Yazdanpanah house was that, according to previous research and books, houses with a central courtyard are a suitable answer to the region's climatic conditions. For this reason, measuring the temperature and humidity in this house and simulating it in DesignBuilder software, apart from validating the software, can also help to understand the thermal behavior of these sample houses.

In order to experimentally investigate the amount of thermal behavior of research, the amount of dry bulb temperature and relative humidity were taken in two rooms of this house. Figures 1 to 4 show the plan, section and detiels of Yazdanpanah's house and the location of two particular rooms.

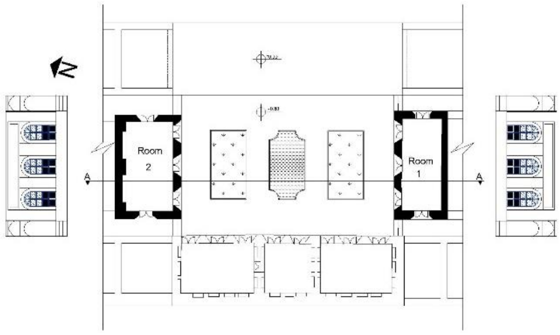

Figure 1. Position of the room one and room two according to the courtyard and their elevations

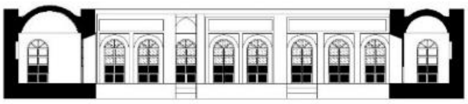

Figure 2. Section A-A

Figure 3. View of Yazdanpanah's courtyard

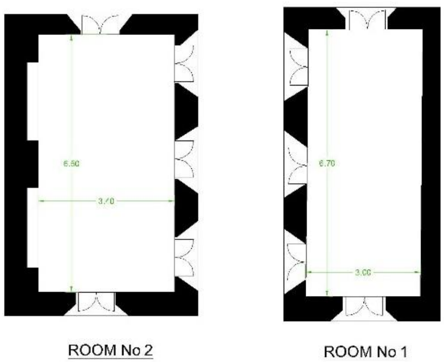

Figure 4. Two examined room's plans

Experimental tools

The thermometer was used for the experimental measurements (Figure 5). On 1st of July 2022, the thermometer was installed at the center of room one and room two, and dry bulb temperature and relative humidity were collected every 3 minutes in 6 steps.

In the second part of the experimental measurement, by using a psychrometric chart, the amount of enthalpy of air was calculated. Then the amount of heat gain was computed for each time step according to changes in enthalpies.

Since air comprises different gases and evaporated water, heat gain causes temperature and humidity ratio changes. Also, the enthalpy of the air comprises the sensible and latent heat; therefore, the amount of heat gained to the air can be calculated through changes in the enthalpy of air.

This instrument measures the indoor dry bulb temperature and humidity ratio in space. The temperature measurement range of this device is +50 to 0 degrees Celsius and +122 to +32 degrees Fahrenheit. The humidity measurement range is 10-95%.

The following equation was used to calculate heat gain in room one and room two.

$$Q = \rho_a V_d (h_2 - h_1)/d_t \quad (1)$$

where,
Q: heat flow
ρ_a: density of air
V_d: air volume
h_1: enthalpy of air at the first time of dry bulb
h_2: enthalpy of air at the second time of dry bulb
d_t: time difference between two measurement

DesignBuilder software

In this research, DesignBuilder software was investigated and validated. Considering the importance of the results obtained from the DesignBuilder software, this software has been validated. DesignBuilder is the most acceptable software for studying building energy, lighting, CO_2, and comfort performance created to find out the energy performance of a building by simulation [22]; DesignBuilder helps designers quickly understand the energy behavior of the building and consider strategies. DesignBuilder has the ability to model quickly, calculate and simulate the energy performance and the behavior of building in terms of daylight. DesignBuilder is the leading thermal simulation motor for Energy Plus software [23, 24].

Considered parameter

Weather data

Weather data is the most critical parameter for indoor temperature and thermal comfort stabilization. It is also essential for estimating the comfort in the building during energy simulation [25]. The occupancy of a building is an essential parameter that affects building energy performance [26]. Since the house of Yazdanpanah is empty of residents, the simulation settings in DesignBuilder were also chosen accordingly.

Air infiltration

One of the other important factors that increase energy consumption and thermal behavior in the building is air infiltration [27]. The location of the building affects the wind speed around the building. Therefore, not paying attention to the exact location and correct weather data can affect the simulation results [28].

Openings

The opening and closing of the windows play an important role in the internal heat of the building [29]. Since, in traditional houses, openings facing the courtyard are not used for commuting, there is less chance of error in the simulation process.

Figure 6 shows the model of Yazdanpanah's house that was simulated in DesignBuilder software. Because the selected rooms are only adjacent to other spaces inside the house and are not related to the neighboring buildings, there was no need to investigate the neighboring buildings and simulate them during the simulation process. Therefore, the house model was examined alone.

Construction details for wall, roof and floor of all models are based on common materials which have been used in traditional houses in the hot and 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/m^{2}k, respectively in all models.

Figure 5. Experimental tool (Thermometer)

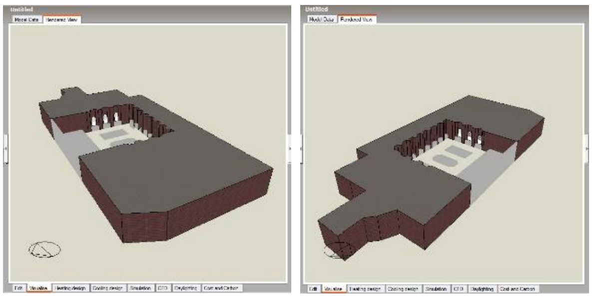

Figure 6. Simulated models of Yazdanpanah's house

Window-doors in these rooms are half glassed in the upper part of the window and half wood in the lower part of the door. The glasses that are used in the actual model are single-glazed. The exact situation is simulated in DesignBuilder with a 3.835 U-value for glasses and the 3.633 U-value for the wooden frame (Table 1).

FINDING AND DISCUSSION

Experimental measurement

The rooms on the north and sought sides of the courtyard were selected to be surveyed. In traditional architecture, these rooms are used primarily in winter and summer. The winter using room (that is called room no. two) is in the north part of the courtyard with openings facing to the south, and the room used in summer (called here room no. one) is located in the south part of the courtyard with openings facing to the north. The width, length, and height of room 1 are 3, 6.7, and 4.2m. This room has three window-doors with 14.49 WWR facing north at a 17° angle. The width, length, and height of room 2 are 3.4, 6.5, and 4.2m. This room has three window-doors with 14.94 WWR facing north at a 163° angle. The materials of window-doors frames are wooden with single glazed glass. The dimensions of the selected rooms can be seen in Table 2.

In order to determine the amount of heat gain, temperature and relative humidity were measured in 3-minute steps by the thermometer. The thermometer is located at the center of each room. Both rooms were empty during the measurement, and there was no furniture and equipment.

The above table shows the amount of temperature fluctuation from 9:00 AM (first sampling) to 2:00 PM (last sampling). Table 3 shows that dry bulb temperature increases from 9:00 AM to 2:00 PM, and relative humidity has an opposite behavior and decreases.

In the next step, the specified values in Table 1 were transferred to the psychrometric web software (https:www.psych-chart.com), and the enthalpy value of temperature and humidity change in these 3 minutes was obtained.

Figure 7 shows the process of obtaining the enthalpy, which can be seen in Table 4. Adding the amount of dry bulb temperature and relative humidity to the psychrometric chart can calculate the amount of enthalpy and absolute humidity.

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
Window	Glass	0.003	3.835	-	3.820
	frame	0.02	9.50	0.275	3.633

Table 2. Specifications and details of each room

Room	Orientation faced	ORI	X	Y	Z	Room area (m^2)	WWR
1	north	17°	3	6.7	4.2	20.1	**14.49**
2	south	163°	3.4	6.5	4.2	22.2	**14.94**

Table 3. Measured temperature and relative humidity

Time	Room 1		Room 2	
	Temperature [°C]	Relative Humidity [%]	Temperature [°C]	Relative Humidity [%]
9:00	30.1	32.3	31.1	30.5
9:57	30.9	30.8	31.3	30.1
10:00	31.7	29.4	31.5	29.8
10:57	32.5	28.1	32.9	27.5
11:00	33.6	26.4	34.9	24.6
11:57	33.7	26.3	35.3	24
12:00	33.9	26	36.1	23
12:57	34.3	25.4	36.9	22
13:00	34.6	25	37.7	21.1
13:57	35.1	24.3	37.8	21
14:00	35.4	23.9	38.1	20.7

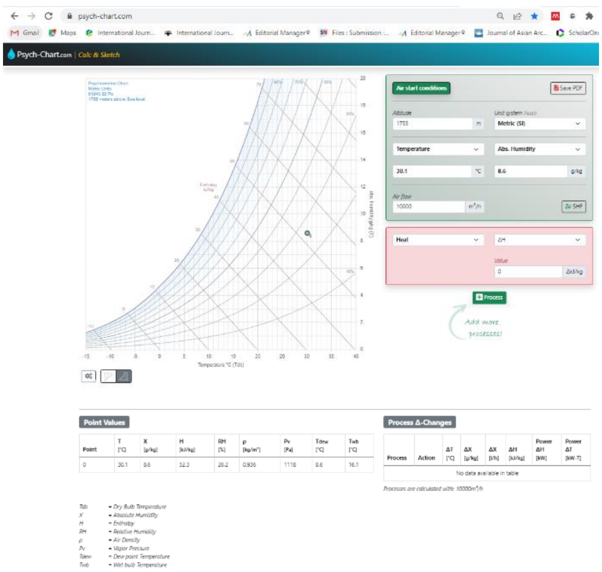

Figure 7. psychrometric software (https:www.psych-chart.com)

Table 4 shows the results of calculating enthalpy in the two north and south rooms adjacent to the central courtyard, which have openings to the north and south.

Therefore, the dry bulb temperature and relative humidity of two rooms located north and south of the central courtyard in Yazdanpanah house were measured. In the first step, the amount of these factors was taken using a thermometer and hygrometer. In the next step, the values in Table 3 were used in the heat gain equation to measure the amount of heat gain in the experimental model.

The total heat gain is calculated with the equation in the last step of experimental measurement.

Table 4. Measured enthalpy

Room 1				
Time	**Temperature [°C]**	**Absolute Humidity [g.kg]**	**Enthalpy [kJ.kg]**	**Relative Humidity [%]**
9:00	30.1	8.6	52.3	32.3
9:57	30.9	8.6	53.1	30.8
10:00	31.7	8.6	53.9	29.4
10:57	32.5	8.6	54.7	28.1
11:00	33.6	8.6	55.8	26.4
11:57	33.7	8.6	55.9	26.3
12:00	33.9	8.6	56.1	26
12:57	34.3	8.6	56.5	25.4
13:00	34.6	8.6	56.9	25
13:57	35.1	8.6	57.4	24.3
14:00	35.4	8.6	57.7	23.9
Room 2				
Time	**Temperature [°C]**	**Absolute Humidity [g.kg]**	**Enthalpy [kJ.kg]**	**Relative Humidity [%]**
9:00	31.1	8.6	53.3	30.5
9:57	31.3	8.6	53.5	30.1
10:00	31.5	8.6	53.7	29.8
10:57	32.9	8.6	55.1	27.5
11:00	34.9	8.6	57.2	24.6
11:57	35.3	8.6	57.6	24
12:00	36.1	8.6	58.4	23
12:57	36.9	8.6	59.2	22
13:00	37.7	8.6	60	21.1
13:57	37.8	8.6	60.1	21
14:00	38.1	8.6	60.4	20.7

DesignBuilder software

After taking field measurements, similar conditions were simulated on the same day(first of July) in DesignBuilder software using weather data related to Kerman city. This weather data was obtained from the airport meteorological synoptic station, which included dry bulb temperature and wet temperature, humidity, solar heat gain, etc.

The obtained information compares the amount of solar gain in the experimental measurement with the simulation conditions. Table 5 shows the results of this simulation.

The difference between the results in Table 5 was carried out to the percentage. The maximum difference between software simulation and experimental measurement results is around 10%.

Figures 8 and 9 show the difference between received values in field measurement and simulation mode. Although the difference between the numbers does not have a predictable movement in the entire path of the graph, it provides the results in acceptable conditions and with a slight difference.

Various studies of different software have been done. In research conducted by Nikpour et al. [30], with a

Table 5. Comparison of the simulation results and experimental results

Room 1				
Time	**Temperature T [°C]**	**Enthalpy H [kJ.kg]**	**Heat gain kW.h Experimental**	**Heat gain kWh Simulation**
9:00	30.1	52.3	168.84	160
10:00	31.7	53.9	281.4	255
11:00	33.6	55.8	281.4	260
12:00	33.9	56.1	393.96	365
13:00	34.6	56.9	225.12	230
14:00	35.4	57.7	337.68	355
Room 2				
Time	**Temperature T [°C]**	**Enthalpy H [kJ.kg]**	**Heat gain kWh Experimental**	**Heat gain kWh Simulation**
9:00	31.1	53.3	556.92	510
10:00	31.5	54	371.28	360
11:00	34.9	57.2	371.28	385
12:00	36.1	58.4	408.408	365
13:00	37.7	60	371.28	350
14:00	38.1	60.5	247.52	270

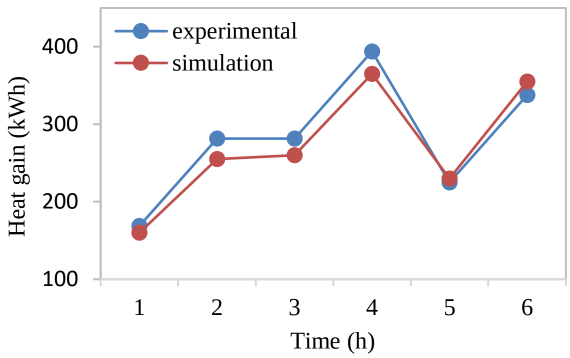

Figure 8. Comparison of the results of simulation and experimental measurement in term heat gain (kWh) in Room 1 according to different times

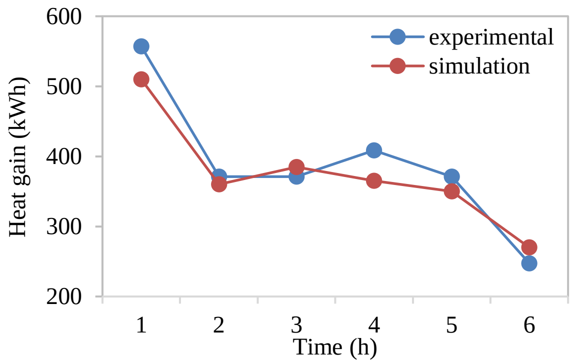

Figure 9. Comparison of the results of simulation and experimental measurement in term heat gain (kWh) in Room 2 according to different times

similar method (comparison of software simulation with field measurement), they investigated the validity of IES software. The results showed that this software has enough credibility to check the amount of heat gain in the researched office building. The results showed that no more than a 10% difference between the simulation and experimental results could be ignored [30].

Jain et al. [31] have investigated the reliability of Ecotec software in estimating the illuminance entered into the space. The results showed that due to the lack of capabilities of the Ecotect software in calculating the incoming light and illuminance, in some cases, the software does not respond appropriately, and the difference between the results of simulation and field measurement is about 15% [31].

In another study, Fathaliyan and Kargarsharifabad [32] investigated DesignBuilder software in calculating the amount of energy consumption throughout the year compared to an existing model. The software simulation results show a difference of less than 1.6% [32].

Ahmad et al. [33] investigated the amount of daylight factor in a dormitory building. In this research, Ecotect software was compared with experimental conditions. After simulating conditions utterly similar to the building under study, the results showed that most of the time, the software results are more accurate and can be easily measured. At the same time, in the experimental method, the measurement steps are complicated and time-consuming [33]. The experimental measurement and simulation results were compared, and the differences between results were less than the specified range. Since the DesignBuilder software simulation engine is Energy Plus, and Ashrae has approved this engine, and since the results obtained from this research show a 10% difference, it can be concluded that DesignBuilder software is valid for calculating the amount of heat gain in the rooms adjacent to the central courtyard in Kerman.

CONCLUSION

This study estimated the validation of simulation software compared with experimental measurement. For this purpose, the simulation was performed using DesignBuilder and field measurement of two rooms in a courtyard house. The validation studies were carried out by comparing the results of model thermal simulation with the field measurement of air temperature.

According to results and the amount of difference in the two tested samples, it can be concluded that the DesignBuilder software provides acceptable results in estimating the amount of heat gain in the building.

The results show that the heat gain was different on both the simulated day and Field measurement. The differences between the simulated and the measured heat gain results were below 10% in all the tested steps.

For future research, it can be suggested to validate the DesignBuilder in terms of other parameters such as daylight factor and uniformity; furthermore, the results of other simulation software can be compared with the results of DesignBuilder.

CONFLICT OF INTEREST

There is no conflict of interest.

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Persian Abstract

چکیده
تکنیک‌های جدید طراحی اخیراً در مراحل مختلف طراحی ساختمان‌ها به منظور انطباق ساکنین با آسایش حرارتی مورد استفاده قرار می‌گیرد. با توجه به طیف گسترده مصرف انرژی در یک ساختمان، تصمیم‌گیری مناسب در مورد تاثیر استراتژی‌های مختلف بهره‌وری انرژی بدون ابزارهای شبیه‌سازی غیرممکن است. معماران باید صحت و دقت نرم‌افزارهای شبیه‌سازی را درک کنند تا از آن‌ها به عنوان ابزاری مفید برای پیش‌بینی مصرف انرژی استفاده کنند. هدف از این تحقیق بررسی اعتبار نرم‌افزار شبیه‌سازی دیزاین بیلدر با استفاده از خانه سنتی واقعی از نظر دریافت گرما می‌باشد. در این تحقیق از روش مقایسه‌ای برای تعیین تفاوت دریافت حرارت در یک خانه حیاط سنتی در کرمان استفاده شد که با استفاده از نرم‌افزار DesignBuilder شبیه‌سازی و به صورت تجربی اندازه‌گیری شد. این مطالعه نشان می‌دهد که تفاوت بین نتایج شبیه‌سازی و اندازه‌گیری تجربی بیش از ۱۰ درصد نیست. از این رو می‌توان نتیجه گرفت که DesignBuilder از اعتبار کافی برای محاسبه میزان دریافت حرارت در اتاق‌های مجاور حیاط مرکزی برخوردار است.