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Field Measurement Test to Estimate Level of Accuracy between Actual and Simulated Air-Temperature: Case Study of Mosque Buildings

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Abstract

One of the main drawbacks of current simulation tools is inaccuracy and each simulation software has a set of different calculation algorithms, which is also prone to limitations and errors. Although the results can be achieved from running the simulation analysis, these results may not reflect the actual performance of a building in in real world scenarios. Additionally, when using simulation software for decision-making tools or to build a numerical model, validation tests are required to ensure the quality of the obtained results. This paper conducted a field measurement test to record the interior air temperature for specific period of time and compare it with EnergyPlus™ simulation results at the same time. A digital recorder of Temperature Humidity Tester Thermometer Clock Hygrometer KT-908 was applied and the results showed that the difference between the measured and simulated air temperatures did not exceed 0.55˚C. As there was no significant difference between the measured and simulated air-temperatures, which gives credibility and attests to the quality of the EnergyPlus™ simulation results.

Keyword: Field measurement, Building Simulation, Indoor Air Temperature, Sustainable Mosques.

1. INTRODUCTION

Modeling and simulating software are widely recognized recently and have proven to be powerful tools for studying the environmental performance of the building with the ability to engage energy use through the design process[1]. Nowadays, building simulation models calculate the energy required for cooling, heating, and predicting the future energy use for buildings. Furthermore, these energy estimation models can be used by engineers, architect designers, policy makers, and energy auditors to compare between different design aspects, and investigate the optimum design solutions for energy efficiency for both new or existing buildings [2]. The increase dependent on building energy models to estimate the energy consumption by variety number of users and engineers have highlighted the need for providing high level of accuracy in these models[3]. Based on achieved from running the simulation analysis, these results may not reflect the actual performance of a building in reality and prone to errors[4]. During the model development process and involvement of simulation software such as EnergyPlus™, eQuest, Ecotect, and TRNSYS, validation of these energy models is pertinent and accuracy of results required to be verified to assure that using these models can be trusted [5].
One of the main drawbacks is that each simulation software has a set of different calculation algorithms, which is also prone to limitations and errors[6]. The validation between the actual and predicted values is required in order to test the level of accuracy, quality, and reliability for the obtained results[3]. Despite the need for large number of parameters to integrate within developing building energy models, previous studies revealed that only few works have been done to validate results of these models with the real-life situations[5]. Similarly, in regard with mosques, very few works have conducted a validation test to assure the quality of their results. Several previous studies have not carried out any validation test for their simulation results with unrealistic rates of energy reduction such as [7, 8, 9, 10, 11]. The aim of this work is to develop a decision-making tool that can assist designers during the design stage. the development of the decision tool is based on the results obtained from running a simulation analysis through EnergyPlus software analysis software which required a validation test to estimate level of quality and accuracy of obtained results.

2. METHODOLOGY

Comparing between different methods to validate the simulation results. However, the field measurement test to record the indoor air temperature and compare it with the results form simulation analysis were found by numerous studies to be more accurate and consistency in obtaining quality results[3, 5, 13, 15].

2.1 Field Measurement Test

This paper conducted a field measurement test to record the interior air temperature for specific period of time and compare it with EnergyPlus™ simulation results at the same time. To do so, a digital recorder namely as Digital Temperature Humidity Tester Thermometer Clock Hygrometer KT-908 was applied, which can save information as per set to monthly, daily, hourly.Figure 1, shows the interface for the digital recorder.

FIGURE 1
DIGITAL TEMPERATURE TESTER THERMOMETER CLOCK HYGROMETER KT-908

Specification and instruction for the digital recorder for indoor air temperature include the dimensions: 110 × 59mm × 13mm and temperaturemeasurement range (indoor): - 10 ° C ~ + 50 ° C (+ 14 ° F ~ + 122 ° F). Temperature measurement range (-50 ° C ~ + 70 ° C (-58 ° C ~ + 158). Humidity Measuring range: 20 to 99%. Operating voltage 1.5V, ultra-low power. Between (-10 to 50) ° C. Accuracy is (±05 ° C). Additionally with values that are less than (-10 and more than +50° C the accuracy is (± 1 ° C).

2.2 Case Study

Al WalidaynMosque case study was selected which represented a medium sized mosques as the common type especially in urban areas with increase number of populations. Al WalidaynMosque case study is located in Al-Madinah, Saudi Arabi. Figure2 displays its front view of Al Walidayn Mosque.

FIGURE 2
FRONT VIEW OF THE ALWALIDAYN MOSQUE

With a total area of 800 m^2, the Al Walidayn Mosque is a rectangular shaped building with a 2:1 length-to-width aspect ratio, 7 m high ceiling, and 750-person capacity. The mosque faces southeast with long windows facing in all directions. The women's prayer hall is separated by a 2-meter-high partition wall while the ablution area is located outside the building. The structure of the mosque is made of reinforced (hordy) concrete with a brick infilled frame. The walls are brick with plastered surfaces on the inside and cement and sand rendering covering the façade. All the windows are single glazed and fitted into aluminum frames. The height of the minaret is 23 m while the *mihrab* faces southeast; the direction of the *Kaaba* in Makkah.
In addition, the temperature file of Al-Madinah was successfully downloaded using the Ladybug download EWP weather file plugin from www.energy plus.net/weather.Figure 3 shows the temperature in Al-Madinah over a one-year period, from January to December.

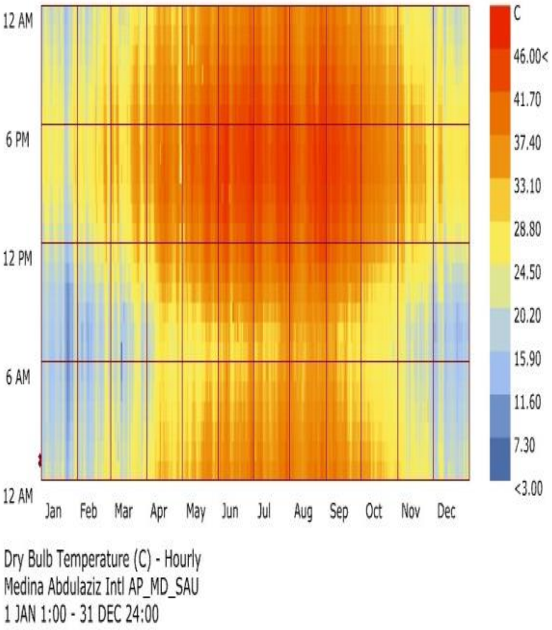

FIGURE 3
THE TEMEPRATURE IN AL-MADIANH OVER ONE-YEAR PERIOD

As seen in Figure 2, the maximum temperature in Al-Madinah was 46°C in the peak summer months while the minimum temperature was 3°C in the winter months. In addition, the external air temperature was brought from the report of the meteorological authority in Al-Madinah city.

2.3 Simulation Analysis Tool

To estimate the indoor air-temperature for the Al WalidaynMosque, EnergyPlus™ software was selected as the most preferred energy simulation tool among researchers and designers.EnergyPlus™ software was developed by the U.S. Department of Energy and has proven to have extremely high calculation accuracy and calculates the heating, cooling, electrical loads, ventilating, lighting, and other energy flows in adjustable points of time where accurate results are provided enabling the realistic evaluation of the radiant heating, cooling and inter-zonal loads[12].Al Walidayn Mosque case study was modeled through Rhiniceros and Grasshopper 3D software and simulated throughEnergyPlus™ software as shown in Figure 4. Then a comparison between the results with actual indoor air temperature of mosque geometry is conducted.

FIGURE 4
RENDERED PERSPECTIVE OF AL WALIDAYN MOSQUE

3. RESULTS AND DISCUSSIONS

3.1 Indoor Air-Temperature through Field Measurements

The air temperature was recorded during the winter months in order to obtain accurate results, where the A/C system for the interior building was off. Several studies recommended recording the indoor air temperature for seven days duration in a set of three hours intervals, because of the possible change in weather condition[3, 13, 14, 15]. According to Sabbagh &Almalti, [16], the climatological report showed that the winter months in Al-Madinah city are known to be December, January, and February. Furthermore, January is the coldest month in Al-Madinah city. However, this research conducted a field measurement test during the winter months in Al-Madinah for seven days in a set of three hours intervals. The field measurement started from 13th of December till the 19th of December 2020, and the indoor air temperature was recorded in a set of three hours intervals. The indoor air-temperature of the mosque case study was naturally ventilated, and the A/C system of the indoor mosque was off. The automated data recording tool to record the air temperature measurements was set in the center of the mosque main hall space.
The measured temperatures were compared with the one generated by the EnergyPlus™ simulation in Grasshopper for the same space. In addition, the external air temperature was brought from the report of the meteorological authority in Al-Madinah city.
KT-908 digital temperature humidity tester thermometer clock hygrometer was used to record the indoor air temperature at the Al Walidayn Mosque.The results showed that the highest indoor temperature (33.65°C) was recorded at 3:00 PM on 13th of December 2020, indicating that the Al Walidayn Mosque received the most heat between 1:00 PM and 5:00 PM. The lowest indoor temperature (20.90°C) was recorded on the 16th of December 2020 while the average indoor temperature over the seven-day period was 26.52°C. The results showed that the temperature gradually increased between 12:00 PM to 6:00 PM due to excessive sunshine and the heat gained through the windows before decreasing slightly for the remaining hours. Significant thermal discomfort was also noted inside the case study mosque due to several reasons; such as poor building design, lack of adequate insulation, and choice of construction materials.

3.2Indoor Air-Temperature through EnergyPlus™ Simulation

The base geometry of Al WalidaynMosque was set for non-conditioned for the simulation measurements. The specifications for the base model geometry were set within Grasshopper and EnergyPlus™ software. The modeled case study was run for a specific period of time between 13th and 19th of December 2020; as viewed through the Grasshopper 3D graphical interface. The results of recorded indoor temperature were saved in a Microsoft Excel file. In addition, the analysis period to record the interior air temperature was changed from monthly to hourly calculation.
The highest indoor temperature (33.10°C) was recorded on the 17th of December 2020 at 3:00 PM while the lowest indoor temperature (20.56°C) was recorded on the 16th of December 2020 at 6:00 AM. The average indoor temperature over the seven-day period was 26.13°C. The results also showed that peak air-temperatures were recorded between 12:00 PM to 6:00 PM before they decreased gradually for the remaining hours.

3.3Accuracy and Comparison of Actual and Simulated Results

The field measurement results were compared with that of the simulated results obtained from EnergyPlus™ to estimate the accuracy and ensure the quality of the obtained results. Table 1 shows a comparison of the minimum, maximum, and average results of both field measurements and EnergyPlus™ simulation over seven days.

TABLE 1
COMPARISON OF FIELD MEASUREMNT AND *ENERGYPLUS*™ SIMULATION RESULTS

No	Comparison between the two results	Maximum temperature	Minimum temperature	Average temperature
1	Field measurements	33.65°C	20.10°C	26.52°C
2	EnergyPlus™ simulation	33.10°C	20.56°C	26.13°C
∑	Level of Error %	0.55°C	0.46°C	0.38°C
3	Outdoor (External) Temperature	30.20°C	14.36°C	21.18°C

As seen in at Table 1, differences between the minimum, maximum, and average air-temperatures of the simulated and measured results were 0.46˚C, 0.55˚C, and 0.388˚C, respectively. The results show that the difference between the measured and simulated air temperatures did not exceed 0.55˚C. As there was no significant difference between the measured and simulated air-temperatures, it lends credibility and attests to the quality of the EnergyPlus™ simulation results. Therefore, the established medium-size mosque energy simulation model can be used as a decision-making tool during the design stage. Figure 5 presents a graphical comparison of the measured and simulated air-temperatures

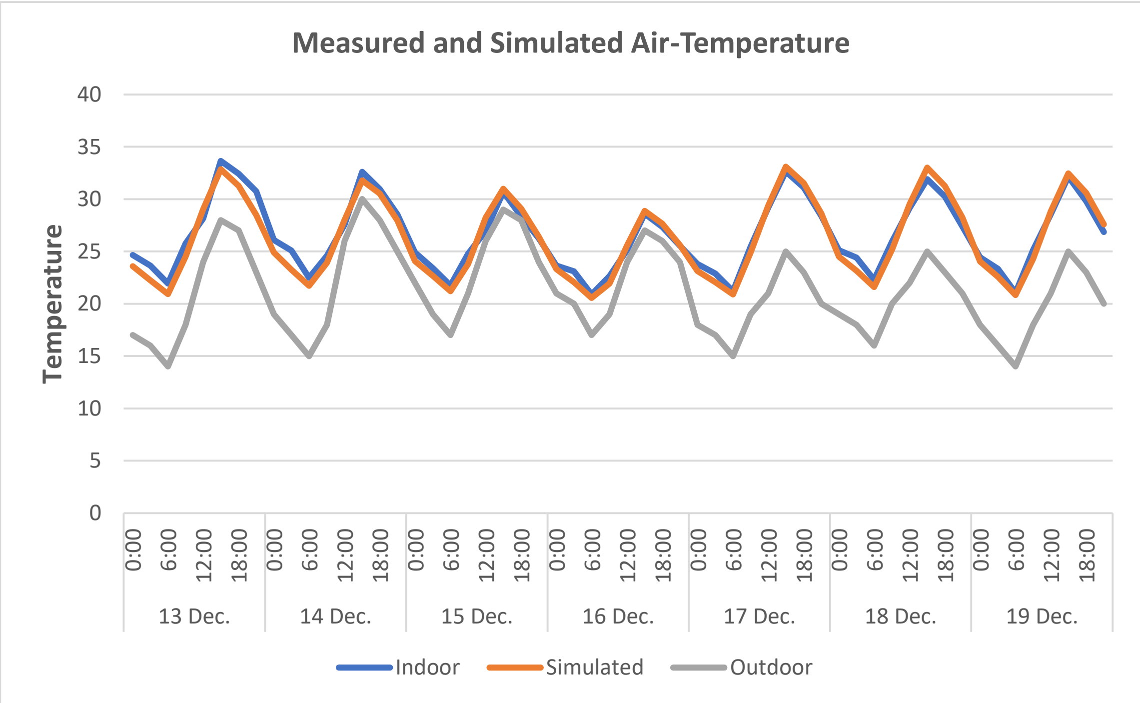

FIGURE 5
COMPARISON BETWEEN THE MEASURED AND SIMULATED AIR-TEMPERATURE

4.CONCLUSION

This paper mainly aims to develop a decision-making toolto assist designers during the design stage. The development of the tool is based on the results obtained from EnergyPlus™ software which required to be verified and validated before the implementation. In this context, the field measurement test was conducted to record the indoor air temperature of AlWalidayn Mosque and compare the results with the simulated one. The results from the comparison indicated thatthe difference between the measured and simulated air temperatures did not exceed 0.55˚C. As there was no significant difference between the measured and simulated air-temperatures, it lends credibility and attests to the quality of the EnergyPlus™ simulation results. As a result, the established medium-size mosque energy simulation model can be used as a decision-making tool during the design stage.

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