Evaluation of Thermal Conditions in a Secondary School Building in Middle East: A Comparison Study of Computed and Measured Conditions

S.Zahiri1,* and H.Altan1

[1]School of Architecture, The University of Sheffield,
Sheffield, UK

ABSTRACT
To improve the physical comfort and learning efficiency of the students in classrooms, it is important to evaluate the thermal conditions of indoor environments in school buildings. This paper presents a series of field studies conducted in a female secondary school in Tehran, Iran, by using physical measurements and computer modelling. The field studies assessed thermal conditions of two classrooms during lesson hours in the warm spring period of April/May for one week. The thermal comfort variables such as indoor air temperature and relative humidity were measured with the use of HOBO data loggers in various floors. The study also evaluates the thermal performance of the classrooms using an environmental analysis software package, which in this case is DesignBuilder (DB). The simulation tool has been used to assess the thermal performance of the classrooms in order to improve the indoor environments of the typical school building. Furthermore, a comparative analysis was performed on the result of field measurements and the building simulation modelling from the classrooms that were located on first and second floors. In the study, the differences between simulation predictions, field measurements and the parameters that caused uncertainty in simulation modelling have been analysed. In addition, the pros and cons of using the simulation tool have been discussed and the issues within the development of thermal simulation modelling have been further described. The study shows that the greatest difference in the results between the measurements and the simulation has been caused by the users' behaviour and the outside climate conditions. Converting the actual outside climatic data into the simulation tool has a significant influence on the accuracy of the simulation results compared to the average climatic data used in the simulation tool, which is provided by default. The findings indicate that DesignBuilder is a satisfactory simulation tool which can be used to perform building environmental simulation analysis.

KEYWORDS
Building simulation, Physical measurements, Indoor environment, Comfort analysis, School buildings

INTRODUCTION

Thermal condition in the classrooms has a great effect on the academic performance, comfort and attendance of the students in school buildings (CABE 2010). Therefore, improving the thermal conditions of the classrooms increases the physical comfort and learning ability of the students (Hoffman 2009). Recently school design in Iran has been improved enormously. However, climatic characteristic of the buildings and the comfort of the occupants have not been considered appropriately (Iravani 2010). The main reason is the lack of applicable environmental design guidelines for providing comfortable indoor environment in school

* Corresponding author email: sahar.zahiri@gmail.com

buildings. According to Central Bank of Iran (CBI 2009), more than 13 million students aged 6 to 18 studied in around one hundred and thirty thousand schools in Iran in 2008-09 (CBI 2009). These statistics show that there are many school buildings in Iran with the large numbers of students, which highlights the importance of examining the thermal conditions in school buildings. Evaluation of thermal conditions of the classrooms during the design process is necessary in order to provide comfortable indoor environments. This paper presents a series of field studies and simulation modelling in a female secondary school building in Iran. The thermal comfort variables such as indoor air temperature and relative humidity have been measured with HOBO data loggers. Thermal comfort is affected by four environmental factors including indoor air temperature, radiant temperature, relative humidity and air velocity. Beside environmental factors, two personal factors have an effect on thermal comfort of the occupants as well which are clothing insulation and metabolic heat rates. The personal factors were not considered in this study as they were the fix parameters during the field studies. Moreover, the influence of mean radiant temperature and mean indoor air temperature is nearly equal with light clothing and still air (Fanger 1970). As the field studies have been conducted during the warm spring period, the occupant worn light clothing and the air velocity was still based on the local weather station. Therefore, in this study the main concern was on the indoor air temperature and relative humidity only. In addition, thermal performance of the classrooms has been simulated using DesignBuilder, an environmental analysis software package. The main aim of the study is to evaluate the thermal performance of the classrooms during the lesson hours with DesignBuilder in the city of Tehran for one week in the warm spring period of 2010. Furthermore, the results of field measurement and simulation analysis have been compared and the accuracy of the simulation package using different weather data sets have been analysed.

Climate of Iran and the City of Tehran

Iran is a country located in the Middle East and extends between latitudes 25 °N and 40 °N and longitude 44 °E and 63 °E. The city of Tehran has hot and dry summers and cold winters. The annual precipitation is low and the average rainfall on the plain is around 200 mm (Kasmaei 1993). Figure 1 shows the hourly average temperature in Tehran. The graph shows that the maximum dry bulb temperature is around 40 °C in July and decreases to -3 °C in January. According to Climate Consultant 5 (Anon.), both temperature ranges in January and July do not fall within the comfort temperature which is between 21 °C and 27 °C. Climate Consultant 5 (Anon.) is a graphic-based computer programme that helps architects and designers to understand their local climate easier. In addition, the average annual relative humidity in Tehran is more than 60% in December and drops to 27% in July (Anon.).

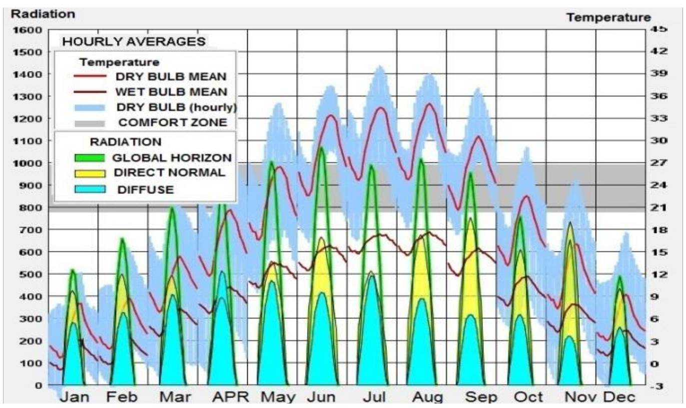

Figure 1. *(Anon.)*

RERSEARCH METHODS

This research is based on the assessment of indoor thermal condition in a female secondary school building in the city of Tehran using DesignBuilder, simulation software package. The reference case is a four storey building and the building's main facade is faced south. In order to evaluate the thermal condition of the classrooms in DesignBuilder, indoor air temperature and relative humidity of the classrooms were measured with HOBO data loggers. The field measurements and simulation modelling were performed in two classrooms with south facing. The Classroom 1 and the Classroom 2 are located on the first and second floors respectively (Figure 2). The simulation analysis has been performed to predict the thermal condition of the classrooms with some realistic input assumptions from the field studies in order to improve the indoor environments. The measurements assessed thermal conditions during the lesson hours from 7:30am till 1:00pm for the morning period and from 1:30pm to 5:00pm for the afternoon period. In order to assess the accuracy of DesignBuilder simulation tool, indoor air temperature and relative humidity of the classrooms were measured with HOBO loggers and the results were compared against the simulation results.

Figure 2. *Monitored building and the classroom*

Physical Measurement

In order to assess the thermal performance of the classrooms, thermal comfort variables such as indoor air temperature and relative humidity were being measured during the warm spring period of May 2010 for one week on the first and second floors. Indoor air temperature and relative humidity were measured continuously by HOBO data loggers which were located in front of the classrooms and at a height of 0.6 metres above the floor for seated occupants. HOBO loggers were gathering thermal characteristic of the building with the logging interval of 15 minutes. In addition, daily local weather data were also obtained from the local weather station reports. All measurements were undertaken without any cooling system operation and the classrooms were naturally ventilated during the field experiment. Table 1 shows the average indoor and outdoor temperature and relative humidity in classrooms 1 and 2.

Table 1. *The mean climatic variables in the classrooms located on the first and second floors measured with HOBO data loggers*.

Climatic Variables	*Classroom 1*	*Classroom 2*
Mean Indoor temp (℃)	24.36	24.55
Mean Indoor RH%	28.13	29.53
Outdoor temp (℃)	17.6	
Outdoor RH%	42.23	

The Simulation Modelling

To evaluate the current thermal condition of the classrooms, the school building was simulated in DesignBuilder using some realistic input assumption from the field studies. DesignBuilder is an environmental analysis software package used for simulating building energy consumption, lighting, comfort performance and CO_2 emissions in early stages of the design (Anon. A). DesignBuilder analyses the comfort performance of the building based on EnergyPlus data requirement. EnergyPlus (Anon. B) developed by the U.S Department of Energy (DOE) and is a building energy simulation programme for modelling building heating, cooling, lighting, ventilating, and other energy flows (Anon. A). One of the main aims of this paper is to evaluate DesignBuilder tool by comparing the output simulation result against measured climate variables by HOBO data loggers.

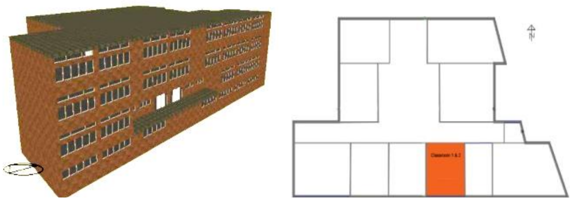

Figure 3. *Reference case model in DesignBuilder*

RESULTS

Filed Measurement

The building monitoring results for the classrooms located on the first and second floors have been collected with HOBO data loggers from 1st of May 2010 for one week. This week was selected for monitoring to represent the warm spring season before the school closure. In addition, outdoor temperature and relative humidity have been obtained from the nearest local weather station for the same period. Figures 4 and 5 present the result of the monitoring for the first week of May 2010. Classroom 1 and Classroom 2 are located on the first and second floors respectively. The graphs show that the air temperature in classrooms 1 and 2 has the same trend and the level of relative humidity in both classrooms is similar as well.

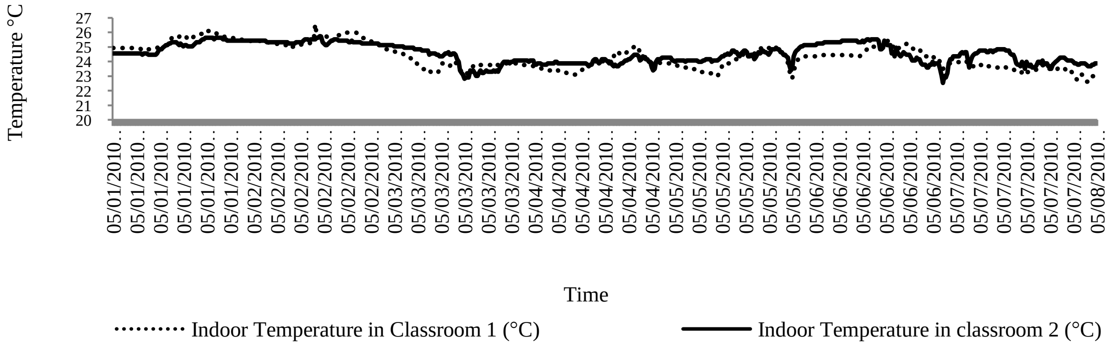

Figure 4. *Measured temperature profiles in classrooms 1 and 2*

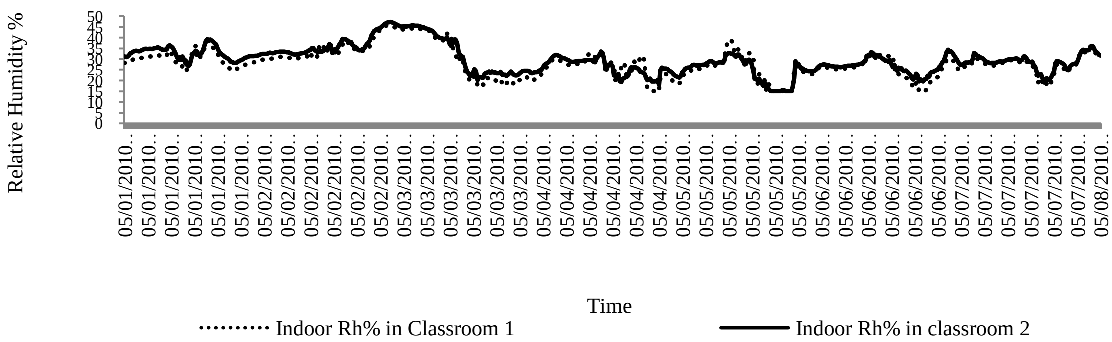

Figure 5. *Measured relative humidity profiles in classrooms 1 and 2*

Simulation Analysis

In the simulation modelling the main focus is on the classrooms 1 and 2 which are located on the first and second floors respectively. As for the climate data, the EPW file for Tehran from EnergyPlus was used as a base in DesignBuilder. In this study, both the average and the actual climatic data were used in the simulation modelling and the results were compared afterwards (Figures 6 and 7). The graphs illustrate that using the actual and the average weather data in the simulation tool make some changes on the result of the simulation.

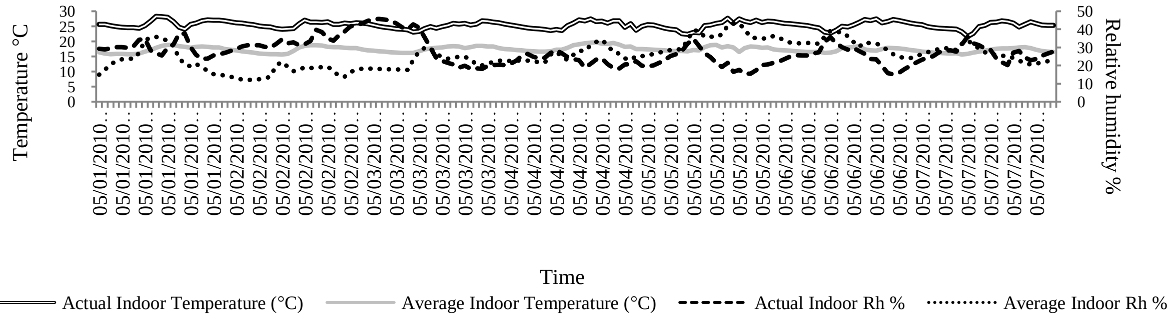

Figure 6. *Simulated temperature profile for a typical warm spring period in Classroom 1 using actual and average climatic data*

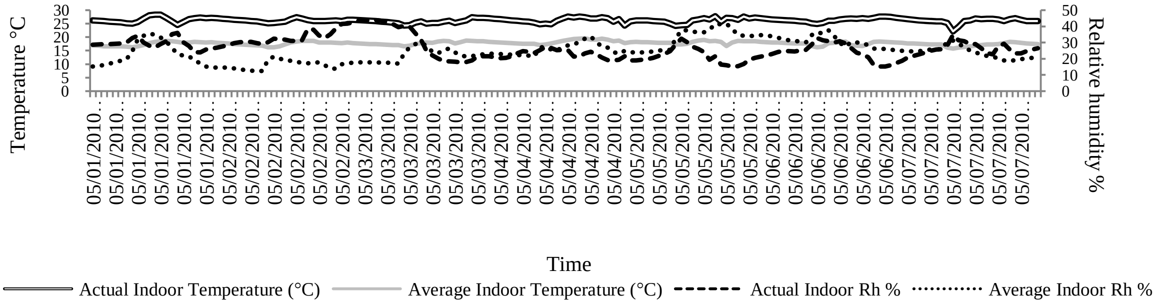

Figure 7. *Simulated temperature profile for a typical warm spring period in Classroom 2 using actual and average climatic data*

Moreover, for the base model, it was considered that the external windows are fully open and the internal doors are closed during the occupancy periods to represent the real situation of users' behaviour. In addition, all materials and construction details of the school building were applied to the simulation programme as well as the real weather data file for Tehran.

Comfort Condition

In this study, the thermal comfort analysis was based on the analysis of Climate Consultant 5 (Anon.) and ASHRAE Standard 55 (ASHRAE 2004).

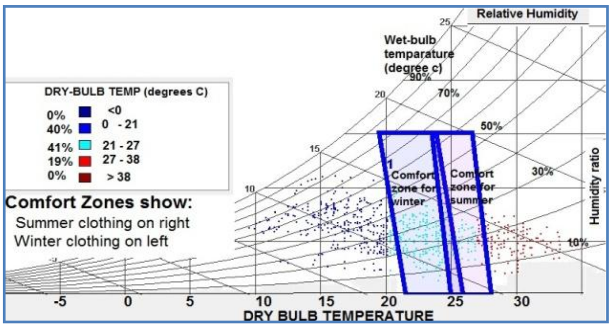

Figure 8. *Psychrometric chart in normal temperature for the city of Tehran (Anon.).*

According to Climate Consultant 5 (Anon.) which is based on ASHRAE Standard 55, the internal comfort zone in the city of Tehran with summer clothing is between 25 ℃ and 27 ℃ and with winter clothing is between 21 ℃ and 26 ℃ (Figure 8).

Evaluation of Simulation Modelling

To ensure the accuracy of the findings, the measured indoor air temperature and relative humidity by HOBO data loggers have been compared to interior temperature and relative humidity predicted by DesignBuilder using the actual weather data from the metrological records. Figure 9 and Figure 10 show the predicted temperature profile for the classrooms 1 and 2 for the reference case in DesignBuilder (DB).

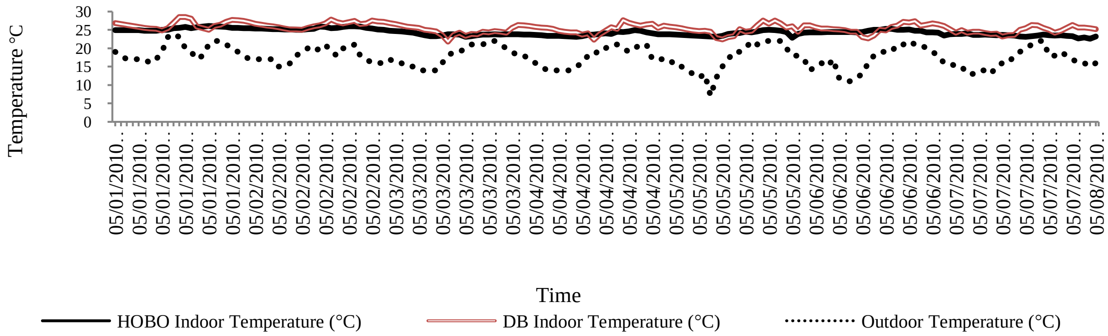

Figure 9. *Simulation results against measured results for Classroom 1*

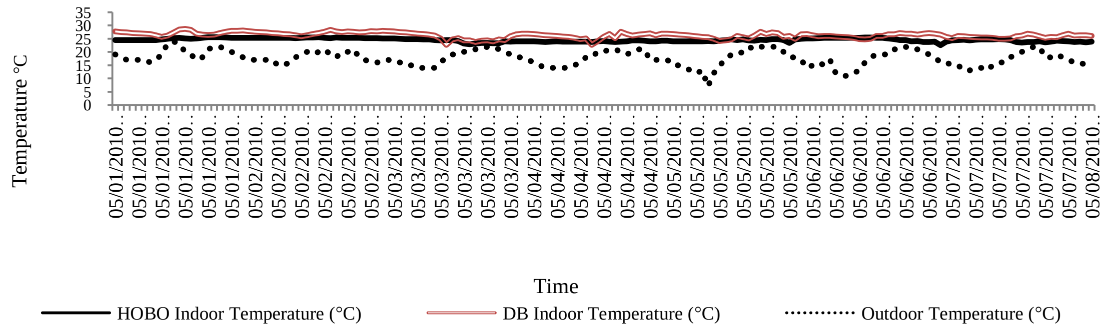

Figure 10. *Simulation results against measured results for Classroom 2*

In addition, the measured relative humidity for the classrooms 1 and 2 by HOBO data loggers has been compared to the simulation results to ensure the accuracy of DesignBuilder (Figures 11 and 12).

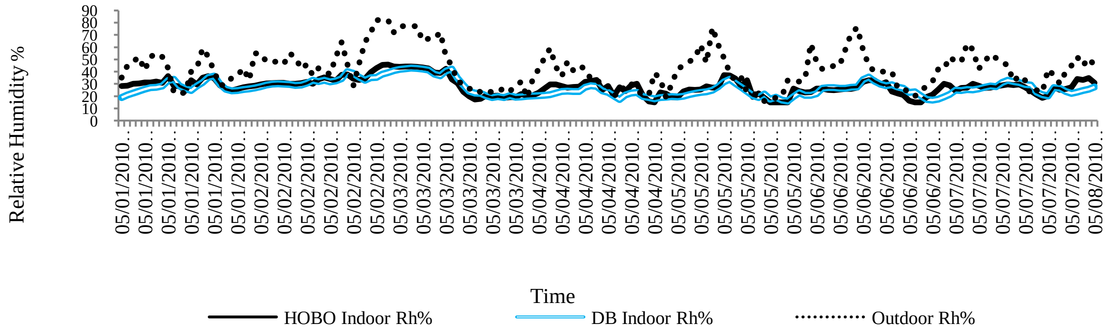

Figure 11. *Simulation results against measured results for Classroom 1*

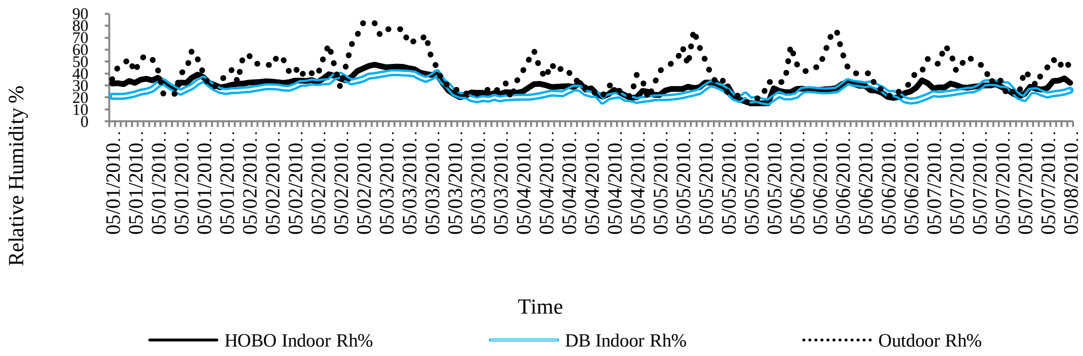

Figure 12. *Simulation results against measured results for Classroom 2*

Furthermore, a comparison was carried out to assess the agreement of the measured result with HOBO data loggers against the predicted simulation result by DesignBuilder (DB) from the classrooms 1 and 2 which are located on the first and second floors. The results show that the measured air temperature and relative humidity in both classrooms have a maximum 10% difference with the result of simulation modelling. However, the graphs show that the simulation results fluctuate more than the monitoring results.

DISCUSSION

Generally studying this type of building in Tehran using measured climatic data by HOBO data loggers and simulation result by DesignBuilder (DB) demonstrates that there is a difference between the result of the simulation tool and the measured indoor climatic variables. The building monitoring results demonstrate that indoor air temperature in Classroom 2 is slightly higher than Classroom 1 with 1% to 2% difference (Figure 4). One possible reason behind this is the roof insulation materials and its ability to store heat. As the classrooms were naturally ventilated during the field experiments and the average temperature in both classroom were around 24 ℃, the level of humidity in both classrooms were the same and the average was around 28% and even the slight changes in indoor air temperature in both classrooms did not have any effect on the level of humidity during the field studies.

Furthermore, the simulation results show that converting the actual outside climatic data into the simulation tool has a significant influence on the accuracy of the simulation results compared to the average climatic data used in the simulation tool, which is provided by default (Figures 6 and 7). The average climatic data has 30% difference with monitoring results in terms of relative humidity and has 20% difference in terms of air temperature. In addition, the study explains that during the field studies, the indoor air temperature in both classrooms was between 23 ℃ and 26 ℃ which falls inside the comfort zone with winter clothing. As the experiment was in the female secondary school building and the female students in Iran wear special uniform which includes head cover and a coat, for cultural and religious reasons, they may feel comfortable in the comfort zone with winter clothing although the summer comfort zone is between 25 ℃ and 27 ℃. However, as the temperature increases and reaches up to 27 ℃ and over, they may feel uncomfortable as they have to use the same uniform for all year around (Figure 8).

One of the main considerations of this study was the suitability of DesignBuilder for environmental simulation of the school building. By comparing the measured indoor air temperature with the simulation results using the actual weather data from the nearest weather station, it can be noticed that the simulation tool predicted the higher temperature range comparing to the measured temperature in both classrooms but the results have a satisfactory agreement with the maximum difference of 10% and there is no significant difference between them (Figures 9 and 10). Moreover, the comparison of measured relative humidity and the predicted relative humidity shows that they have a good agreement with a maximum difference of 10% as well (Figures 11 and 12) which confirm that the results from DesignBuilder is valid for the warm seasons for the naturally ventilated buildings in Tehran. One of the reasons that there were some small differences on the results of simulation and field measurements is the users' behaviour, as the occupants are able to manage the openings at any time. However, in the simulation tools only one option can be defined at any stage.

CONCLUSION

From this study, it can be concluded that DesignBuilder is a satisfactory simulation tool which can be used to perform building environmental simulation analysis in order to improve the thermal indoor quality for the school buildings in the city of Tehran. However, to get more accurate results, the actual weather data file needs to be used in DesignBuilder rather than the average climatic data. In addition, during the simulation process, it should be considered that the climatic data is variable for each year and the special limits need to be defined for various regions at early stages of the design. Moreover, studying the thermal behaviour of this building under Iranian climatic condition shows that the average temperature and relative humidity were in the comfort zone with winter clothing. As the female students use the special uniform all year around, because of the cultural and religious reasons, they may feel comfortable in lower comfort zone comparing to the one which is predicted by ASHRAE 55 (2004) in warm seasons, and it is important that the designers take this point into consideration for school buildings for females. Finally, using building simulation package helps designers to develop their designs at the early stages. Moreover, in order to create a low energy thermal environment for the school buildings in Tehran, it is important to consider the differences between the average and the actual weather data in the simulation modelling.

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