Thermal Performance of Female Secondary School Buildings in Tehran

With Particular Concern to Thermal Comfort and Passive Design Strategies

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Abstract

The quality of indoor environment has a great influence on the students' learning performance and ability to learn in indoor spaces. Due to a lack of appropriate environmental school design guidelines in Iran, it has historically been difficult to create comfortable and productive learning environments for the students. In order to develop school design guidelines, it is necessary to assess the current design methods used by the educational authorities in Iran and to examine the performance of existing schools. This research studies a female secondary school building in the city of Tehran. In recent years the quality of construction and school design in Iran has been improved significantly. However, most of the existing schools have been constructed without any concern for the comfort of the occupants and the adaptation to the local climate. The main reason is the lack of relevant design guidelines.

This thesis describes a series of field studies that used questionnaire surveys and field measurements conducted for two periods in the warm spring and cold winter seasons. The on-site monitoring assessed thermal conditions of six classrooms in each season. Moreover, around 460 students in 25 classrooms completed questionnaires covering their thermal sensations and thermal preferences in both seasons. Thermal comfort variables, such as indoor air temperature and relative humidity levels, were measured with HOBO data loggers in a total of twelve classrooms. A comparative analysis was performed on the result of field measurement and questionnaire surveys.

Moreover, the study also evaluated the thermal performance of the classrooms using a building simulation software package, DesignBuilder. The thermal simulation analysis were carried out by inputting actual data gathered from the field studies in order to examine and improve the indoor thermal environment in the typical school building based on the students' requirements and passive design strategies. Various passive design strategies were applied to the simulation software such as orientation, glazing, shading devices, thermal mass, insulation and ventilation. This starts from the basic school model, investigating the various strategies to predict the optimum conditions for the school building. The simulation results determined how to provide more comfortable classrooms for the students using passive design strategies and how to reduce energy loads of the building.

The result of the field studies indicate that most of the occupants found their thermal environment not to be comfortable during both seasons and the simulation results indicate that the building fabric and the thermal properties, as well as the glazing and ventilation, had a significant influence on the indoor temperature in the classrooms. Therefore, in order to create a high quality indoor environment and to increase the learning performance of the students, it is necessary to use the appropriate passive design strategies which also reduce the need for mechanical systems in the school buildings and therefore save energy.

Dedication

I dedicate this thesis to my father with love, who was a source of inspiration, support and encouragement throughout my life.

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Chapter 1: Introduction

1.1. Introduction

Climatic school design solutions can have a significant effect on reducing the long term impact of school buildings on the environment. It also improves the physical comfort of the students and reduces the buildings’ energy loads (Hoffman, 2009). To create comfortable and healthy indoor spaces in school buildings, the main subjects that need to be considered during a design process are temperature, humidity, lighting, ventilation and the thermal comfort of the occupants. Thermal conditions in classrooms affect not only health and comfort, but also students’ learning efficiency (CABE, 2010). Providing an acceptable indoor climate in a building with regards to passive design strategies is necessary in order to make it more comfortable for the occupants and also to control its energy consumption to make it more sustainable. Thermal comfort studies can help to frame sustainable design standards for buildings (Nicol and Humphrey, 2001). To provide a comfortable environment within a building, the use of mechanical means is generally acceptable in the modern world but it results in increasing energy consumption in buildings such as schools. School buildings are one of the major energy consumers in recent decades (Gorji-Mahlabani, 2002). Designers and architects need to develop methods for low energy architecture and to consider sustainability in their designs in order to conserve energy and provide comfortable indoor environment.

Current school buildings in Iran follow limited models of design which are mostly based on box and classroom based model. Some have been designed with respect to climatic conditions but unfortunately thermal comfort of the occupants has not been considered deeply, which results in reducing the students’ ability to learn. Moreover, due to the lack of appropriate climatic school design guidelines in Iran, it has historically been difficult to create comfortable and productive learning environments for students. In order to develop climatic school design guidelines, it is necessary to assess current design methods used by the educational authorities in Iran and to examine the thermal performance of existing schools.

In this research, a series of field studies were conducted that used questionnaire survey and field measurements in a female secondary school building in Tehran, Iran. Later, results of field studies and the characteristics of the typical school buildings in Tehran were incorporated into the simulation tools to investigate and improve the thermal performance and thermal condition in the secondary school buildings. Finally, a set of guidelines were suggested to provide comfortable conditions in the classrooms which helped to create healthier educational environments for students with the minimum energy loads in the building.

1.2. The scope of the research problem

In recent years the quality of construction and school design in Iran has improved significantly. However, most existing schools have been constructed without concern for the thermal comfort of the occupants in classrooms and energy use of the school building. The main reason for this is the lack of appropriate environmental school design guidelines in Iran in order to create comfortable and healthy environments with the minimum energy loads. Thermal comfort studies show that poor thermal environments in classrooms reduce students' productivity; thus a comfortable classroom will increase students' efficiency to study and also the application of environmental design will reduce energy consumption in school buildings, which has been increased recently.

Current school design in Iran has a box and classroom based model, which is a typical contemporary school design in the country. Also most of the school designs are poorly adapted to the climate of the regions in Iran, and little attention have been paid to modifying the thermal conditions of the schools, which results in increasing the energy loads of school buildings throughout the year. One of the key strategies to improving a school building's energy consumption with respect to students' thermal satisfaction is to use specific environmental design guidelines for each climatic region. By using suitable building materials, including thermal mass and thermal insulation with an appropriate thickness, the application of shading devices and appropriate glazing types, as well as considering the orientation of the building, the benefits of natural energy sources can be obtained and, as a result, the energy loads of school buildings reduced.

The experimental work in this study contains two parts: the field study and the application of building thermal simulation modelling. The field study consists of measurements of climatic variables and a questionnaire based survey concerning the students' thermal satisfaction. The aim of this part was to identify the thermal condition and thermal satisfaction levels in the classrooms. However, by performing the simulation modelling with the application of passive design strategies, the appropriate environmental design guidelines were produced for female school buildings in Tehran, with respect to their thermal satisfaction.

According to the annual report of the Central Bank of Iran (CBI, 2009), the total number of students aged 6 to 18 was 13,512 thousand in 2008-09 and 135,453 schools had been built in Iran since 1979. These statistics indicates that there are many school buildings in Iran with a large number of students, which shows the importance of conducting a thermal comfort study and producing a set of environmental design guidelines for Iranian schools.

1.3. Significance of the research

In order to maximise students' ability to learn in a healthy environment, as well as reducing energy consumption of school buildings in Iran, there is a need to have some referable guidelines for climatic school design. This research presents the results of field experiments and computer simulations on thermal comfort and thermal condition in a female secondary school building's classrooms in the city of Tehran. On the basis of findings and evidence, a set of guidelines for climatic design of the secondary school building is introduced in hot dry climate of Tehran. A typical school building has been chosen in the city of Tehran as the case study because Tehran is one of the biggest cities in Iran, with a hot-dry climate; and compared to the other cities it has the largest percentage of students in its population. As most of the climatic regions of Iran have a hot climate the results and outcome of this research can be applicable to any schools located in similar regions.

1.4. Research questions

This research tried to fulfil the overall aims and objectives through answering the following fundamental questions:

- Do indoor air temperatures match female students' thermal requirements in classrooms during warm and cold seasons in the city of Tehran?
- What are the female students' thermal sensations and thermal preferences in the classrooms in Tehran?
- What is the preferred temperature in the classrooms of the female secondary school buildings in warm and cold seasons in Tehran?
- To what extend can passive design strategies' enhance thermal performance and thermal conditions in the selected female secondary school in Tehran with regards to the female students' thermal satisfaction?

1.5. Research hypothesis

Passive design strategies can improve the thermal performance of female secondary school buildings in Tehran with regards to students' thermal satisfaction and preferences. The level of thermal comfort in female school buildings is different when compared to other type of buildings. Climatic school design can reduce the long term impact of school buildings on the environment, not only by reducing the energy use in the building but also, as a result, increasing the students' ability to learn.

1.6. Aim and objectives

The aim of this study is to improve the thermal performance of the female secondary school buildings with a particular focus on passive design strategies and the students' indoor thermal satisfaction in their classrooms in the city of Tehran. This will be achieved through the following objectives:

- To investigate the indoor thermal condition of the classrooms and thermal preferences of the students during the lesson hours in the warm spring period and the winter season.

- To incorporate field study results into the building simulation tool to examine the impact of passive design strategies on indoor air temperature, aiming to enhance the thermal behaviour of the school buildings in Tehran.

- To establish school design guidelines for designers and architects based on passive design strategies and to make recommendation for future school design in Tehran. The design guidelines can then be used to provide low energy comfortable learning environments for female secondary school buildings in the climatic region of Tehran.

1.7. Methodology

In order to achieve the aim, and fulfil the research objectives, this study was structured in several parts, including a literature review; a field study and the thermal simulation part and school design guidelines. These studies are summarised in the following main steps:

- A literature review is given in chapters' two to four. The studies were concerning the educational system of Iran, current school design and building guidelines in Iran and the city of Tehran, as well as the climatic characteristics of the country, which are described in Chapter 2. Later, thermal comfort and related studies in school buildings are considered in Chapter 3 of the thesis. A literature survey was also performed on passive design strategies in Chapter 4 to explore the appropriate climatic design for the school building in Tehran.

- A series of field studies that used on-site measurements and a questionnaire based survey were conducted in a female secondary school building in the city of Tehran, in Iran which are described in chapters 5 and 6 respectively. The field studies was performed during the spring and winter seasons (warm and cold seasons) assessing the thermal conditions of classrooms. Approximately 460 students in 25 classrooms completed questionnaires while thermal comfort variables, such as indoor air temperature and relative humidity levels, were measured with HOBO data loggers.
- A comparative analysis was performed on the result of the field studies from the classrooms, which were located on the first and second floors, facing north and south sides of the school. The results from

the field measurement are compared to the results of the questionnaire survey which are explained in chapters 5 and 6.

- An evaluation stage is carried out in Chapter 7, based on thermal simulation and modelling using DesignBuilder, the building thermal simulation package, to evaluate the current thermal performance of school building by incorporating field studies data. First the building simulation tool and the weather data which were used in the simulation analysis have been examined and validated by comparative analysis between the field measurement result and the simulation result using climatic information obtained from the meteorological organisations as well as on-site monitoring results.
- A study further investigated how to improve thermal performance and thermal conditions in classrooms in order to create more comfortable learning environments for students by carrying out assessments based on passive design strategies and the students' thermal sensations and thermal preferences, which is demonstrated in Chapter 8. Finally, environmental design guidelines were produced for future schools, based on the result of this study, which are summarised in Chapter 9. Chapter 10 is the conclusion to this thesis.

The following diagram (see Figure 1.1) summarises the outline for the research methodology by referring to the thesis' chapters:

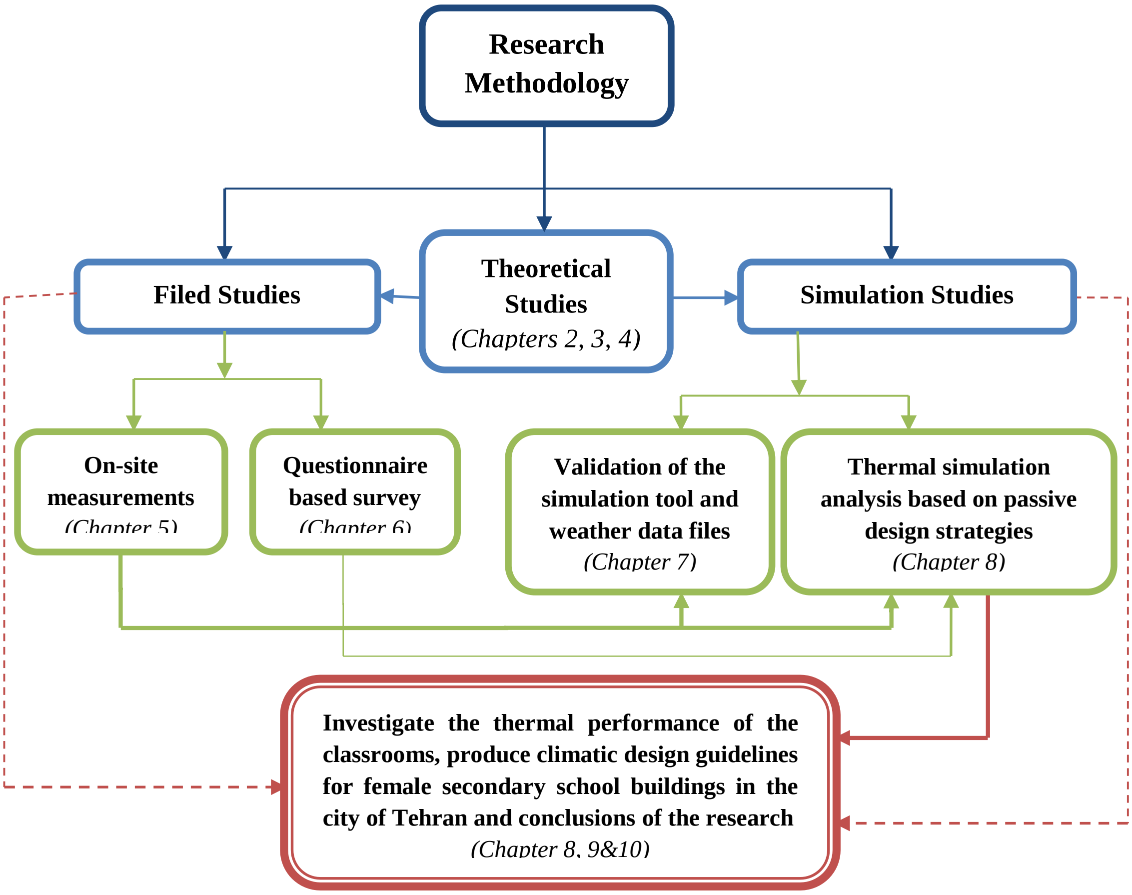


Figure 1. 1: Research methodology

1.8. Thesis structure

This thesis was organised into nine chapters, which are described as follows:

- Chapter 2 reviews school design in Iran and describes the climate and geography of Iran and the city of Tehran.
- Chapter 3 provides an introduction into thermal comfort and gives a literature survey on thermal comfort studies in school buildings in various climatic regions.
- Chapter 4 addresses the passive design strategies which will verify the parameters used in the simulation analysis.
- Chapter 5 explains the on-site monitoring of climatic variables in the case study secondary school building during the warm spring period and cold winter season.
- Chapter 6 describes the questionnaire based survey which was conducted in spring and winter seasons in the selected female secondary school building.
- Chapter 7 investigates the validation of the building simulation package and the weather data which can be used in the thermal simulation analysis in this study.
- Chapter 8 presents the thermal simulation analysis based on passive design strategies and discusses the results with regards to the students' thermal comfort sensations and preferences in the case study building in Tehran.
- Chapter 9 presents the environmental design guidelines for the female secondary school buildings in the city of Tehran.
- Chapter 10 provides conclusions to the study and recommendations for climatic secondary school building design in the city of Tehran based on female students' thermal satisfactions.

Chapter 2: School Buildings and the Climate in Iran

2.1. Introduction

In this chapter the educational system, teaching methods and school population as well as school design principles in Iran were identified to get a background for creating a healthy and comfortable learning environment for Iranian students. Building energy regulations and construction materials in Iran were investigated, in addition to the building characteristics in masonry buildings, as most of the school buildings in Iran have a masonry construction (Mahdizadeh, 2011). This chapter also gives an introduction to the environmental and sustainable school design in the UK as there are many useful guidelines on school building design that are extensive and can be changed to meet individual requirements for a particular design. The climate and geography of Iran were studied in this chapter also and the climatic characteristic of the city of Tehran were reviewed, in order to be incorporated into the field studies and simulation analysis, which are discussed in chapters 5 to 8.

2.2. Structure of education and teaching methods in Iranian schools

The educational system in Iran has changed a lot over the years. Currently, the Iranian educational system is controlled by three ministries including Ministry of Education and Training, Ministry of Science, Research and Technology and Medical academic. Each organisation has a separate responsibility. The Ministry of Education and Training is responsible for the school system and training of children aged below 18. It also manages all issues related to schools, pupils, teachers and staffs. However, the higher education system in Iran is administrated by the Ministry of Science, Research and Technology and the Ministry of Health and Medicine Education. The educational system of Iranian schools is under the authority of the Ministry of Education. The structure of education in Iranian schools is divided into five levels (see Table 2.1).

Table 2.1: Five levels of the educational system of Iranian schools

Age	Level of education	Duration
5-6	Pre-elementary school	1
6-11	Elementary school	5
11-14	Middle school	3
14-17	Secondary school	3
17-18	Pre-university school	1

One of the important features of the Iranian educational system in schools is that boys' and girls' education is completely separated and they split into single sex schools. However, they need parallel facilities, administration and the same instruction. Teaching methods and curriculum in Iran are based on a class group organisation which distinguishes students' by age group. Each classroom normally accommodates around 30 to 40 students (Ai, 2009). Teaching methods in Iran have developed over the years but traditional western methods of education are still the basis of Iranian education (Gorji-

Mahlabani, 2002) and have been adapted since 1851 (Zamiri, 1992). The method of education in Iran is dependent on the theory that children are more or less ambivalent and inactive toward education and it is generally teacher-centred. Teaching in schools is a matter of direction, compulsion and restraint (Gorji-Mahlabani, 2002). Nevertheless, recently attempts have been made to change educational approaches in Iran. The aim is to incorporate more student-centred approaches based on western examples (Ai, 2009).

2.3. School population in Iran

In order to design school buildings, it is necessary to study the school population and the population growth rate. The population of Iran has increased sharply, especially in the last century. After the Islamic revolution in 1979, Iran's population grew rapidly, with a 3.8% annual average population growth rate. It passed from 36 million to 66 million from 1979 until 2000 and 42.5% of this population was aged between 0 and 18 years old (Gorji-Mahlabani, 2002). According to Iran statistical centre (2011), Iran's population was over 75 million in 2010 and 26% of this population was aged between 0 to14 years old (UNESCO, 2010). The large percentage of population who were young shows the responsibility of the government to provide good facilities, including schooling, for these young people. According to the annual report of Central Bank of Iran (CBI, 2011), the total number of students aged 6 to18 were 13,234 thousand in 2011-12. The following statistic shows that there were a large number of students in school building in Iran during this period. It is obvious that the quality of these schools needs to be considered in order to provide healthy and comfortable study spaces for students. Table 2.2 presents the number of students in schools in Iran from 2007-08 to 2011-12.

Table 2.2: Numbers of students in Iran from 2007 to 2012 (CBI, 2011)

School types	**Number of students** (thousand persons)				
	Academic year				
	2007-08	**2008-09**	**2009-10**	**2010-11**	**2011-12**
Nursery schools	511	456	452	464	405
Elementary schools	5,726	5,655	5,592	5,633	5,702
Middle schools	3,708	3,478	3,292	3,245	3,228
Secondary schools	2,832	2,782	2,563	2,364	2,273
Pre-university centres	439	447	411	435	441
Others [1]	1,219	1,115	1,099	1,210	1,186
Total	14,435	13,968	13,408	13,352	13,234

In addition, around 1.1 million of the students were studying in private schools in 2011-12 (Nosazi Madares, 2013b), around 9% of the overall number of students.

---

[1] Others include adult students in primary schools, junior secondary schools, secondary schools and pre-university centres.

2.4. School building stock in Iran

According to the Central Bank of Iran (CBI, 2011), there are more than 112,500 schools in Iran, from nursery schools to pre-university schools, including around 545,000 classrooms in 2011-12 (see Table 2.3). Also the indices of educational quality in Iran are stated in the annual report (see Table 2.4) produced by Central Bank of Iran (CBI, 2011). It presents that the number of students to school building was around 113 and the number of students to classrooms was around 23 in 2011-12 (see Table 2.4). The following statistic shows that there are many school buildings in Iran with a large number of students. The numbers of the students, school buildings and classrooms in Iran (see Table 2.2 and 2.3) show that the average numbers of the students in each classroom is around 23. Also there are approximately 54 million square metres of school land in Iran. This covers 112,568 schools with around 13 million students and, as a result, the average educational space for each student is around 4 square metres per head.

Table 2.3: Numbers of schools, classrooms and teaching staff in Iran (CBI, 2011)

Number of schools, classrooms and teaching staff					
Academic year	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
Number of schools	141,265	135,453	126,981	130,100	112,568
Number of classrooms	624,628	597,528	575,090	568,609	544,596
Teaching staffs (person)	847,466	807,600	754,710	825,333	847,771

Table 2.4: Indices of educational quality in Iran (CBI, 2011)

Indices of educational quality					
Academic year	**2007-08**	**2008-09**	**2009-10**	**2010-11**	**2011-12**
Student to school	98.9	100.1	102.7	98.8	113.4
Student to classroom	22.4	22.7	22.7	22.6	23.4

Moreover, considerable numbers of school buildings are in use in the city of Tehran, the capital of Iran. Based on Ministry of Education of Iran (2014), just over 1.8 million students are studying in around 5000 schools in Tehran. Around 1,000 of the schools are private and non- public schools, with around 85,000 students (Iusnews, 2014, Teo, 2010). These statistics show that there are significant numbers of students as well as school buildings in Tehran and around 13% of the students in Iran are studying in around 5% of the school buildings in the city of Tehran. This indicates that in many cases the school buildings in Tehran might be overcrowded. It should be mentioned that, in 2012 each students had 3.5 square metres per head study area (Nosazi Madares, 2013a). However, it has increased to 4.3 square metres per head recently.

In this study, the field studies were conducted in a female secondary school building in the city of Tehran, Iran. The case study was chosen to be in Tehran as it is the capital of Iran and has the largest number of the students and school buildings comparing to the other cities in Iran (CBI, 2011). Also 13% of the school buildings in Tehran, covering around a 2 million square metres area, need refurbishment and renovation, as they have the old construction (Nosazi Madares, 2013a). The result of this study can be used in similar school buildings in Tehran. Figure 2.1 shows the year of construction of school buildings in Tehran. It can be seen that most schools were constructed between 20 and 45 years ago, but the number of newly built schools has grown in recent years (Panahi et al., 2013). In addition, the case study school building represents a typical school building in Iran in terms of structure, design type and the average number of the students in the classroom, which are around 23. The school building has a masonry structure and 90% of the school buildings in Iran have a masonry structure ((Mahdizadeh, 2011) as explained in detail in section 2.10. The rest of the school buildings have steel and concrete structures. Also the school design has a box and classroom based model, which is a typical contemporary school design in Iran (Iravani, 2010b, Iravani, 2010a) and explained in detail in section 2.5. In the case study school building the average study space for each student was 1.1 square metres per head in each classroom.

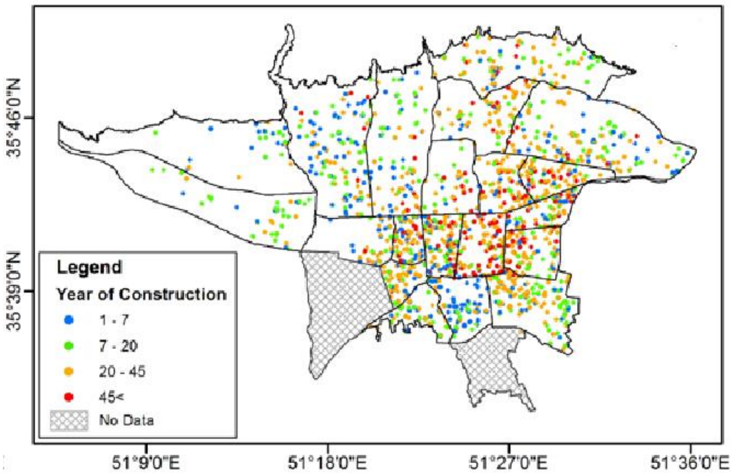


Figure 2. 1: School buildings year of construction in Tehran (Panahi et al., 2013)

Performing a thermal comfort survey is one of the objectives of the study and the focus is on the secondary school female students aged between 15 to 18 years old, as they can easily understand their thermal sensations and preferences compared to the smaller age group, and have less difficulty in answering the questionnaires. Also Tehran has a hot and dry climate like most regions of Iran (Kasmai, 1993) and the result of this study will be representative of similar climatic regions in further studies. The only restriction in this study was the choice of the subjects. Because of the religious ground in Iran, boys and girls go to the separate schools and female students need to wear special uniforms and they also cover their hair with a scarf. Wearing the special uniform and headwear makes the female students' have different sensations of comfort compared to the male students, which might affect the comfort zone in the school buildings for girls.

2.5. School Design in Iran

Based on Iravani (2010a), most of current school designs in Iran follow limited models of design which are mostly based on the box model and the classroom based model. Some of these schools have been designed with respect to climatic design but unfortunately the thermal comfort of the occupants has not been considered enough during the design process, which might result in reducing the students' efficiency and ability to learn. These models have had an effect on Iranian school design for over a hundred years, without regard to changes in education philosophy (see Figure 2.2).

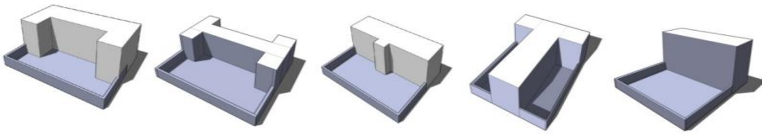


Figure 2.2: Box and classroom based model structures (Iravani, 2010a)

In recent years the variety of material and the quality of constructions has increased significantly. The structure and design of schools is better than in the past. However, most have nevertheless been constructed without paying attention to climatic design and thermal comfort of students in classrooms. Currently, around 13 million Iranian students spend the most critical years of their lives in schools (Iravani, 2010a). Because of this large number of students, it is necessary to consider the quality of the school designs in order to create comfortable learning spaces and increase students' efficiency and ability to learn in classrooms. Iranian school architecture and the concept of educational spaces have been divided into two main categories: traditional architecture and contemporary architecture. Most current school designs are based on contemporary models rather than traditional ones, although the traditional architecture of school buildings was more sustainable and most traditional educational buildings were built with regard to the climatic design of its region (Ghaffari, 1998).

2.5.1. Traditional school design in Iran

In the past the architectural principles of school buildings were different and mostly depended on the traditional culture and architecture of Iran. Climate and people's lifestyles influenced the design and construction of school buildings and structures. Most schools had the same structure, techniques and even decoration with regards to the site location and environmental and climatic features of its region, which displayed great variety, both structurally and aesthetically. The most significant feature of architecture in many of these schools is the focus on interior space as opposed to the outside and rectangular units of classrooms, which are typically organised around an inner courtyard. The open-air interior courtyard performs an important function as a modifier of climate in hot dry regions. Moreover, the courtyard allows for outdoor activities with protection from wind and sun. The buildings usually have a single entrance (Ghiasvand et al., 2008). Figure 2.3 shows some examples of traditional school building models in Iran.

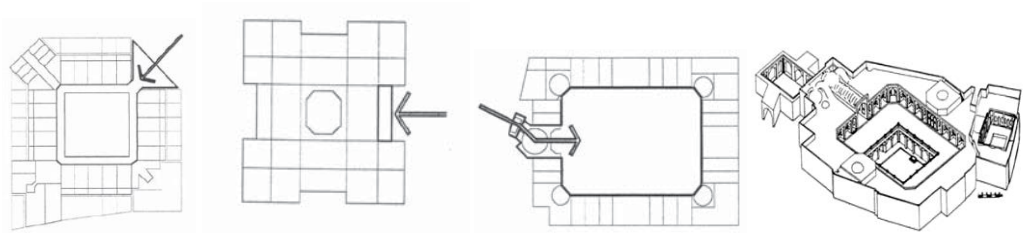


Figure 2.3: Example of traditional school models in Iran (Ghaffari, 1998)

Another characteristic of traditional school buildings in Iran was that residential spaces were supplied to students within the school buildings. Furthermore, Ivan (balcony), Courtyard and the chambers were training places. Chambers provided enclosed spaces and the Ivan provided semi-opened spaces, but the courtyard was the only place which provided open spaces at the heart of buildings and is related to the hot and dry climatic condition of the region, being used to protect occupants from high temperatures and providing comfortable area for them (Iravani, 2010b).

2.5.2. Contemporary school design in Iran

According to Irvani (2010b), the changes in the traditional educational system in Iran caused many changes in educational buildings structures and architecture, from 150 years ago. Since then most schools have been planned and designed on a classroom-based model, with a series of classrooms along one or both sides of the corridors. In 1975, an institution called State Organisation of Schools Renovation, Development and Mobilisation was established in Iran. The main aims of this organisation were designing schools, providing excellent educational spaces and improving educational standards based on the needs of students as well as adapting the learning environments with the new training methods. However, the climatic conditions and the architectural style of the areas have been ignored in many of these school designs. They have the same shape in different climatic regions and all are classroom-based models. Figure 2.4 presents a typical plan for school buildings in Iran, which is the cells and bells model. This model is suitable for controlling students in the corridors. In this kind of school there is no semi-open space, like a balcony. All activities are performed in the classrooms, labs and sports halls (Iravani, 2010b).

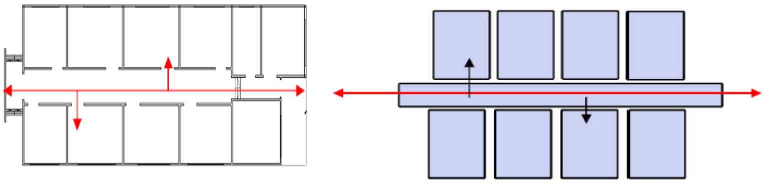


Figure 2.4: Samples of classroom-based models of school buildings in Iran (Iravani, 2010b)

Figures 2.5 to 2.12 show two examples of newly built school buildings by the State Organisation of Schools Renovation, Development and Mobilisation. Both schools are steel framed and located in Tehran, with its hot-dry climate. They have central heating systems and their cooling system employs water-based coolers. The first school is a four storey secondary school building with 20 classrooms, named Beheshti School. The main materials that have been used for its Facade are brick and stone. It has brick walls and aluminium framed double glazed windows. The following figures illustrate a typical plan of the school building and some views from inside and outside of the building:

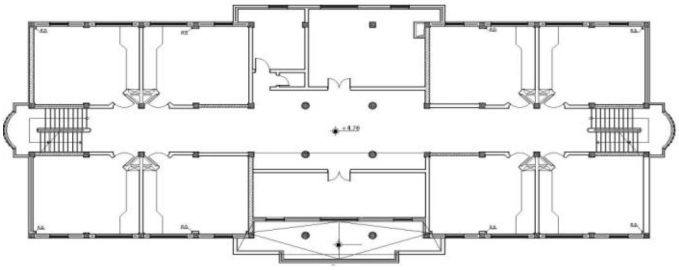


Figure 2.5: Typical plan of Beheshti school building in Tehran (Nosazi madares, 2010)

Figure 2 6: South elevation of Beheshti School

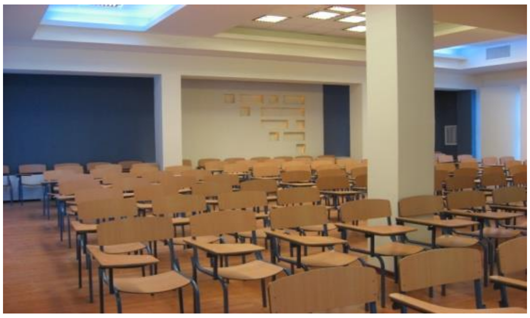


Figure 2.7: Assembly hall of Beheshti School

Figure 2.8: Main Corridor of Beheshti School

The second school is a four storey middle school with 12 classrooms called Zeinab School. The main material used for its Facade is stone. It has brick walls and UPVC framed single glazed windows. The doors also have steel and wooden frames. However, the school has a different model from typical school plans in Tehran. The following figures present some images from the school building:

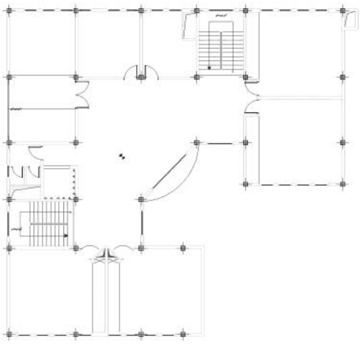


Figure 2.9: A typical floor plan of Zeinab (Nosazi madares, 2010)

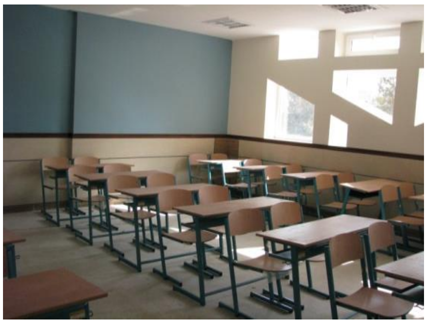


Figure 2.10: A typical classroom of Zeinab Scho

Figure 2.11: Main corridor of Zeinab School

Figure 2.12: South façade of Zeinab School

According to Irvani (2010a), while historical and cultural changes result in changing Iranian school design from traditional concepts, no significant improvement has been made in school buildings to make better educational spaces. Although some of the schools have progressed in models and shapes, the age of students has never been considered in the school design. In addition, the school buildings have been constructed without thinking that school design should be based on children's requirements and mental aspects in order to create more active study spaces (Iravani, 2010a).

2.6. The current principles of climatic design for Iranian schools

Considering the climatic conditions in building design is essential, especially for school buildings, because children spend most of their critical years in this environment. Climatic design is important because it increases the quality of comfort and health in indoor spaces and also leads to lower energy bills. Educational buildings are usually occupied during the day, so considering climatic design strategies in those buildings and using the beneficial elements of nature, such as sun, wind, earth, air temperature, plants and moisture, helps to create healthier and more energy efficient school buildings (Watson, 1983). According to Ghazizadeh (1993), school building design in Iran has not been considered seriously in the last decades and there was no complete source of design guidelines for Iranian schools. He added that, although limited studies had been undertaken and some guidelines suggested, there was still a lack of practical resources, especially for the climatic design of buildings appropriate for Iranian schools (Ghazizadeh, 1993).

In addition, the design of school buildings has a considerable impact on energy usage in school buildings. Considering the climatic design features based on the climatic regions of the school building can have a significant influence on the energy use of the school building and can have economic benefits as well. Energy demand in schools can be considerably decreased by improving thermal insulation, air-tightness, using the maximum amount of natural light and using passive design strategies (DCSF, 2008). There are some guidelines for climatic school design in Iran but these guidelines needs to be updated and modified, as they are general, and the students' thermal satisfaction from the indoor environment is not considered in the previous guidelines. Kasmai (1994) has conducted a series of research studies in school buildings in different regions of Iran on the impact of different climatic conditions on Iranian schools designs. He reviewed available documents on the thermal performance of school buildings, as well as climatic features, such as temperature and humidity, in order to divide educational buildings into different types in different regions. He provided some instructions for school design in different regions of Iran and presented a climatic zoning map for school buildings (see Figure 2.13).

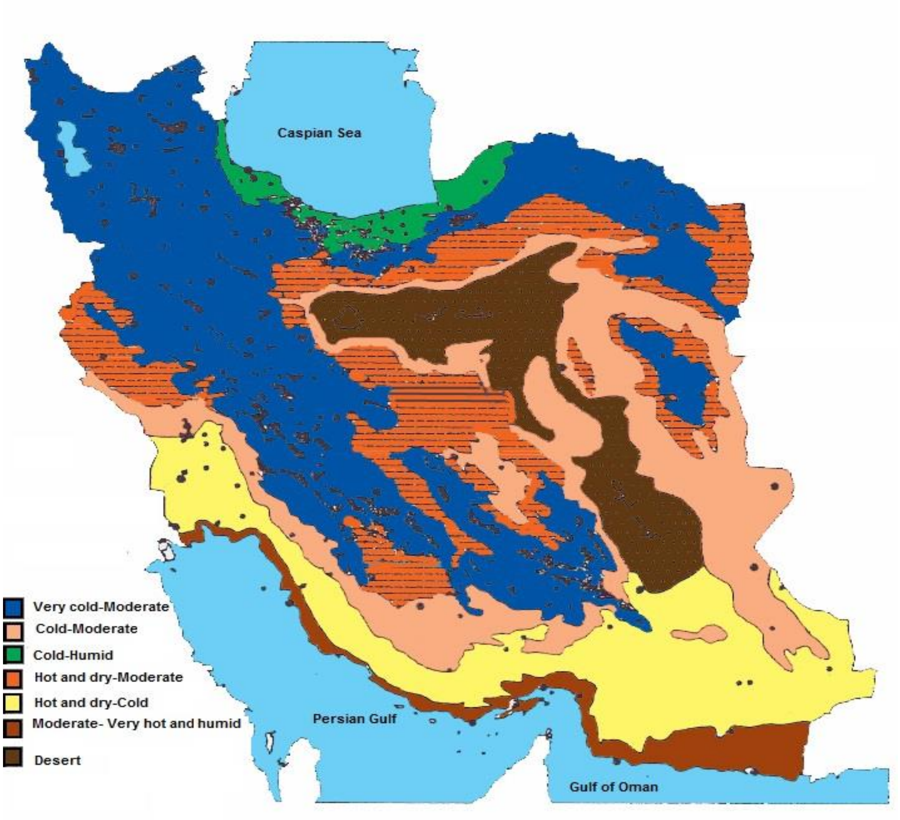


Figure 2.13: Climatic classification of Iran according to school building types (Kasmai, 1994)

He divided Iran into the following six climatic regions:

- Very cold and moderate
- Cold and moderate
- Cold and humid
- Very hot-dry and moderate
- Hot-dry and cold
- Very hot-humid and moderate (see Figure 2.13)

The study included 201 Meteorological stations in different regions of Iran. The meteorological data from these stations were used to predict the air temperature within classrooms of various sizes, shape, and location and with different openings, in school buildings from primary to pre-university levels. In order to predict the indoor air temperature of various classrooms, the indoor heating load including metabolic heat, solar radiation and the mean radiant temperature were considered by the software used to define the indoor air temperature. The input data that was used contained all the physical dimensions of the classrooms as well as the hourly ambient air temperature and solar radiation in 24 different geographical orientations. To examine the accuracy of the program's output, the ambient and indoor air temperature of 108 different classrooms in four schools from two different cities were recorded in periods when schools' heating facilities were not in use. As a result of this analysis, and with a comparison of indoor thermal conditions of different classrooms, 201 populated areas of the country were grouped into 31 groups within 6 zones. The geographical boundaries of these 6 climatic zones were plotted on the geographical map of Iran for school buildings (see Figure 2.13). Based on the results of the study, thermal conditions in classrooms during the academic year were predicted. Also, school design guidelines, including building orientation, plan organization and layout, size of fenestration, size of desired shading devices and building materials were defined for various regions of Iran for educational buildings based on the climatic design standards for various regions; and the summary is presented in Table 2.5.

Table 2.5: Summary of climatic Iranian school design guidelines (Kasmai, 1994)

Climate group	Climatic features	Building orientation	Materials	Window size
Very cold and moderate	• Maximise solar gain • Minimise mechanical heat gain	Orient south-east to maximise exposure to winter sun.	Use materials with appropriate insulation for exterior walls and roof with dark colours	30% of exterior building surface area
Cold and moderate	• Minimise mechanical heat gain • Avoid overheating in classrooms during warm seasons	Orient south-east to maximise exposure to winter sun	Use materials with appropriate insulation for exterior walls and roof	30-60% of exterior building surface area
Cold and humid	• Protect buildings against rainfall • Use natural ventilation in warm season • Avoid heat loss in cold seasons	Orient south-east to south west to maximise exposure to summer breezes in warm seasons and minimise winter wind turbulence	Use materials for roofs and exterior walls that are resistant to humidity and rain	40% of exterior building surface area
Very hot-dry and moderate	• Minimise mechanical cooling and heating	Orient south-east to maximise exposure to winter sun and minimise summer sun	Use high-capacitance materials for exterior walls and roofs to store solar heat gain in cold seasons	30% of exterior building surface area
Hot-dry and cold	• Avoid overheating in classrooms in most of the months	Orient north or south east to minimise summer sun	Use high-capacitance materials to store solar heat gain in cold seasons	30% of exterior building surface area
Very hot-humid and moderate	• Avoid overheating in classrooms • Minimise humidity level in classrooms	Orient north to minimise summer sun and maximise summer breezes	Use high-capacitance materials to store solar heat gain in cold seasons	45% of exterior building surface area

However, these guidelines are general and only useful to get the overview of the environmental designs of Iranian schools and need to be improved and updated, as the research on which it is based was conducted 20 years ago and the average climatic data of the cities has changed since then (Irimo, 2013). Also the thermal satisfaction of the students was not considered during these studies which would have helped to create a comfortable study space based on the students' thermal needs. In order to create environmentally wise buildings, more specific data are needed, such as a categorisation of materials for construction, occupancy period and students' thermal perceptions during teaching hours. It will also be useful to know the appropriate cooling and heating systems that are more sustainable. Table 2.5 summarises Kasmai's findings (1994) in different regions of Iran.

This research, then, attempts to update the mentioned climatic school design guidelines, based on recent outdoor climatic data, measured indoor climatic data, students' thermal satisfaction and typical school building construction data, as well as occupancy through undertaking field studies, including a thermal comfort survey and measurements of climatic variables in a secondary school building in the city of Tehran. As mentioned previously, the case study school building is of a female secondary school in Tehran which has a typical construction and design, as well as having the average classroom occupancy in Iran. Also the school is located in the city of Tehran, near local weather station in Mehrabad airport, which has a hot and dry climate.

Later the result of the field measurements is incorporated in the building thermal simulation software in order to evaluate the software and weather data. Afterwards, various passive design strategies, which are reviewed in Chapter 4, are applied to the simulation software including orientation, solar shading devices, glazing, thermal mass and cavity external walls, as well as wall and roof insulation and their effect on indoor air temperatures in order to identify optimal solution. Based on the optimum solution, a design guideline for school building in the city of Tehran with hot and dry climate is defined and Kasmai's (1994) climatic design guideline for educational building in hot and dry climate is updated. In Kasmai's study the various strategies was not incorporated into the building simulation tool for evaluation and were only predicted based on the thermal condition of the typical schools with regards to climatic design in the region.

2.7. Climatic school design in hot and dry climate of Iran

A few studies give general guidelines for climatic design of school building in the hot and dry climate of Iran, but these guidelines are very limited and have not been produced based on the students' thermal satisfaction. The summary of these guidelines is presented below:

2.7.1. Heating and thermal performance

In the winter period it is important to get the maximum solar radiation on the buildings' facade in order to make the indoor environment warmer. However, appropriate shading devices should be considered for the windows to avoid solar radiation reaching the indoor environment in warm and hot seasons (Chegeni, 2011). It is important to increase the air tightness of the buildings to reduce the infiltration rate and keep the indoor environment warmer in winter (Poorgolian et al., 2007).

2.7.2. Ventilation

It is suggested to provide a low natural ventilation rate in hot and dry climatic regions, especially during the warm and hot seasons to prevent the outdoor air flowing in through the windows. However, it is advised that wind towers should be employed in the buildings to supply natural ventilation (Kasmai, 2008).

2.7.3. Orientation

The long axis of the school buildings should be laid in an east-west direction in hot and dry climatic regions. The suggested orientation for the school buildings in hot and dry climates is 15° to 30° east and the worst orientation in hot and dry climatic regions is 30° to 60° west (Poorgolian et al., 2007). The classrooms can be located in parallel to the long axis of the building on both south and north sides of the building, with a corridor in between.

2.7.4. Windows and shading devices

The area of the windows should be as small as possible. The suggested window to wall ratio is 30% in a hot and dry climate. Appropriate shading devices can be used for the windows to reduce the effect of solar radiation in summer. In addition, it is suggested that a balcony or trace to be designed into the classrooms to create shading for the buildings in the hot season. Extra attention needs to be given to create shading for the south facade in September and November, as this facade gets the maximum solar radiation in these months (Poorgolian et al., 2007). Studies show that internal shading devices reduce the effect of solar radiation by between 20% and 25% but outdoor shading devices reduce this effect by 90% (Kasmai, 2008).

2.7.5. Building materials and the colour of facades

It is suggested that materials with high thermal capacity for buildings components should be used to store heat during the day time and release it at night while the outside temperature is colder. The building's facade should be bright in colour, to avoid heat observation during the hot season. Thermal insulation materials should be employed in the external layers of the external walls, as this increases the effect of the thermal mass of the external walls (Poorgolian et al., 2007, Kasmai, 1994).

2.7.6. Mechanical cooling and heating system

An installation of the mechanical cooling and heating systems is necessary for school building in hot regions in Iran to create a comfortable indoor environment for students, as this region has hot and dry summers and cold winters (Poorgolian et al., 2007).

2.7.7. Thermal insulation

Studies show that the effect of thermal insulation with 28cm thickness is 25% less than 40cm thermal insulation on the indoor air temperature. In addition, the impact of thermal insulation with 10cm thickness is similar to 15cm of the same type of material (Fardchian, 2011). It is suggested that a thermal insulation layer should be employed in the outside layers of the roof and the concrete layer to prevent the transfer of heat to the indoor spaces, because the thermal material absorbs heat before it reaches the concrete and, as a result, the concrete layer absorbs and releases less heat to the interior spaces (Kasmai, 2008).

2.8. Building energy regulation in Iran

Building energy regulations can have a considerable effect on the thermal performance of a building. To improve the energy efficiency of buildings in Iran an energy conservational building code, Code 19, was defined by the Ministry of Housing and Urban Development of Iran in 1991 to achieve a better thermal performance for all types of buildings. The initial edition of the code was based on German standards and the climatic variables were not considered in the code. The primary parameter which was considered in this code is related to building energy conservation (Kari and Fayaz, 2006). The features of all building types in Iran have been addressed by Code 19 but the code has some restrictions and an appropriate balance between different energy variables for the Iranian climate has not been defined yet.

2.8.1. Lack of information concerning the energy code

Although the code has been revised after the first edition, there is a considerable lack of information and the code still needs to be improved. Code 19 has applicable information regarding the design of the building envelope. However, in regards to ventilation, indoor heat gain and solar heat gain, Code 19 needs some improvement (Fayaz and Kari, 2009). Generally Code 19 needs improving in the following areas:

- Code 19 points to the reduction of energy consumption in buildings in general and there is no certain level of standard for energy reduction, such as Turkey, which aims at 50%-70% reduction in energy consumption (Demirtas, 2002).
- In Code 19, internal heat gain is not considered for building design and the solar heat gain is defined for the cold climatic regions only. The heating and cooling degree days and humidity conditions are considered for hot periods in Code 19. However, the heating and cooling degree hours need to be defined, along with the degree days.
- There is no standard for the air flow rate and air change for the building design, as ventilations is not considered in Code 19.
- The building is assumed to be a single thermal zone. In the next revised edition of the code, all standards should be considered for multiple thermal zones (Fayaz and Kari, 2009).

The code defined the U-value separately for all the buildings' components from intensive and moderate energy conservation levels to low and very low levels. In addition, the recent version of the code is based on the ASHRAE standards. It should be stated that, although considering Code 19 in building design in Iran can decrease the buildings' energy consumption, the design of private building types hardly rely on the recommendation of the code. However, a few energy efficient buildings have been constructed in Iran but these buildings are not cost effective because of the price of the construction materials (Nasrollahi, 2009).

2.8.2. U- value, R-value, Air Permeability and MVHR

There are no defined standards for the amount of energy consumption of the buildings in Iran. However, Iranian National Building Code, Code 19, which is about energy saving in buildings, presents the amount of thermal resistance (R-value) and thermal transmittance (U-value) of the buildings 'components. Based on Code 19 (2009), the amount of R-value and U-value of the various buildings' components of the building's envelope depend on the climate of the region; the amount of heating and cooling degree days; the population of the city in which the building is situated; and building usage. Table 2.6 presents the amounts of thermal resistance of building components recommended by Code 19 for various buildings with different energy intensity levels, from buildings with maximum energy saving to buildings with minimum energy saving. In addition, Code 19 stated the various U-values for the building components of the different buildings with various levels of energy intensity, including maximum intensity, medium intensity and minimum intensity (see Table 2.7). The U-values are defined for the buildings which use electrical energy and non-electrical energy separately.

Table 2.6: Thermal resistance of the thermal envelope components defined by Code 19 (Ministry of Housing and Urban Development, 2009)

Building component	**Building component type**		**Building energy intensity**		
			max	**med**	**min**
Wall	**Light**	**Thermal resistance (R-value) m^{2}k/w**	2.8	2.1	1.5
	Heavy		1.9	1.4	1.0
	Adjacent to uncontrolled space		1.5	1.1	0.8
Roof	**Light**		5	3.7	2.7
	Heavy		4	3.0	2.2
	Adjacent to uncontrolled space		3.1	2.3	1.7
Floor	**Light**		3	2.2	1.6
	Heavy		2.4	1.8	1.3
	Adjacent to uncontrolled space		1.8	1.3	1.0
Ground floor	**Ground circumstantial insulation**		3.7	2.7	2.0
	Floor Insulation		1.7	1.3	0.9

Table 2 .7: Thermal transmittance of thermal envelope components (Ministry of Housing and Urban Development, 2009)

Energy Type in building		Non electricity			Electricity		
Building energy intensity		max	med	min	max	med	min
Wall	**Thermal transmittance (U-value) w/m^{2}k**	1.10	1.39	1.61	0.92	1.16	1.34
Flat or slope roof		0.55	0.69	0.80	0.46	0.58	0.67
Floor above open space		0.55	0.69	0.80	0.46	0.58	0.67
Floor at earth		1.60	2.02	2.34	1.33	1.68	1.95
Transparent envelope		3.40	4.28	4.96	2.83	3.57	4.14
Door		3.50	4.41	5.11	2.92	3.68	4.26
Uncontrolled space		0.70	0.88	1.02	0.58	0.74	0.85

In addition, it is necessary to limit the travel of energy from the inside to the outside of the building and ensure minimal breeze and wind intrusion in terms of saving energy and maintaining the comfort of the occupants in indoor spaces. For this reason it is important to measure the quality of the systems' sealing, to ensure that all the opening segments seal together well in order to reduce the amount of air travelling through the systems. For this reason air permeability testing was performed in some countries, which is measured in units of m^3/(h.m^2) for the overall area and m^3/(h.m) for air permeability over the panel joint. Air Permeability refers to the amount of air that will travel through a window or door system in its closed position (IQGlassUK, 2014). Some countries introduce a limit for air permeability for various types of building stock. For example, maximum air permeabilities of 10, 6 and 1.8-3.8 m^3/(h.m^2) at 50 pa were defined for the housing stock in the UK, Netherlands and Germany, to assess the airtightness of the buildings (Energy Saving Trust, 2007). However, there is no clear standard for the air permeability of buildings in the Iranian building code. Only the Institute of Standards and Industrial Research of Iran has established an air leakage test method for calculating the air permeability of the buildings' openings, such as windows, exterior doors and curtain walls, at pressure differences of 100 Kilo Pascals, between the interior and exterior of the buildings' envelope (Institute of Standards and Industrial Research of Iran, 2003). Some top tips were introduced along with the test method for ensuring the openings are as air tight as possible. The value of the calculation is then compared to the current and more common international standards and regulations in the world, based on the designers' point of view. On the other hand, in Code 14 of the Iranian National Building Code (National Building Code, 2009b) which is related to thermal installation, air changes and the HVAC system, there are some recommendations for minimum fresh air levels for various building stock, including educational buildings (see Table 2.8).

Table 2.8: Minimum fresh air in Iranian building stock (National Building Code, 2009b)

Building Stock in Iran		**Per person**		**Per square metre**		**Per room**	
		Litre per sec	**Cube feet per minutes**	**l/m^2.sec**	**f^3/f^2.min**	**Litre per sec**	**Cube feet per minutes**
Residential buildings	Room	7.5	15	--	--	--	--
	Kitchen	--	--	--	--	--	--
	Toilet and bath	--	--	--	--	50	100
	Private parking	--	--	--	--	25	50
	Public parking	--	--	7.5	1.5	50	100
Office buildings	Offices	10	20	--	--	--	--
	Meeting rooms	10	20				
Hotels	Guest room	--	--	--	--	15	30
	Lobby	--	--			--	--
	Meeting room	7.5	15			--	--
	Bath	10	20			18	35
Meeting rooms	--	7.5	15	--	--	--	--
Restaurants	Main lounge	10	20	--	--	--	--
	Kitchen	7.5	15	--	--		
	Coffee shops	10	20	7.5	1.5		
Shops	Basement	--	--	1.5	0.3	--	--
	Other floors			1	0.2		
	Storage			0.75	0.15		
Cleaning rooms	--	13	25	--	--	--	--
Sport Centre	Spectators area	7.5	15	--	--	--	--
	Sport spaces	13	25	--	--		
	Swimming pool			2.5	0.5		
Educational buildings	Classroom	7.5	15	--	--	--	--
	Lab	10	20	--	--		
	Library	7.5	15	--	--		
	Workshop	10	20	--	--		
	Changing room			2.5	0.5		
Public spaces	Corridors	--	--	0.25	0.05	--	--
	Public toilet			--	--	--	--
	Changing room			2.5	0.5	25	50

Moreover, using a Mechanical Ventilation Heat Recovery system (MVHR) in the buildings is another way of saving energy and providing a healthy indoor environment. It exchanges stale air for fresh air, recovering heat in the process, and also reduces CO_2 emission from the building (Banfil et al., 2011). It extracts the warm, moist air from the indoor environment. The air is passed through a heat exchanger and then ducted outside. Fresh air from outside is drawn in and passed through the heat exchanger, which warms it, and then ducted to the other rooms, such as living rooms or bedrooms in dwellings. Some systems have a feature so that when it is warm outside, the air can bypass the heat exchanger to help keep the house cool. Generally, an MVHR system produces fresh air in relatively airtight buildings. Although opening a window provides ventilation, the building's heat and humidity will then be lost in the winter and gained in the summer, both of which are undesirable for the indoor climate and for energy efficiency. However, MVHR introduces fresh air to a building and improves climate control, whilst promoting efficient energy use. The difference between MVHR and Air conditioning (AC) systems is mainly on the re-circulation of air and the gradual heating or cooling of it with every cycle. This is the reason why the windows should be kept shut when AC systems are in operation. Such heating or cooling is done actively, with the use of relatively little electrical energy (SHS., 2014).

In Iran the use of MVHR in buildings has been much studied recently, as the use of electrical energy for operating cooling and heating systems has increased considerably, along with the related costs. It is necessary to reduce the heating and cooling energy consumption of the buildings, as there are some serious problems in providing the electrical energy required, especially during the summer. On this approach, one of the best choices is using heat recovery combined with an air conditioner, which many researchers have noticed (Delfani et al., 2012). The first pilot study on the use of the heat recovery system in Iran was performed in the city of Bandar Abbas in 2012. The study shows that using a heat recovery system for cooling purposes in Bandar Abbas reduced the energy use of a public building from 960 kw.h to 540 kw.h (Hamshahri, 2012). However, the use of MVHR is not regular in Iran yet and an air conditioning system is mostly used instead.

2.9. Construction materials and building fabrics in Iran

Generally most buildings in various parts of Iran with different climatic regions are constructed with masonry materials. Due to building regulations, one and two story buildings can be constructed using masonry (often bricks) and a concrete structural framework. However, buildings with more than two floors must use a concrete or steel structure and the external and internal walls must be constructed with bricks. In addition, the roofs are concrete or occasionally brick with steel beams. Very few low-rise individual houses are built with prefabricated materials or lightweight materials.

2.10. Building characteristic in masonry school buildings

School buildings in Iran usually have three main types of structure including steel, concrete and masonry structures. However, a few schools have other types of structure such as wooden, stone and adobe (Mahdizadeh, 2011). The majority of the school building structures in Iran are built with masonry, compared to the other type of structures; just around 90% (see Figure 2.14). Most of the masonry types of school buildings were constructed before 1989. However, between 1989 and 2000, around 28% of the school buildings in Iran were constructed with masonry structure (see Figure 2.15). It should be noted that these percentages relate to all school buildings which are still in use (Mahdizadeh, 2011).

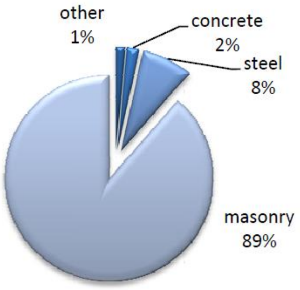


Figure 2.14: The percentage of the school buildings' structural types in Iran (Mahdizadeh, 2011)

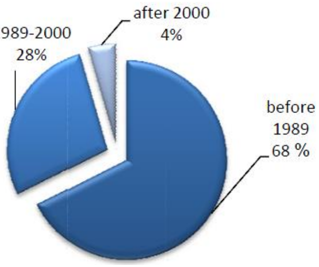


Figure 2.15: Percentage of masonry school buildings based on the constructed year (Mahdizadeh, 2011)

Based on Mahdizadeh (2011), a considerable number of masonry structural schools are one storey buildings, at around 68%, and only 12% of them have two storeys and the rest have three storeys or more, which increase the vulnerability of the buildings against earthquakes (see Figure 2.16).

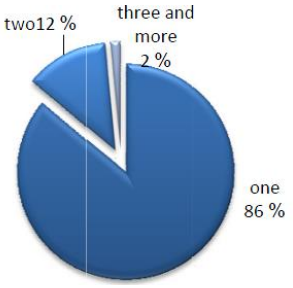


Figure 2.16: Percentage of number of stories of the masonry schools in Iran (Mahdizadeh, 2011)

Iranian building regulations for masonry buildings (National Building Code, 2009) define the appropriate construction materials for this type of building in detail, as explained below:

2.10.1. Walls

The most common materials used in masonry buildings in Iran are brick, concrete blocks and stone. The height of the rooms can vary from 2.7 m to 4 m and the walls can be constructed up to 4 m height. The minimum thickness for the load bearing walls in masonry buildings should be 35 cm and the non-load-bearing walls should have at least 8 cm to 11 cm thickness (Zomorshidi, 2007). The non-load-bearing walls are usually constructed with prefabricated plaster or clay blocks or only bricks. The minimum thickness for prefabricated plaster and clay blocks in non-loaded walls should be 8 cm and for the walls with brick it should be 11cm. Thermal insulation is rarely used in external walls. In addition, the internal and external walls usually have 2.7 cm to 3 cm exterior and interior finish of plaster and rendering accordingly (Mporg, 2006).

2.10.2. Openings

The opening in masonry buildings should have a maximum length of 2.5 m and its area should not exceed one third of the wall area (Zomorshidi, 2007).

2.10.3. Roof and floor

The roof of the building can be flat or sloped. The common type of roof and ceiling in masonry buildings in Iran is a flat roof with a steel joist frame and clay blocks (joist and block system). The thickness of the joist and block system of the roof varies from 25cm to 35cm (Mporg, 2011). In addition, usually 5cm of thermal insulation material is employed in the external layers of the roof, with 1cm to 3cm of damp-proofing. The finishing thickness of the floors is around 10 cm (Mporg, 2006).

2.10.4. Heating and cooling in hot and dry climatic regions

The humidity level in the city of Tehran is usually low, especially during the warm and hot seasons. Evaporative coolers or air coolers are usually used as a mechanical cooling system in Tehran, compared to the other types of air conditioning systems, as the installation and operating cost is much lower. Evaporative coolers require electricity. However, in some buildings, the indoor environments are cooled by natural ventilation systems to keep the building cost at a lower level (Nasrollahi, 2009). Heating stoves are sometimes used in Iran as heating equipment, which consumes natural gas and in some cases kerosene. Also a central heating system with air handling units, radiator or fan-coil is used for heating purposes in some buildings, which consumes gas oil and natural gas. In recent years, heating packages have been used for heating purposes in newly built buildings. In addition, split units are also used in some buildings for both heating and cooling purposes (Nasrollahi, 2009).

2.11. Sustainable and environmental school design: lessons from the UK

There are various baseline school design guidance are published in the UK to set out standardised approach to school building. Also there are many useful guidelines and standards on a school building design that are extensive and can be changed to meet individual requirements for a particular design, and there are many good examples of school buildings designs in the UK. The Department for Education, formerly known as the Department for Children, Schools and Families (DCSF), published several bulletins and documents about school building designs which provide useful guidelines for architects, designers, engineers and even clients in the UK. These guidelines are appropriate for all school types and contain useful recommendations for school designers (DfES, 2004b). Several organisations in the UK are responsible for the health, air quality and environmental performance of schools that published many good sources of information concerning school designs.

In addition, improving the quality of learning environments and young children’s wellbeing are always the key factors that need to be considered during the design process of an educational building for pupils. Designing a good building for education has a positive influence on the young generation’s lives and allows them to live in more sustainable communities. It also reduces the impact of the buildings on our environment. Based on CABE (2010), students’ performances and behaviour are closely related to school design and a well-designed school increases their efficiency in learning. However, a badly designed school has negative impact on students’ learning capacities and also affect teaching quality and the sustainability of a learning environment. A successful school design depends not only on designers’ hard work, but also on occupants’ requirements for a learning environment. Design alone is not able to reach sustainable goals and poor design prevents the raising of educational standards, so it is vital to consider all aspects of high quality standards for educational building in all stages of design. Recent studies on school design show that a school building with high quality standards can:

- Increase students’ performance and help them to study more productively.
- Help to employ and retain staff.
- Develop thinking about teaching and learning (CABE, 2010).

According to PricewaterhouseCoopers (2007), several principles have been introduced by the British Council for School Environments and the British Educational Suppliers Association which support an effective school environment. Sustainability, participation and design quality are some of these standards. Figure 2.17 presents these principles (PricewaterhouseCoopers and DCSF, 2007).

Figure 2.17 : Principles of an effective school environment (PricewaterhouseCoopers and DCSF, 2007)

Well designing school buildings by considering the occupants' efficiency and comfort in indoor environments with regards to sustainable and climatic design can reduce the energy consumption of educational buildings. At the moment, the energy regulations are based on perspective and performance-based standards, but are shifting from being prescriptive to performance based, with the intention of providing greater flexibility for designers (Raslan et al., 2007).

Prescriptive standards offer distinct and discrete actions to directly complete a building project with the aim of achieving higher efficiency. They include a series of options defining minimum or maximum values for different elements in a building project which the designers and architects can choose from, such as R-values for insulation, acceptable infiltration rates, and efficiency requirements for mechanical systems. However, performance-based standards consist of wide, qualitative energy efficiency targets that need building simulation modelling to investigate compliance. In Performance-based standards a reference building is usually defined in order to establish a baseline energy budget for evaluation. In performance-based standards the new buildings are equal to or lower than the baseline reference building. The comparison is defined through the use of building simulation tools that predict building energy consumption, based on inputs describing materials, systems, climate, and expected use, such as occupancy schedules and internal gains. Each type of standard has some advantages and disadvantages, as summarised in table 2.9 (Spataro et al., 2011).

Table 2.9: Performance-based vs. Prescriptive standards (Spataro et al., 2011)

Performance-based Standard		Prescriptive Standard	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Flexible • Takes a whole building approach. • Supports evaluation of measures that yield the lowest cost and greatest energy savings.	**Incomplete** • Unregulated loads are not considered. • Requires significant staff expertise in the building department to review modelling submittals in a meaningful way. • No enforcement mechanism to ensure building operates at the energy use level predicted by modelling software.	**Familiar** • Commonly used framework. • Building owners and designers know what is expected.	**Incomplete** • Plug and process loads not considered; these unregulated loads can be significant.
Innovative • New technologies are integrated earlier. • Allows more flexible approach to design strategies.	**Optimistic** • Assumes equipment is installed and performing correctly.	**Simple** • Provides a clear description of accepted energy efficiency measures.	**Shallow** • Does not utilize a whole building approach • Can encourage selection of items with the least initial cost over system efficiency.
Transparency • Clearly stated goals and objectives.	**Limited** • Modelled results are only as good as the data entered.	**Easy** • Compliance is simple to verify by inspectors.	**Reductive** • Only includes items that are easily verified.
--	**Expensive** • Often requires specialty software and a trained energy modeller.	--	**Overly Optimistic** • Assumes equipment is installed and performs correctly.
--	--	--	**Difficult to update** • As efficiency targets become more stringent, prescriptive codes must be reviewed and updated regularly.

The performance-based approach in UK building regulations is underpinned by a set of approved documents providing non-prescriptive and increasingly performance-based design guidance that is open to interpretation and encourages the uptake of innovation (Sexton and Barret, 2005). In general, using a performance-based approach in the building design process is more complicated and expensive than using the simpler prescriptive standard. When simple buildings are concerned or well proven technologies are used, the use of prescriptive codes results in more effective, efficient, faster, and less costly construction. As a result, prescriptive specifications might continue to be useful in many situations. However, for complex projects, using performance based regulations at every stage is necessary, in particular during the design and evaluation phases. In performance-based evaluation through energy modelling, there is an opportunity to be more creative and to evaluate different systems to work collaboratively to meet the energy goals of a project (Rohde, 2014) .

2.11.1. Sustainable school design

As stated in Building Bulletin 95 (DfES, 2002), school buildings have a considerable effect on the environment mostly because of their energy usage during their lifetime. Sustainability in school buildings is mainly about providing healthy indoor environment for pupils, reducing waste and avoiding the use of pollutants as well as conserving energy and reducing CO^2 emissions. It is also about protecting social progress and meeting the needs of the community (CABE, 2007). Sustainability is an environmental and social aim and needs to be considered during building design process (DfES, 2002). Sustainable school design includes efficient lighting and ventilation, ideally by natural means; environmentally friendly building materials; water conservation; the use of natural lighting in indoor spaces; good sound insulation; and acceptable heating for thermal comfort. When a new or a refurbished school is being planned, sustainability and education for sustainable development needs to be taken into account and, as a result, the school building process itself can be a teaching resource in sustainability for young children (CABE, 2007). According to the Scottish Executive (2007), the achievement of acceptable environmental standards for learning and teaching is an issue that always needs to be investigated during a sustainable school design process. Energy use in school buildings and environmental design of interior spaces are closely related to each other; and to reaching acceptable environmental design standards low carbon design solutions are required which are acceptable for occupants and produce satisfactory indoor climates (Scottish Executive, 2007). Nicol and Humphreys (2001) argue that an acceptable indoor climate in buildings is essential to the success of a building in making it a convenient place for occupants to live and also for providing a high quality indoor environment by reducing energy consumption, which is one step toward sustainability. Previous designers of thermal standards and building regulations had not considered sustainability in their studies. However, with the increase in pollution and climate change, those thermal standards are no longer reliable without sustainability, and considering thermal comfort of the buildings’ occupants can help to provide sustainable standards for indoor climates (Nicol and Humphrey, 2001). BREEAM Standards (BREEAM, 2009) introduced ten categories for sustainability and each category covers some issues that try to reduce the impact of new or refurbished buildings on the environment. These categories involve:

- Management
- Health & Wellbeing
- Energy
- Transport
- Water
- Materials
- Waste
- Land Use and Ecology
- Pollution
- Innovation (see Table 2.10)

Table 2.10 : Summary of BREEAM categories of sustainability (BREEAM, 2009)

Management	**Waste**
· Commissioning · Construction site impacts · Security	· Construction waste · Recycled aggregates · Recycling facilities
Health and Wellbeing	**Pollution**
· Daylight · Occupant thermal comfort · Acoustics · Indoor air and water quality · Lighting	· Refrigerant use and leakage · Flood risk · NO^x emissions · Watercourse pollution · External light and noise pollution
Energy	**Land Use and Ecology**
· CO2 emissions · Low or zero carbon technologies · Energy sub metering · Energy efficient building systems	· Site selection · Protection of ecological features · Mitigation/enhancement of ecological value
Transport	**Materials**
· Public transport network connectivity · Pedestrian and Cyclist facilities · Access to amenities · Travel plans and information	· Embodied lifecycle impact of materials · Materials re-use · Responsible sourcing · Robustness
Water	**Innovation**
· Water consumption · Leak detection · Water re-use and recycling	· Exemplary performance levels · Use of BREEAM Accredited Professionals · New technologies and building processes

Table 2.10 shows that the occupants' thermal comfort is one of the key issues in the health and wellbeing category, along with daylight, acoustic, lighting, indoor air and water quality. To provide a healthy and comfortable space for pupils in a school building, it is necessary to study and consider those issues during building design and construction.

2.11.2. Guidance on environmental design in schools

In order to identify what is achievable, it is required to be conscious of what others have achieved. Every design project has its particular features but, from the best practice cases, good ideas can be found for future designs. Even by reviewing less successful outcomes of projects, many useful concepts can be delivered because there is a chance to know about potential difficulties which may be faced with during the design process (CABE, 2007). Moreover, there are many useful guidelines and standards on building design that are extensive and can be changed to meet individual requirements for a particular design. The UK has many good examples of school building design. Building Schools for the Future was a big school-building investment programme in England that aimed to rebuild or renew most secondary schools. It can offer good examples of how to create a sustainable school, although the UK Government is currently cutting its budget and *"BSF schemes yet to reach financial close would not go ahead"* (Fulcher, 2010).

- **Regulations and guidance documents**

The Department for Children, Schools and Families (DCSF) published several bulletins and documents about school building designs which provide useful guidelines for architects, designers, engineers and even clients in the UK. These guidelines are appropriate for all school types and contain useful recommendations for school designers (DfES, 2004b). Some of the relevant bulletins and case studies are mentioned below:

BB87 - Guidelines for Environmental Design (DfES, 2003a)
BB90 - Lighting Design for Schools (DfEE, 1999)
BB94 - Inclusive School Design (DfEE, 2001)
BB95 - Schools for the Future: Designs for learning communities (DfES, 2002)
BB98 -Briefing Framework for Secondary School Projects (DfES, 2004a)
BB101 - Ventilation of School Buildings (DfES, 2006a)
Classrooms of the Future (DfES, 2003b)
Design of sustainable schools: case studies (DfES, 2006b)
Exemplar Designs: concepts and ideas (DfES, 2003c).

In the UK several Governments have established organisations that are responsible for the health, air quality and environmental performance of schools, and published many good sources of information concerning school design:

The Department for Children, Schools and Families (DCSF)
The Partnership for Schools (PfS)
The Commission for Architecture and the Built Environment (CABE) (Monodraught, 2009).

- **Standards for environmental conditions and energy conservation for new school buildings**

The following guidelines are a summary of lighting, ventilation and thermal performance standards for school buildings defined by BB 87, Guidelines for Environmental Design, (DfES, 2003a) for newly built schools in the UK:

- **Lighting**

The uniformity ratio of the daylight should be in the range 0.3 to 0.4 for side-lit rooms. Where spaces are top-lit then higher uniformities should be expected of the order of 0.7. The uniformity ratio of the electric lighting in teaching areas should be not less than 0.8 over the task area. A minimum glazed area of 20% of the internal elevation of the exterior wall is recommended to provide adequate external views. A maintained illuminance at floor level in the range 80-120 lux is recommended for stairs and corridors. Entrance halls, stairs, lobbies and waiting rooms require a higher illuminance in the range 175-250 lux on the appropriate plane. The type of luminaires should be chosen to give an average initial circuit luminous efficacy of 65 lumens/ circuit watt for the fixed lighting equipment within the building, excluding track-mounted luminaires and emergency lighting.

- **Thermal performance and glazing**

Vertical glazed areas should not normally exceed an average of 40% of the internal elevation of the external wall. However, where a passive or daylight design strategy has been adopted, the percentage glazing may exceed 40%, provided the insulation of the rest of the building fabric is increased to compensate for the increased heat loss through glazing or where heating plant carbon intensity is traded up accordingly. Horizontal or near horizontal glazing should not normally exceed 20% of the roof area.

- **Ventilation**

It is recommended that, in classrooms, ventilation systems, whether natural or mechanical, are capable of providing approximately 8 litres per second of fresh air per person. Spaces where noxious fumes or dust are generated may need additional ventilation. Design technology areas may require local exhaust ventilation. All washrooms in which at least 6 air changes per hour cannot be achieved on average by natural means should be mechanically ventilated and the air expelled from the building. Heat recovery fans can be used as well. During the summer, when the heating system is not in operation, the recommended design temperature for all spaces should be 24°C with a swing of not more than +/− 4°C. It is undesirable for peak air temperatures to exceed 28°C during normal working hours but a higher temperature for 80 hours during the summer term is acceptable (DfES, 2003a).

- **BREEAM scheme**

BREEAM (Building Research Establishment’s Environmental Assessment Method) is an environmental assessment method for buildings. It introduces standards for best practice in sustainable designs (BREEAM, 2009). It is supported by the UK Government to ensure optimum environmental performance of buildings and covers all ranges of buildings, including secondary schools (Monodraught, 2009). Some of the main aims and objectives of BREEAM are described below:

  - To reduce the impacts of buildings on the environment
  - To ensure that the best environmental practice is combined in building design
  - To increase the awareness of clients, occupants and designers that buildings have less effect on the environment

It also covers the area relating to natural ventilation, daylighting and thermal comfort (BREEAM, 2009).

- **Building School for the Future programme**

Building Schools for the Future (BSF) was a programme to rebuild or refurbish all secondary schools in England by 2020. It aims were to provide 21st-century facilities for all students in secondary schools and help them to study in more healthy and comfortable environments (PricewaterhouseCoopers and DCSF, 2007). Recently, this scheme has been scrapped (Richardson, 2010) and many projects stopped (DfE, 2010). One of the main reasons is to get the best value for money. “*Bringing an end to Building*

Schools for the Future programme (BSF), in the light of the public finances, it would have been irresponsible to carry on regardless with an inflexible, and needlessly complex programme" (DfE, 2010). However, it is a fact that good ideas given in this programme can be applied to any region of the world and can offer good lessons for the future school building.

2.12. Geography of Iran

Iran is a country located in the Middle East and borders Azerbaijan and Armenia to the Northwest, Turkmenistan to the Northeast, Pakistan and Afghanistan to the East and Turkey and Iraq to the West. The Caspian Sea borders Iran to the north and the Persian Gulf and the Gulf of Oman forms Iran's southern border (see Figure 2.18). Iran covers over 1,648,195 km² with a land area of 1,531,595 km² and water area of 116,600km². The geographic coordinates of Iran are 32ºN and 53ºE (CIA, 2013).

Figure 2.1 : Iran's geographic location (Google Map, 2013)

Iran covers a considerable part of the Persian plateau situated at the centre of the Eurasian belt (Heidari, 2000) and is a mountainous country. Alborz and Zagros are two major ranges of mountains in Iran, located on the North and West of Iran. The Zagros mountain range stretches from the North West of Iran to the Persian Gulf and Alborz lies along the southern shore of the Caspian Sea. Significant parts of Iran are occupied by deserts, such as Dasht-e-Kavir and Kavir-e-Loot. Dasht-e-Kavir is located in central Northern part of the country and Kavir-e-Loot lies to the East.

2.13. Climate classification in Iran

Iran extends between latitude 25° and 40° N and longitude 44° and 63° E and is classified as a hot-dry climate zone (Kasmai, 2008). Iran's climate changes from sub-polar to sub-tropical. Several climatic classification methods have been used in Iran, such as W. Koeppen's method and the Olgyay method (MHUD, 1993).

According to Kasmai (2008), a modified Koppen classification method is the most used method in Iran, which has divided Iran into four major climatic zones (see Figure 2.19) :

- Humid and mild (southern coast of the Caspian Sea)
- Cold (mountains of western Iran)
- Hot and dry (central plateau of Iran)
- Hot and humid (southern coast of Iran).

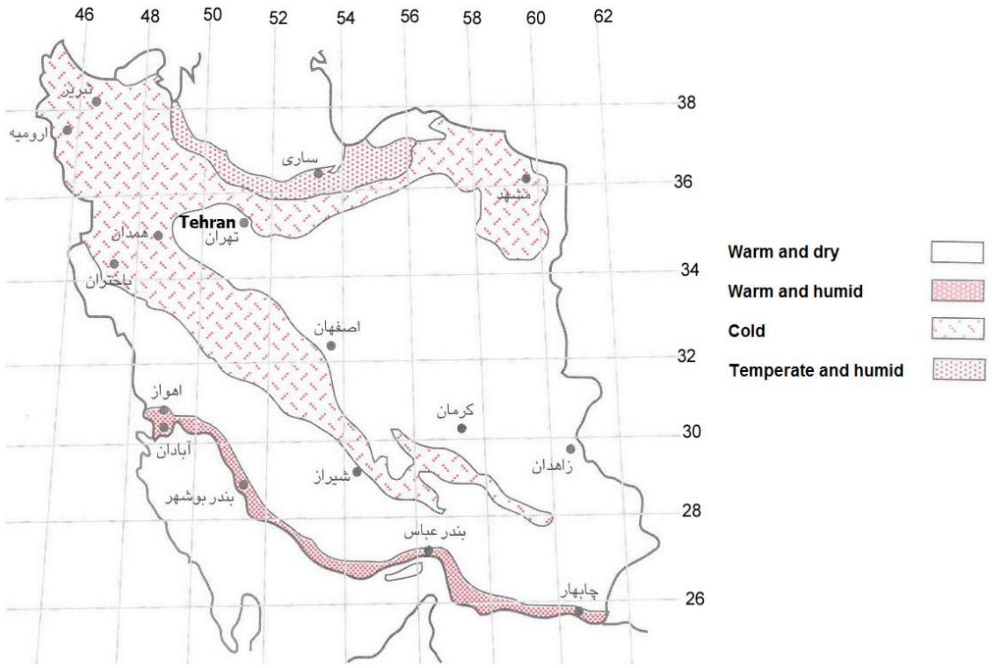


Figure 2.19: Climatic regions of Iran according to Köppen classification (Kasmai, 2008)

2.13.1. Humid and mild

Humid and mild area extends between the south and east coast of the Caspian Sea and to the north of the Alborz mountain range. The average temperature during summer days is between 25°C and 30°C. However, it varies between 20°C and 23°C during the night and is usually above 0°C in winter. The level of humidity is quite high in this area and relative humidity is usually more than 60% throughout the year (Heidari, 2000). This region has mild winters and a hot and humid summers (Kasmai, 1993).

2.13.2. Cold

The western part of Iran is a mountainous area with a cold climate. Winters are cold with high humidity levels but summers are warm and dry (Heidari, 2000). The average annual temperature is more than 10°C during the summer and less than -3°C during the winter. This region has a long winter, which lasts from December until April (Kasmai, 2008).

2.13.3. Hot and dry

A dry and warm region is located in the central of Iran. The main part of this area contains deserts. This region has a cold winter and a hot and dry summer. The temperature in summer days is between 40°C to 50°C and falls to 15°C to 25°C during the nights (Kasmai, 2008). It also rises above 16°C in the winter days and drops to between 0°C to -3°C during the night (Gorji-Mahlabani, 2002). The summer lasts from June to September in a hot, dry region.

2.13.4. Hot and humid

Humid and warm region has a mild winter and a warm and humid summer. It is located in the southern part of Iran and the northern parts of the Persian Gulf and the Gulf of Oman. The annual average temperature is between 23°C and 27°C. The temperature goes up to 42°C and 46°C during the summer days and declines to between 18°C and 28°C at night (Gorji-Mahlabani, 2002). Relative humidity in this region is usually high and it reaches 70% at its highest level (Kasmai, 1993).

2.14. Climate and geography of the city of Tehran

2.14.1. Geography of Tehran

Tehran is the Capital of Iran located in Tehran province. It surrounded by Alborz Mountain to the North and desert to the south.

Figure 2.20: Tehran geographic location (Iran Meteorological Organization, 2012)

Tehran has different heights of the land on the north and the south, which cause different temperatures and rainfall rates (Gharai, 1999). Tehran's geographic coordinates are 35º68´N and 51º32´E. It lies 1191 metres above sea level and is located on the central plateau of Iran (Iran Meteorological Organization, 2012). Tehran province is bounded in the north by Mazandaran, in the west by Qazvin, in the east by Semnan, in the south-west by Markazi and in the south by Qom provinces (see Figure 2.20). The surface area of Tehran province is 18,909 square kilometres and includes thirteen urban regions.

2.14.2. Climate of Tehran

Tehran is located on the southern border of Alborz Mountain. Based on Kasmai (2008), Tehran is located in the hot and dry climatic region of Iran. Generally Tehran has warm and dry summers and cold winters (Kasmai, 2008). The climate of Tehran is generally characterised by its geographic location and it is usually cooler on the north side compared to the southern part; and while the north part of the city is cold, the central part is moderate. The annual precipitation is low and the average rainfall on the plain is about 218mm and the maximum rainfall is about 50mm in November (Kasmai, 2008). Figure 2.21 illustrates the temperature range and Table 2.11 shows the average climatic data in Tehran. The average temperature during the hottest period is 29.6°C in July and during the coldest period is 3.1°C in January. However, a minimum temperature of -1.5°C in winter and maximum temperature of 36.4°C in summer can be found in the city of Tehran. In general, the coldest period is from December to February and the hottest period is from June to August (see Figure 2.21). The relative humidity level varies from a minimum of 16% in June and August to a maximum of 76% in January (see Table 2.11).

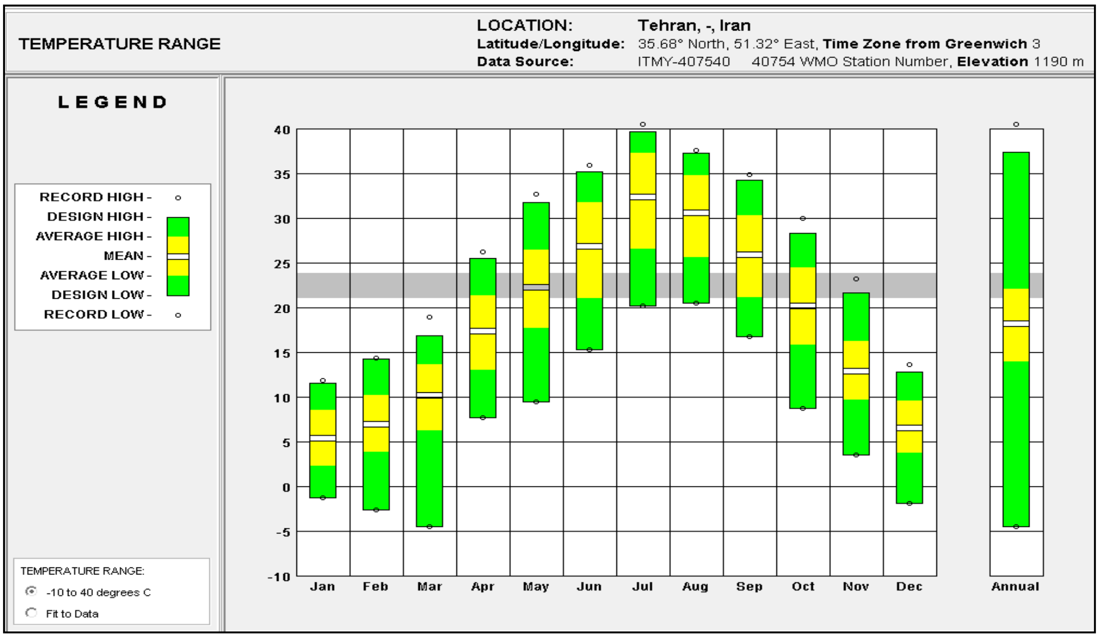


Figure 2.21: Temperature range in Tehran (Climate Consultant, 2010)

Table 2.11: Climatic data of the city of Tehran (Kasmai, 2008)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T max (C˚)	7.7	10.3	15.5	21.5	28	23.8	36.4	35.4	31.3	24.5	16	9.7
T min (C˚)	-1.5	0.4	4.6	9.8	15.3	19.9	22.8	22.1	18	12.2	5.4	0.3
T ave (C˚)	3.1	5.4	10	15.6	21.6	26.8	29.6	28.7	24.7	18.4	10.7	5
Rh max (%)	76	66.0	60	55	42	32	31.5	30	31	44	61	70
Rh min (%)	52	41	35	30	21	16	17	16	18	26	34	45
Rh ave (%)	64	53.5	47.5	42.5	31.5	24	24.25	23	24.5	35	47.5	57.5

Wind is one of the important factors in the design of natural ventilation systems for buildings. Table 2.12 shows the average wind speed and its direction for the city of Tehran. It can be seen that the prevailing wind mostly comes from a westerly direction from February until May, as well as in December, while from June to August it comes from the South East and in September and October from a North Westerly direction.

Table 2.12: maximum wind speeds and direction in Tehran (Kasmai, 2008)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum wind speed m/s	2.01	5.97	6.53	6.38	5.86	3.19	3.5	3.04	3.04	2.52	5.04	5.71
Direction	N	W	W	W	W	S-E	S-E	S-E	N-W	N-W	N	W

A more detailed climatic analysis of the city of Tehran was conducted using Climate Consultant 4 weather tool (Climate Consultant, 2010). As a weather data input, an EPW weather file for Tehran from the EnergyPlus website (EnergyPlus, 2013) was obtained and used in the weather tool. The weather file contains the average climatic data for 10 years, measured at the nearest weather station in Mehrabad national airport in the west of Tehran. The Climate Consultant helped the visualisation of weather variations using the EPW file. Figures 2.22 to 2.26 present the average annual summary of the climatic data of the city of Tehran from January till December. In can be seen that the maximum dry bulb temperature was reached during the month of May to August, mostly from 8:00am to 2:00am and the rest were between 21°C and 27°C. However, the dry bulb temperature was less than 21°C from the last week of September to the beginning of May (see Figure 2.22).

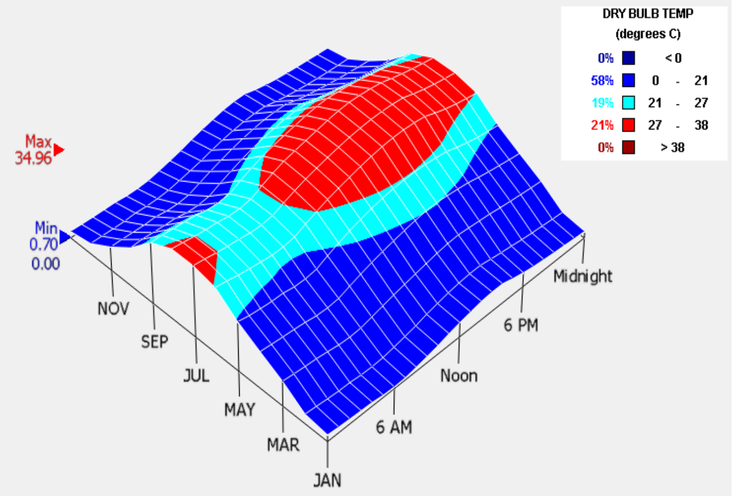


Figure 2.22: Average dry bulb temperature in Tehran (Climate Consultant, 2010)

In addition, the average relative humidity level in Tehran was mostly below 40% throughout the year, registered from March to the beginning of November. From May to August, it reached its minimum level, just below 20%, during the midday. From November to early March the maximum relative humidity level occurred mostly from midnight to midmorning, increasing from 60% to 80% (see Figure 2.23).

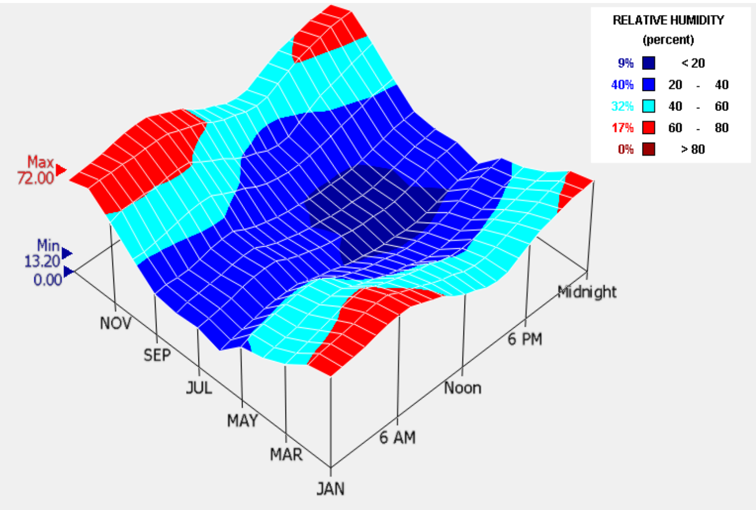


Figure 2.23: Average relative humidity level in Tehran (Climate Consultant, 2010)

Figure 2.24 shows the average annual direct solar radiation in the city of Tehran. It can be seen that extreme maximum radiation occurred in the most months, except December. However, from January to May it reached to its maximum level for only 2 to 4 hours a day, up to 474 wh/m^2. From March to April the records shows the intensity reduction of solar radiation compared to February. This decrease might be related to the cloudy and partly cloudy skies during these months, which generate a declining trend of solar radiation.

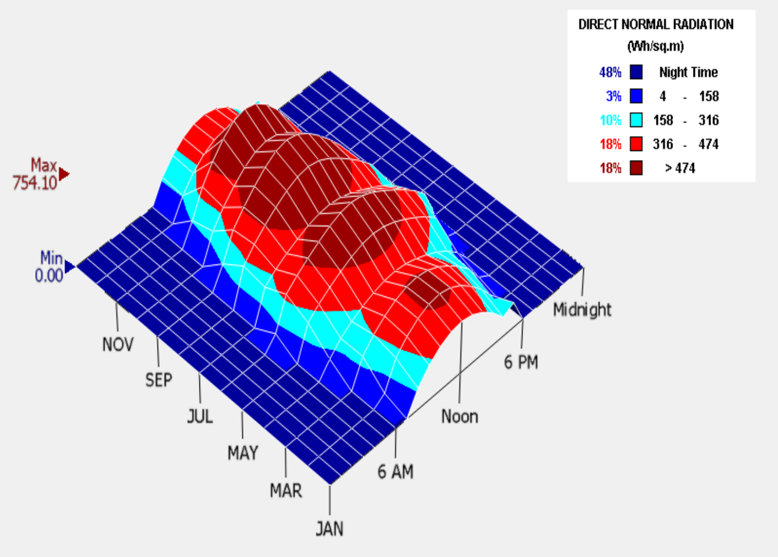


Figure 2.24: Average direct normal radiation in Tehran(Climate Consultant, 2010)

With respect to wind speed in Tehran, the maximum air speed occurred from midday in March to May and from September to October, at around 5 to 9 m/s (see Figure 2.25). Figure 2.25 shows that the wind speed was mostly between 3 and 5 m/s from around noon until midnight in most months of the year. However, from midnight to late morning it is mostly between 2 and 3 m/s.

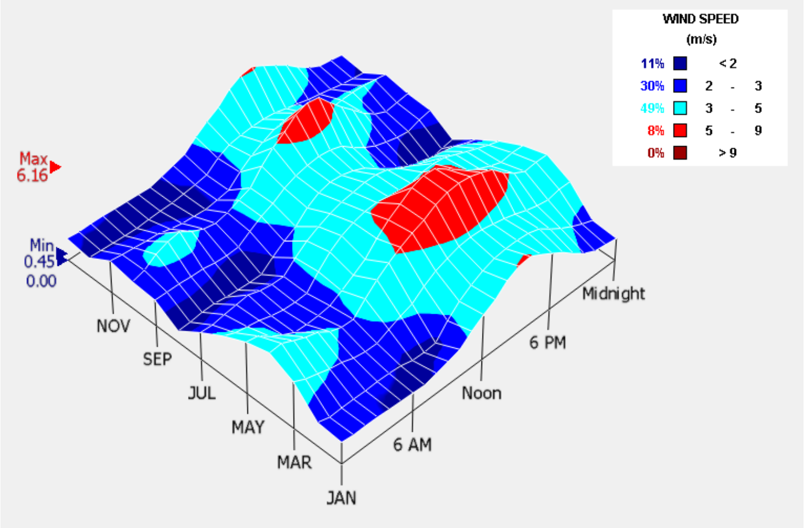


Figure 2.25: Average wind speed in Tehran (Climate Consultant, 2010)

Figure 2.26 presents a wind wheel, defined by the climate consultant for Tehran. It displays the wind velocity and frequency of accuracy for each wind direction.

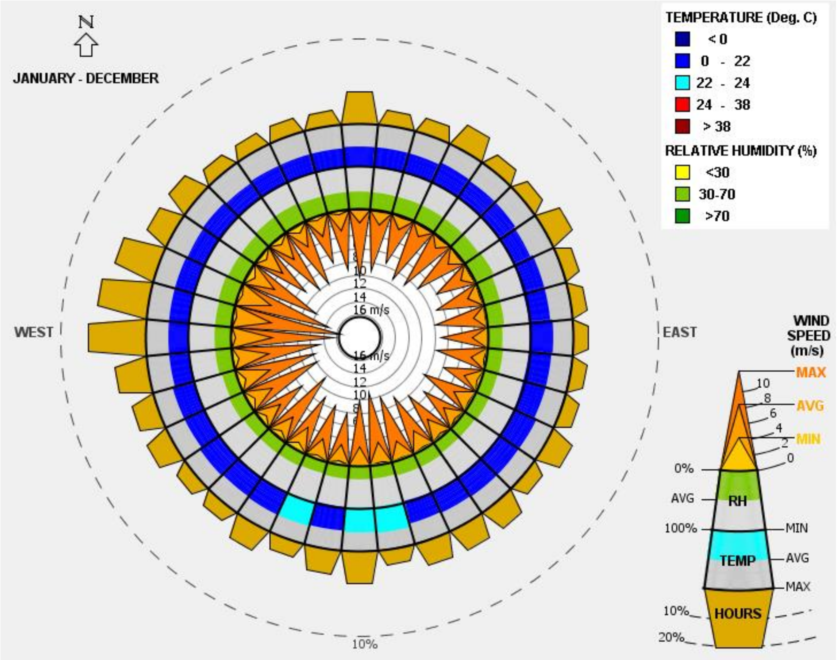


Figure 2.26: Wind wheel for the city of Tehran (Climate Consultant, 2010)

The wind wheel for Tehran shows the maximum, minimum and average wind speed, wind direction, and wind hours, as well as wind temperature and relative humidity. It shows that the average wind in Tehran comes from a westerly direction, which confirms Kasmai's study (Kasmai, 2008). The annual maximum wind speed in Tehran is 16 m/s and comes from a westerly direction. The annual average relative humidity of the wind is between 30% and 70%, and the air temperature is mostly between 0°C and 21°C in all directions but sometimes reaches to 24°C in south direction.

To define a human comfort zone, bioclimatic chart and psychometric chart have been introduced in various studies. These charts are important because they help designers and architects to find out the right solution to create the comfortable spaces. A psychrometric analysis of the climate data is the most appropriate method for preparing interior comfort conditions when using passive design strategies (Nasrollahi, 2013).The relationship between various thermo-physical properties can be defined by a psychometric chart. These properties include dry-bulb, wet-bulb, dew point and relative humidity. Figure 2.27 illustrates the psychometric chart of Tehran by the use of climate consultant 4 and based on a PMV model defined in ASHRAE Standard 55 (ASHRAE, 2004). It suggests practical design strategies from January to December. Based on Figure 2.27, a mechanical heating system is needed in the buildings to keep the indoor environment in an acceptable condition for around 28% of the year; otherwise, it is below comfort level. In addition, the indoor air temperature is above the comfort zone for 22% of the year and a mechanical cooling system is needed to keep the indoor environment within the comfort zone during the warm and hot seasons.

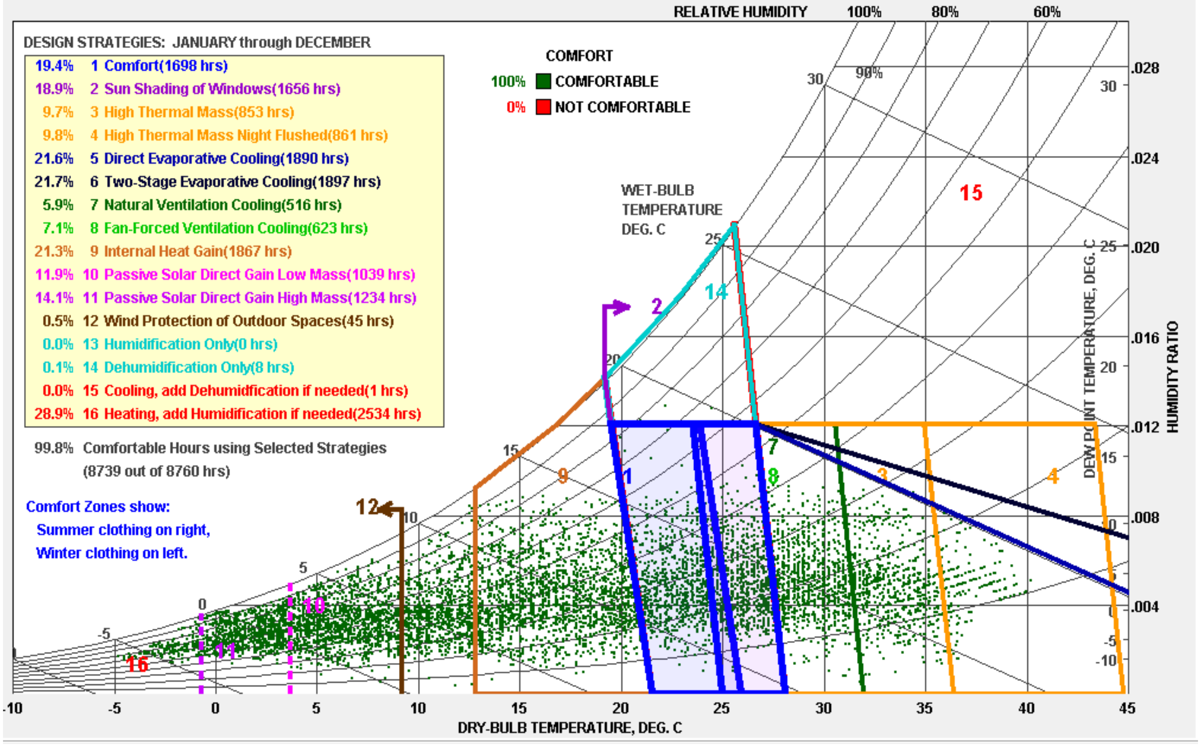


Figure 2.27 : Psychometric chart in Tehran (Climate Consultant, 2010)

Based on the proposed psychometric chart for Tehran, the heating for the indoor environment can be obtained by various strategies in the cold season:

- Through passive or direct solar heat gain in Tehran which can be used for about 26% of the year.
- Internal heat gains can maintain the comfort temperature in indoor environment for around 21% of the year.
- For around 28% of the year a mechanical heating system can be used for heating purpose.

In addition, to make the indoor environment cooler in hot and warm seasons the following strategies are suggested:

- A solar shading device is suggested to be used for 19% of the year in order to protect the facade and indoor environment from direct solar radiation and as a result to keep the indoor air temperature at a lower level and protect the building from overheating in hot periods.
- Natural ventilation is another strategy to keep the indoor air temperature low. It absolutely has no cost at all and can be used for about 6% of the year.
- Evaporative cooling and fan-forced cooling are another two strategies for cooling in Tehran. Evaporative cooling produces moisture and causes higher humidity levels in internal environments during the hot season and while the humidity level is low.
- Using high thermal mass materials in the building envelopes can keep the indoor environment in an acceptable condition for about 20% of the year.

It should be said that the need for heating and cooling in indoor environments mostly depends on the building's architectural design, its buildings components and its construction materials (Nasrollahi, 2013), and the proposed strategies are only one design suggestion of many which could be used in Tehran.

2.15. Conclusions

In this chapter the educational system and school design principles in Iran were reviewed as well as construction and structure of school buildings. This chapter also gave an introduction to the sustainable school design in the UK as there are many useful guidelines on school building design that are extensive and can be changed to meet individual requirements for a particular design. Later the climate and geography of Iran and the city of Tehran were studied in order to be incorporated into the field studies and simulation analysis in this research.

Chapter 3: Thermal Comfort and Related Studies in School Buildings

3.1. Comfort

In order to create a comfortable and healthy internal environment for building occupants, it is important to understand humans' comfort levels. There are several factors that need to be analysed to design a desirable building space for its occupiers which particularly relates to the human senses, such as touch, smell, hearing and vision (CIBSE, 2006). Thus air quality, visual comfort, acoustic comfort and thermal comfort should be considered at all stages of a building design. As people have unequal comfort levels, comfort is subjective and it is impossible to provide comfort for all occupants at once (CIBSE, 2006).

3.2. Thermal comfort

According to ASHRAE Standard 55, *"thermal comfort is that condition of mind which expresses satisfaction with the thermal environment"* (ASHRAE, 2004). Thermal comfort is where a large number of people are satisfied with their thermal environment. One of the main goals of thermal environment design is to create a comfortable indoor space for building residents and to try to keep them satisfied while they are inside (CIBSE, 2006).Thermal comfort is mostly related to people's individual sensations of the surrounding area and it is necessary for human productivity, ability and well-being (Akande and Adebamowo, 2010). Human thermal comfort is mainly affected by four main climatic factors of climate, as follows:

1. Air temperature
2. Mean radiant temperature
3. Relative air speed
4. Humidity

Moreover, metabolic heat production and clothing insulation are two personal factors that influence people's thermal perceptions (CIBSE, 2007).

3.2.1. Air temperature (t_a)

The room temperature of the air around the occupant's body is generally known as the air temperature (ASHRAE, 2004). It is described as a dry bulb temperature of the internal environment which affects heat transfer of the body by convection and evaporation and is usually measured using thermometers (CIBSE, 2006). In addition, it is one of the most important factors that have an impact on people's thermal comfort (CIBSE, 2007).

3.2.2. Mean radiant temperature (t_r)

Based on ASHRAE (2004), mean radiant temperature is *"the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space" (ASHRAE, 2004)*. Mean radiant temperature can be calculated mathematically by measuring the surface temperature, air temperature and air velocity in the same space and at the same point. It also affects radiant heat transfer and is measured by a globe thermometer. The combination of mean radiant temperature and room air temperature is called the operative temperature (t_o) (CIBSE, 2006). It is *"the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment"* (ASHRAE, 2004). According to the CIBSE Guide A (2007), operative temperature is the average air temperature and the mean radiant temperature, while the air speed of the space is 0.1 m/s:

$$t_o = 1/2\ t_a + 1/2\ t_r \text{ (CIBSE, 2007)} \qquad \text{Eq. 3. 1}$$

3.2.3. Relative air speed

The rate of air movement in the space, regardless of its direction, is air speed (ASHRAE, 2004). Relative air speed is the air movement across the skin or clothing surface which transfers convective heat and helps the body to lose heat by evaporation and causing a cooling effect. If the air speed is very high, it can increase draughts but the low air speed may cause poor indoor air quality which is heavy and stale. Ordinarily the acceptable air speed in indoor environments is between 0.1 to 0.3 m/s for the occupants (CIBSE, 2006). Human activities increase the relative air speed around the body and an increase in the air velocity generates a cooling effect which rises as the air temperature drops. On the other hand, reduction of air speed at higher temperatures may result in discomfort and the generation of heat (Givoni, 1976).

3.2.4. Humidity

Humidity has a significant impact on the warming effect of the body, especially if the skin is wet and sweaty (CIBSE, 2007). It also has an indirect impact on the body's heat loads and only affects evaporation. Air humidity may be stated in different ways, such as relative humidity, absolute humidity, specific humidity and vapour pressure (Givoni, 1976). Humidity is generally known as a percentage ratio of the amount of water vapour that exists in the air at a particular condition, compared to the maximum amount of water vapour in the air at the same temperature and the same pressure. The acceptable humidity level in a moderate thermal environment is usually between 40% and 70%. Relative humidity under 30% can cause shocks and if it is under 25%, it might cause eye and skin drought.

However, the humidity rate of over 80% can make the human body sticky and make us feel uncomfortable (CIBSE, 2006).

3.2.5. Metabolic heat production

Metabolic heat production is basically based on human physical activities such as work and office activities (CIBSE, 2007). The transformation rate of chemical energy to heat and mechanical work by metabolic activities in the body is generally known as metabolic rate (ASHRAE, 2004). According to Givoni (1976), environmental conditions have an impact on metabolic heat rate and it is maximised by thermal stress. If the metabolic heat rate rises, working muscles need more oxygen and also extra amounts of heat required to be exchanged from the body to the surrounding environment (Givoni, 1976). To estimate the metabolic heat rate, many aspects need to be considered. For instance, people's metabolism rates are not similar and can vary when they do different tasks under specific environmental conditions. Moreover, it should be taken into account that people can have different feeling to thermal condition of their surroundings at the same time because they have different metabolic rates (Smolander, 2002). As mentioned before, metabolic rate fluctuates significantly, depending on activity, person and condition, so it is important to know the rate of work which has been done under different conditions and various physical activities in order to select optimal conditions for comfort and health (ASHRAE, 2005). Table 3.1 shows metabolic rates for some typical activities:

Table 3.1: Metabolic rates for typical tasks (ASHRAE, 2004)

Activity	**Met Units**	**Metabolic rate** W/m^2	**($Btu/h.ft^2$)**
Resting			
Sleeping	0.7	40	(13)
Reclining	0.8	40	(15)
Seated, quiet	1.0	60	(18)
Standing, relaxed	1.2	70	(22)
Walking (on level)			
0.9 m/s,3.2 km/h,2.0 mph	2.0	115	(37)
1.2 m/s, 4.3 km/h, 2.7 mph	2.6	150	(48)
1.8 m/s, 6.8 km/h, 4.2 mph	3.8	220	(70)
Leisure Activities			
Dancing, social	2.4-4.4	140-255	(44-81)
Calisthenics/exercise	3.0-4.0	175-232	(55-74)
Tennis, singles	3.6-4.0	210-270	(66-74)
Basketball	5.0-7.6	290-440	(92-140)
Office Activities			
Seated, reading or writing	1.0	60	(18)
Typing	1.1	65	(20)
Filing, seated	1.2	70	(22)
Filing, standing	1.4	80	(26)
Walking about	1.7	100	(31)

3.2.6. Clothing insulation

The amount of clothes worn by people depends on internal thermal conditions and outdoor temperatures, which affect insulation. The meaning of clothing insulation refers to heat exchange that is transferred from the core of the body through the skin and to the surrounding environment outside the layer of clothing (CIBSE, 2007). It also helps the body to resist against the variation of air temperature and velocity and reduces its sensitivity. If the air temperature drops below 35°C, clothing can reduce the rate of dry heat loss from the body and result in supplying a heating effect. When the temperature increases above 35°C, the dry heat gain from the environment reduces. However, the level of humidity rises and air velocity over the skin decreases, which causes a reduction in the cooling gained from sweat evaporation. According to American indoor clothing standards, *"clo" value* is the unit of thermal resistance which is equal to 0.18 deg C h m^2/ kcal (0.88 deg F h ft^2/Btu) (Givoni, 1976). During the cold season people generally wear thicker and heavier clothes, with insulation values between 0.8 and 1.0 clo, but in warm seasons they wear lighter clothes with less layers, with the insulation value of 0.35 to 0.6 clo. Table 3.2 indicates the clothing insulation value for typical ensembles:

Table 3.2: Clothing insulation value for typical ensembles (ASHRAE, 2004)

Clothing description	**Garments included**	I_{cl} **(clo)**
Trousers	1) Trousers, short-sleeve shirt 2) Trousers, long-sleeve shirt 3) #2 plus suit jacket 4) #2 plus suit jacket, vest, T-shirt 5) #2 plus long sleeve sweater, T-shirt 6) #5 plus suit jacket, long underwear bottoms	0.57 0.61 0.96 1.14 1.01 1.30
Skirts/Dresses	7) Knee-length skirt, short-sleeve shirt (sandals) 8) Knee-length skirt, long-sleeve shirt, full slip 9) Knee-length skirt, long-sleeve shirt, half slip, long-sleeve sweater 10) Knee-length skirt, long-sleeve shirt, half slip, suit jacket 11) Ankle-length skirt, long-sleeve shirt, suit jacket	0.54 0.67 1.10 1.04 1.10
Shorts	12) Walking shorts, short-sleeve shirt	0.36
Overalls/Coveralls	13) Long-sleeve coveralls, T-shirt 14) Overalls, long-sleeve shirt, T-shirt 15) Insulated coveralls, long-sleeve thermal underwear tops and bottoms	0.72 0.89 1.37
Athletic	16) Sweat pants, long-sleeved sweatshirt	0.74
Sleepwear	17) Long-sleeved pyjama tops, long pyjama trousers, short 3/4 length robe (slippers, no socks)	0.96

Based on ASHRAE (2004), all these six factors should be analysed to define thermal comfort levels and these factors may change in different conditions but they only address thermal comfort in a stable state. Nevertheless, when people enter a space which meets all the requirement of thermal environment standards, they might not find it thermally comfortable because of different environmental conditions and activities which may have an impact on the personal sensations up to an hour after entering to the space (ASHRAE, 2004). The human body is required to be in a thermal balance with its surrounding in order to feel comfortable. In other words, the bodies' heat loss should have an equal rate to the heat gain in order to generate a sensation of being satisfied with the surrounding environment (CIBSE, 2007).

3.3. Some thermal comfort standards

There are many guidelines and standards to determine comfort zone. The standards that we refer to must be practical, reliable and valid. The ASHRAE standards and ISO standards are two important thermal condition standards which are mostly used as the guidelines.

3.3.1. ISO standards and thermal comfort

ISO or International Organisation for Standardisation are international standards which offer more than 18000 standards in different ranges (ISO, 2013). Some of these standards relate to human thermal comfort and are major requirements for improving thermal condition of indoor environments. They have great flexibility because they are not just the standard environments but standard methods (Nicol and Humphreys, 1995). In addition, they consider people's responses to hot, moderate and cold environments. Table 3.3 shows the main ISO standards concerning thermal comfort.

Table 3.3: ISO Standards concerning with thermal comfort (Nicol and Humphreys, 1995)

ISO 7730	Moderate thermal environments- Determination of PMV and PPD standards
ISO 14415	thermal comfort for people with special requirements
ISO 13732	Comfortable contact surface temperature
ISO 14505	Assessment of vehicle environments
ISO 7726	Measuring instruments
ISO 8996	Determination of metabolic heat production
ISO 9920	Estimation of clothing properties
ISO 10551	Assessment of the influence of the thermal environment using subjective judgment scale

ISO 7730 is one of these standards. It relates to PMV and PDD thermal indices and applies to people present in internal spaces (Fanger, 1970). It demonstrates a method to predict the thermal sensation and the people's discomfort levels exposed to a moderate thermal environment. An acceptable thermal environmental condition is also specified to predict the comfort zone for people living in indoor spaces (Nicol and Humphreys, 1995).

3.3.2. ASHRAE standards

The American Society of Heating, Refrigerating and Air Conditioning Engineers, ASHRAE, published a series of standards related to HVAC systems. ASHRAE Standard 55(2004), Thermal Environmental Condition for Human Occupancy, has useful guidelines about indoor environmental conditions which are thermally acceptable. It produces thermally acceptable environments for specific group of occupants. PMV and PPD calculation methods and the idea of adaptation are defined in this standard, which is generally used in design and testing of buildings thermal performance, as well as their HVAC systems. It also refers to evaluating the thermal conditions of internal environments. The aim of this standard is to describe the mixture of personal factors and indoor thermal environmental factors which will generate acceptable thermal environmental conditions for most occupants (ASHRAE, 2004).

3.4. Predicted mean vote, predicted percentage of dissatisfied

Per Olaf Fanger is a Danish scientist who developed a set of equations which allows calculating the average thermal comfort sensation to design thermally controlled indoor spaces. It is known as PMV and is based on studies in controlled environment chambers (Kotbi et al., 2010). According to CIBSE (2003), Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) are two thermal indices. *"PMV predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale"* (e.g. hot, warm, slightly warm, neutral, slightly cool, cool and cold) and the occupants have the same clothing insulation and activity in the same environment. However, *"PPD establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from PMV" (ASHRAE, 2004).* Fanger (1970) stated that a condition for absolute thermal comfort can be defined by the satisfaction of the thermal equation. PMV equation for thermal comfort is a stable state and it only demonstrates how different thermal comfort variables should be mixed to produce optimal thermal comfort for occupants (Fanger, 1970). To predict and measure the thermal sensation of people for any mixture of 6 comfort factors, a seven point ASHRAE scale is generally used, which is defined to determine people thermal perceptions. It is a numerical scale and allows for statistical analysis (ASHRAE, 2005). Table 3.4 shows the seven point ASHRAE thermal sensation scale:

Table 3.4: ASHRAE Thermal sensation scale (ASHRAE, 2005)

Index value	Thermal sensation
+3	Hot
+2	Warm
+1	Slightly warm
0	Neutral
-1	Slightly cool
-2	Cool
-3	Cold

As discussed previously, the PMV equation for thermal comfort is a steady model. The graph below presents the PPD as a function of the PMV (see Figure 3.1). It is based on a method that usually applies to a group of people in the same space who undertake activities with an average metabolic rate between 1.0 met and 2.0 met and with average clothing insulation of 1.5 clo or less. Moreover, the PMV model is related to six factors of thermal comfort mentioned in section 3.2 and the PPD index is referred to the PMV, as shown in Figure 3.1 (ASHRAE, 2004).

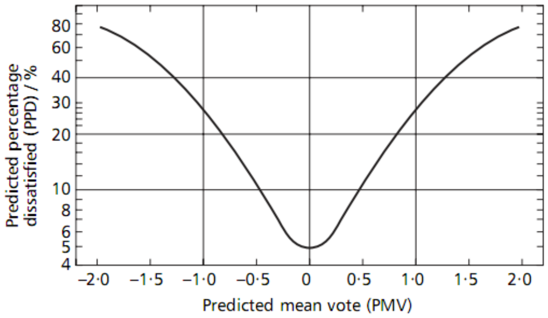


Figure 3.1: PPD as a function of PMV (CIBSE, 2007)

Table 3.5 shows three classes of thermal comfort which have been suggested by ASHRAE Standards 55 and based on PPD allowed. These ranges are for typical applications and should be specified by the occupants (ASHRAE, 2004).

Table 3.5: Three class of acceptable thermal environment for general comfort (ASHRAE, 2004)

Comfort Class	PPD	PMV Range
A	< 6	-0.2 < PMV < + 0.2
B	< 10	-0.5 < PMV < + 0.5
C	< 15	0.7 < PMV < + 0.7

According to ASHRAE Fundamentals (2009), thermal comfort and thermal sensation can be estimated in different ways. One way is using the ASHRAE model defined for winter and summer comfort zones (see Figure 3.2) and the other is referring to the PMV-PPD model that Fanger (1970) predicted.

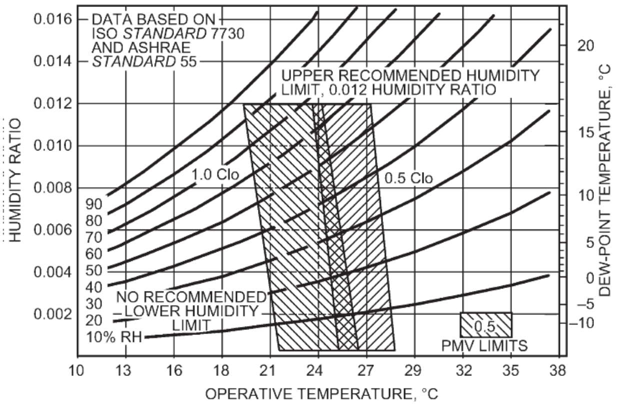


Figure 3.2: ASHRAE summer and winter comfort zones (ASHRAE, 2009)

Fanger (1970) stated that comfort data are closely related to physiological variables such as metabolic rate, mean skin temperature and sweat rate influencing heat transfer. As a comfort equation is quite complex, he used computer programmes to describe the mixture of thermal variables in various comfort diagrams for four different clothing values at three different activity levels. These diagrams determine comfort lines (ambient temperature vs. wet bulb temperature with relative velocity as parameter) that meet most of the requirements of thermal equations and will provide optimal thermal comfort (Fanger, 1970). Figures 3.3 to 3.5 present some examples of the comfort lines for persons with different activity in various clothing value:

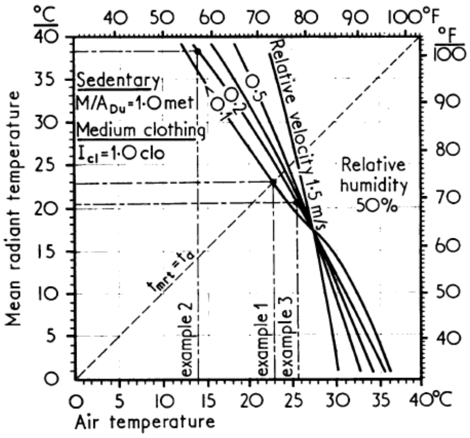


Figure 3.3: Combined impact of mean radiant temperature and air temperature for sedentary persons in medium clothing (Fanger, 1973)

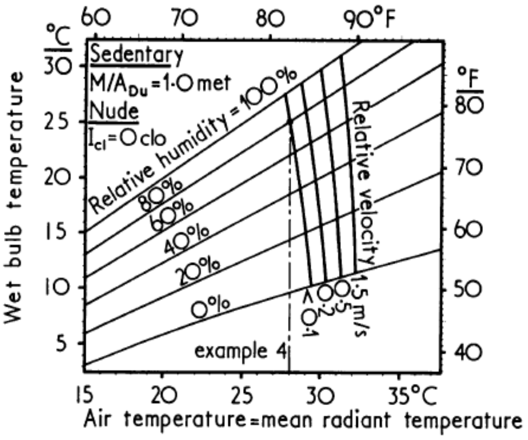


Figure 3.4: Humidity and ambient temperature for sedentary persons (Fanger, 1973)

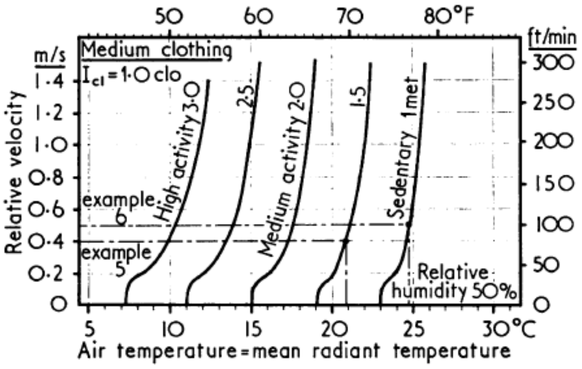


Figure 3.5: Combined impact of air velocity and ambient temperature for persons wearing medium clothing persons (Fanger, 1973)

3.5. Thermal adaptation

According to ASHRAE Fundamentals (2005), it is generally assumed that most people are able to adapt themselves to hot or cold environments by exposure to these environments. In order to examine the effect of adaptation on preferred ambient temperature, many studies have been carried out for many years. De dear et al. (1997) reviewed some studies about thermal adaptation in the built environment. His studies show that many thermal perceptions are affected most by the complexities of people's thermal history, and their cultural and technical performances. Moreover, behavioural adjustment, and physiological and psychological adaptation are usually related to thermal adaptation (Brager and de Dear, 2000).

Fanger carried out several experiments about adaptation in indoor environments. One of his experiments was conducted for two groups of people who were exposed to cold every day. The members of one group had been doing household jobs in cold environments for 8 hours every day for the duration of one year and the other group members swam in the sea every day in winter. In the other experiment, a group of people who came from tropical countries was tested in Copenhagen immediately after arriving by plane. The results showed that there were only small differences in desirable ambient temperature and physiological parameters in the comfort conditions between the two groups of people in the two experiments. According to Fanger (1973), people cannot adjust themselves to desirable warmer or colder surroundings and, as a result, the same comfort conditions can be used all around the world (Fanger, 1973). Based on Nicol and Humphrey (1973), there are considerable differences in clothing habits in different parts of the world, related to outdoor weather conditions, culture and religious views. However, thermal adaptation has a small effect on the preferred ambient temperature (ASHRAE, 2005).

3.5.1. Adaptive model of thermal comfort

According to Brager and de Dear (2000), ASHRAE Standard 55 has tried to supply an objective standard for thermal comfort and their primary aim was to provide guidelines for centrally controlled HVAC. In order to improve ASHREA Standard 55 to be a more adaptive field basis alternative for naturally ventilated buildings, a proposal have been suggested by ASHRAE- funded research and a series of research studies have been carried out. The results indicate that occupants of naturally ventilated buildings prefer a wider range of temperature compared to the occupants of centrally controlled HVAC buildings (see Figures 3.6 and 3.7). Figure 3.6 and Figure 3.7 compare a field-based adaptive model to a lab-based PMV model. They demonstrate that the relationship between outdoor temperature and indoor comfort temperature might be affected by thermal adaptation. In Figure 3.6 the observed and predicted lines are very close together, showing that comfort temperature can be estimated successfully by PMV in centralised HVAC buildings, but the observed line is twice as steep as the predicted line in naturally ventilated buildings. Brager and de Dear (2000) argued that *"behavioural adaptation, such as* *changes in clothing insulation or indoor air speed, could account for only half of the observed variance in thermal preferences of people in naturally ventilated buildings"* (Brager and de Dear, 2000).

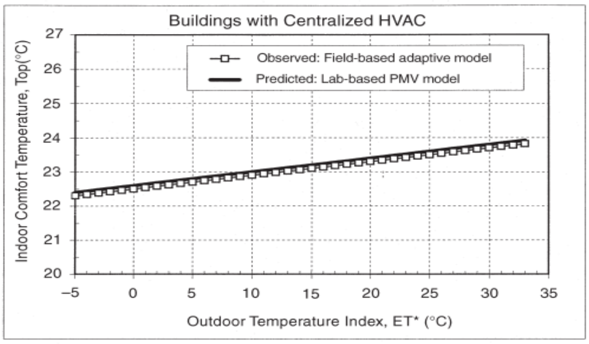


Figure 3.6: Observed and predicted comfort temperature in centralised HVAC (Brager and de Dear, 2000)

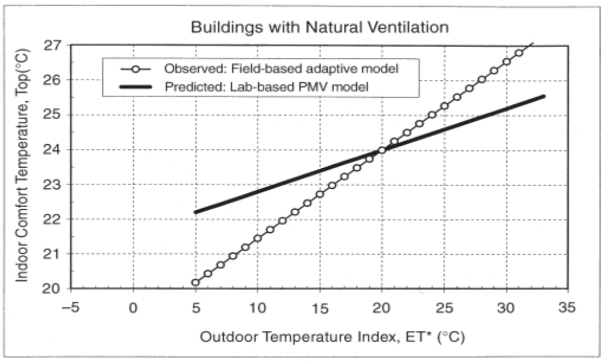


Figure 3.7 : Observed and predicted comfort temperature in Naturally Ventilated buildings (Brager and de Dear, 2000)

3.5.2. Fanger vs. Adaptive thermal comfort

Current comfort standards are necessarily based on heat balance or adaptive thermal models. Different models like Fanger and Adaptive are mostly for defining the comfort zone (Saberi et al., 2006). One of the most significant models developed by Fanger (1970) is the Predicted Mean Vote (PMV) (Hooi Chyee Toe and Kubota, 2013) which were discussed in detail in section 3.4. The Fanger model is applied to the International Organization for Standardisation 7730 (ISO 7730, 2005) and ASHRAE Standard 55 (2004). Another model is also used in ASHRAE Standard 55 for naturally ventilated buildings, and in European Standard (EN) 15251 for buildings without mechanical cooling systems (Hooi Chyee Toe and Kubota, 2013). Fanger used a heat balance equation to predict a value for a degree of thermal sensation. The heat balance model analyses thermal physiology in detail by assuming controlled steady-state conditions and high accuracy for six analysed variables, including air temperature, mean radiant temperature, relative air speed, humidity, metabolic heat rate and clothing insulation (Fanger, 1970). The Fanger comfort equation is based on experiments with American college age persons.

On the other hand, the adaptive thermal model, which was discussed in section 3.5, verifies the links between the occupants and their surroundings, based on the occupants' indoor thermal satisfaction and by investigating the methods of maintaining the comfort level in the buildings. In terms of the adaptive model, it can be said that thermal comfort temperature is a function of outdoor temperatures (Nicol and Humphrey, 2001). The adaptive thermal comfort model is the correlation between indoor neutral temperature and outdoor temperature. The adaptive model employs one set of entry data and gives the comfort zone or neutral temperature for free running buildings, which is easy to use (Saberi et al., 2006). Hence, the adaptive model has higher flexibility in linking ideal indoor temperatures with outdoor climate, especially in naturally ventilated buildings (de Dear et al., 1997, Nicol and Humphrey, 2001). Fanger’s model underestimates the thermal impression in the actual case. Field studies show that, in a naturally ventilated building, PMV predicts thermal sensations to be warmer than those that the occupants actually feel; thus is no longer valid for use in certain climates (Chew and Yau, 2014). Therefore, the adaptive standards are more appropriate for defining the comfort for indoor spaces (Nicol and Humphrey, 2001, Brager and de Dear, 2000).

3.6. Neutral temperature and comfort temperature

Based on Fanger (1970), the condition in which the occupants prefer neither cooler nor warmer environments is thermal neutrality. The neutral temperature is the temperature at which people experience a thermal sensation, which is neither cold nor warm. At this temperature the mean vote of the occupants regarding their thermal sensation is in the middle of the seven point ASHRAE scale. Under the adaptive standard, various field studies have been carried out to analyse the neutral temperature. The results agree with the primary argument of Humphrey (1978), which was the correlation between the thermal sensation of the occupant and the monthly average of outdoor temperature. In addition, comfort temperature is the temperature at which the individuals state their comfort feelings by voting within the middle category of the comfort scale, known as comfortable. In spite of this, and because of similar results from thermal sensation and comfort scales, comfort temperature can be the same as the neutral temperature (Heidari, 2000).

3.7. Preferred temperature and acceptable conditions

Although individuals might vote in the middle of the thermal sensation scale or comfort scale, they might prefer a cooler or warmer environment below or above the middle category (McIntyre, 1980). The preferred temperature is the temperature at which an occupant prefers no change in indoor air temperature or the majority of occupants vote for no change in indoor air temperature. A preferred temperature can be obtained through a direct question and by using present time conditions: would you like to be: Cooler or No change or Warmer? (McIntyre scale). If most of the occupants prefer no change, the indoor thermal condition can be acceptable for the subject. Another more common method is an indirect measure that represents acceptability within the central three categories of the seven-point thermal sensation of ASHRAE scale. Based on ASHRAE standard 55 (2004), if 80% of the subjects vote in central three categories of the ASHRAE scale (slightly cool, neutral, slightly warm), it shows the thermal acceptability of the environment. Generally, to predict the neutral or comfort temperature, a recognised equation is used which determines the neutral temperature as a function of the average outside temperature. The simple linear regression formulated by simple equation is thus:

$$T\boldsymbol{n}=b+\boldsymbol{a}X \qquad \text{Eq. 3. 2}$$

Where:
Tn is neutral or comfort temperature
X is monthly mean air or glob temperature
a is slope of regression
b is regression constant

3.8. Neutral temperature in various studies

Several studies were carried out to find the relationship between neutral temperature and indoor air temperature. Humphreys (1976) carried out a series of field studies in Africa, America, Australia and Europe which had various weather conditions, including warm-dry, warm-humid, temperate, Mediterranean and cold. He found a strong relationship between mean indoor air temperature (Ti) and neutral temperature (Tn). The founded Tn value varies from 17°C to 30°C. The related equation is

$$Tn = 0.83\ Ti + 2.56 \qquad \text{Eq. 3. 3}$$

Auliciems and de Dear (1986), defined another equation that presented comfort as a function of mean indoor air temperature:

$$T\boldsymbol{n} = 0.73\ T\boldsymbol{i} + 5.41 \qquad \text{Eq. 3. 4}$$

Heidari and Sharples, conducted long term and short term thermal comfort studies in Iran to identify a neutral temperature for the city of Ilam. Their proposed equation for neutral temperature in the short term studies is presented below with regards to indoor air temperature:

$$T\boldsymbol{n} = 0.68\ T\boldsymbol{i} + 7.42 \qquad \text{Eq. 3. 5}$$

However, a different equation was obtained for the long term studies:

$$T\boldsymbol{n} = 0.76\ T\boldsymbol{i} + 5.54 \qquad \text{Eq. 3. 6}$$

Based on Humphrey (1978), there is a strong relationship between the monthly mean outdoor temperature and indoor comfort for free-running buildings. The related equation is

$$T\boldsymbol{n} = 11.9 + 0.534\,\boldsymbol{Tout} \qquad \text{Eq. 3. 7}$$

Auliciems and de Dear (1986) proposed another equation based on the outdoor temperature. They used a broad database from different climatic regions of the world, including tropical, warm-humid, Mediterranean, equatorial humid, cold, and humid subtropical, as well as desert and semiarid. The following equation is for free-running and air conditioned buildings.

$$T\boldsymbol{n} = 17.6+0.31\,\boldsymbol{Tout} \qquad \text{Eq. 3. 8}$$

In Heidari's (2002) short term studies, the proposed equation for neutral temperature is very close to Auliciems and de Dear's equation (see Eq.3.8):

$$T\boldsymbol{n} =17.3+0.36\,\boldsymbol{Tout} \qquad \text{Eq. 3. 9}$$

The data from the long term studies of Heidari (2002) give the following equation:

$$T\boldsymbol{n} =18.1+0.292\,\boldsymbol{Tout} \qquad \text{Eq. 3. 10}$$

From the Heidari and Sharples' (2002) thermal comfort studies in Iran, it was found that for the hot season, the neutral temperature for the short term and long term studies was from 26.7°C to 28.4°C respectively. For the cold season the neutral temperature decreased to between 20.8°C and 21.2°C for the short term and long term studies which show a good agreement between both studies. Heidari (2010) conducted an extensive thermal comfort survey in Iran. Around 5000 sets of data were gathered during the 10 years of study in various climatic region of Iran. He confirms that the adaptive action in indoor environments depends on the outdoor temperature and causes various neutral temperatures in different seasons. According to his study, the indoor neutral temperature depends on outdoor temperature and can be obtained from the following equation:

$$T\boldsymbol{n} = 17.8+0.30\,\boldsymbol{Tout} \qquad \text{Eq. 3. 11}$$

This equation is very close to Auliciems' and de Dear's (1986) equation (see Eq.3.8) while the outdoor temperature should be between 5°C and 30°C. Heidari (2010) stated that Iranian people can achieve comfort at more than 30°C in the hot period and less than 20°C in the cool season. He also said that, in the hot and dry climate of Iran, people can make themselves comfortable if they wish between 16.5°C and 22°C in the cold season and between 28°C and 34°C in the hot seasons by adjusting their clothes, activity levels and air velocity (Heidari, 2010). However, based on ASHRAE 55 (2004), the thermal comfort boundaries were defined for 90% of the occupants acceptability at 5K (2,5°C on either side of the neutral temperature) and for 80% of occupants acceptability at 7K (3.5°C on either side of the neutral temperature) in a free-running building. On the other hand, Nicol and Humphreys (2001) stated that the range of acceptable conditions at any time was in the region of ±2°C, if the occupants have no control on the indoor condition to make themselves comfortable. However, giving them free control over the condition will increase this range.

3.9. Psychrometric charts

According to ASHRAE Fundamental (2009), a psychrometric chart illustrates the thermodynamic properties of moist air as well as giving illustrative solutions to many moist air problems. Seven different psychrometric charts for different altitudes were developed by ASHRAE and oblique-angle coordinates of enthalpy and humidity ratios were used in every chart. A psychrometric chart describes thermodynamic properties of moist air such as dry-bulb temperature, web-bulb temperature, dew point, relative humidity, humidity ratio and specific volume. Figure 3.8 shows the ASHRAE psychrometric chart number one.

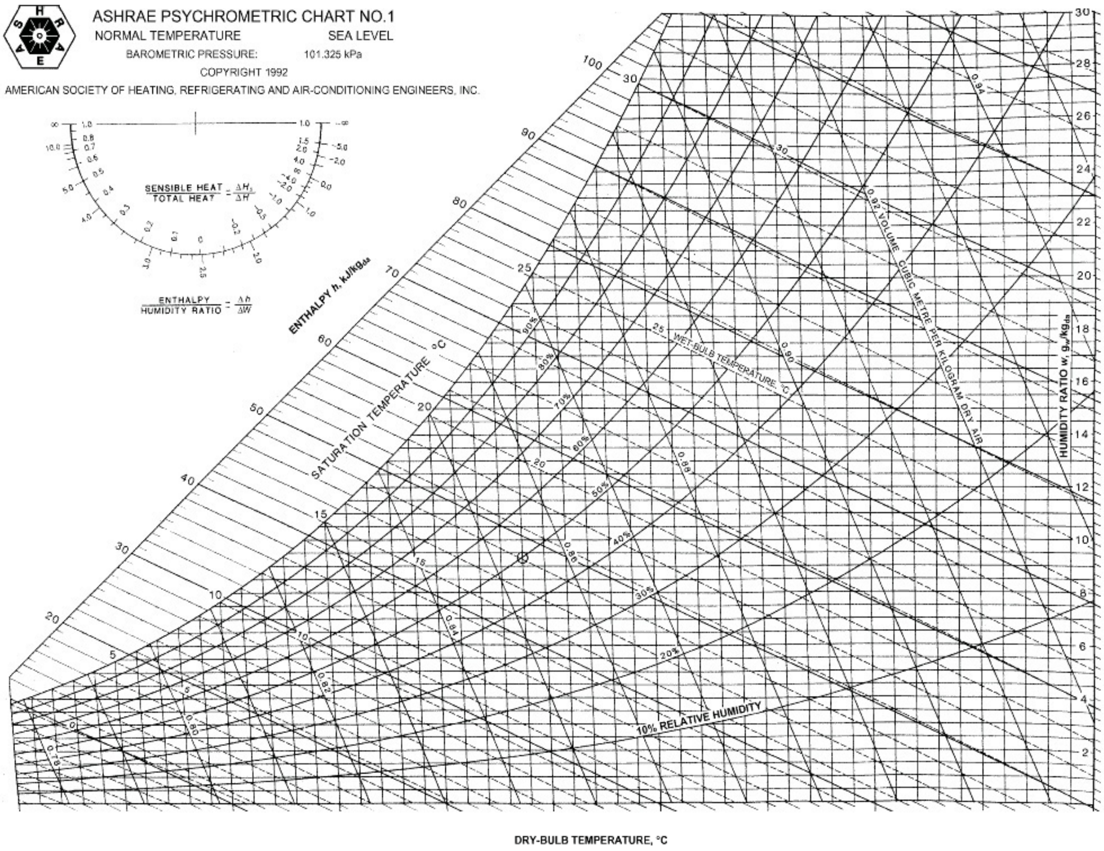


Figure 3.8 : ASHRAE Psychrometric Chart No. 1 (ASHRAE, 2009)

One of the advantages of the psychrometric chart is that, if three independent properties of climate factors are known, the other properties can be found easily. Much examination and modification has been done on the ASHRAE psychrometric chart in order to specify the comfort zone for different regions (Givoni, 1998).

3.10. Building bioclimatic charts

A bioclimatic chart is a diagram which illustrates the climate characteristics of a specific location and represents the human comfort zone on a psychrometric chart. They can also provide some guidelines for building designers to increase the internal comfort conditions when the building naturally ventilates (Saberi et al., 2006). The Bioclimatic charts were developed by several researchers, such as Olgyay (1973) and Givoni (1976).

3.10.1. The bioclimatic charts of Olgyay

The first person who defined Bioclimatic chart was Olgyay (1973). He developed the chart to incorporate the outdoor climate variables into a building design in order to create comfortable indoor spaces for occupants. The chart shows the relationship between occupant comfort zones and climatic factors such as humidity, mean radiant temperature, wind speed, solar radiation and evaporative cooling and it is mainly based on climatic factors (Saberi et al., 2006).

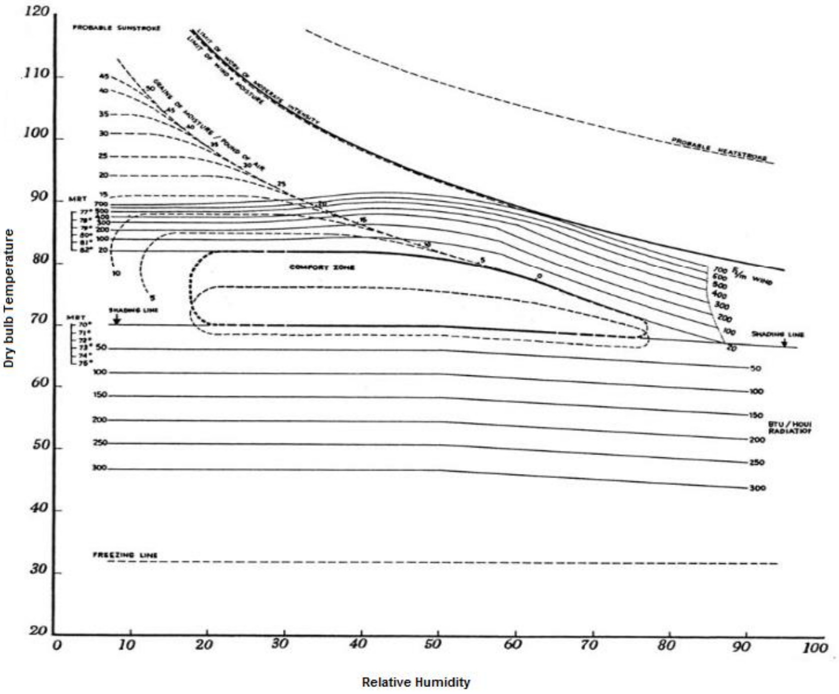


Figure 3.9: Bioclimatic Chart of Olgyay (Olgyay, 1973)

Figure 3.9 shows the bioclimatic chart of Olgyay. The diagram specifies the comfort zone in the centre, with winter and summer ranges and upper and lower limits. The relative humidity in this chart is defined as abscissa and temperature as ordinate (Givoni, 1998). When the temperature is higher than upper limit of the comfort zone, it is described as “overheated”. If the temperature and relative humidity drop below the lower limit, shading is needed to maintain comfort, but if they rise above the upper limit, the cooling effect of air is necessary to reach the comfort zone (Olgyay, 1973).

3.10.2. The bioclimatic charts of Givoni

Givoni modified the Olgyay's Bioclimatic chart and developed a new diagram to predict the indoor condition of the spaces according to outdoor weather conditions and is based on the indoor temperature in the buildings. The Givoni's chart indicates the boundaries of the climatic conditions within different building design strategies. It also suggests that passive and low energy cooling systems can provide comfortable indoor spaces in hot climates without air conditioning. The cooling options include daytime ventilation, high mass with or without nocturnal ventilation, and direct and indirect evaporative cooling (Givoni, 1998). The chart combines different temperature amplitudes and vapour pressures of the ambient air shown on the psychrometric chart and associated with specific boundaries of the passive cooling techniques presented in the diagram (see Figure 3.10).

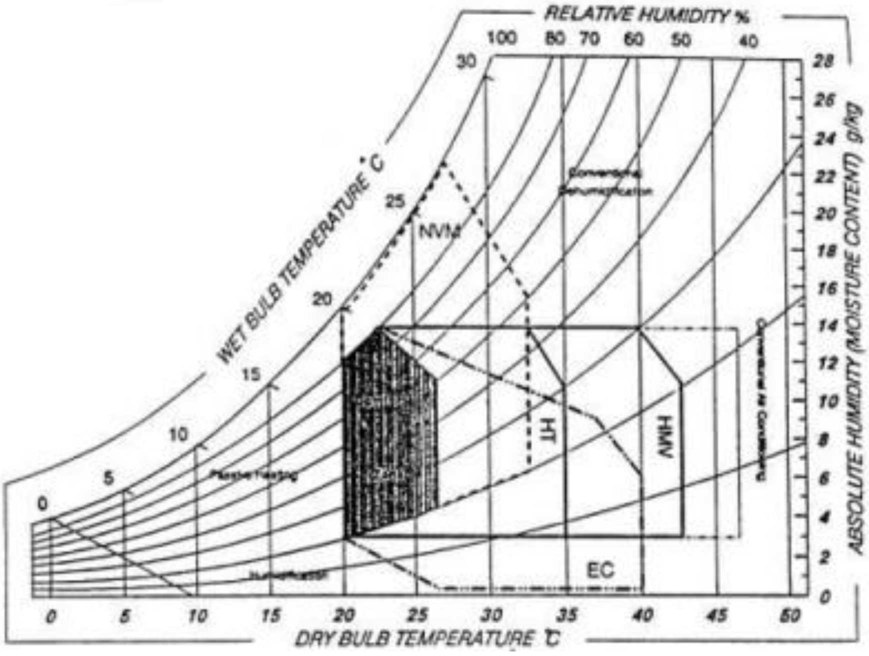


Figure 3.10: The Bioclimatic charts of Givoni

3.11. A review of thermal comfort studies in school buildings

In order to create a comfortable and healthy learning environment for students, the main subjects that need to be considered during the design process are lighting, ventilation, acoustics, and thermal comfort. It is suggested that all four factors should be studied in the early stages of design and also it should be planned to design comfortable educational environments (Scottish Executive, 2007). According to CABE (2008), investigating the environmental comfort in schools is very important because children are very sensitive to temperature variations, and considering their physical comfort is a critical issue. Providing comfortable thermal conditions in classrooms is also necessary to increase students' concentration levels and reduce the heat stress, particularly in countries with hot climates (Prescott, 2001). It has been argued that the thermal conditions of school buildings need to be convenient to the activities and clothing of the students (DfES, 2003a).

As described in Section 3.2, thermal comfort is a measurement of people's interaction with their thermal environment. Moreover, temperature, humidity, air movement and air quality are four main factors that are considered in thermal comfort studies (Scottish Executive, 2007). Thermal comfort is a balance between the heat produced by the body and its heat loss. Usually the hourly rate of heat production by the children changes with their activities (DfES, 2003a). One of the main goals of studying thermal comfort in school buildings is to design a space which students feel satisfied with and is neither too hot nor too cold, so they can concentrate more (Scottish Executive, 2007). Hussein et al. (2009) cited that thermal comfort is usually influenced by heat, convection, radiation and evaporative heat loss and actual thermal comfort standards are based on laboratory research developed in climatic chambers. However, the interaction between students and their environments, which could affect their comfort, is ignored. The surveys on thermal comfort in classrooms show that occupants are comfortable in a wider range of conditions and can adapt themselves to the environment quickly. This interaction needs to be considered in order to design sustainable school buildings for the adaptive approach. As a result, thermal comfort is introduced, which is based on the field study experiments and thermal comfort survey results (Hussein et al., 2009). The adaptive approach tries to present what enables people to feel more comfortable and suggests some useful guidelines for building design (Nicol, 2008). In order to understand thermal comfort in educational buildings and predicting comfort zones in different seasons, some field study experiments on thermal comfort in schools are reviewed.

3.11.1. Thermal comfort in classrooms in the tropics

A two day field experiment on thermal comfort was carried out by Wong and Khoo (2003) in a secondary school classrooms in Singapore during the students' lesson hours in summer. All classrooms were mechanically ventilated by four ceiling fans. The aim of this study was to assess the thermal conditions of classrooms during the students' lesson hours, and the main objectives of the study were:

- To examine and compare thermal conditions of classrooms with that recommended by ASHRAE Standard 55 (2004).
- To find out the students' thermal comfort perception in classrooms and their acceptable temperature.

Reviewing the experiment shows that the field study was conducted in two days and thermal comfort variables were measured while 506 respondents completed a thermal comfort questionnaire on their sensory reactions to the indoor environment of classrooms. The indoor air temperature, relative humidity and air velocity were measured with data loggers as well as metabolic rate and clothing insulation. All measurements were taken at the height of 0.6 metre above the floor at students seated level. The study results determined that, although thermal conditions in classrooms were not falling within the comfort zone of the ASHRAE 55 Standards, most of the students were satisfied with the conditions, which shows that the ASHRAE 55 Standard is not acceptable for free-running buildings. In addition, a new PMV model was founded in this study which combines two common forms of adaptation-reducing activity: pace and expectation. The result shows that there is a difference in predicting actual thermal sensations, particularly at lower temperatures.

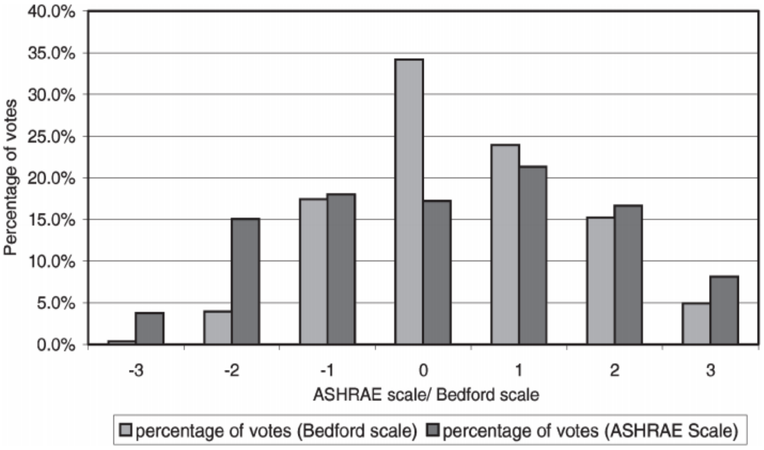


Figure 3.11: Distribution of votes on the ASHRAE Bedford scales on both days (Wong and Khoo, 2003)

In this research several methods of assessing thermal acceptability, such as Bedford and ASHRAE, were studied and compared. It indicates that different scales give different results; and the Bedford scale gives the highest level of acceptability. Figure 3.11 shows the relative frequency of votes on the ASHRAE and Bedford comfort scales on two days. It indicates that the Bedford scale had larger number of votes compared to the ASHRAE scale (Wong and Khoo, 2003).

3.11.2. Field experiments on thermal comfort in classrooms in sub-tropical climate countries

Kwok, Chun (2003) and Hwang et al. (2006) also conducted Field experiments on thermal comfort in classrooms in the subtropical climate of Japan and Taiwan. Kwok and Chun (2003) carried out the field study to show the relationship between comfort and the physical environment in naturally ventilated and air-conditioned classrooms in Japan. The field experiment consisted of a survey questionnaire and physical measurements of indoor climate variables. 74 students responded to the survey during the field measurements. Moreover, another field study was led by Hwang et al. (Hwang et al., 2006) in 10 naturally ventilated and 26 air-conditioned classrooms in Taiwan, using survey questionnaire and field measurements of climatic variables in the classrooms. The aim of the research was to apply ASHRAE methodology for thermal comfort study in classrooms in Taiwan and find the important aspects which have an impact on students' thermal sensations. One of the most common findings in both studies is that indoor climate conditions in field studies of naturally ventilated classrooms felled outside the summer comfort zone of the ASHRAE 55 standards. However, most of the respondents found the indoor climate conditions acceptable. Nevertheless, physical measurements in air-conditioned classrooms felled within the ASHRAE 55 standard summer comfort boundaries and the students found the thermal environment acceptable.

3.11.3. Thermal comfort in Italian classrooms under free running conditions

Corgnati et al. (2009) investigated the thermal conditions of classrooms in North-West of Italy during heating and mid-season in free running conditions. The field experiment was carried out by measuring the indoor climate variables, such as indoor air temperature, mean radiant temperature, relative humidity, air velocity and outdoor air temperature. It was also based on behavioural observations and a survey questionnaire on thermal sensations, thermal acceptability and thermal preference, using subjective scales during lesson hours. The study was carried out in two university classrooms in three different surveys and a total number of 230 students were interviewed. The Predicted Mean Vote and Predicted Percentage of Dissatisfied people in addition to clothing insulation and metabolic heat rate were also calculated and an adaptive model was applied to get acceptable ranges for the indoor operative temperature. The result of the questionnaire survey was compared to the results of the field measurements. Furthermore, the results of field study during mid-season were compared to the hot season and it shows a trend characterised by a steady change in thermal preference from the hot season to the mid-season.

Based on Corgnati’s (Corgnati et al., 2009) experiment, the main findings of correlation between the prediction and observed subjective responses are as follows:

- Thermal indoor environments which are assessed to be “neutral” or “slightly warm” are accepted by occupants.
- In thermal environments which are predicted “neutral”, ‘‘no change’’ people prevail and there are nearly no votes of ‘‘wanting warmer’’ and ‘‘wanting cooler’’.
- In thermal environments which are assessed to be “slightly warm”, ‘‘no change’’ votes are a high percentage compared to ‘‘wanting cooler’’.
- In thermal environments which are assessed as being “slightly cold”, the percentage of ‘‘no change’’ is comparable to ‘‘wanting warmer’’ votes.

In this study an interesting hypothesis was suggested in regard to a trend in the thermal preferences, as a function of the season. The dashed line from the heating season to the mid-season shows a hypothetical trend, while the dotted lines from the mid-season to the warm season present possible continuations of the trend line, as shown in Figure 3.12.

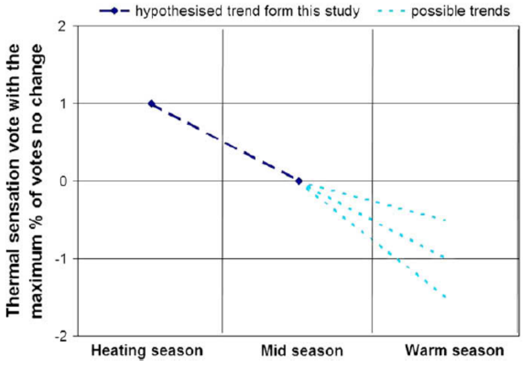


Figure 3.12: Trends of the thermal preferences as a function of the season (Corgnati et al., 2009)

3.11.4. Experimental study of human thermal comfort sensations in classrooms: evaluation of building envelope performance and questionnaire survey.

An experimental study was conducted in the University of São Paulo to assess methods of thermal performance of a building envelops and its correlation with human comfort sensations (Mendonça de Moraes et al., 2004). Climate variables of the indoor environment were measured in a classroom with 130 students at the beginning of autumn semester, and the data were recorded by data loggers in hourly occurrences. A questionnaire survey was also conducted to investigate the students' thermal comfort sensations. The classroom was monitored and simulated into several computational tools such as Arquitrop and Ecotect in order to compare the results with the comfort thermal sensation responses acquired from the questionnaire survey. The main aim of this study is to identify the limits of precision presented by building performance and human behaviour. In addition, further work was developed to apply the thermal comfort methods introduced by Fanger, ASHRAE, OLGYAY, Mahoney, Voght, Humprhreys and Givoni to study whether, and if so, to what extent, they illustrated limitations to human comfort zones in indoor spaces. For instance, the current study deals with the methods that define the value of the comfort zone to be analysed in optimised building conditions introduced as building providences. Figures 3.13 and 3.14 show the evaluations gained from the survey and deal with control issues.

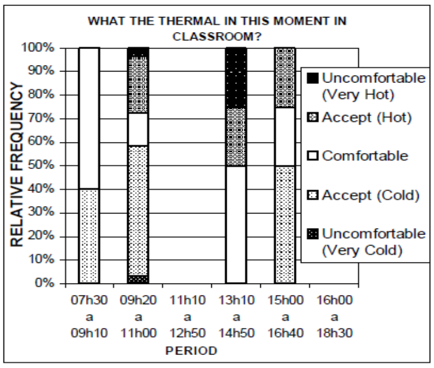


Figure 3.13: Evaluation questionnaire (Mendonça de Moraes et al., 2004)

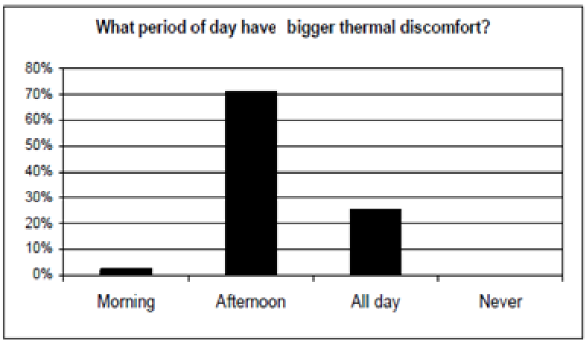


Figure 3.14: Evaluation questionnaire (Mendonça de Moraes et al., 2004)

One of the main conclusions of this research is that simulation tools are very important for predicting worst temperature scenarios and assessing the effectiveness of correction measures. However, they might not be useful alone to evaluate human thermal sensations and the thermal behaviour of a building. It is suggested that the real experimental building should be monitored as well as using the simulation tool, in order to achieve better simulator models for the prediction of occupants' comfort zones (Mendonça de Moraes et al., 2004).

3.11.5. A study of the thermal comfort of primary school children in summer

Humphreys (1977) conducted an experimental field study on thermal comfort and clothing of primary school children during the heating season. He said that the requirement of young children for thermal comfort is different from adults and even secondary school children. As there were no studies on the thermal comfort of primary school children, he decided to carry out a study on thermal comfort for children aged 7 to 9 in five primary schools. The field experiment was carried out by measuring indoor climate variables, such as temperature, by thermographs. A questionnaire survey was also carried out with a total number of 309 participants. The children were asked to express their sensation of warmth by choosing one of the 7 thermal comfort scales from "much too hot" to "much too cold". The important conclusions from this study are:

- Almost less than half of the children could use the thermal comfort rating scale to provide reliable information for analysis but their capability grew with their age. In order to provide more reliable results, it is suggested to develop a new method of investigation for younger children.

- It was found that the level of discomfort was associated with temperature variables rather than temperature itself. The study showed that fewer students were uncomfortable when the temperature was 2°C below the mean for the indoor environment. Humphreys (1977) expressed that the possible answer might be that children were sent to school wearing clothes which were warm enough for cooling hours but that they usually did not take off their clothes as the temperature increased during the day.

Chapter 4: Passive Design Strategies

4.1. Introduction

In this chapter passive design strategies are reviewed and the benefit of using these strategies in building design discussed. Based on Kasmai (2008), several passive design strategies can be employed in the buildings in the hot and dry climate of Tehran, which is cold in the winter period. These strategies include orientation, ventilation, shading devices, thermal mass, insulation and glazing, as well as lighting. The relevant passive design strategies are subsequently examined in this research (see Chapter 8 for further details) using thermal simulation to investigate the effect of these strategies on the climatic condition of the classrooms in the case study building and provide the optimum solution for female secondary school buildings in Tehran.

4.2. Benefits of passive design

Passive design means a low energy and energy efficient building. It uses building architecture to minimise the energy consumption of the building and improves the thermal comfort of the occupants. According to Mikler et al (2009), the correlation of the local climate with the shape and the thermal performance of the buildings is one of the main consideration of the passive design buildings, in order to reduce the energy use of the building and increase the thermal comfort of the occupants. In general, the foundation of passive design depends on simple concepts. It relies on natural sources of energy and reduces the need for mechanical systems for cooling, heating and lighting purpose of the building (Light House Sustainable Building Centre and Guido, 2009). Using the surrounding environment is one of the key factor in minimising the heating and cooling loads of the building as well as having low operating and maintenance costs (Jaques and Mardon, 2008). In addition, the concept of passive design is to let the daylight, heat and air flow in, when they are needed and exclude them from the indoor environment when they are not in need (Autodesk Ecotect Analysis, 2013). To put the passive design strategies into effect, the criteria of the thermal comfort, the local climate data as well as the building's thermal performance target should be examined first (Mikler et al., 2009). Using passive design strategies in the buildings has several benefits. It can provide a comfortable and healthy indoor environment with the minimum use of the mechanical systems in cold and hot seasons. It is affordable, and it also has minimum impact on the environment, as it minimises the energy consumption of the building (Simmonds Mills Architects, 2012).

4.3. Orientation and zoning

Building orientation is a feature which is described for any external walls of the buildings. Normally the angle between the north direction and the normal to the wall represents the building's orientation. However, it can be defined using cardinal points as well (see Figure 4.1). For instance, if the angle between the north and the normal to the wall is 75°, this facade can be defined as an East-oriented wall (Ford et al., 2007).

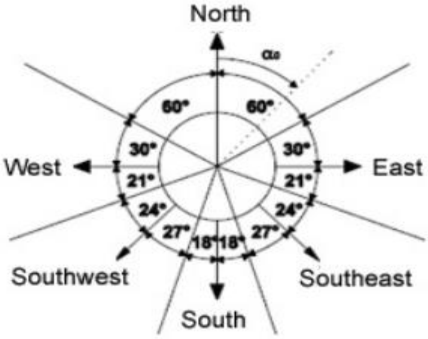


Figure 4.1: Orientation (Ford et al., 2007)

According Bansal et al.(1994), orientation is an essential factor in climatic building design, especially with regards to wind and solar radiation. They can be satisfactory or unsatisfactory in providing a good indoor environment depending on the climatic condition of the region and the seasonal changes. With accurate building design, solar radiation and the air flow can be excluded from the indoor environment or even redirected into the building, if and when they are needed (Bansal et al., 1994).

Generally the level of solar radiation received by the building facades creates variations between the external walls. The south-facing facade of the building receives maximum solar radiation in the northern hemisphere and can be considered as the main facade to get the maximum solar radiation during the winter period, and as a result reduces the required heating energy demands in heating seasons (Bahrami, 2008). Moreover, it is suggested that the long axis of the building lies east and west, with the maximum glazing area on the south-facing walls (Bansal et al., 1994). The location of the building zones should be considered carefully, based on the requirement for solar radiation in order to get the highest benefit from the shaded indoor area during hot and warm seasons, and from the wind protected area when the weather is cold (Autodesk Ecotect Analysis, 2013).

Building orientation is one of the main strategies for the passive design of a building. Facade orientation associates with solar shading, window to wall area ratio, windows position and performance, as well as building’s exterior colour in order to create a comfortable low energy building (Mikler et al., 2009). According to Mikler et al (2009), building orientation has an influence on the amount of solar radiation received by the building envelope. The roof surface, followed by the east and west facing walls, receive the highest radiation during the summer. As a result, for cooling purposes, in hot regions, it is advisable that the buildings’ long axis lies in an east-to-west direction, and that short walls face east and west to receive the minimum solar radiation (Bansal et al., 1994). However, during the winter season, south-facing facades gain the highest solar radiation, which can be used for heating purposes. The influence of the solar radiation during the hot and warm seasons can be decreased by considering a well-insulated envelope. Moreover, the amount of solar radiation received by the building facades in various orientations can be defined by the window-to-wall area ratio (Light House Sustainable Building Centre and Guido, 2009).

To get the benefits of passive solar heating, the building should be oriented to the direction which can capture the solar radiation in the desirable zones during the winter period when the sun angle is low. The window-to-wall area ratio on the west and east facing side of the building should be considered carefully, especially in the west façade, which gets the highest solar heat gain during the hottest time of the day (Mikler et al., 2009). Generally the window-to-wall area ratio should be at a minimum in the east and west facades, or glazing area should be avoided, if possible, as the solar radiation level is very low during the winter and the control of it is more complicated during the summer than on the south-facing side of the building (Ford et al., 2007). The east and west facing sides of the buildings are exposed to the low-angle summer sun during the morning and afternoon, which should be avoided in the hot season as they gain the highest solar heat gain (Autodesk Ecotect Analysis, 2013). On the other hand, the angle of the sun is higher in summer than winter. This allows the use of overhangs or horizontal shading devices to shade the windows during the summer and get the maximum use of the solar energy during the winter, when the angle of sun is lower and solar heating is required (Autodesk Ecotect Analysis, 2013).

In order to produce comfortable study spaces with the minimum energy use in the school buildings, the classrooms should receive the maximum solar heat gain during the winter and the minimum radiation during the hot and warm seasons. Moreover, the rooms which are used for short periods throughout the day, such as the dining room and meeting room, as well as unconditioned spaces, such as storage rooms, can be located on the west side or east side of the building to protect the study spaces from the hot morning and afternoon sun during the hot season (Bansal et al., 1994) or can be placed on the north facing side of the building, which gains minimum solar radiation in summer.

4.4. Building shape

Building shape is the characteristic of the building, which is described by the external walls that separate the indoor environment from the outdoor space (Ford et al., 2007). Many aspects have an impact on the building shape, such as building cost, the form of the surrounding buildings, functional requirements and aesthetics. However, the form of the building has an influence on the energy consumption of the building (Nicholls, 2006). Based on Mikler et al. (2009), a good building form can reduce the energy consumption of the building but sometimes factors such as the cost of the building, has an influence on the shape of the building, without any consideration of energy consumption, as discussed previously. Some common building forms can reduce the energy performance of a building in heating seasons. For example, increasing the envelope area to the volume ratio decreases the buildings heating demand in cold seasons (Mikler et al., 2009). In addition, buildings with a smaller envelope area can produce a better energy performance in the building (Light House Sustainable Building Centre and Guido, 2009). Also compactness is another important factor in reducing energy demands of a building in heating and cooling seasons in hot and cold regions, as the exposed surface area of the building is low (Kasmai, 2008). According to Nicholls (2006), changing the shape of the building can decrease the energy consumption in one area but at the same time increase the energy intensity in another. For instance, expanding an external area of the building envelope can increase the heat loss rate of the fabric but it allows the building to gain free energy flows. In addition, increasing the volume of the building increases the ventilation heat loss rates. However, ventilation and cooling energy consumption of the building decreases in warm and hot seasons, so it is very important to adjust the overall reduction in building energy consumption during the cooling and heating seasons (Nicholls, 2006).

4.5. Solar radiation and shading devices

A shading device is a part of window design. The design of shading devices has two important purposes. One is controlling the lighting levels or outdoor views from inside the building; and the other is to avoid heat gain (Gelfand and Freed, 2010, McLeod et al., 2011) and overheating during the summer, especially where south-facing walls' glazing is maximised (McLeod et al., 2011). However, they should not be a barrier to preventing daylight and natural ventilation from reaching the indoor environment through the glazing area (Ochoa and Capeluto, 2008). Seasonal shading is essential in passive design strategies. Shading against the long angles of summer sun in the west, east and south facades should be considered as well during the design process (McLeod et al., 2011). Various types of shading devices have been used in vernacular architecture for many years. Louvers, shutters, blinds and overhangs are some of the common types of shading devices which are included in passive building design to control heating and glare (Baker, 2009). Also cooling energy demand can be reduced by applying an appropriate shading device to the windows to reduce the extra heating during the summer season. However, they should be designed in an adequate way to let the sun in during the winter period and avoid it reaching in during the hot period (see Figure 4.2) which consequently helps to reduce the cooling and heating demands in the summer and winter seasons (Bahrami, 2008).

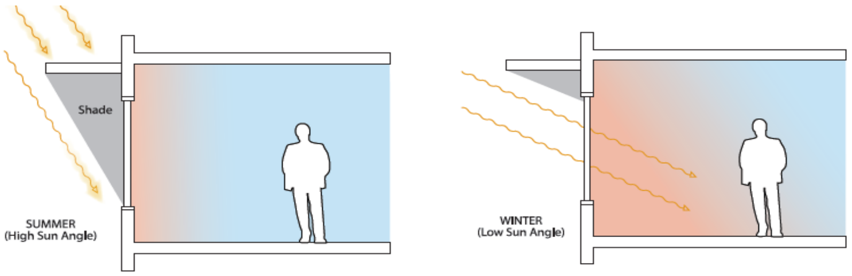


Figure 4.2: Winter and summer performance of the external overhangs (Mikler et al., 2009)

Shading devices are categorised in four types, including external, internal, interpane and integrated and can be applied to the exterior or interior sides of the glazing area (Mikler et al., 2009). The effect of external shading devices is greater than internal ones and can reduce solar gain during the hot season (McLeod et al., 2011) but internal shading devices are cheaper (Baker, 2009). The differentiation between the external and internal shadings is considerable (see Figure 4.3) because each type of shading has various effects on the aesthetic, daylighting, comfort and mechanical energy system requirements, although both prevent solar rays from reaching in (Mikler et al., 2009).

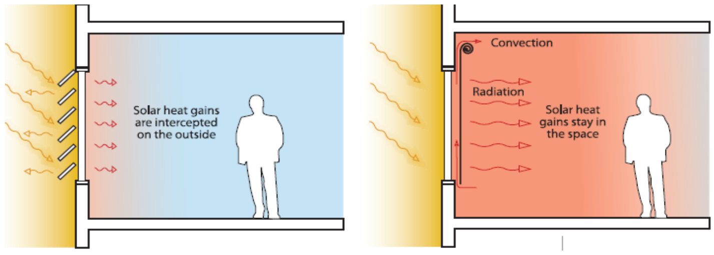


Figure 4.3 : Example of the effect of internal and external shadings (Mikler et al., 2009)

External shading devices can be classified into five variations:

- Overhangs (fixed or retractable)
- Louvers (fixed, retractable and adjustable)
- Fins (fixed and adjustable)
- Blinds (retractable)
- Perforated Screen (fixed) (Baker, 2009).

However, internal shading devices are more limited and the most common types of internal ones are horizontal louver and roller blinds. Interpane shading refer to devices held between the cavity of a double skin envelope and integrated shading are devices such as light shelves which address selective shadings and consist of a combination of the above types (Baker, 2009). In addition, curtains can be used to improve the performance of the glazing area but they are not as effective as shading devices, as the solar heat gain is already inside the building envelope. Blinds can decrease glare, but they are not able to block solar heat gain properly (Light House Sustainable Building Centre and Guido, 2009). Moreover, interior shading devices limit the view and air movement inside the building (Sharma et al., 2003). Automated shading devices, such as automated blinds, cannot be considered as passive, as they consume energy (Light House Sustainable Building Centre and Guido, 2009). As mentioned before, external shadings have a better effect on improving the quality of the indoor environment than internal shadings. External shading absorbs and reflects solar rays before it reaches the external surface of the building, which causes lower external heat gain through the building's external surfaces and lower temperature on the building's envelope (Mikler et al., 2009). In addition, they can be either adjustable or fixed, based on the outside view, air movement and lighting and the rain direction (Sharma et al., 2003). However, although internal shadings avoid the solar radiation being diffused to internal spaces, solar energy is still conducted through the window frames and the warm surface will heat the indoor environment (Mikler et al., 2009). Overall, shading devices should be designed based on surface orientation with the consideration of seasonal variation in temperature and the angle of the sun, to supply a suitable performance in winter and summer (Mikler et al., 2009). According to Givoni, 80% of solar heat gain can be reduced through the glazing area by applying adjustable and moveable shading devices (Givoni, 1981).

4.6.Glazing and solar energy

Windows are one of the most considerable components of buildings in providing comfort within the indoor environment in warm and cold seasons. Glazing areas can be used for natural ventilation and allow for outdoor views, as well as providing daylight through external walls (Mikler et al., 2009). Windows are the most energy-transmissive materials of the buildings' envelope, and as a result it has a significant impact on the buildings performance (Baker, 2009) and should be carefully designed, based on passive design strategies in order to provide a comfortable environment for the occupants and reduce the mechanical energy demands of the buildings. Windows in general can save the indoor spaces from undesirable heat gain and heat loss during the summer and winter periods consequently. The thermal quality of the glazing area has an effect on its performance in terms of heat gain or heat loss. Solar radiation transmits through the window into the indoor environment and can heat the indoor space, which is essential for the cold seasons and should be avoided during the warm period, as it may cause overheating during the summer season (Light House Sustainable Building Centre and Guido, 2009).

As discussed before, the heat loss and the heat gain through the windows should be considered carefully during the design process, to provide comfortable indoor space. Heat loss through the glazing area depends on the windows U-value. The decrease in the U-value of the windows results in lower heat loss through the glazing area in the winter period and also reduces the building heating energy demands (Ford et al., 2007). Based on Baker (2009), thermal and optical transmittance are the key aspects of windows which affect the performance of glazing in terms of daylight and the outdoor view. They also keep the heat in or out when it is needed. There should be a balance between U-value and the optical transmittance of the windows, as increasing the glazing area lets more daylight in. However, it increases heat transmission at the same time (Baker, 2009) which should be avoided in the cold seasons. Thermal Transmittance of the windows refers to the U-value of the glazing area. Lower U-value causes lower heat loss. The example of the typical U-value of the most used glazing types has been stated below:

- Single glazing: 5.4 W/m^{2}K.
- Double glazing. 2.8 W/m^{2}K.
- Triple glazing. 1.9 W/m^{2}K.(Baker, 2009).

Window replacement with a lower U-value shows a significant improvement on the thermal performance of indoor spaces, especially during the winter season, and also on the north side of the building. It also reduces infiltration rates of buildings (Ford et al., 2007). Other than insulation or the U-value of the glazing area, the area of the window and its framing type are another additional thermal characteristic of the glazing area (Mikler et al., 2009). The amount of window-to-wall ratio has a significant impact on the energy consumption of the building. The larger window areas on the east, west and south-facing sides of the building allow more solar gain during the winter but cause more heat loss at the same time through the glazing area (Mikler et al., 2009). In addition, the solar radiation which gets into the room through the glazing area can reduce the heating energy demand in winter but increase the cooling energy demand in summer (Ford et al., 2007). Therefore, as a result, there should be a good balance between the window's size and its materials, as well as the location, to get the benefit of solar radiation in an appropriate season based on the climatic region of the area, and also to avoid overheating during the summer while benefitting from solar radiation in winter.

The conductivity of the windows' frames has an impact on thermal performance of buildings as well and can change the overall U-value of the gazing area (Light House Sustainable Building Centre and Guido, 2009). For instance, the U-value of the double glazing low-e inert gas window, with an aluminium frame, is 2.7 W/m^{2}K, but the U-value of the double glazing low-e inert gas window with timber frame is 1.8 W/m^{2}K. The common materials used for the windows frame are aluminium, UPVC and wood. The thermal conductivity of UPVC is nearly as low as timber, 0.2 W/m°C and 0.13 W/m°C subsequently (Baker, 2009). The optical characteristic of the windows are mostly defined by the material of the glass and the location of the surface. The amount of light and heat that absorb, reflect and transfer through the glazing area define the optical characteristic of the windows (Mikler et al., 2009). Clear, tinted and reflective glass have a different energy transmission in relation to short wave radiation. Figure 4.4 shows the energy transmission of the various types of glasses. For example, the clear window transmitted 80% of solar energy, while the reflective windows transmitted only 25% of solar energy and reflected 70%, and absorbed the remaining 5% (Baker, 2009).

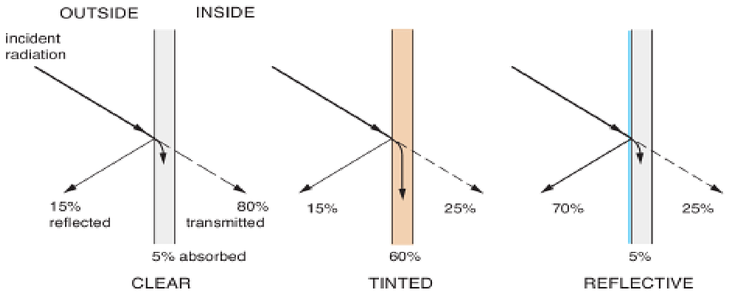


Figure 4.4: The transmission of energy through different type of glasses (Baker, 2009)

Overall, a well designed glazing area can reduce heat gain during the summer and prevent heat loss during the cold seasons which both help to reduce energy demands of the buildings as well as providing a comfortable environment for the occupants. An energy efficient design uses suitable materials for the windows, including glasses and frames. In addition, appropriate window-to-wall area ratios will balance aesthetics and energy performance of the buildings (Mikler et al., 2009).

4.7. Airtightness and infiltration

Achieving a good airtightness level within the building is an essential factor in reducing the heating energy demands of the building in cold seasons and preventing the moisture build up within the building materials, which reduces the energy performance of the building in winter (McLeod et al., 2011, Simmonds Mills Architects, 2012). Achieving a good airtightness level in the buildings requires using an appropriate membranes or barrier within building elements, such as tape and wet plastering (McLeod et al., 2011). Moreover, the junction of the buildings elements should be constructed without any gaps and cracks, to reduce air leakage (Ford et al., 2007) as this can cause buildings to lose around 25% of their energy (Light House Sustainable Building Centre and Guido, 2009). The leakage of the air through the unwanted gaps and cracks of the building can cause discomfort for occupants during the cold season, as the infiltration results in a lake of cold air and increases the temperature difference between the various floors of the building (Ford et al., 2007). Infiltration can occur through unwanted cracks around windows, doors and construction joints (Mikler et al., 2009). In general, common infiltration paths are junctions around main structural envelope elements; joints between buildings components; surroundings of opening areas, such as windows, doors and roof lights; gaps in membranes and finishes, during service penetration, and around access openings and through permeable materials (Webb and Barton, 2002).

On the other hand, a very airtight building without a ventilation system can have a bad indoor air quality and have an excess humidity which reduces the comfort level of the indoor environment. In order to reduce the risk of bad indoor air quality, a good ventilation system with heat recovery system is required in very airtight buildings (Ford et al., 2007). Careful consideration should be given to the buildings envelope and the intersection between the floors, joints of walls, openings and the roof (Light House Sustainable Building Centre and Guido, 2009). The difference between outdoor and indoor temperatures causes air flows through cracks, as they have various densities and can carry moisture as well, which diffuses with the air and can be gathered within the building fabrics. The extra moisture can be trapped within the buildings’ envelope and can cause discomfort in an indoor environment, as a result of growing fungus and mildew (Mikler et al., 2009).

Based on Mikler (2009), for high-performance heavy-weight envelopes it is suggested to use “sandwich like” assemblies with an almost thick layer of concrete or masonry which is adequately air tight and helps to keep infiltration at a satisfactory level. The thick layer should face the indoor environment to keep the effect of thermal mass but the layer of thermal insulation, with a protective vented rain-screen, should face the outdoor environment (Mikler et al., 2009). However, for the conventional lightweight envelope, assemblies such as steel or wood frames and a continuous vapour barrier should be applied to the interior face of the building's envelope or just at the back of the finished surface layer. A continuous rain screen should be applied on the exterior side of the envelope, with a thin vented air gap which separates it from the insulation to make the indoor environment air and moisture tight (Mikler et al., 2009).

4.8. Natural ventilation and passive cooling

Ventilation is a controlled flow of air into and out of a building through the building's openings, which can be mechanical or natural (Webb and Barton, 2002). Natural ventilation is a passive ventilation method used to circulate the air within buildings without relying on mechanical energy supplements (Baker, 2009). In order to supply fresh air for the indoor environment and exchange foul air with the minimum energy use, it is suggested to circulate the air by the provision of natural ventilation (Bahrami, 2008). When there is a difference between indoor and outdoor temperatures, fresh air can be provided for the indoor environment by natural means, while removing the warm and stale air (Light House Sustainable Building Centre and Guido, 2009). The influence of this type of ventilation relies on the airflow rate as well as the size, location and shape of the openings (Nicholls, 2006). Based on Givoni (1998b), ventilation helps to keep the indoor air quality in an acceptable condition by a regular supplement of fresh air. In hot climates the conductive heat loss from the body can be increased by natural ventilation to achieve thermal comfort by increasing the air flow rate around the body. In addition, it can decrease the temperature of the building structure mass by removing heat from the building while the indoor air temperature is higher than the outdoor temperature (Givoni, 1998b). It is important to consider passive ventilation for the building during the design process as various architectural factors may impact on the airflow rate within the building, such as the shape of the building, the layout of interior walls, floors and furniture, as well as prevailing wind direction (Mikler et al., 2009). There are three common types for natural ventilation including single sided ventilation, cross-flow ventilation and stack ventilation (Bahrami, 2008). Single side ventilation (see Figure 4.5) is the simplest approach to natural ventilation strategy (Mikler et al., 2009).

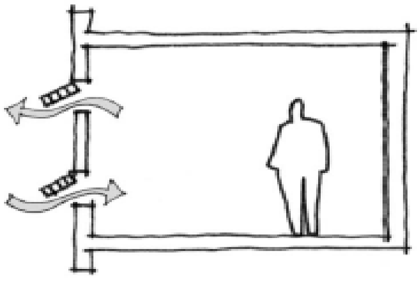


Figure 4.5: Single sided Ventilation (Mikler et al., 2009)

The outdoor air enters to the building through the windows on the exterior walls and move out from the same openings. This type of ventilation can be enhanced by the use of double openings (see Figure 4.6). Based on Nicholls (2006), single sided ventilation is available up to the depth of 6 m from the exterior wall and for deeper depth it is suggested to use cross ventilation if it is possible for up to the plan depth of 13 m without any partition across the space as it close the ventilation pathway.

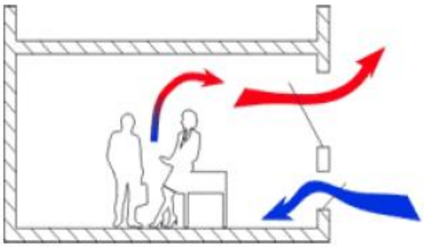


Figure 4.6: Double openings in single sided ventilation (Dyer, 2013)

Another type of approach to natural ventilation is cross-ventilation (see Figure 4.7) which is more effective than single-side ventilation, as the air enters to the indoor environment from the windows in the exterior walls while the warm and stale air moves out through the openings on the opposite side, which provides a higher air flow rate and, as a result, is more useful than single-side ventilation (Bahrami, 2008). In order to get the advantages of cross-ventilation in a unit, there should be at least two exposed walls to the outdoor environment (Mikler et al., 2009). For both single-sided ventilation and cross-ventilation, it is suggested to employ a high level of ventilation openings, which can clear the indoor pollutants without creating any draughts and causing any disturbance to the occupants (Nicholls, 2006).

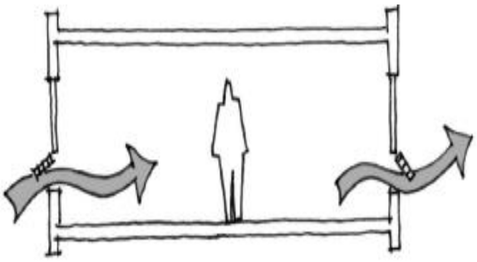


Figure 4.7: Cross-Ventilation (Mikler et al., 2009)

In larger buildings with considerable core space, it is suggested that stack ventilation (see Figure 4.8) with high spaces such as atria, a wind tower and stacks are used to create optimised solution for natural ventilation (Mikler et al., 2009). The indoor air moves out from the high level openings and the fresh air replaces from the lower opening in each unit (Dyer, 2013).

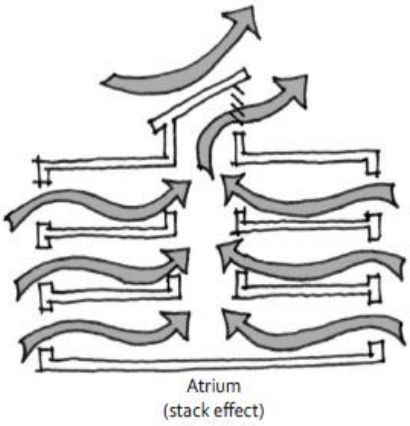
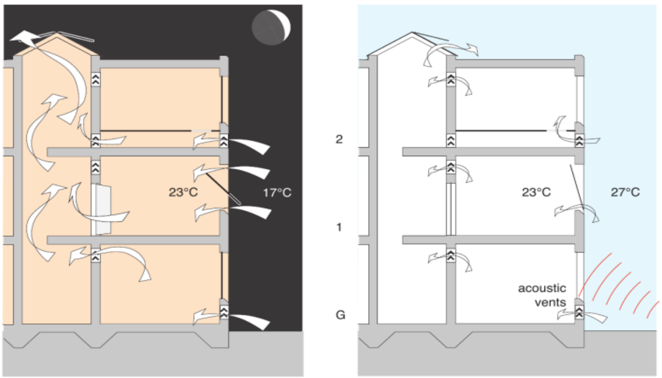


Figure 4.8 : Stack Ventilation (Mikler et al., 2009)

During the warm and hot seasons, natural ventilation system can be used as a passive strategy for cooling purposes, especially in hot climatic regions. However, it should be ensured that enough air quality is provided for the building without over-ventilation and infiltration during the cold seasons. Based on Baker (2009), “the principle is build tight, ventilate right”.

Night time ventilation is another strategy which can cool the high structural mass of the building (Baker, 2009). The outdoor air temperature usually drops during the night, compared to indoor air temperature (see Figure 4.9). This temperature difference can be used for cooling the building fabric in advance of the following day, as the cooled outdoor air temperature can enter the building through the openings and restore in the structural mass of the building and provide a heat sink for the internal heat gain during day time (Baker, 2009). In other words, in a hot day, the heat is absorbed by the internally exposed building mass and causes a steady increase in internal air temperatures, which usually reach the highest level during sunset, while the outdoor temperature decreases (Givoni, 1998a). To achieve the convective cooling of the building mass, there should be enough high air temperature difference between the ambient air and building structure during the night-time (Artmann et al., 2006). Based on Givoni (1998a), to achieve the maximum benefit from night-time ventilation, some practical factors in the design of the openings are suggested. These factors include type and total area of the openings, such as windows and the orientation of the openings with regards to the wind direction. Based on Lomas (2007), the drive of the airflow in naturally ventilated buildings is mostly caused by naturally occurring wind pressure, which is created by the internal heat sources. The pressure difference between inside and outside of the building is caused by the air movements produced by air temperature and winds (Hyde, 2008). To get the maximum benefit of the airflow rate which is required for the cooling purpose by natural ventilation, it is suggested that the airflow rate is kept within 10 air changes (Ghiau and Roulet, 2005).



maximum ventilation minimum ventilation

Figure 4.9: Night time ventilation vs. day time ventilation (Baker, 2009)

The airflow paths, as well as an adequate thermal mass, supply acceptable cooling in warm periods (Bahrami, 2008). One of the disadvantages of natural ventilation is the presence of external air and noise pollution in indoor environments, so the design should ensure naturally ventilated buildings are far from environmental pollution, such as main roads and factories, or the openings should be placed far enough from the source of these pollutants (Nicholls, 2006).

4.9. Thermal mass

According to Nicholls (2006), the thermal mass of a building is the capability of the internal materials to absorb heat and gradually release it. Thermal mass is used to define high thermal capacity building materials which can reduce the temperature fluctuation within the building on a diurnal and longer term basis. Thermal mass can be in the form of masonry walls, exposed concrete soffits to intermediate floors or embedded phase change materials. Mainly, thermal mass is any mass that absorbs and retains heat (Ford et al., 2007). When the external surface of a building facade absorbs heat and solar radiation during the day its temperature increases, based on the thermal capacity of the materials. If it has a high thermal capacity, such as block work and concrete, it can absorb more heat than the low thermal capacity materials, such as timber and plasterboard. This heat is then stored and transmitted in the building fabric and gradually released during the night to the indoor environment. The heat releasing period depends on the thermal capacity of the building's mass and the thickness of the material. Heavier denser materials have more ability to store heat and take much longer to release it (Gregory et al., 2008). Generally, an increase in wall density results in increasing the thermal mass of the building. However, it may not have any impact on the thermal resistance of the building (Chiraratananon and Hien, 2011). When there is a temperature difference between the building's mass and the surrounding temperature and the indoor air temperature is more than the interior side of the wall, the heat transfers from the room to the wall. However, when the wall temperature is higher than the room temperature, the heat moves from the wall to the room, which increase room temperature (Nicholls, 2006). In a building with high capacity materials, thermal mass of the building helps to reduce the peak temperature of the indoor environment, especially during the summer days, as the outdoor heat will be transferred slower to the indoor environment because of the high density materials. In addition, thermal mass can be cooled through night time ventilation, which reduces the cooling demands during the following day. On the other hand, during the cold season, the heat is absorbed by high thermal capacity material during the day and will be transferred to the indoor environment when the temperature decreases, during the night, and as a result decreases the building's heating demands (Bahrami, 2008). Studies show that ventilation and shading can enhance the impact of thermal mass (Sanjay and Chand, 2008), as it mostly depends on the shading and solar heat gain of the building (Sheta, 2012). Generally lightweight materials such as timber respond to temperature changes quickly and therefore it is suggested to use these materials in rooms which need to be cooled or warmed rapidly. However, heavyweight building fabrics, such as concrete, stone and brick, store heat during the day time and release it at night (see Figure 4.10).

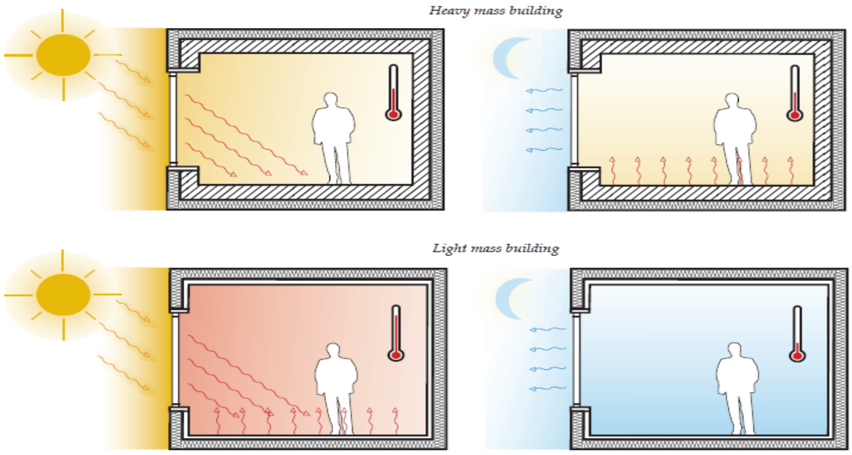


Figure 4.10: Effect of heavy and light mass buildings on the indoor air temperature (Mikler et al., 2009)

These materials can be used in the climatic regions which have a considerable temperature difference between day and night. If the heat that is gained through the day is higher than expected, it can be lost through night ventilation. The thermal mass of the building is a heat distributer that can delay heat transfer by up to 10-12 hours (Autodesk Ecotect Analysis, 2013). The thermal mass of the building has several advantages. It can reduce peak energy demands and, as a result, decrease energy use in the building. It can also help to maintain a more stable environment in the buildings (Mikler et al., 2009). Based on Jaques and Mardon (2008), several aspects need to be considered for designing the thermal mass of buildings. The most important aspects include the followings: existing building elements and heavyweight fabrics should be placed ideally in a well shaded area during the summer and should get solar radiation during the winter. It should also be well insulated on the outside of the building to get the most benefit of the mass (Jaques and Mardon, 2008). The effect of thermal mass is considerably useful when there is a significant various between daytime and night-time outdoor temperatures (Autodesk Ecotect Analysis, 2013).

In addition, there is an interrelationship between thermal mass and occupancy patterns in indoor environments. The way a building is used by the occupants, such as opening windows, misuses the mechanical cooling or heating systems, and artificial lighting has a significant effect on energy use. There is no direct relationship between the occupancy period and energy use in buildings though. However, energy use in buildings relates to the thermal mass characteristics of the buildings' materials and the behavioural patterns of the occupants (Hawkes et al., 2010). Heavyweight fabrics and high levels of thermal mass are more efficient for higher occupancy patterns, depending on the climatic variations of the region. However, lightweight fabrics are more efficient for lower occupancy patterns, which demand rapid control of environmental conditions and offer a fast response system. If the building is left unoccupied for a long period, a high thermal mass will increase energy use substantially. Thermal mass usually has a modest impact on overheating. Reduction of internal gains and increasing ventilation at appropriate times are far more effective (Stevenson and McNaboe, 2011). In a specific month, for a whole day occupancy, the buildings may perform better with higher thermal mass, while for an evening occupancy, a lower thermal mass may be the best solution (Rigopoulos, 2013). In the buildings which occupied during the night period, thermal mass is relatively ineffective at reducing overheating hours. However, controlling internal gains and increasing ventilation during periods of overheating are more effective (Stevenson and McNaboe, 2011). In general, the amount and distribution of thermal mass in the building materials has an effect on the thermal performance of the indoor spaces. Heavyweight buildings respond slowly to heat gain from both solar and internal sources and as a result delays and reduces the peak temperature, which is an advantage for the high occupancy pattern. It also increases the temperature usefully during the night time, as it absorbs solar heat gain during the day and releases it at night. However, some buildings with short occupancy patterns will benefit from lightweight materials. If the building is well insulated, its indoor environment will respond more quickly and therefore will not require a long lead-in time to warm up. The thickness of the mass has an effect on the time lag of the heat: the thicker the mass, the longer the time lag (Hawkes et al., 2010).

4.10. Insulation

The amount of heat flow through the buildings' components is based on the thickness of the materials and the thermal conductivity of the building fabrics. Thermal conductivity or thermal transmittance of the building is known as the U-value. Increasing the thickness of the building materials decreases the thermal transmittance of the buildings (Alhomoud, 2005). If the building component has a small U-value, less heat loss occurs in the indoor environment compared to having a higher U-value. By using an appropriate insulation material, it is possible to achieve smaller U-values for the buildings' components, while having thin layers (Bansal et al., 1994). In addition, an appropriate insulation can eliminate the unsatisfactory impact of the undesirable radiant energy from the warm surfaces in summer or cold surfaces in the winter period, while preventing extra heat loss or heat gain in both seasons.

Insulation is the main basis of energy saving building design. Apart from insulation, air tightness, heat bridges and openings of the buildings should be considered carefully in order to get the maximum benefit of the insulation material. It should be borne in mind that the increase in the number of openings, may reduce a building's energy performance (Light House Sustainable Building Centre and Guido, 2009). The insulation material should be applied throughout the building's envelope without being thermal bridges, in order to receive the benefits of thermal insulation. It reduces heat loss in the cold seasons and heat gain in warm periods and, as a result, provides thermal comfort in the indoor environment throughout the year. However, during the summer it should be ensured that a good shading protection is provided, as well as sufficient ventilation to help the decrease in indoor air temperature (Mead and Brylewski, 2011). Studies show that using external insulation in passive design buildings reduces thermal bridging within the building, which should be eliminated wherever possible, to reduce heat loss. Thermal bridges mostly occur in junctions within the building's structure, as the heat loss paths might be created in the structural connections such as buildings corners (McLeod et al., 2011). Infiltration is another factor which needs to be taken into account in building design. Infiltration is air movement through the building envelope cracks and openings, driven by the stack effect and wind pressure. The use of thermal insulation material reduces the infiltration rate in indoor environments (Roaf et al., 2004).

The use of thermal insulating in the layers of roof, walls and floor of the building makes a barrier between the outdoor environment and indoor spaces and, as a result, during extreme weather conditions, it provides pleasant thermal comfort for the occupants. The rate of the heat flow, whether outward or inward, is decreased by using an appropriate insulation material which helps to save a considerable amount of energy and increase the buildings energy performance (Autodesk Ecotect Analysis, 2013). For selecting an appropriate insulation material for the building's envelope, two important factors need to be considered. One is the position of the insulation material, whether placed on the internal surface of the building's envelope or on the external side of the exterior walls (Alhomoud, 2005). In addition, the thickness of the insulation material is an important factor for the thermal resistance levels of the building (Bolatturk, 2008). It is suggested to place thermal insulation on the external side of the thermal mass of the building in hot climatic regions in order to get the maximum benefit of both materials. The thermal mass of the building absorbs the extra heat of the indoor environment and makes a balanced conditions inside the building (Gregory et al., 2008). Moreover, besides being an energy barrier between the indoor and outdoor environments, insulation material can supply fire resistance, noise reduction and humidity control as well. For example, woodfibre is an insulation materials which is sensitive to water exposure and humidity (Light House Sustainable Building Centre and Guido, 2009).

4.10.1. Insulation for ground floors

It is suggested that insulation materials above the slab with reinforced screed on top are added to provide insulated thermal mass. This option supplies some main functions of thermal storage related to heavyweight construction. The impact of this benefit is mostly achievable if dense conductive materials, such as ceramic tiles, are used as a floor finish. However, floor finish materials such as carpets will reduce this effect (Baker, 2009).

4.10.2. Insulation for floors

Studies show that heat can flow through various floors due to temperature differences but this flow is considerably less than the heat loss through the building envelope an as a result, it is not cost effective to use insulation materials in intermediate floors, except in exceptional conditions, such as where significant temperature differences exist between the floors. If there is a need to use insulation between the intermediate floors, it is suggested that load-bearing insulation above the slab with reinforced screed above be used. This option provides a significant amount of thermal mass (Baker, 2009).

4.10.3. Insulation for walls

Insulation of the walls decreases heat flow through the walls. The U-value expresses the average heat flow through the wall. An accurate insulation material reduces heat losses during the cold season and as a result, increases interior surface temperatures and the thermal comfort of the occupants. In addition, it reduces excess humidity within the interior environment. During the hot seasons, it decreases the heat flow from outside to inside, including the heat created by solar radiation on the exterior surface. Insulation materials also support night time ventilation and cooling energy efficient strategies, whenever the interior temperature drops below the exterior surface temperature (Ford et al., 2007). Insulation materials can be applied to both solid walls and cavity walls. Solid walls have been constructed of stone, brick, concrete blocks and situ concrete. Other materials, such as timber-framed walls filled with clay or mud, which is used in historical buildings, can be categorised as solid walls. However, cavity walls are walls of double leaf masonry, such as brick, stone and concrete. The main aim of these walls is to restrict the transmission of moisture and humidity from the outside to the indoor environment. It also increases thermal resistance compared to the same amount of solid materials. Composite walls might include cavities in their construction (Baker, 2009). It is suggested that external insulation is used for external walls, as it keeps the effect of thermal mass for the interior space, as the thermal mass is still coupled with the indoor environment. It also protects the structure from solar heat gain and usually prevents cold bridges developing. In addition, the effect of insulation materials for the cavity walls depends on ventilation and air movement to the outside. The more restricted the air flow, the more insulation impacts on the building (Baker, 2009).

4.10.4. Insulation for roofs

An insulated roof also decreases heat transfer through roof construction in both directions, during the cold and warm seasons. During the warm season the roof is exposed to solar radiation more than the exterior walls and it is more likely to receive more heat from the roof than the wall. To reduce heat transfer an accurate insulation material should be used, with an appropriate thickness. Good insulation of the roof is necessary to reduce heating energy demands in the winter season and decrease the summer heating loads (Ford et al., 2007). In a solid flat roof, which is the case for this study, the insulation materials can be applied on top of the waterproof membrane material, or between the waterproof membrane and the structural deck. The roof can also be internally insulated (Baker, 2009).

4.11. Daylighting

Daylighting is another factor which needs to be considered for a passive design strategy. It maximises the use of naturally diffused daylight in indoor environments, which decrease the need for artificial light. However, preventing overheating through accurate design and balancing this against solar heat gains is necessary to achieve the most benefit from daylight design and to reduce glare considering that the appropriate shading devices will maximise the effect of daylighting. The quality and the style of windows, and the interior layouts, as well as skylight design, also have an important effect on providing daylight in interior spaces (Light House Sustainable Building Centre and Guido, 2009). Providing a suitable daylighting design for internal spaces, as well as using appropriate shading devices will save more energy and eliminates the need for artificial lighting (Ford et al., 2007). Based on Gelfand (2010), daylighting can be integrated with opportunities for natural ventilation and providing fresh air.

4.12. Conclusions

This chapter reviews the effect of passive design strategies on indoor environment. Various passive design strategies can be applied to the buildings to achieve low energy architecture in hot and warm regions. These strategies include orientation, ventilation, shading devices, thermal mass, insulation, glazing and lighting. Considering these strategies at an early stage of building design can help to keep the indoor environment in an acceptable thermal condition with the minimum heating and cooling load. The appropriate passive design strategies are investigated in the case study school building, using thermal simulation in order to keep the classrooms in a comfortable condition during teaching hours (see Chapter 8 for further details).

Chapter 5: On-site Measurement

5.1. Introduction

Environmental school design can have a considerable effect on improving the physical comfort and learning efficiency of students. It can also reduce the long term impact of school buildings on the environment (Zahiri et al., 2011). This chapter describes the results of the field experiments on the climatic variables of six classrooms, carried out in a four-storey female secondary school building in Tehran, Iran, in the warm spring period and cold winter seasons. The school buildings in Tehran were selected as the case study because Tehran is the capital of Iran and, compared to other Iranian cities, has the largest percentage of students in its population.

In addition to the field measurements, questionnaire-based surveys were conducted on thermal sensations of the students in the case study school building during the on-site monitoring period, to identify the conditions considered comfortable by students and to investigate the thermal condition of the classrooms during the lesson hours (see Chapter 6 for further details on questionnaire-based survey). During the field measurement, environmental variables such as indoor air temperature and relative humidity levels were measured with HOBO data loggers in the warm spring period of April/May 2010 and cold winter period of January/February 2011 for seven weeks in total, which included the survey days. The measurements assessed thermal conditions of the six classrooms in the spring and winter seasons (see Figure 5.1). The classrooms were located on the first and second floors of the school building, facing north and south (see Table 5.1). It should be noted that, during the winter field studies the measurements were carried out in Classroom 307 instead of Classroom 308 because that classroom was not in use in the new semester.

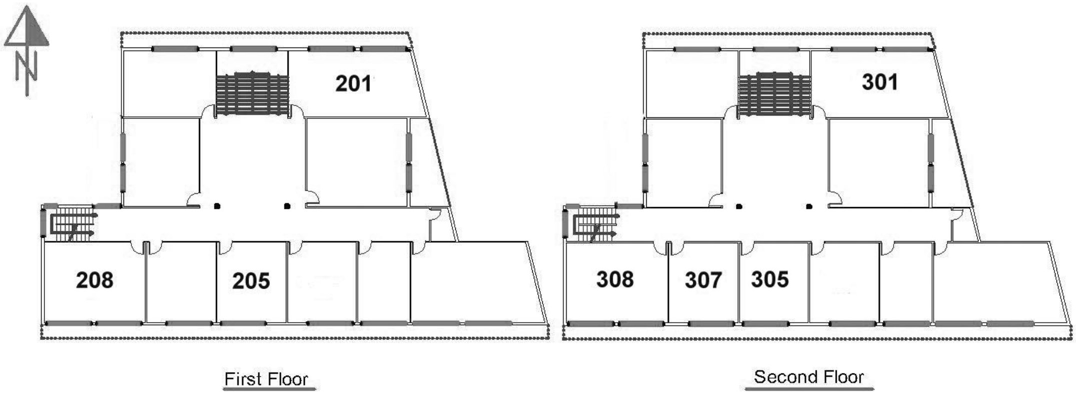


Figure 5.1: Measured classrooms on the first and second floors

Table 5.1: Monitoring classrooms in the secondary school building

Classroom number	201	205	208	301	305	307 and 308
Classroom level	1st	1st	1st	2nd	2nd	2nd
Classroom location	N	S	S	N	S	S

In addition, two questionnaire based surveys were conducted in the warm and cold seasons as thermal comfort variables were being measured with HOBO data-loggers. Students answered the questionnaires covering their thermal sensations on the 4th May 2010 and 9th February 2011 at midday. Details of the overall classroom occupants in the two seasons' experiments are given in Tables 5.2.

Table 5.2 : Summary of samples

Months	Number taking part in survey
April/May 2010	260
Jan/Feb 2011	199
Total	459

5.2. On- site monitoring

Thermal comfort is affected by four environmental factors, including indoor air temperature, radiant temperature, relative humidity and air velocity. Besides these environmental factors, clothing insulation and metabolic heat rates are personal factors which have an impact on the thermal comfort of occupants as well. In this study, the main concern was indoor air temperatures and relative humidity levels. However, air velocity was considered as a fixed parameter, at about 0.1 m/s, as the air was still in the classrooms during the field studies because the windows were closed in the winter season. Also in the spring period, although the windows were open, the outdoor air velocity was quite low.

Moreover, the mean radiant temperature was assumed to be equal to indoor air temperatures in the measured classrooms. According to Fanger (1973) and Santamouriser (2008), when the occupants have sedentary activity less than 1.5 met and the air velocity is below 0.1 m/s, or the air is still in the indoor environment, the mean radiant temperature can be assumed to be equal to indoor air temperatures (Santamourisr, 2008, Fanger, 1973). In addition, in this study, the indoor environments were not exposed to direct sunlight, and the layout in the classroom did not leave the environment around each seating area different to any other point in the room which caused the mean radiant temperatures measures to be similar to the indoor air temperature (Limbachiya et al., 2012). Moreover, according to Fanger (1973) and as mentioned above, the mean radiant temperature can be assumed equal to the mean indoor air temperature when the air speed is below 0.1 m/s and in this case it is desired to determine mean air temperature as equal as mean radiant temperature (the ambient temperature) in thermal comfort studies.

In order to obtain the appropriate information for the climate variable in the school building, data-loggers were set to record indoor air temperatures and relative humidity levels inside the classrooms. The measurements assessed thermal conditions of the classrooms during the warm spring and cold winter periods. The first period was from 23rd April to 13th May 2010 and the second was from 14th January to 10th February 2011. These days was selected for monitoring to represent the warm spring season and cold winter period before school closure for winter and summer holidays and just before the exam period (Zahiri and Altan, 2012a). Indoor air temperature and relative humidity levels, the two thermal comfort variables, were measured by HOBO data-loggers. For the environmental measurement, one HOBO was used for each classroom and was located at a height of 0.6 metres above the floor for seated occupants, as suggested by ASHRAE 55 (ASHRAE, 2004). It was kept away from direct solar radiation in order to measure the climate variable more accurately. The HOBOs gathered indoor air temperature and relative humidity levels with a logging interval of 15 minutes. The total of six classrooms was monitored in each season. The classrooms were located on the first and second floors and faced north and south. In addition, daily local weather data were also collected from local weather station reports (Irima, 2012).

5.3. Aim of monitoring

The main aim of the field measurement and on-site monitoring was to establish a database for the indoor air temperature and relative humidity levels, in order to be able to predict the comfort levels of the students and also their thermal satisfaction while staying in the classrooms during the questionnaire survey days, which will be discussed in Chapter 6. The results are also used to verify the building’s thermal performance and to evaluate the thermal condition of the classrooms with the use of thermal simulation software, which will be used for thermal modelling and thermal analysis of the school building in chapters 7 and 8.

5.4. Equipment

For monitoring the indoor climate variables inside the classrooms, HOBO data loggers (see Figure 5.2) were used, which are known to be the most accurate and reliable data-loggers. The loggers can be easily set up and used for monitoring air temperature and relative humidity (Onset Co., 2013). They collected the climate data during the field studies in warm and cold seasons.

Figure 5. 2 : HOBO data-loggers

5.5. Output of monitoring

The HOBO loggers extracted a detailed database of the internal air temperature and relative humidity levels in a female secondary school building. The loggers collected the climatic information in six classrooms during the spring period for three weeks. They also gathered the data in six classrooms during the winter period as well for four weeks. This equipment was arranged to record the indoor environmental variables at 15 minute intervals. The information gathered by HOBO data loggers can be stored as an onset file on a computer or can be downloaded as a Microsoft Excel spreadsheet file for further analysis.

5.6. Outdoor climate data

The outdoor climatic measurements were obtained from the nearest meteorological station, which is located at approximately three km from the case study area in Mehrabad airport, at an elevation of 1191 m. The outdoor climatic variables were gathered from Iran Meteorological Organisation (Irimo, 2013) and Weather Underground (Weather underground, 2011). Outdoor air temperatures, relative humidity levels, wind direction and wind speed, as well as weather conditions during the field experiment period, have been obtained from the station for the whole period of monitoring in spring and winter seasons.

5.7. Measured internal air temperature and relative humidity levels

5.7.1. Spring season

This part of the field measurement was carried out in the warm spring period before the school closure for summer holidays and final exams. The field study was conducted for three weeks starting from 23rd April 2010 and ended in 13th May 2010. This time of the year is the warmest period of the academic year and occurred before the final exams (Kasmai, 1994). Exam periods were exempt from the field study as the students did not have any classes in this period. Figure 5.3 illustrates the indoor air temperature of six classrooms during the spring period, located on the first and second floors. As can be seen, classroom 208 had a maximum and minimum internal air temperature during the three weeks of study.

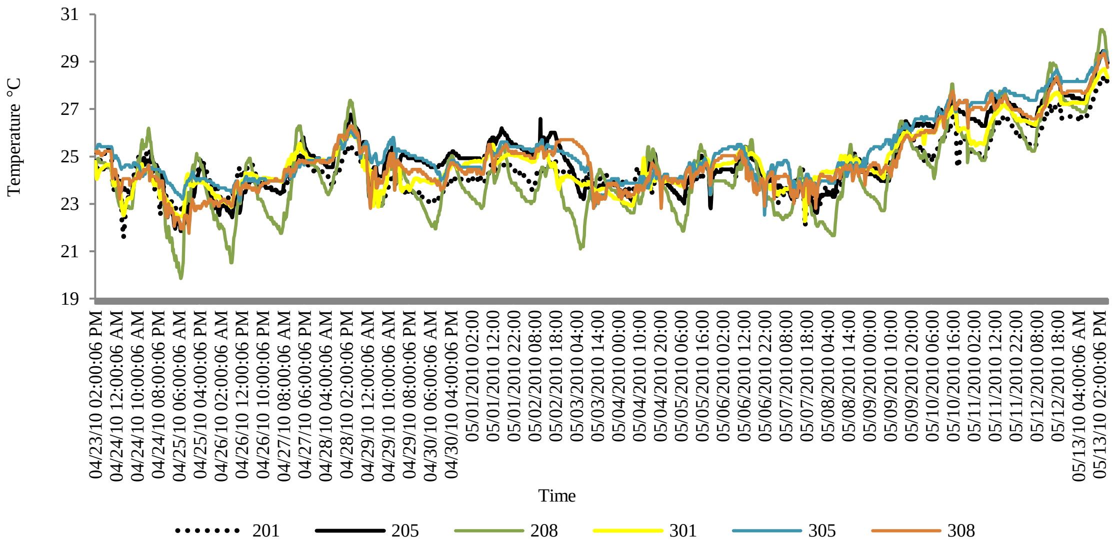


Figure 5.3: Indoor air temperatures in six classrooms during the spring season

Table 5.3 presents the minimum, maximum, average and standard deviation of the internal air temperature in each classroom. Classroom 208 has the maximum standard deviation, at about 1.7, which shows that it fluctuated more than the other classrooms during the field experiment. The minimum and maximum indoor air temperatures during this period were 19.9°C and 30.4°C respectively, recorded in classroom 208. These results show that Classroom 208 might have a lower airtightness level compared to the other classrooms, as it had the highest standard deviation as well as the highest and lowest indoor air temperatures. It also was dependent on outdoor air temperatures more than the other classrooms. However, the mean indoor air temperatures in all classrooms have very small differences.

Table 5 3: Mean, standard deviation, max and min of air temperature during warm spring season in all classrooms (April/May)

Classroom	**201**	**205**	**208**	**301**	**305**	**308**	**All**
Mean ˚C	24.5	24.9	24.3	24.8	25.2	24.9	24.8
Min ˚C	21.6	21.9	19.9	22.3	22.5	21.8	19.9
Max ˚C	28.4	29.5	30.4	28.7	29.5	29.4	30.4
SD	1.1	1.4	1.7	1.2	1.4	1.4	1.4

In addition, the climatic data records are divided into various categories, based on whether they were located on the first or second floors and facing north or south. Table 5.4 summarises these divisions. It can be seen that the maximum standard deviation was recorded in south-facing side classrooms, 1.5. The classrooms located on the first and second floors had lower standard deviation, at about 1.4, and the classrooms on the north–facing side had the lowest standard deviation. The maximum and the minimum indoor air temperatures were measured on the first floor. The possible reason might be the airtightness of the classrooms, which might have been lower on the first floor, which had higher variations in indoor air temperatures. In addition, south-facing side classrooms had the maximum indoor air temperature, as they faced south and usually received solar radiation during the day. However, the mean indoor air temperatures in all classrooms were very close, varying between around 24.5°C to just below 25°C.

Table 5.4: Mean, standard deviation, max and min of air temperature during warm spring season according to classroom location (April/May)

Classroom	North-facing	South-facing	First floor	Second floor
Mean °C	24.6	24.8	24.5	24.9
Min °C	21.6	19.9	19.9	21.7
Max °C	28.7	30.4	30.4	29.4
SD	1.2	1.5	1.4	1.4

Figure 5.4 presents the indoor air temperature in all six classrooms, compared to the outdoor air temperature. From the graph below it can be seen that the internal air temperature in all classrooms was usually higher than the outdoor temperature during the field measurements made in the spring period. It should be mentioned that all the classrooms were naturally ventilated during the field study in this season. The indoor air temperature trends in all classrooms followed outdoor air temperature during the spring, but at higher levels, and were more stable than outdoor air temperature.

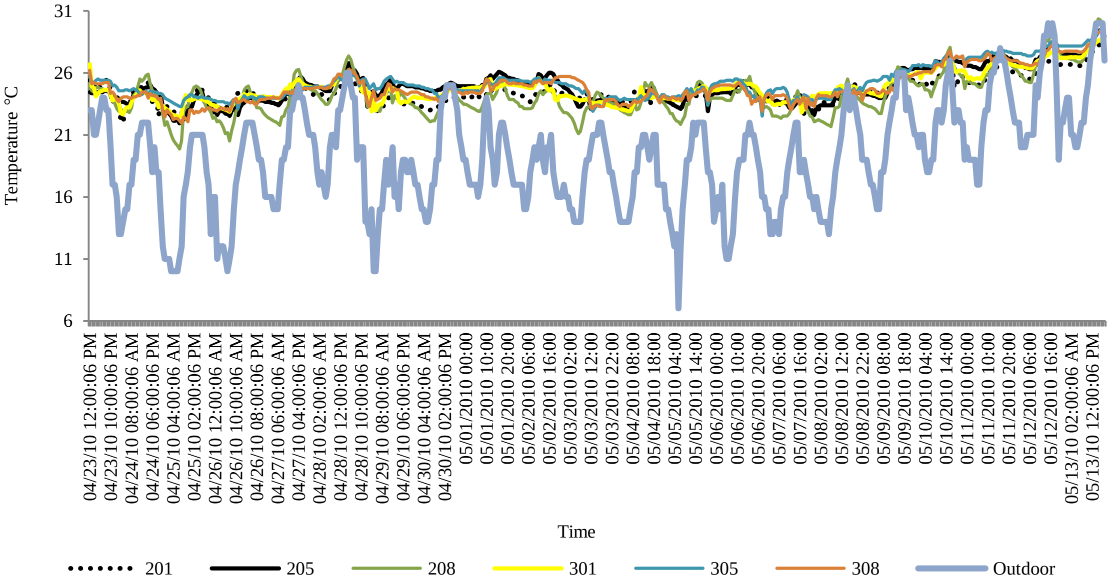


Figure 5.4 : Indoor air temperatures in six classrooms and outdoor temperature during the spring season

In addition, the relative humidity levels inside all six classrooms were measured by HOBO data-loggers as well. Figure 5.5 shows the relative humidity levels in all classrooms during the three week study in the months of April/May. The relative humidity levels in all classrooms had a similar trend during the monitoring period. The humidity levels were different in each classroom but they were usually close to each other. Similar to the indoor air temperatures during the spring season, the maximum and minimum relative humidity levels were recorded in classroom 208 during the field study period.

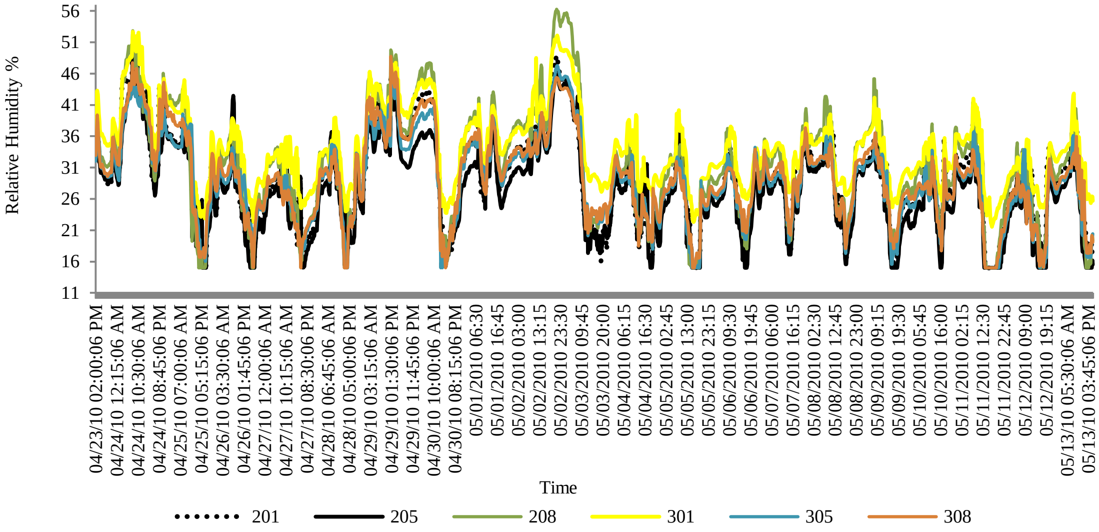


Figure 5.5: Indoor relative humidity levels in six classrooms during the spring season

Table 5.5 shows the average, minimum and maximum as well as the standard deviation of the relative humidity levels in all classrooms during the spring season. It can be seen that classroom 208 had the maximum standard deviation compared to the other classrooms at around 9. The maximum and minimum relative humidity levels were recorded in classroom 208, at 15% and 56%, respectively, which confirm the view that Classroom 208 might have had lower airtightness levels, as discussed above. In addition, the average humidity levels were different in each classroom, ranging from around 27% to around 34%. A possible reason might be the number of students, which caused various humidity levels, and the wind direction as well as air flow rate.

Table 5.5: Mean, standard deviation, max and min of relative humidity during warm season in all classrooms (April/May)

Classroom	**201**	**205**	**208**	**301**	**305**	**308**	**All**
Mean %	29	27	31	34	28	29	30
Min %	15	15	15	21	15	15	15
Max %	48	50	56	52	47	48	56
SD	7	7	9	6	7	7	9

The relative humidity levels of the classrooms were divided into various categories, based on locations (see Table 5.6). Table 5.6 shows that the classrooms which were located on the first floor and faced south had the maximum standard deviation, at 9. In addition, the average relative humidity levels in north-facing side classrooms was higher than south-facing side classrooms, which were acceptable, as the north-facing side classrooms did not receive any solar radiation and, as a result, the indoor relative humidity levels was slightly lower than in the south-facing side classrooms.

Table 5.6: Mean, standard deviation, max and min of relative humidity during warm season according to classroom direction (April/May)

Classroom	North-facing	South-facing	First floor	Second floor
Mean %	32	29	30	31
Min %	15	15	15	15
Max %	53	56	56	53
SD	7	9	9	7

Figure 5.6 shows the indoor relative humidity levels in all classrooms during the spring season study compared to the outdoor relative humidity level. It can be seen that the outdoor relative humidity level was usually higher than the internal relative humidity levels in all classrooms during the measurements. However, it was sometimes equal to the indoor relative humidity levels. A possible reason might be the cooling system of the school building, which is natural ventilation. As the classrooms were naturally ventilated, the level of indoor and outdoor humidity might be close, especially when there were no occupants in the classrooms. In addition, human breathing produces moisture during occupancy, which increases the level of humidity inside classrooms and results in higher indoor relative humidity during occupancy. Figure 5.6 also shows that the indoor relative humidity trends usually followed the outside relative humidity level during the spring season.

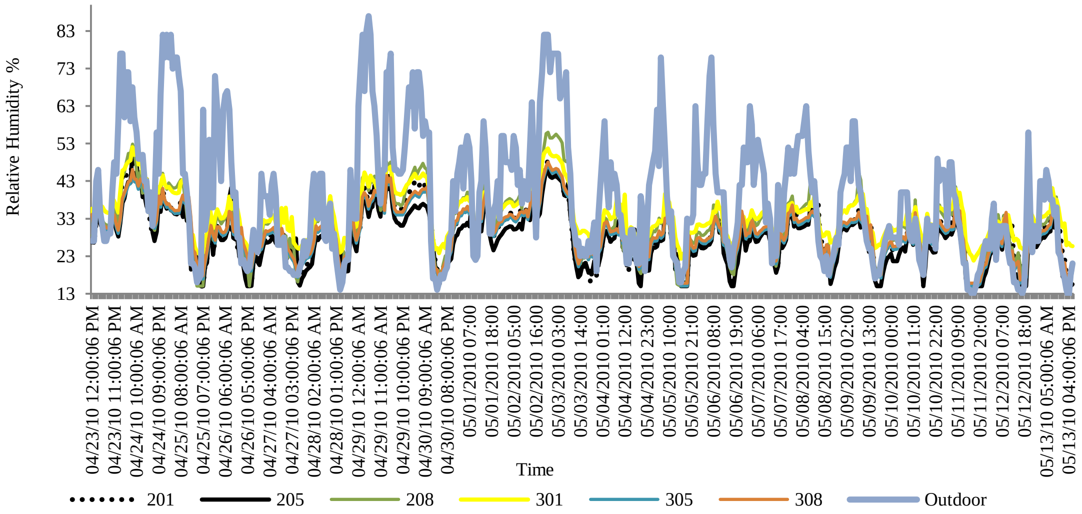


Figure 5 6: Indoor relative humidity levels in six classrooms and outdoor relative humidity level during the spring season

5.7.2. Winter season

The field measurements during the cold season were quite complicated, compared to the spring results. All the measurements were undertaken while the heating system was operating for heating purposes during the winter season. The heating system of the school building was a hot water radiator system using natural gas fuel, operating 24 hours a day. All the classrooms were heated by hot water radiators, which were adjustable manually and could be adjusted by all occupants. Measurements were conducted in the cold winter period before the school closure for exams and winter holidays. The field study was carried out for four weeks, starting on 14th January 2011 and ending on 10th February 2011. This time of the year falls into the coldest period of the academic year (Kasmai, 1994).

Figure 5.7 shows indoor air temperatures in six measured classrooms during the winter period. From the graph below, it can be found out that the minimum and the maximum indoor air temperatures in each classroom varied considerably compared to the other classrooms, regardless of their locations. A possible reason might be the manual heating system's adjustment, which might have caused each classroom to have a considerable temperature difference with the other classrooms. In addition, graph 5.7 illustrates that Classroom 208 had the minimum indoor air temperatures, as during the spring season. However, Classroom 301 had the maximum indoor air temperature, although it was located on the north-facing side of the building and did not receive any solar radiation. As discussed above, the manual adjustment of the radiators in each classroom might be the possible reason and it might have been set to higher temperature levels in Classroom 301 than in other classrooms.

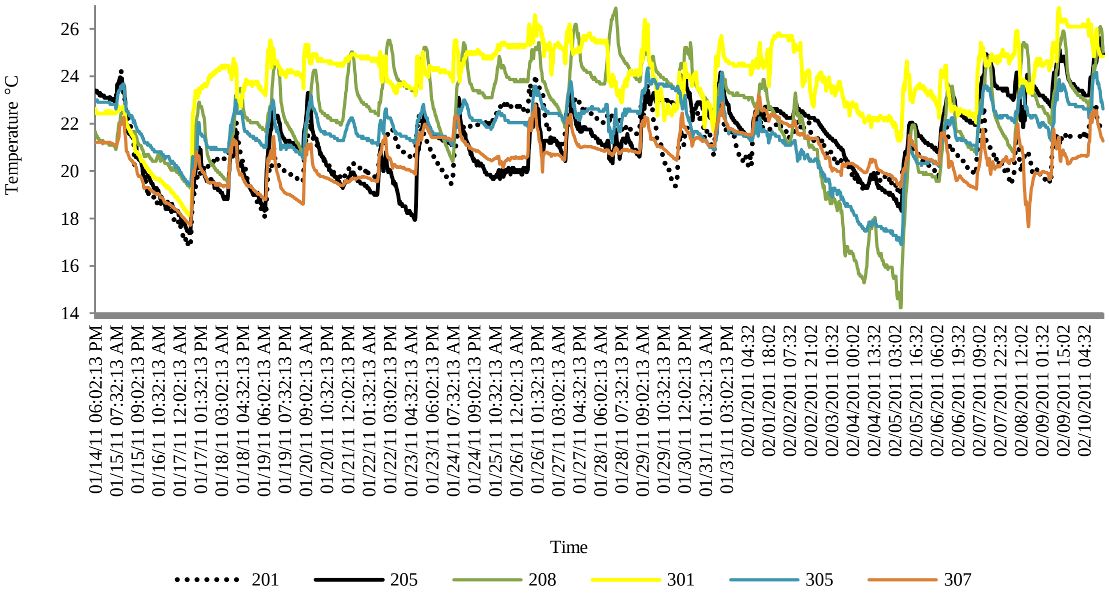


Figure 5.7: Indoor air temperatures in six classrooms during the winter season

Table 5.7 presents the average, minimum, maximum and standard deviation of six classrooms during the winter period. Classroom 208 had the minimum indoor air temperature, at around 14.2°C and Classroom 301 had the maximum indoor air temperature of 28°C. However, Classroom 208 had the maximum standard deviation compared to the other five classrooms, as seen in the spring results. A possible reason might be the lower airtightness of this classroom. In addition, Classroom 301 had the highest indoor air temperature, although it was located on the north-facing side of the building. A possible reason might be the higher temperature set point for Classroom 301 and better airtightness of the envelope.

Table 5.7: Mean, standard deviation, max and min of indoor air temperatures during cold season in all classrooms (Jan/Feb)

Classroom	**201**	**205**	**208**	**301**	**305**	**307**	**All**
Mean °C	19.7	21.4	22.3	23.9	21.6	20.6	21.8
Min °C	16.8	17.4	14.2	18.1	16.9	17.7	14.2
Max °C	24.3	25.6	26.9	28	24.4	27.7	28
SD	1.3	1.7	2.2	1.6	1.4	1	2

The results above show that the indoor air temperature in Classroom 301 was slightly higher than the other classrooms, which resulted in lower humidity levels in Classroom 301. Although Classroom 301 was facing north, its indoor air temperature was higher than the south-facing classrooms. As mentioned before, the heating system in the school was hot water radiator heating and it could be adjusted manually by the occupants to meet their needs. It can be assumed that, in general, when the heating system is off, Classroom 301 is colder than the south-facing classrooms, as it does not gain any solar radiation in winter (Zahiri and Altan, 2012b). Since the radiators could be adjusted manually by the occupants, they increased the heating set point temperature when they felt cold, which they might do in Classroom 301. However, as the south-facing classrooms gained direct solar radiation at midday from the roof and the south-facing side of the building, which increases the indoor temperature, especially when the building has low thermal mass materials or no shading devices, the heating set point of the radiator was not increased by the occupants as much as in the north-facing classrooms (Zahiri and Altan, 2012b). If the building had a larger thermal mass, it would have prevented the indoor environment from getting too cold or too hot, as it would have absorbed energy when the surrounding air temperature was higher than the mass (Kasmai, 1993).Therefore, occupants in the classrooms would have felt more comfortable. Table 5.8 presents the result of the indoor air temperature measurements in the school building based on the location of the classrooms. It can be seen that the north-facing side classrooms and the classrooms which were located on the second floor had the maximum standard deviation, at 2 and 1.9, respectively. Also the mean indoor air temperature was higher on these floors.

Table 5.8: Mean, standard deviation, max and min of air temperatures during cold season in all classrooms according to classroom location (Jan/Feb)

Classroom	**North-facing**	**South-facing**	**First floor**	**Second floor**
Mean °C	22.5	21.5	21.6	22
Min °C	16.8	14.2	14.2	16.9
Max °C	28	27.6	26.9	28
SD	2	1.7	1.8	1.9

Figure 5.8 shows the indoor air temperatures in all classrooms compared to the outdoor temperature. It can be seen that the indoor air temperatures in all classrooms were higher than the outdoor air temperature during the winter season study. As mentioned before, a hot water radiator heating system was operating to keep the temperatures high in indoor spaces, which can be adjusted manually. In addition, indoor air temperature trends usually follow the outdoor air temperature trends in most

classrooms during the winter, although the heating system was operating in the classrooms and the windows were closed. A possible reason could be the infiltration rate of the building, which might be high because of a low airtightness level.

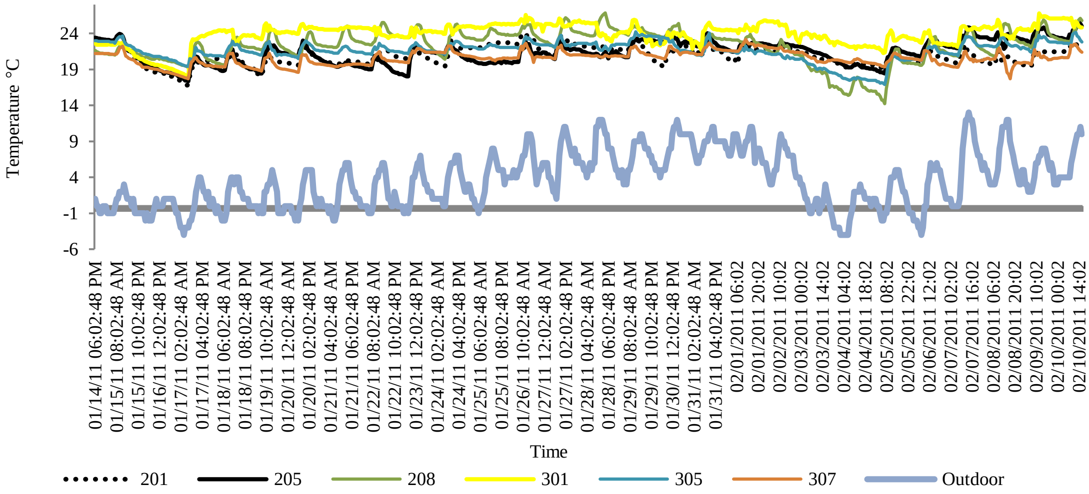


Figure 5.8 : Indoor air temperatures in six classrooms and outdoor temperature during the winter season

Figure 5.9 presents the relative humidity levels in all classrooms during winter season. Based on Figure 5.9, Classroom 307 had the maximum relative humidity levels during the study period. A possible reason is the lower indoor air temperature in the classroom, which resulted in higher humidity levels. However, the minimum relative humidity levels in all classrooms were similar except 307.

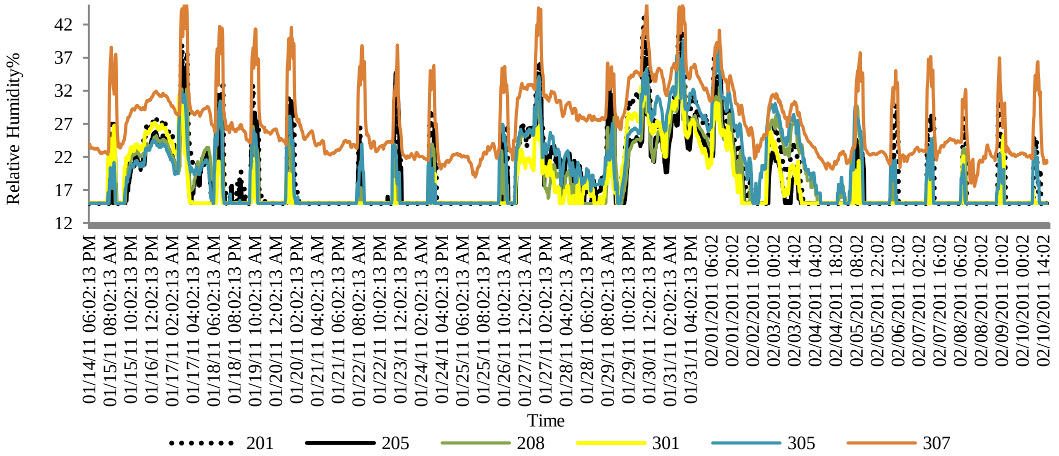


Figure 5 9: Indoor relative humidity levels in six classrooms during the winter season

Table 5.9 shows the average, minimum, maximum and standard deviation of indoor relative humidity levels during the winter period study. The maximum relative humidity was recorded for classroom 307. However, the minimum relative humidity in all classrooms was 15%. The maximum standard deviation belonged to classroom 201 and 305 and the minimum was for rest of the measured classrooms, which showed stability in humidity change.

Table 5.9: Mean, standard deviation, max and min of relative humidity levels during cold season in all classrooms (Jan/Feb)

Classroom	201	205	208	301	305	307	All
Mean %	21	18	19	18	20	28	20
Min %	15	15	15	15	15	18	15
Max %	43	37	36	37	40	46	46
SD	6	5	5	5	6	5	6

In addition, the maximum standard deviation of relative humidity was recorded on south-facing classrooms and the classroom located on the second floor (see Table 5.10). As discussed before, the lower heating set point in south-facing classrooms might be the possible reason.

Table 5.10: Mean, standard deviation, max and min of relative humidity levels during cold season in all classrooms according to classroom location (Jan/Feb)

Classroom	North-facing	South-facing	First floor	Second floor
Mean %	19	21	19	22
Min %	15	15	15	15
Max %	43	46	43	46
SD	5	6	5	6

Figure 5.10 illustrates outside relative humidity level in comparison to indoor relative humidity levels in all classrooms.

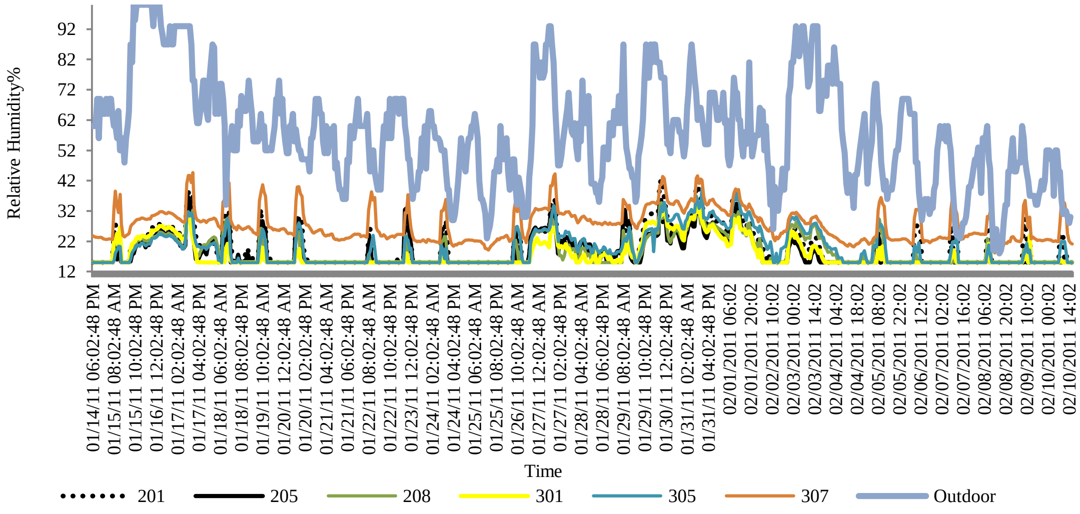


Figure 5.10: Indoor relative humidity levels in six classrooms and outdoor relative humidity level during the winter season

Outdoor relative humidity was higher than indoor relative humidity, which is acceptable, as the heating system was operating in all classrooms, so the higher temperature resulted in lower relative humidity. Indoor relative humidity trends sometimes followed outdoor relative humidity during wintertime.

5.7.3. Comparison of relative humidity and air temperature during the spring period

Figure 5.11 illustrates outdoor relative humidity levels against outdoor air temperatures. According to Figure 5.11, the minimum and maximum outdoor air temperatures recorded during the spring season experiment were around 7°C and 30°C, respectively. In addition, the minimum outdoor relative humidity level was around 15% and the maximum more than 90% during the spring period. It can be seen that, as the outdoor air temperature increases, the relative humidity drops.

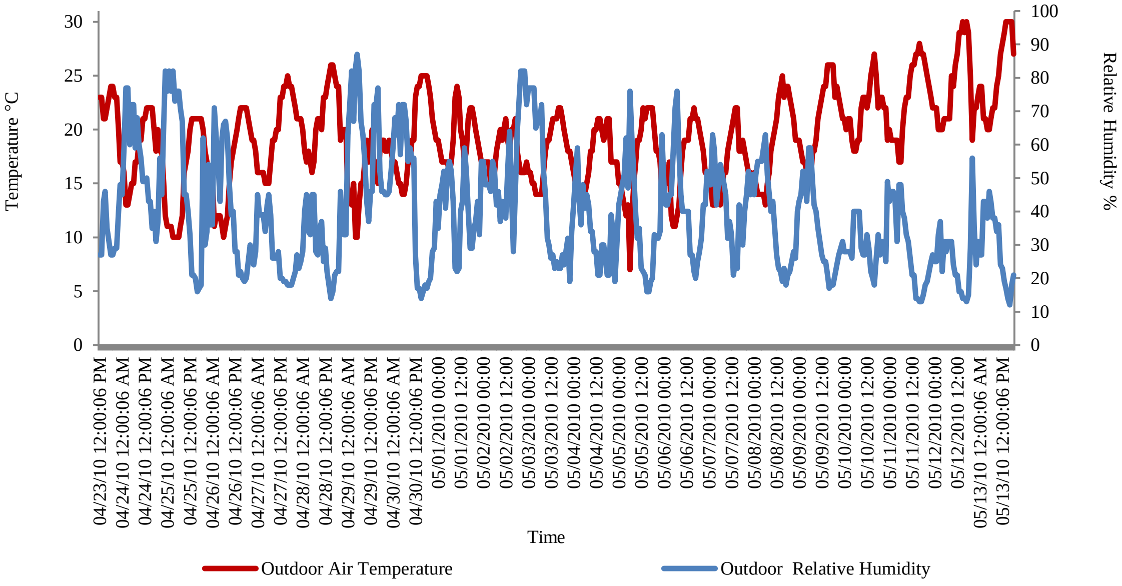


Figure 5.11: outdoor air temperature against outdoor relative humidity level in spring period

Figures 5.12 to 5.17 illustrate recorded indoor air temperatures against indoor relative humidity levels during the warm spring period for three weeks in all classrooms separately. Generally, indoor air temperature was more stable compared to relative humidity levels in all classrooms. However, relative humidity levels fluctuated considerably during the twenty one day measurement period. For example, the maximum relative humidity level belonged to Classroom 208, at around 56% on the 2nd May 2010, during the night. However, it dropped to around 20% on the following day in the afternoon and increased to around 35% on the day after that, in the morning. On the other hand, the minimum indoor air temperature in Classroom 208 was measured at around 20°C on the 25th April 2010, during early morning. This increased to around 25°C on the same day in the afternoon and dropped to around 20°C the following day, in the morning.

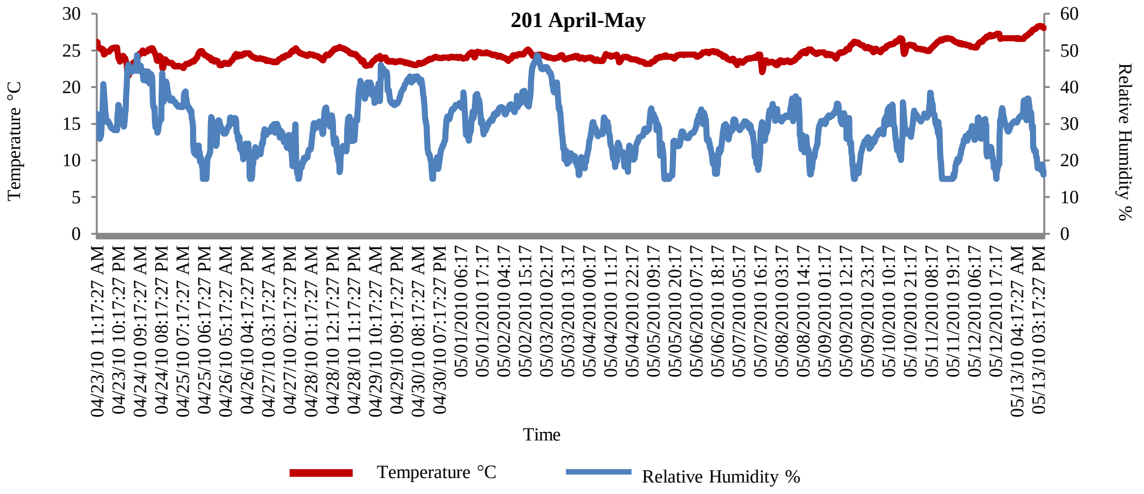


Figure 5.12: Indoor air temperature and indoor relative humidity level in spring period in classroom 201

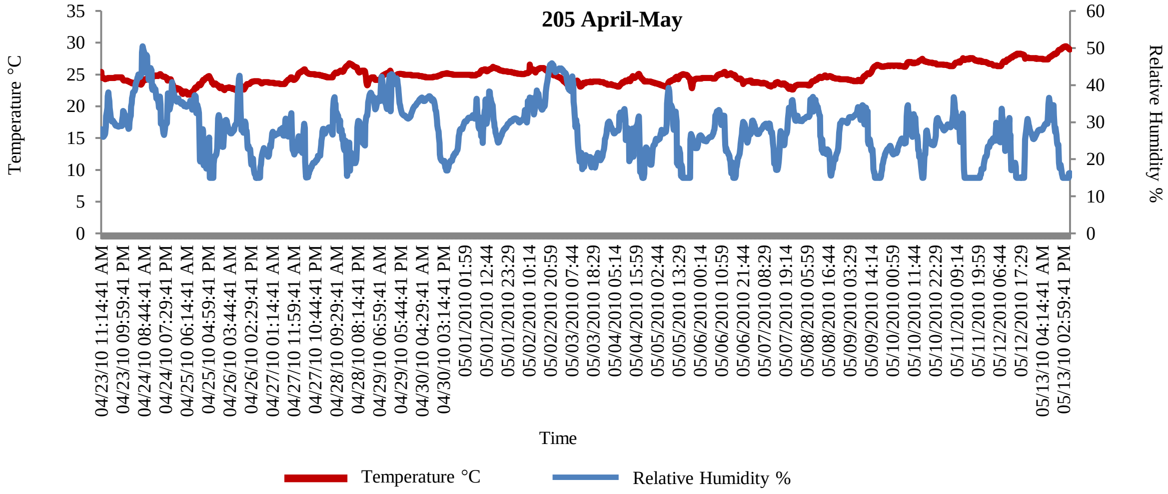


Figure 5.13 : Indoor air temperature and indoor relative humidity level in spring period in classroom 205

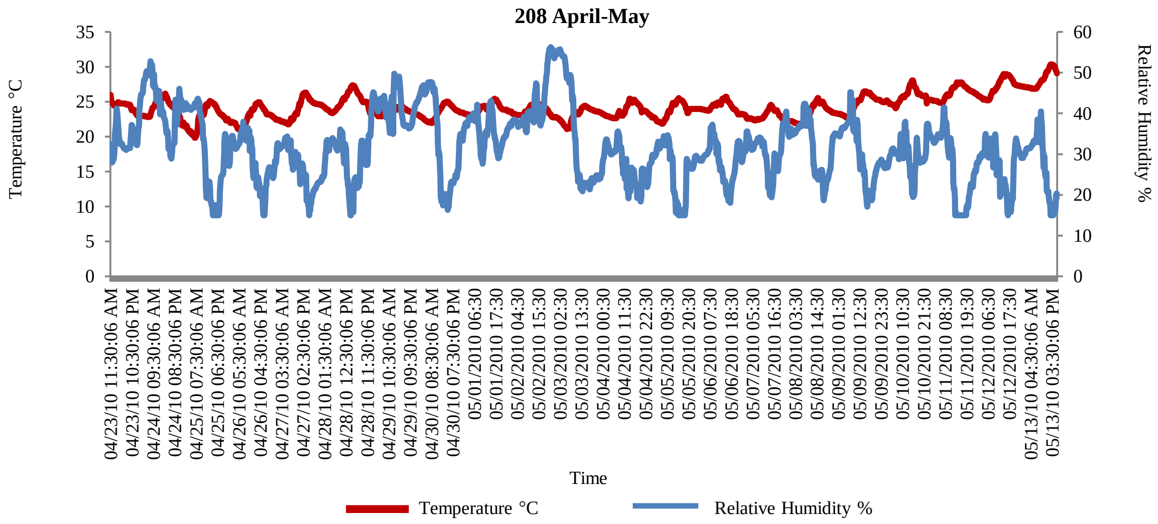


Figure 5.14: Indoor air temperature and indoor relative humidity level in spring period in classroom 208

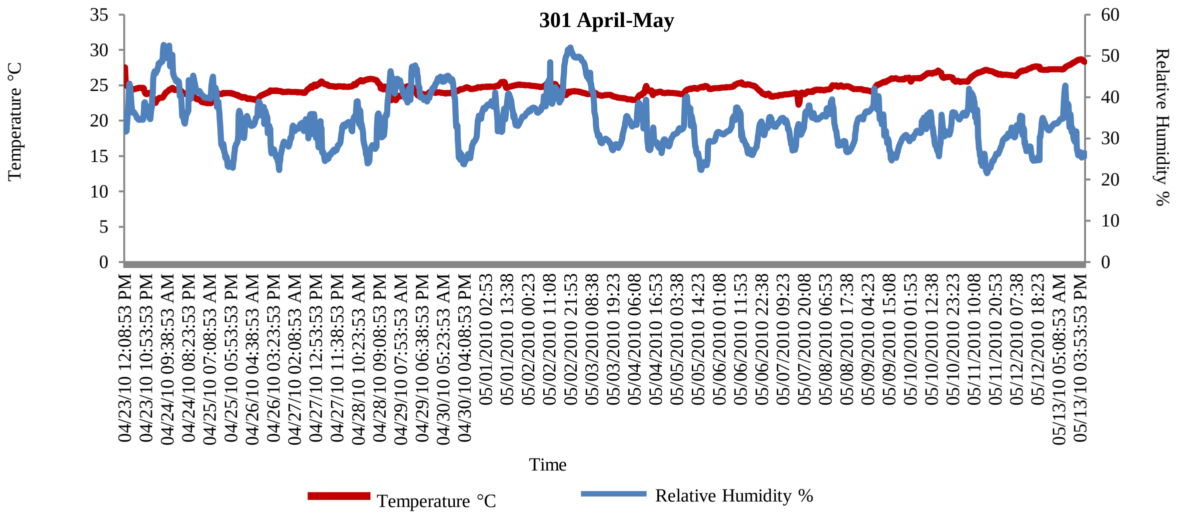


Figure 5.15: Indoor air temperature and indoor relative humidity level in spring period in classroom 301

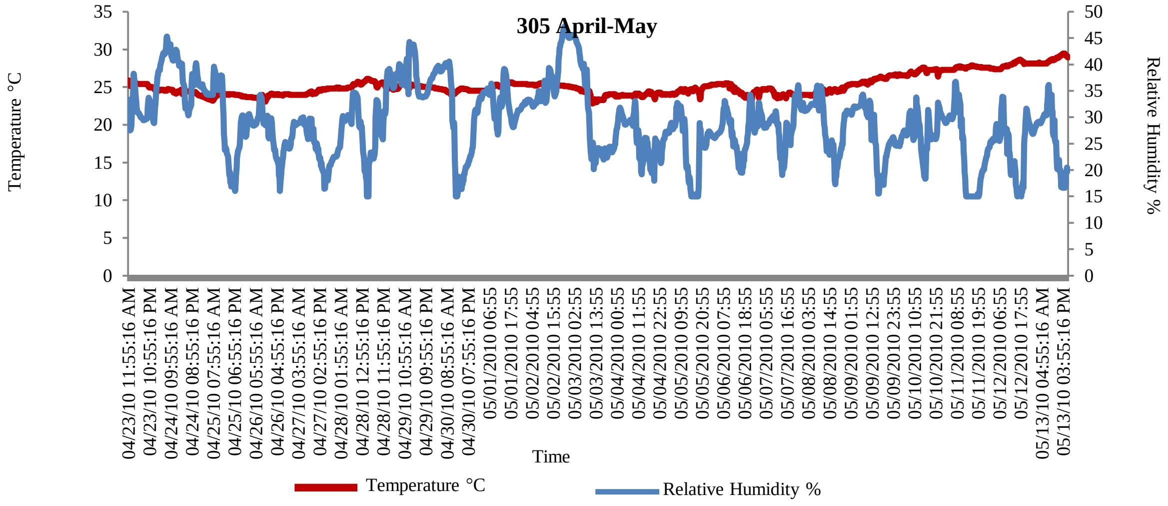


Figure 5.16: Indoor air temperature and indoor relative humidity level in spring period in classroom 305

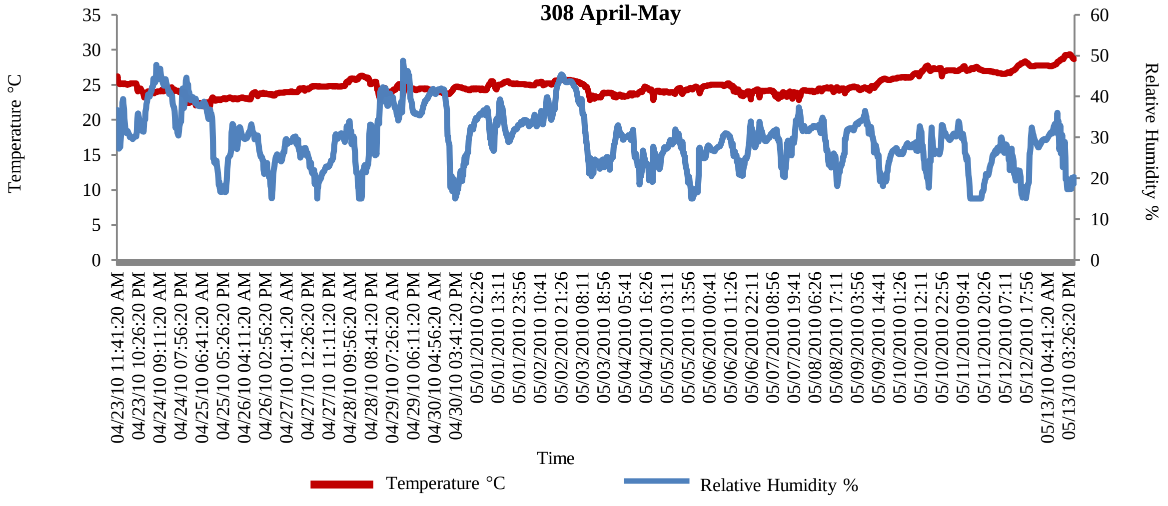


Figure 5.17 : Indoor air temperature and indoor relative humidity level in spring period in classroom 308

Figures 5.18 and 5.19 illustrate the scatter diagram of indoor air temperatures against indoor relative humidity levels in all classrooms on the first and second floors during the spring season. It can be seen that the correlation between indoor relative humidity levels and indoor air temperatures was negative during the field study experiment. As the temperature rises in all classrooms the relative humidity levels drops consequently. The lowest correlation coefficient was in classroom 205 on the first floor, and in classroom 305, on the second floor. However, the maximum correlation coefficient was in classrooms 208 and 301 on the first and second floors respectively. Classrooms 205 and 305 were located in the middle of the building and were surrounded by indoor spaces from three directions. However, classrooms 208 and 301 were surrounded by the indoor environment from two directions, which might be the reason for a higher correlation coefficient.

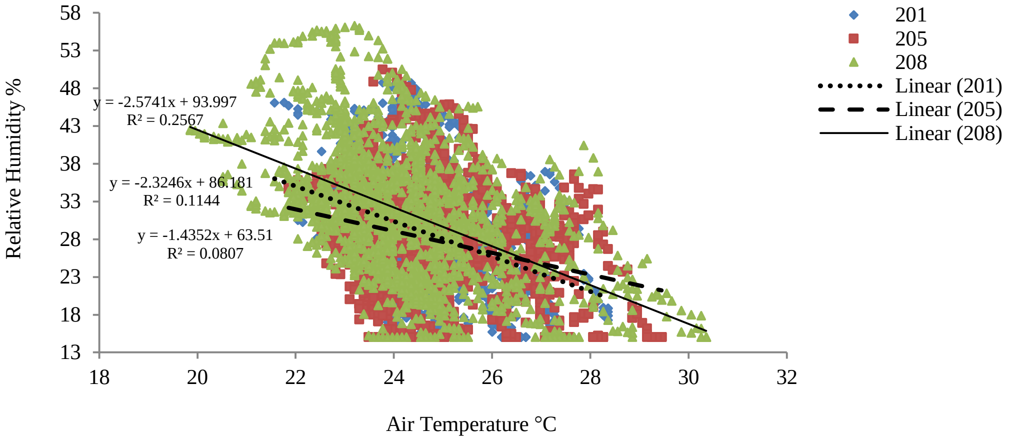


Figure 5.18: Scatter diagram of indoor air temperatures against indoor relative humidity levels in spring period in first floor classrooms

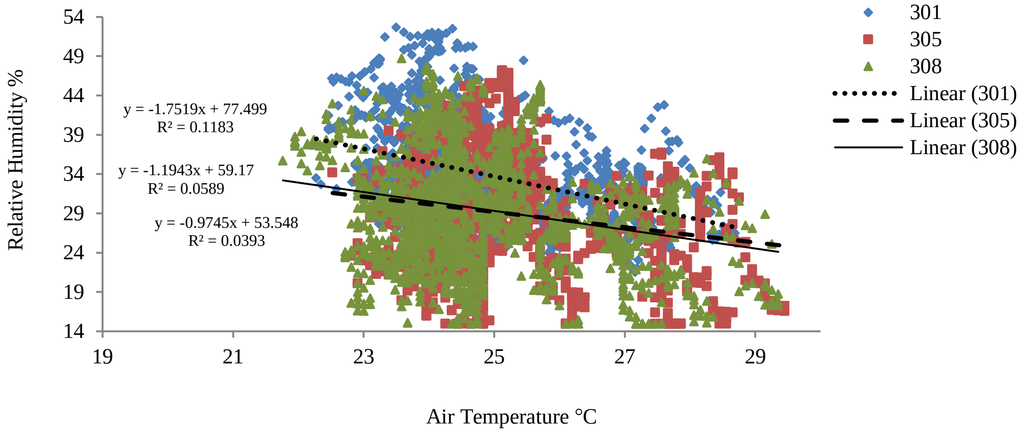


Figure 5.19: Scatter diagram of indoor air temperatures against indoor relative humidity levels in spring period in second floor classrooms

In addition, the relationship between indoor air temperatures and outdoor air temperatures during the field experiment in the spring season was studied. Figures 5.20 and 5.21 show the scatter diagram of outdoor air temperatures against indoor air temperatures in all classrooms on the first and second floors. The correlation between indoor air temperatures and outdoor air temperatures in all classrooms was positive. As the outdoor air temperature increased, the internal air temperature in all classrooms also rose, which confirms that the outdoor air temperature had a direct impact on indoor air temperature.

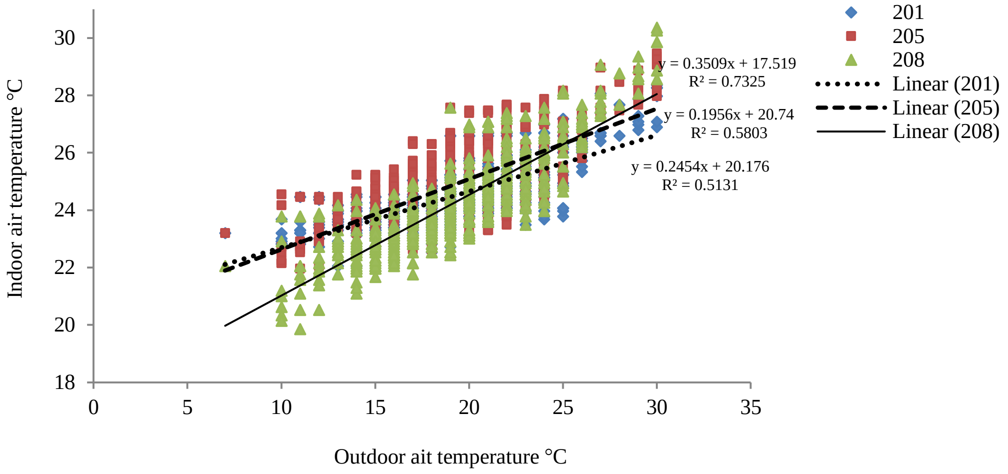


Figure 5.20: Scatter diagram of indoor air temperature against outdoor air temperature in spring period in first floor classrooms

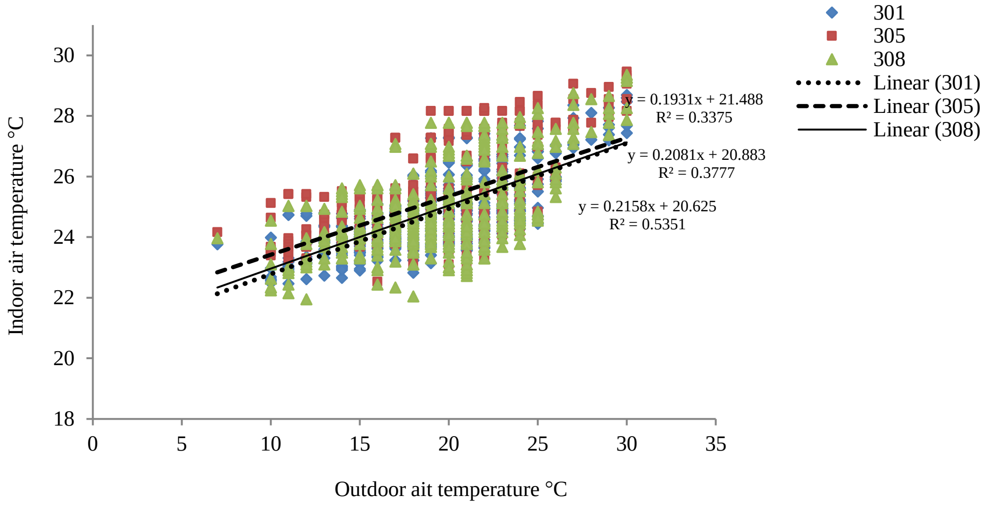


Figure 5.21: Scatter diagram of indoor air temperatures against outdoor air temperatures in spring period in second floor classrooms

Figures 5.22 and 5.23 present the relationship between outdoor relative humidity levels and indoor relative humidity levels in all classrooms during the field study period in the spring season. Similar to indoor and outdoor air temperatures, the outdoor relative humidity levels had a direct effect on indoor relative humidity levels in all classrooms.

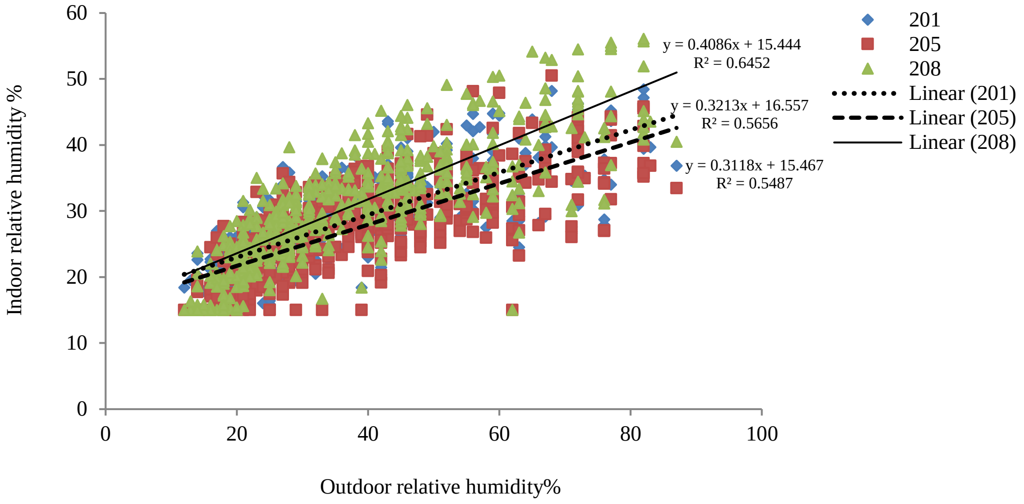


Figure 5.22: Scatter diagram of indoor relative humidity levels against outdoor relative humidity levels in spring period in first floor classrooms

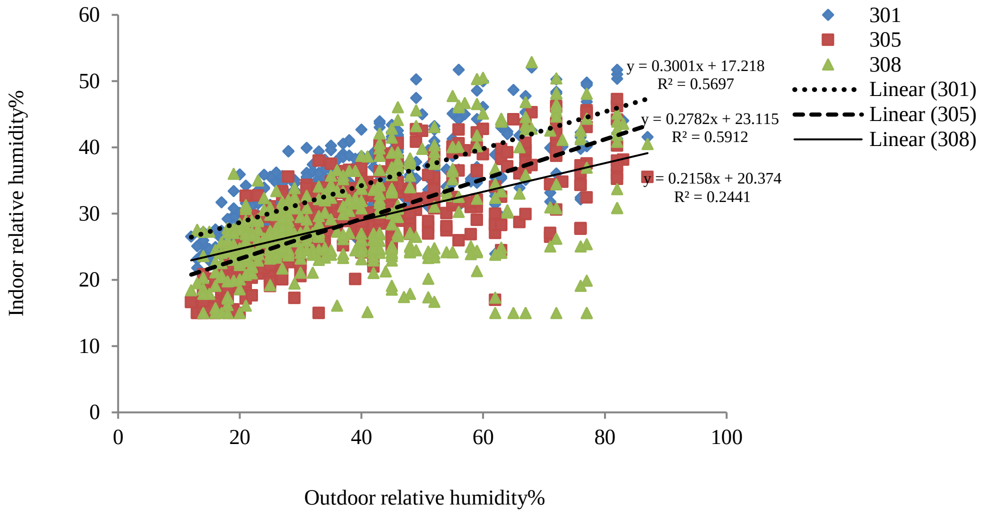


Figure 5.23: Scatter diagram of indoor relative humidity levels against outdoor relative humidity levels in spring period in second floor classrooms

5.7.4. Comparison of relative humidity and air temperature during winter period

Figure 5.24 illustrates outdoor air temperatures against outdoor relative humidity levels during the field experiment study in winter. According to Figure 5.24, the minimum and the maximum outdoor air temperatures recorded during the four week period study in winter season were around - 4°C and 13°C respectively. As the outdoor air temperature increased, relative humidity dropped. The minimum outdoor relative humidity level was around 20% and the maximum level was more than 90% during the winter season.

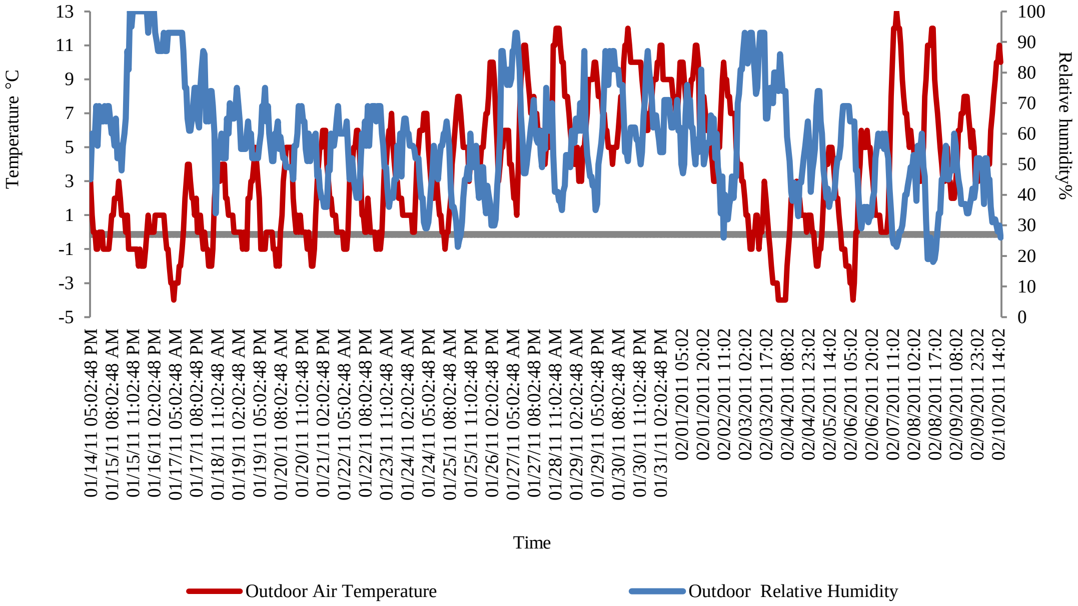


Figure 5.24: Outdoor air temperatures and outdoor relative humidity levels in winter period

Figures 5.25 to 5.30 illustrate indoor air temperatures against outdoor relative humidity levels during the cold winter period, over four weeks. Generally, the indoor air temperature was more stable compared to the relative humidity levels in all classrooms. However, relative humidity levels fluctuated considerably during the field experiment, similar to the spring season's result. In addition, the lowest band of the relative humidity levels was more stable during the winter season, at around 15%. A possible reason might be the HOBO data-loggers' accuracy and they might have started to record the indoor relative humidity from 15% only.

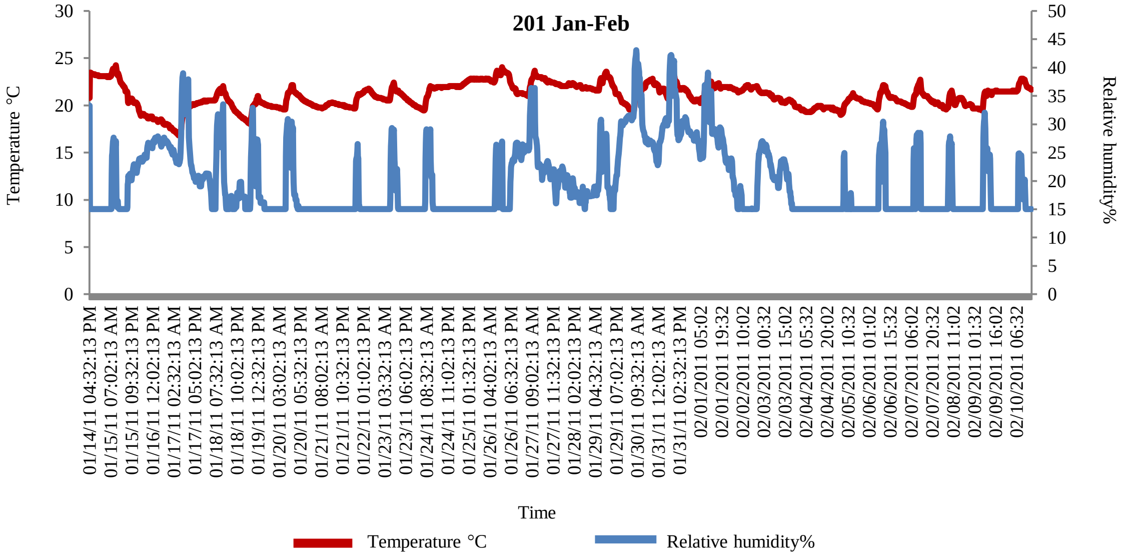


Figure 5.25: Indoor air temperature and indoor relative humidity level in winter period in classroom 201

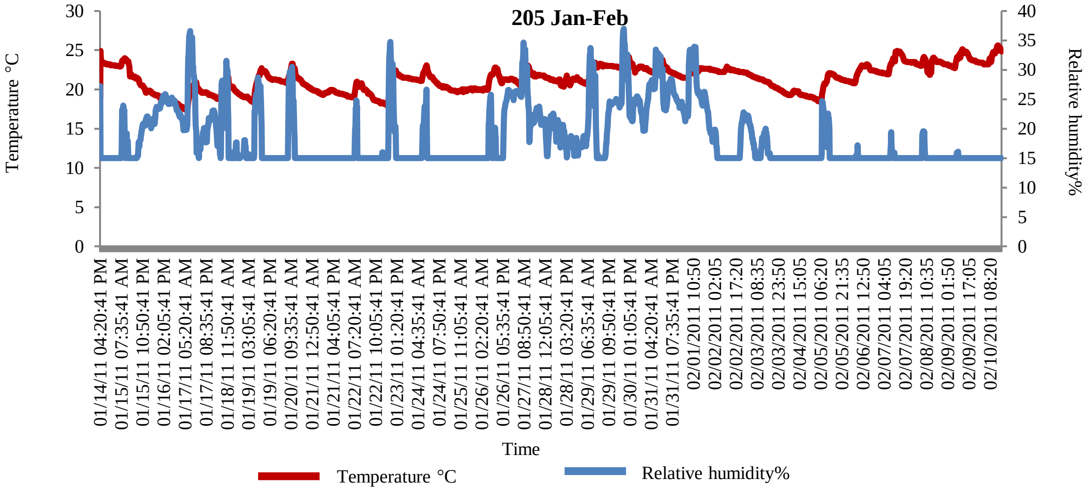


Figure 5.26: Indoor air temperature and indoor relative humidity level in winter period in classroom 205

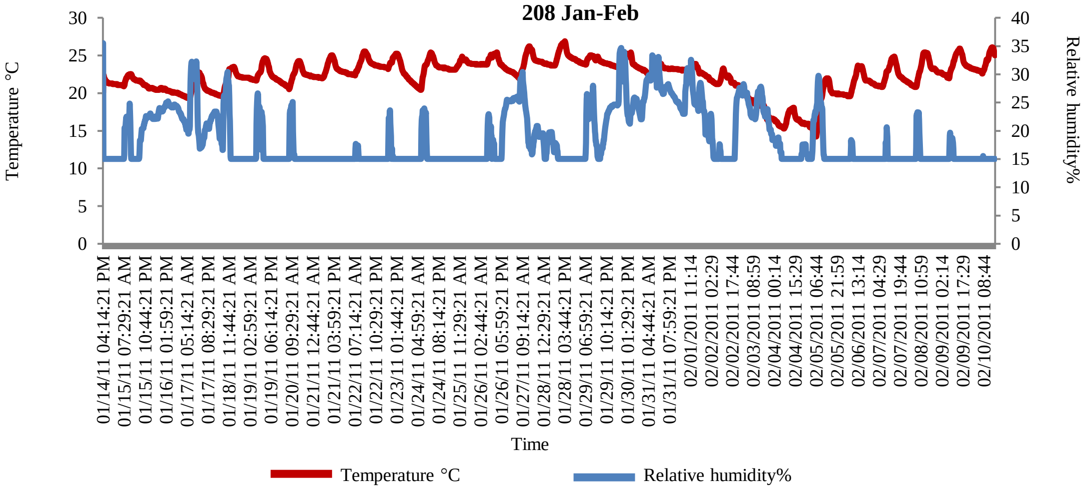


Figure 5.27: Indoor air temperature and indoor relative humidity level in winter period in classroom 208

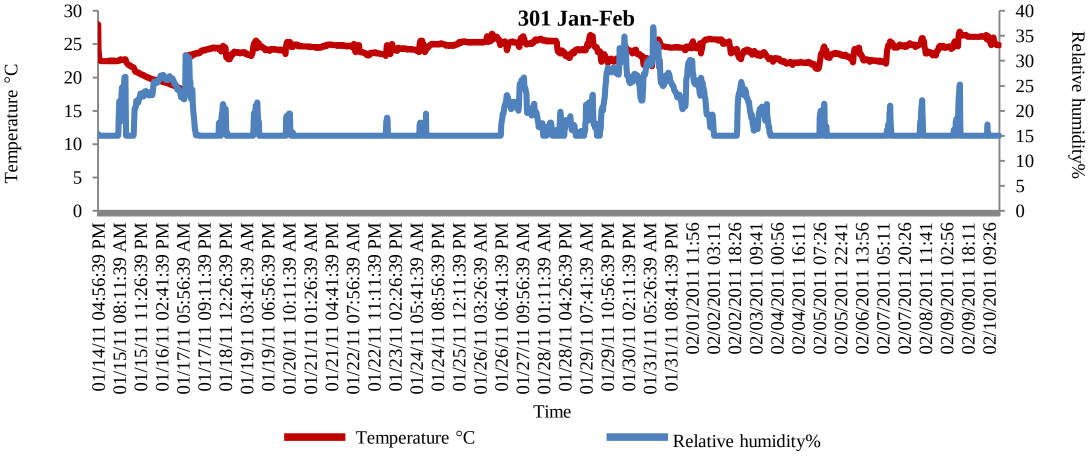


Figure 5.28: Indoor air temperature and indoor relative humidity level in winter period in classroom 301

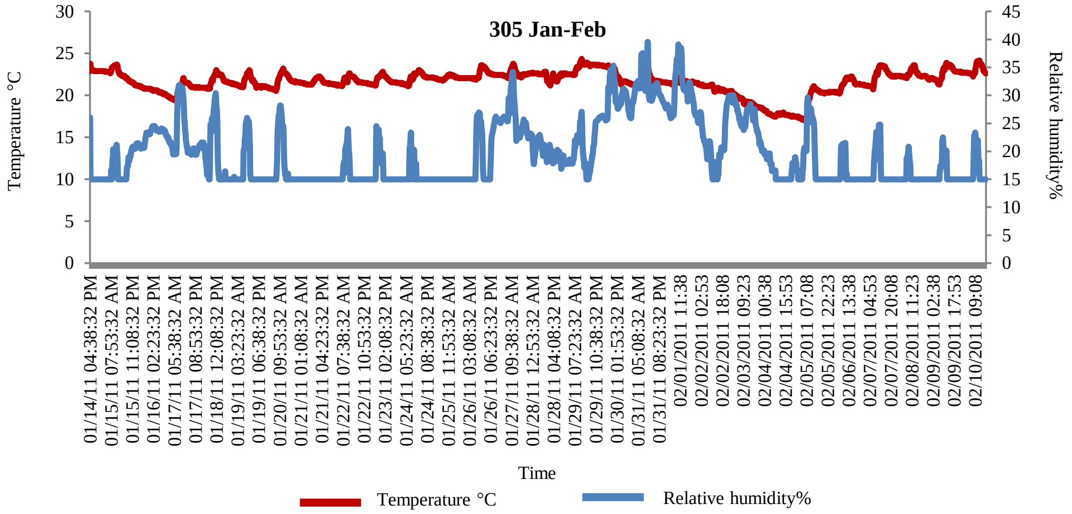


Figure 5.29: Indoor air temperature and indoor relative humidity level in winter period in classroom 305

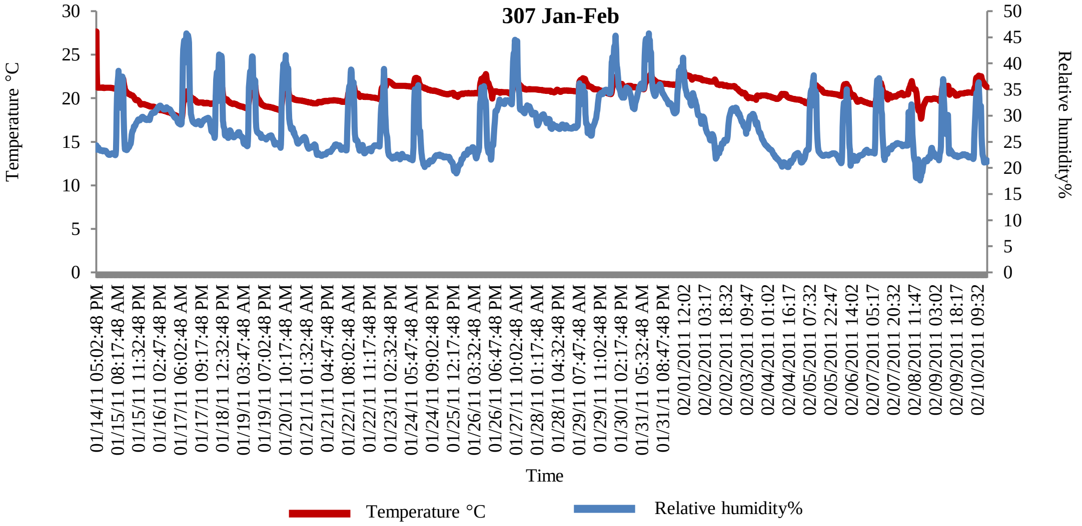


Figure 5.30: Indoor air temperature and indoor relative humidity level in winter period in classroom 307

Figures 5.31 and 5.32 illustrate the correlation coefficient of indoor air temperatures against indoor relative humidity levels in classrooms 201 to 307, in the winter season. It can be seen that the correlation between indoor relative humidity levels and indoor air temperatures was various in each classroom during the field study experiment. In some classroom, the correlation was positive. This shows that, when the temperature went up, the relative humidity did too. However, in some classrooms there was a negative correlation, which shows that, when the indoor air temperature decreased in classrooms, the relative humidity level increased consequently. Normally, when the temperature rises, the relative humidity drops but during the field study experiment in winter the correlation between these two was positive in some classrooms.

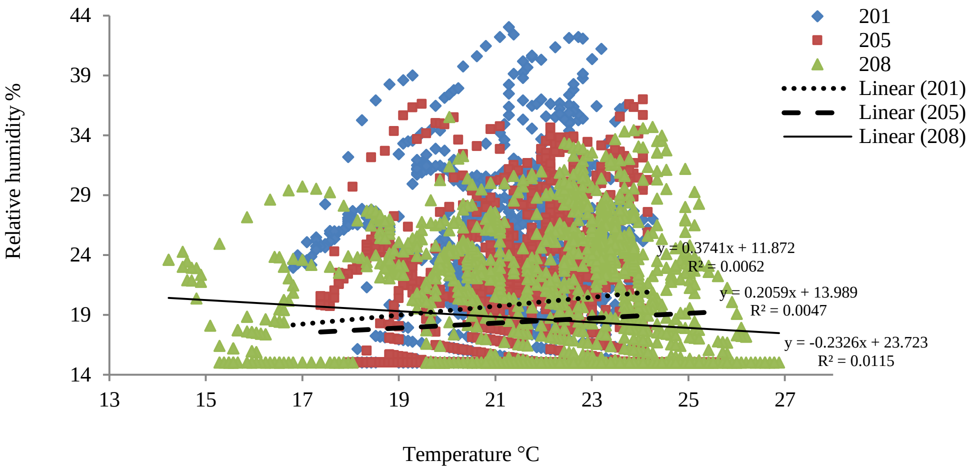


Figure 5 31: Scatter diagram of indoor air temperatures against indoor relative humidity levels in winter period in first floor classrooms

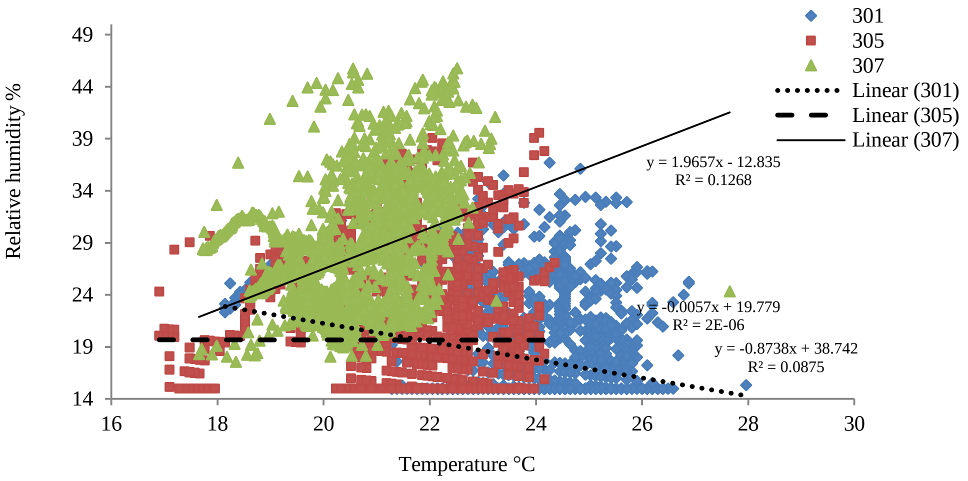


Figure 5.32: Scatter diagram of indoor air temperatures against indoor relative humidity levels in winter period in second floor classrooms

According to Ahrens (2008), a change in the level of relative humidity can be caused by the air’s water vapour volume, as well as changes in air temperature. At the higher temperature, the moisture in the air evaporates and the relative humidity level drops. In this study, during the winter period, moisture produced by human breathing was relatively high, and even at higher temperatures the extra moisture in the air did not evaporate, which resulted in a positive correlation between variables. In addition, outdoor relative humidity levels and poor construction of the building might cause this as well. It was found that the lowest correlation coefficient between relative humidity levels and indoor air temperatures was in Classroom 305, on the second floor. However, the maximum correlation coefficient was in Classrooms 307.

Moreover, the relationship between indoor air temperatures and outdoor air temperatures during the field experiment in the winter season was also studied. Figures 5.33 and 5.34 show the scatter diagrams of outdoor air temperatures against indoor air temperatures in all classrooms on the first and second floors. The correlation between indoor air temperature and outdoor air temperature in all classrooms was positive. As the outdoor air temperature rose, the internal air temperature in all classrooms also increased which confirms that outdoor air temperatures had a direct impact on indoor air temperatures, as was the case in the spring season.

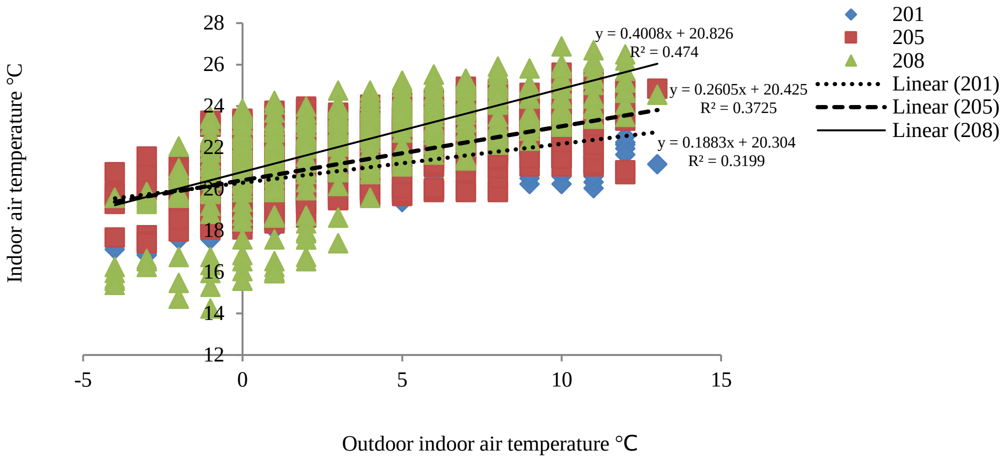


Figure 5.33: Scatter diagram of indoor air temperatures against outdoor air temperatures in winter period in first floor classrooms

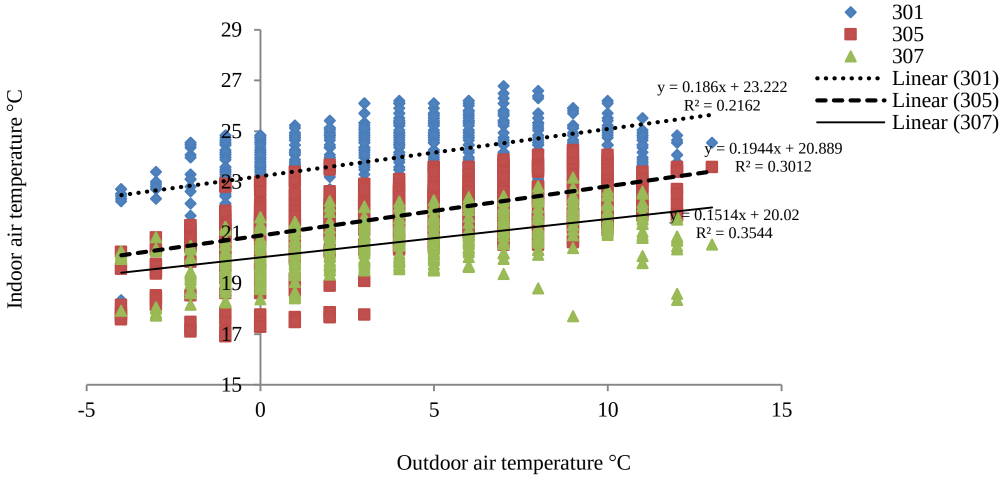


Figure 5.34: Scatter diagram of indoor air temperatures against outdoor air temperatures in winter period in second floor classrooms

In addition, the relationship between indoor relative humidity levels and outdoor relative humidity levels was studied during the field experiment in the winter season. The scatter diagrams of the outdoor relative humidity levels against the indoor relative humidity levels in all classrooms on the first and second floors are presented in Figures 5.35 and 5.36. The correlation between the indoor relative humidity levels and the outdoor relative humidity levels in all classrooms was positive. As the outdoor relative humidity levels increased, the internal relative humidity levels in all classrooms also increased, which confirms that outdoor relative humidity levels had direct impacts on indoor relative humidity levels.

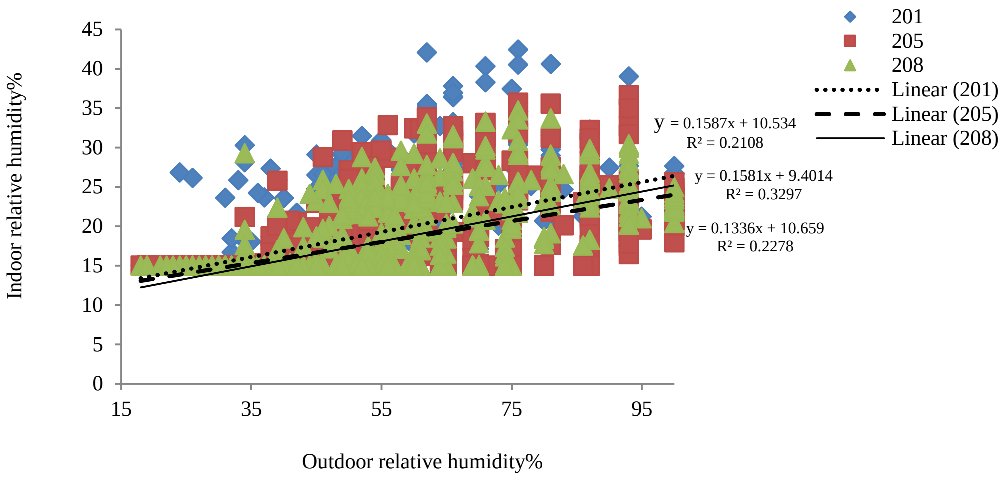


Figure 5.35: Scatter diagram of indoor relative humidity levels against outdoor relative humidity levels in winter period in first floor classrooms

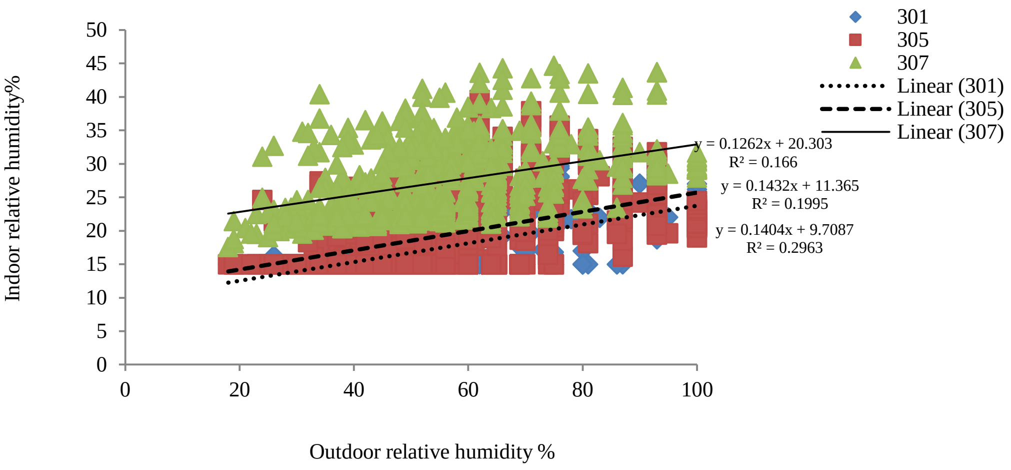


Figure 5. 36: Scatter diagram of indoor relative humidity levels against outdoor relative humidity levels in winter period in second floor classrooms

5.7.5. Comparison of spring and winter seasons' results

Generally, when indoor air temperatures increase, relative humidity levels decrease. A change in the level of relative humidity can be caused by the air's water vapour volume and changes in air temperature (Ahrens, 2008). At a higher temperature the moisture in the air evaporates and the percentage of relative humidity drops. Figure 5.37 presents the mean indoor air temperature and the mean indoor relative humidity levels during the spring and winter periods. In general, the mean indoor air temperatures and the mean indoor relative humidity levels during the spring period were higher than in the winter period. As the classrooms were naturally ventilated during the spring period, the indoor air temperatures and indoor relative humidity levels were higher than in the winter period. During the winter season, a hot water radiator heating system was used for heating purposes, which evaporated extra moisture in the classrooms and helped to decrease the indoor relative humidity levels, despite there being higher outdoor relative humidity levels in winter.

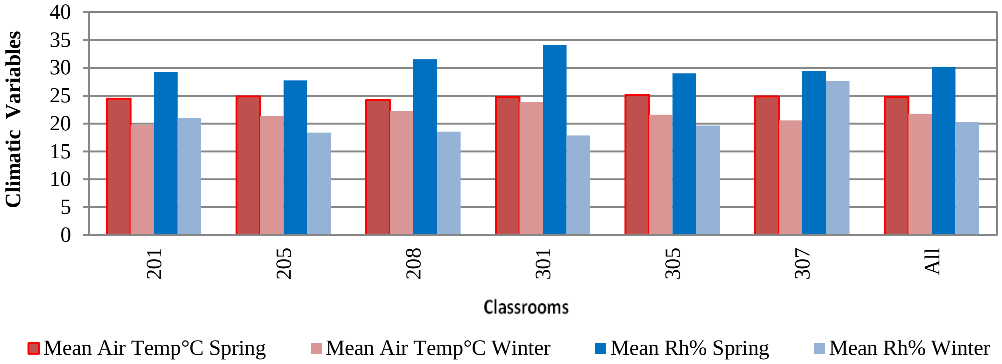


Figure 5.337: Average internal air temperatures and internal relative humidity levels in all measured classrooms during the field study

In addition, during the winter period the outdoor relative humidity level was higher and the outdoor air temperature was lower, compared to the spring period. However, the correlation coefficient of these two variables was higher during the spring period than the winter season (see Figure 5.38) as the classrooms were naturally ventilated in spring. However, the classrooms were heated by the hot water radiator system in winter, which resulted in having more stable weather conditions during the winter period.

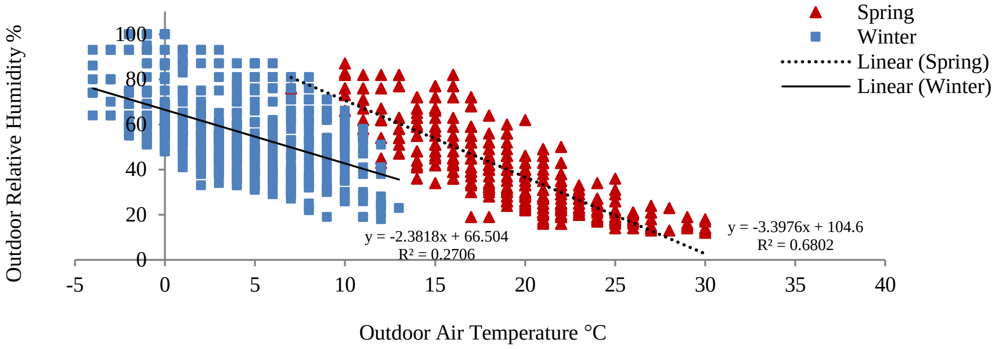


Figure 5.38: Scatter diagram of outdoor air temperatures against outdoor relative humidity levels in winter and spring periods

A comparison of the mean correlation coefficient between indoor relative humidity levels and indoor air temperatures in the spring and winter seasons shows that the correlation between climatic variables was lower in winter than in the spring period (see Table 5.11). In addition, the average correlations in all classrooms matched to the mean outdoor climatic variable correlations in the spring period. The correlation coefficient in some classrooms followed the outdoor correlation coefficient in the winter period and had a negative trend. However, in some classrooms there was a positive correlation.

Table 5.11: Correlation coefficients in all classrooms in two seasons

Outdoor Spring	**201**	**205**	**208**	**301**	**305**	**308**
-0.82	-0.34	-0.28	-0.51	-0.34	-0.20	-0.24
Outdoor winter	**201**	**205**	**208**	**301**	**305**	**307**
-0.52	0.08	0.07	-0.11	-0.30	-0.01	0.36

5.8. Conclusion

In this chapter the result of field measurements of climatic variables, including indoor air temperatures and indoor relative humidity levels, were studied during the spring and winter seasons in 6 classrooms. The field measurements was carried out in two periods, the warm spring period of April/May 2010 and the cold winter season of January/February 2011, just before the exam periods during the summer and winter holidays. The indoor air temperatures and relative humidity levels were recorded for three weeks in the warmest period of the spring season, and for four weeks during the coldest period in winter season. The result showed that the maximum and the minimum indoor air temperatures in all measured classrooms during the teaching hours were mostly within the comfort bands defined by Heidari (2010) for Iranian people. The mean indoor air temperature in all classrooms was just below 25˚C in spring and more than 21˚C in winter. Moreover, the mean indoor relative humidity levels of the classrooms in both seasons were quite low during the teaching hours, compared to the outdoor relative humidity levels. It measured 30% in the spring season and 20% in the winter period.

Chapter 6: Questionnaire-based Survey

6.1. Aims of survey

Based on Nicol et al (1994), one of the main factors that needs to be considered in any buildings' function in all the climatic regions is thermal comfort of the occupants. Moreover, providing a comfortable space in an indoor environment should be the main aim of the buildings' design (Saberi et al., 2006), as the thermal condition of a building has a considerable effect on the health and comfort of the occupants in indoor spaces. According to CABE (2010), the thermal condition of the indoor environment has a great impact on students' attendance and learning motivation (CABE, 2010). Studies show that indoor pollutants and thermal conditions influence students' performances and poor indoor air quality can cause health effects which limits students' learning opportunities and increases absence (Mendell and Heath, 2005). In order to examine the comfort levels of the students and improve the thermal conditions of the classrooms in the female secondary school buildings in Tehran, a questionnaire-based survey was conducted in the spring and winter periods of 2010/11, while the indoor climatic variables were measured by HOBO data-loggers, as discussed in details in Chapter 5. The improvement of thermal performance of the classrooms in school buildings will increase the comfort and learning efficiency of the students during lessons. One of the main aims of the questionnaire-based survey in this study was to obtain a general overview of the students' thermal satisfaction and thermal preferences for various clothing values in the warm spring season and winter periods, which fall in the warmest and coldest periods during the academic year (Kasmai, 93).

6.2. Choice of the area and subjects

The field survey was conducted in a female secondary school building in the city of Tehran, Iran, as Tehran is the capital of Iran and has the largest number of schools and students compared to other cities in Iran (CBI, 2009). Also, Tehran has a hot and dry climate, like most regions of Iran (Kasmai, 1993) and the result of this study is representative of similar climatic regions in other studies. Moreover, the focus of this research is on secondary school female students, aged between 15 to 18 years old, as they can easily understand their thermal sensations and preferences, compared to the smaller age group, and have less difficulty in answering the questionnaires. The only restriction in this study was the choice of the subjects. On religious ground, boys and girls in Iran go to separate schools and female students need to wear a special uniform and cover their hair with a scarf. Wearing the special uniform and headwear makes the female students' have different sensations of comfort compared to male students, which might affect the comfort zone for girls in the school buildings.

To design a thermal comfort survey, the number and representativeness of the samples are the important features required to make inferences about a population from a sample and to ensure the accuracy of the final result. A sample size is a selection of respondents chosen in such a way that they represent the total population as well as possible. To estimate the appropriate number of samples there are a few steps which are essential to calculate the ideal sample size and to ensure the accuracy of the survey. These steps include the overall population, confidence level and accuracy, as well as confidence intervals or margins of error (SurveyMonkey, 2014, Survey System, 2012a). Population is the entire set of people who want to be understood and the sample is going to be the people from this population who actually take the survey. The confidence level and accuracy is the assessment of the risk and the amount of uncertainty that can be tolerated in the survey, which is usually for 90%, 95% or 99% of the population. The confidence interval or margins of error is the amount of error which can be tolerated, that is usually 1%, 5% or 10% (Survey System, 2012a, SurveyMonkey, 2014).

In complicated studies, there may be several different sample sizes involved in the study. For instance, in experimental design, where a study may be divided into various groups, there may be different sample sizes for each group. Sample sizes may be selected in various ways. There are some software and tools, as well as online statistical power analysis and charts, which can calculate and estimate the sample size. This study attempts to estimate the number of the samples by using various calculations and charts and comparing estimations which had a similar results (SurveyMonkey, 2014, Raosoft, 2004, Survey System, 2012a). The equation which is used in the calculations is expressed below:

$$\frac{z^2 p(1-P)}{c^2} = \mathrm{ss} \text{ (Survey System, 2012b)} \qquad \text{Eq 6.1}$$

Where Z = Z value (e.g. 1.96 for 95% and 1.86 for 90% confidence level)
p = percentage picking a choice, expressed as a decimal (0.5 used for sample size needed)
c = confidence interval, expressed as a decimal (e.g., .04 = ±4)

Also, from the following table by choosing an approximate target population and the margin of error, the number of samples can be estimated (see Table 6.1):

Table 6.1: Estimation of sample size based on population, confidence level and interval (SurveyMonkey, 2014)

Population	**Margin of Error**			**Confidence Interval**		
	10%	**5%**	**1%**	**90%**	**95%**	**99%**
100	50	80	99	74	80	88
500	81	218	476	176	218	286
1,000	88	278	906	215	278	400
10,000	96	370	4,900	264	370	623
100,000	96	383	8,763	270	383	660
1,000,000+	97	384	9,513	271	384	664

Based on the survey system calculation, equation 6.1 and table 6.1, the appropriate estimated number of the sample size for the 1.8 million school population in the city of Tehran was around 271 for a 90% confidence level and 384 for a 95% of confidence level with a 5% confidence interval. In this study, the overall number of the sample was around 460 in both seasons, which is more than the 95% of the confidence level.

In addition, the survey was conducted in a female secondary school building in 25 classrooms in total. The questionnaire survey study consists of a short-term survey carried out in extreme periods, one day in winter season and one day in the spring, which represents the warm and the cold teaching days. According to Heidari and Sharples (Heidari and Sharples, 2002), short-term and the long-term field surveys in Iran have a good agreement. The short-term study was performed in a few days with a considerable amount of subjects. However, the long-term study would be performed over a long period (e.g. one year) with a limited number of subjects. This study is based on the short-term study, which is performed in two days with 460 subjects.

The school and its classrooms were selected in order to give a representative sample of a typical secondary school in Tehran school. The school had sufficient numbers of the students in the school building. The average number of students in each classroom was between 19 and 25, which is equal to the average number of students in every classroom in the country, and was therefore representative. Also the school building had the typical plan of school buildings in Iran, with a masonry structure, which is representative of other typical school types in Tehran and similar climatic regions. The representative samples of the school buildings were the secondary school female students, as mentioned previously, who can understand the thermal comfort questions in the questionnaire survey easier comparing to the younger students and, as a result, their answers are more accurate.

There are many thermal comfort surveys conducted in school buildings in different regions of the world. The samples were selected as being representative of typical school buildings and the whole school populations in the region. Most of the studies involved short-term field survey and some were performed as long-term surveys and with considerable amounts of students, in order to increase the accuracy of the results (Prescott, 2001, Kwok and Chun, 2003, Humphreys, 1977, Corgnati et al., 2009, Wong and Khoo, 2003, Hwang et al., 2006, Mendonça de Moraes et al., 2004). The sample size in each study was different to other studies and there was not enough evidence of how the number of the samples was selected for the similar studies. The numbers of the subjects were selected based on the limitations and nature of the study but an attempt was made to choose an appropriate number to carry out the survey and compare the result to similar studies.

6.3. Experimental methods

The field survey was conducted in two days, while the indoor air temperature and the indoor relative humidity levels were measured with HOBO data-loggers. The first questionnaire survey was carried out on the 4th May 2010 and the second on the 9th February 2011. The surveys were conducted in the warm spring and cold winter seasons, before the exam periods and school closure for holidays. 459 questionnaires were distributed to the students in total in both seasons. The students were asked to fill in the questionnaires in the spring and winter seasons and describe their thermal sensations and thermal preferences during lessons in the warm and cold periods. They were also asked to answer some questions regarding their sensation of relative humidity and air movement in the classroom, as well as their clothing insulation and their activities up to 15 minutes prior to the survey.

260 subjects on the 4th May 2010 and 199 subjects on 9th February 2011 took part in the survey. The students were aged 15 to 18 years old and they were located in 15 classrooms during the spring season and 10 classrooms during the winter period. These classrooms included all six classrooms that were measured by HOBO data-loggers. The questionnaire survey was conducted twice on the 4th May 2010, as the school was a double shift school during the first experiment. The first shift started in the morning at 7:30am to 12:30pm and the second shift was from 1:30pm to 5:30pm. The questionnaire survey was carried out at 12:00pm for the morning shift and 2:00pm for the afternoon shift, just before the breaks in the afternoon. However, during the second survey, in the winter period, the school had the morning shift only and the survey was conducted at 12:00pm. Tables 6.2 and 6.3 summarise the questionnaire survey details in the spring and winter periods. The participants were categorised into various groups according to classroom location. The grey boxes present the location of the classrooms.

Table 6.2: Summary of questionnaire survey in Tehran on 4 May 2010

Classrooms	**Location**		**Floor**		**Time**		**Number of questionnaires**
	North-facing	**South-facing**	**1st**	**2nd**	**Start**	**Finish**	
201	▨		▨		12:00	12:30	20
205		▨	▨		12:00	12:30	24
206		▨	▨		12:00	12:30	19
207		▨	▨		12:00	12:30	9
208		▨	▨		12:00	12:30	24
301	▨			▨	12:00	12:30	23
305		▨		▨	12:00	12:30	13
306		▨		▨	12:00	12:30	21
307		▨		▨	12:00	12:30	21
308		▨		▨	12:00	12:30	22
201	▨		▨		2:00	2:30	7
205		▨	▨		2:00	2:30	19
208		▨	▨		2:00	2:30	10
301	▨			▨	2:00	2:30	19
308		▨		▨	2:00	2:30	9
Total no	69	191	132	128	-----	-----	260

Table 6.3: Summary of questionnaire survey in Tehran on the 9th February 2011

Classrooms	**Place**		**Floor**		**Time**		**Number of questionnaires**
	North-facing	**South-facing**	**1st**	**2nd**	**Start**	**Finish**	
201	■		■		12:00	12:30	20
202	■		■		12:00	12:30	20
204		■	■		12:00	12:30	18
205		■	■		12:00	12:30	21
208		■	■		12:00	12:30	23
301	■			■	12:00	12:30	21
302	■			■	12:00	12:30	19
305		■		■	12:00	12:30	17
306		■		■	12:00	12:30	19
307		■		■	12:00	12:30	21
Total no	83	116	102	97	-----	-----	199

Moreover, HOBO data-loggers gathered the environmental variables in six classrooms during the first period of the survey, while the students were answering the questionnaires. The HOBO loggers were located in the same classrooms for the winter period, except that Classroom 308 was not occupied during the winter semester. Classroom 307 was measured instead, which faces south as well, similar to Classroom 308. The winter and spring studies' results were compared afterwards. The measured classrooms included classrooms numbers 201, 205, 208, 301, 305, and 308 (307 in winter).

6.4. Instrumentation

Two environmental variables, indoor air temperature (T) and relative humidity levels (Rh), were monitored with HOBO data-loggers (Onset Co., 2013) during the survey and while the students were answering the questions during the spring and winter seasons. The HOBO loggers were located at a height of 0.6 metres above the floor and in front of the classrooms, far from the direct solar radiation, in order to record the more accurate results. The loggers recorded the climatic variables with a logging interval of 15 minutes for three weeks during the warm spring months of April/May and for four weeks during the cold winter period of January/February, which included the survey days.

6.5. Subjective data

Each student was given an A4 sheet which contained 10 questions. All of the students filled in the questionnaires in Farsi whilst sitting in their classrooms, after performing light activities such as reading or writing 15 minutes prior to the survey. Each questionnaire includes 5 questions regarding comfort of the students in the classrooms which were needed to be answered by ticks. Moreover, students were asked to answer some questions about their lighting preferences, clothing types and activities in the preceding 15 minutes in order to estimate the average clothing insulation value and metabolic heat rate. The sample of the questionnaire both in English and Farsi is presented in Appendix 1. The questions were divided into the following sections:

- Thermal sensation of the students
- Thermal preferences of the students
- Humidity sensation
- Air movement sensation
- Lighting sensation and preferences
- Clothing of the students
- Activity of the students
- A general overview of the thermal acceptance

The students were also asked to answer the questions concerning the lighting condition of the classrooms and the lighting preferences in order to do some further analysis for future studies. In addition, two separate A4 sheets were given to students' representatives, the teachers. The sheet includes the site record form, which was only answered by the students' representative. The representative recorded the lighting, openings and the equipment's conditions whilst the students were completing the questionnaires. The second sheet was the questionnaire instruction which would be explained to the students prior to the survey by the students' representative. Later a comparative analysis was performed on the results of the field studies in the classrooms and the results from the field measurements were compared to the results of the questionnaire survey (Zahiri et al., 2011). In addition, the students' representative signed the consent form on behalf of the students.

6.6. Subjective scale

The current field study was designed according to ASHREA 55 Standard, Thermal Environmental Conditions for Human Occupancy (ASHRAE, 2004). The thermal sensation question is based on the 7-point ASHRAE scale for summer and winter comfort (ASHRAE, 2004). The comfort vote is clearly indicated, as a number, and it ranges from -3 (cold) to +3 (hot) (see Table 6.4). The ASHRAE scale was used for this study because it is the most common scale used in Iran and the Iranian Building Regulations, Energy Code is based on ASHRAE (Kari and Fayaz, 2006). In addition, the translation of the ASHRAE sensation votes scales in Farsi can be understood more easily by Iranian people (Heidari, 2000) compared to other scales at different standards, such as ISO 10551 (ISO 10551, 1995).

Table 6.4: ASHRAE Standard 55 sensations scale

-3	**-2**	**-1**	**0**	**+1**	**+2**	**+3**
Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot

The thermal preference question is to analyse the occupants' preferred temperature in indoor spaces. It was based on the 3-point McIntyre scale (McIntyre and Gonzalez, 1976) which ranged from -1 (colder) to +1 (warmer) (see Table 6.5).

Table 6.5: 3-point McIntyre scale

-1	**0**	**+1**
colder	no changes	warmer

In addition, the participants answered the questions regarding the perception of indoor humidity and internal air velocity in three point scales (see Table 6.6). As it is difficult to differentiate between the levels of the humidity and air movement, especially where the humidity is low and the air velocity variable, the three point scale was defined for the perception of these two environmental variables (Heidari, 2000).

Table 6.6: 3-point air movement and humidity scale

3-point scale	**-1**	**0**	**+1**
Air Movement	Still	Just right	Breezy
Humidity	Dry	Just right	Humid

The clothing and the activities of the students during the survey were measured with the values expressed in ASHRAE Standard 55 (ASHRAE, 2004). The clothing value or the average clothing insulation measure with clo-value and the activity value were measured with metabolic heat rate.

6.7. Climatic variables' measurement

As mentioned in sections 6.3 and 6.4, the indoor air temperature and relative humidity level were measured in six classrooms, during the spring and winter seasons for three and four weeks consecutively, which included the survey days. The aim was to compare the results of the questionnaire survey, based on indoor climatic variables.

6.7.1. Air temperature during the spring survey day

Figure 6.1 presents indoor air temperatures in all six measured classrooms against outdoor temperatures.

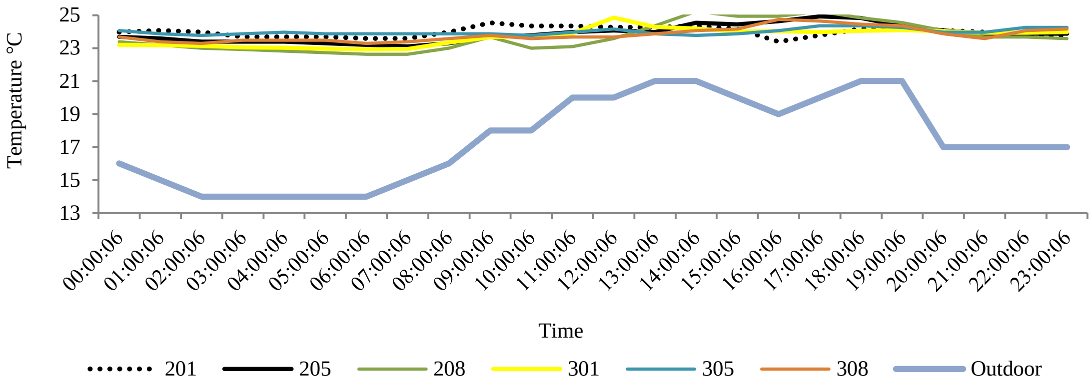


Figure 6.1: Outdoor and indoor air temperatures in six classrooms on 4th May 2010

From the figure 6.1 it is clear that the indoor air temperature in all classrooms was higher than the outdoor temperature during the questionnaire survey on the 4th May 2010. As the classrooms were naturally ventilated during the field study survey in spring, the indoor air temperature trends usually followed the outdoor air temperature, but at the higher level, and tending to remain more constant.

6.7.2. Relative humidity during the spring survey day

Figure 6.2 shows the indoor relative humidity levels in six measured classrooms against the outdoor relative humidity levels. The figure below shows that the outdoor relative humidity was usually higher than the indoor relative humidity levels between midnight and early morning on the 4th May 2010. Afterwards, it started to drop till mid morning and later had an equal level as the indoor relative humidity in the most classrooms. Although human breathing produces moisture, which increases the level of humidity inside the classrooms during the occupancy, it did not affect the humidity level inside the classrooms considerably during the one day survey, as the classrooms were naturally ventilated. Possible reasons might be natural ventilation and the air flow rate, which might remove extra moisture from the classrooms. Figure 6.2 shows that indoor relative humidity trends usually followed outside relative humidity during the survey day.

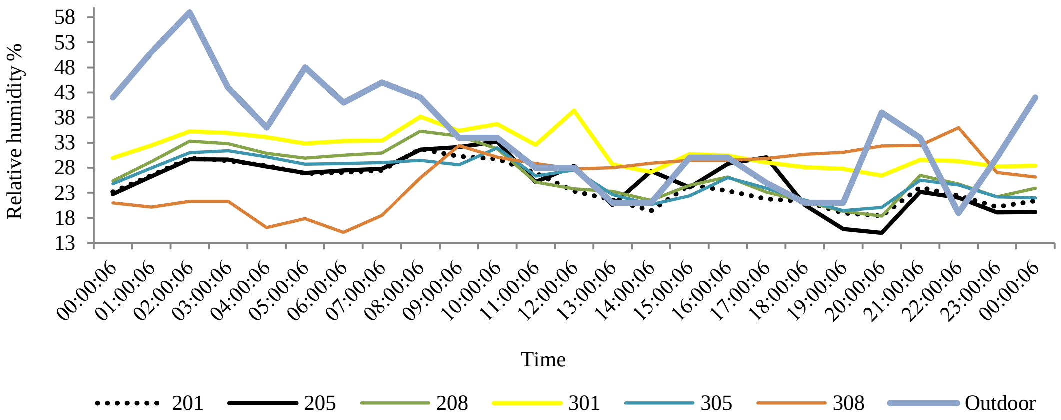


Figure 6. 2: Outdoor and indoor relative humidity in six classrooms on 4th May 2010

6.7.3. Air temperature during the winter survey day

Figure 6.3 shows outdoor air temperature against indoor air temperature in all six measured classrooms during the winter survey days. It shows that indoor air temperatures in all classrooms were higher than outdoor temperatures during the winter season survey. A possible reason could be the use of a hot water radiator heating system in the school building. The heating system was operating to keep the indoor air temperature at high levels, and, as a result, the indoor air temperature was more constant in winter than in the spring period. However, the indoor air temperature trend usually followed the outdoor air temperature, like the spring season temperature, but more constantly. A possible reason for this could be the poor construction of the building and lower infiltration levels.

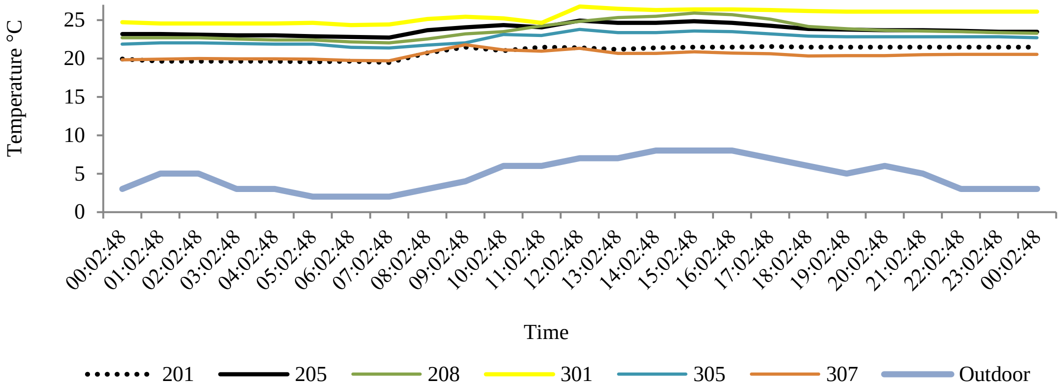


Figure 6.3: Outdoor and indoor air temperatures in six classrooms on 9th February 2011

6.7.4. Relative humidity during the winter survey day

Figure 6.4 illustrates the outdoor relative humidity levels in comparison to the indoor relative humidity levels. Outside relative humidity was higher than indoor relative humidity levels during the winter survey day, which is acceptable as the heating system was operating in all classrooms. The higher indoor temperature resulted in lower relative humidity levels. However, indoor relative humidity trends did not usually follow the outdoor relative humidity levels during the winter season because of the heating system operation and the sensitivity of the HOBO data-loggers. The heating system was operating 24 hours a day and it kept the indoor relative humidity at the lowest level, except during occupancy, when the students' breathing produced moisture. The relative humidity levels increased considerably during lesson hours, from around 7:30am, and it decreased to the lowest level as soon as the occupants left the classrooms, at around 1:00pm. It was found out that the HOBO data-loggers did not measure relative humidity level below 15%, which shows their sensitivity. However, the relative humidity levels below 30% fell out of the comfort zone (Chegeni, 2011) which was the main point in this study, and, as a result, the exact amount were not considered.

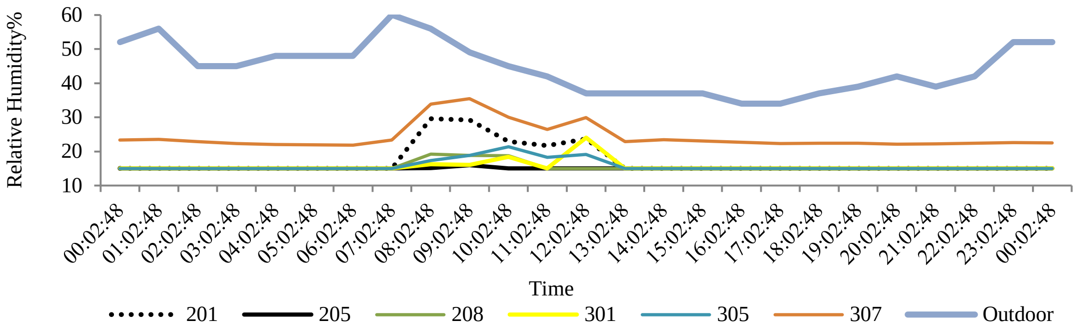


Figure 6.4: Outdoor and indoor relative humidity in six classrooms on 9th February 2011

6.8. Distribution of indoor environmental variables

In this study the indoor air temperatures and the indoor relative humidity levels were measured in six classrooms during the spring season survey, as discussed previously. The climatic data were also measured in the same classrooms during the winter season, except for one classroom. Classroom 308 was measured during the spring period only and Classroom 307 was measured instead during the winter period, as Classroom 308 was not occupied during the winter season experiment. In this study, the air velocity and the radiant temperature, two additional environmental variables for the thermal comfort studies were exempted from the field measurement. According to the thermal comfort study conducted by Humphrey (1976) and Heidari (2000), the indoor air temperature does not differ enormously from the radiant temperature (Oseland, 1992) so it was exempt from the measurements and the indoor air temperature was used as a main comfort index in this study. In addition, as the outdoor air flow rate during the spring season was low and during the winter season the openings were close, the air velocity rate was considered to be at a low rate.

6.8.1. Environmental variables in all classrooms in both seasons

The summaries of the measured climatic variables during the spring and winter season surveys, including average, minimum and maximum values, and standard deviation, in all classrooms, and in both seasons, are categorised in tables 6.7 and 6.8. The minimum and the maximum indoor air temperatures on 4th May 2010 ranged between 22.6°C and 25.4°C in Classroom 208 (see Table 6.7). However, on 9th February 2011 the minimum indoor temperature measured in Classroom 201 was at around 19.5°C and the maximum was 26.9°C in Classroom 301. The mean indoor air temperature in all classrooms was around 24°C on 4th May and around 23°C on 9th February 2011, with only 1K difference between both seasons' mean indoor temperatures. Comparing the standard deviation of the indoor air temperatures for all classrooms, there is a significant difference between the standard deviation in all classrooms in both seasons. The minimum standard deviation was 0.2 for Classroom 305 in May and 0.5 for Classroom 307 in February. The maximum standard deviations calculated for the hot and cold seasons, were 0.9 and 1.2 respectively in Classroom 208.

Table 6.7: Mean, standard deviation, max and min of air temperature on 4th May 2010 and 9th Feb 2011 in six measured classrooms

Season	Temperature ˚C	201	205	208	301	305	307	308	All
Spring	**Mean**	24	23.9	23.7	23.7	24		23.8	23.8
	Min	23.4	23.1	22.6	22.9	23.4		22.8	22.6
	Max	24.5	25.1	25.4	24.9	24.4		24.7	25.4
	SD	0.3	0.5	0.9	0.5	0.2		0.4	0.5
Winter	**Mean**	20.9	23.8	23.7	25.5	22.6	20.5		22.8
	Min	19.5	22.7	22	24.3	21.3	19.7		19.5
	Max	21.6	25.1	25.9	26.9	23.9	21.8		26.9
	SD	0.8	0.7	1.2	0.8	0.7	0.5		1.9

In addition, the maximum indoor relative humidity was measured at 40% in Classroom 301 on 4th May 2010 and was 37% in Classroom 307 on 9th February 2011. The minimum relative humidity was measured at 15% in all classrooms. The reason for this is the accuracy of HOBO data-loggers, which are not able to measure the relative humidity when it is below 15%. The minimum standard deviations were for Classroom 301 in May and Classroom 205 in February, 3 and 0.2 respectively. The maximum standard deviation of the relative humidity was 5 in May and 4 in February in classrooms 205 and 201 respectively. The difference between mean relative humidity in May and February is around 10%. The mean value of the relative humidity in all classrooms was around 27% in May 2010 but it was 10% lower in February 2011 at around 17%.

Table 6.8: Mean, standard deviation, max and min of relative humidity levels on the 4th May 2010 and 9th Feb 2011 in six measured classrooms

Season	Relative humidity%	201	205	208	301	305	307	308	All
Spring	**Mean**	25	26	27	32	20		26	27
	Min	17	15	18	26	18		18	15
	Max	32	34	36	40	33		33	40
	SD	4	5	5	3	4		4	5
Winter	**Mean**	17	15	15	16	16	24		17
	Min	15	15	15	15	15	21		15
	Max	32	16	20	25	22	37		37
	SD	5	0.2	1	2	2	4		4

6.8.2. Environmental variables in different locations and in both seasons

In this study, the mean, maximum, minimum and standard deviation values were categorised into various groups based on the classrooms locations, whether they are located on the first or second floors or facing north or south. Tables 6.9 and 6.10 present the summaries of the climatic data in various locations. According to table 6.9, the maximum indoor air temperature was recorded on the south-facing side classrooms on the first floor, in May 2010, at around 25°C. However, in the winter season it was measured at a higher range at around 27°C on the north-facing classrooms on the second floor. A possible reason is the use of heating system during the winter. The minimum indoor air temperatures in May and February were 22.6°C and 19.5°C for south- and north-facing classrooms respectively, on the

First floor. The mean indoor air temperature in all classrooms was between around 22.5°C and 24°C in both seasons, with only 2K difference. However, the standard deviation of the indoor air temperature was considerably different between the two seasons. It was lower in all classrooms during the May experiment compared to the February study, as the classrooms were naturally ventilated. However, during the winter period, the hot water radiator system was used for keeping the indoor temperature high, which could be adjusted manually by the occupants and might cause higher standard deviation.

Table 6.9: Mean, standard deviation, max and min of indoor air temperature on 4th May 2010 and 9th Feb 2011 in all classrooms according to their locations

Season	Temperature °C	North facing	South facing	First floor	Second floor
Spring	Mean	23.8	23.8	23.8	23.8
	Min	22.9	22.6	22.6	22.8
	Max	24.9	25.4	25.4	25.4
	SD	0.4	0.6	0.6	0.4
Winter	Mean	23.2	22.6	22.8	22.9
	Min	19.5	19.7	19.5	19.6
	Max	26.9	26	26	26.9
	SD	2.5	1.6	1.7	2.2

In addition, maximum relative humidity levels was recorded in north-facing classrooms and on the second floor in May 2010 but it was recorded in the south-facing classrooms on the second floor during the winter season at around 37%. The minimum relative humidity was 15% in all classrooms due to the HOBO data-loggers' limits, as discussed in section 6.8.1. The maximum mean relative humidity level in May was higher than a cold winter day of February. It was measured 12% more than the winter result at around 28% in north-facing side classrooms. The heating system temperature during the winter period might be the reason for having lower humidity level in winter season which might absorb the moisture of the room. The standard deviations were various in all classrooms.

Table 6.10: Mean, standard deviation, max and min of indoor relative humidity levels on 4th May 2010 and 9th Feb 2011 in all classrooms according to location

Season	Relative Humidity%	North facing	South facing	First floor	Second floor
Spring	Mean	28	26	26	28
	Min	17	15	15	18
	Max	39	36	36	39
	SD	5	4	5	5
Winter	Mean	17	18	16	19
	Min	15	15	15	15
	Max	32	37	32	37
	SD	4	5	3	5

6.8.3. Air temperature against relative humidity

Figures 6.5 and 6.6 illustrate the indoor air temperature (ºC) against the indoor relative humidity levels in all classrooms during the measurement period, when the students answered the questionnaires on the survey days in the spring and winter seasons. It can be seen that, while the indoor air temperature in all classrooms changed from just below 23°C in Classroom 208 to over 25°C in the same classroom, the indoor relative humidity varied from 15% in Classroom 205 to just below 40% in Classroom 301 during the spring season.

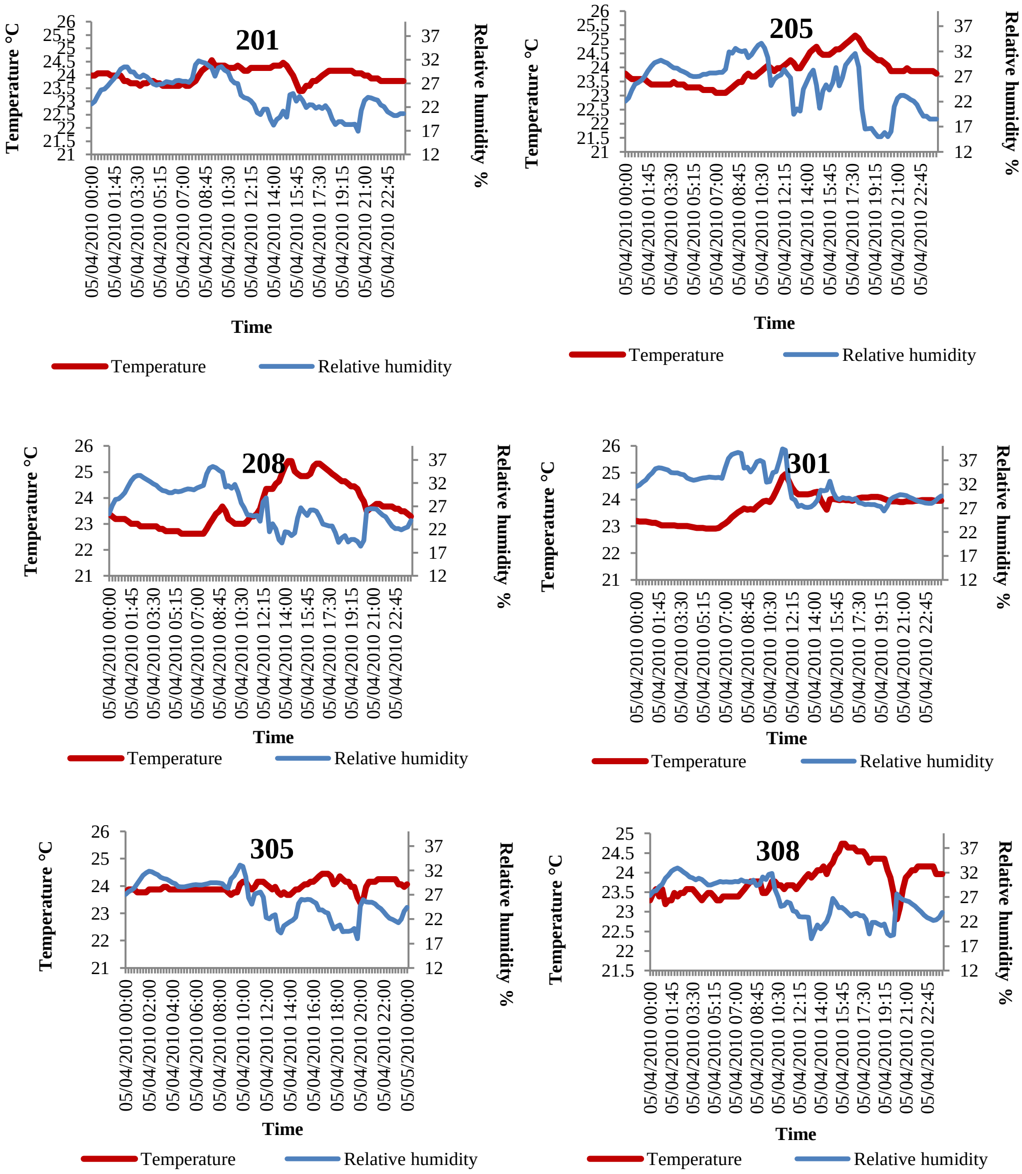


Figure 6.5: Indoor air temperatures and relative humidity levels in all classrooms on 4th May 2010

Generally, the indoor air temperatures in all classrooms varied between 23°C and 25°C respectively. However, the indoor relative humidity levels fluctuated between 15% and around 32% in all classrooms, except 301. The maximum relative humidity in Classroom 301 was around 40% at noon. Some likely reasons are the number of students in the classrooms, the north-facing aspect of the building and the HOBO data-loggers' accuracy. Normally, while the indoor air temperature increased in all classrooms, the indoor relative humidity dropped at the same period, regardless of the number of occupants during the survey day in May.

On the other hand, indoor air temperature ranges were different in all classrooms during the winter survey day. However, the indoor relative humidity trends were more similar on 9th February 2011. The indoor air temperature in all classrooms fluctuated similarly but the minimum and maximum indoor air temperature was different in each classroom. The minimum air temperature was around 19°C in Classroom 201 and the maximum air temperature was less than 27°C in Classroom 301. However, the minimum indoor relative humidity was 15% in all classrooms and the maximum was around 37% in Classroom 307.

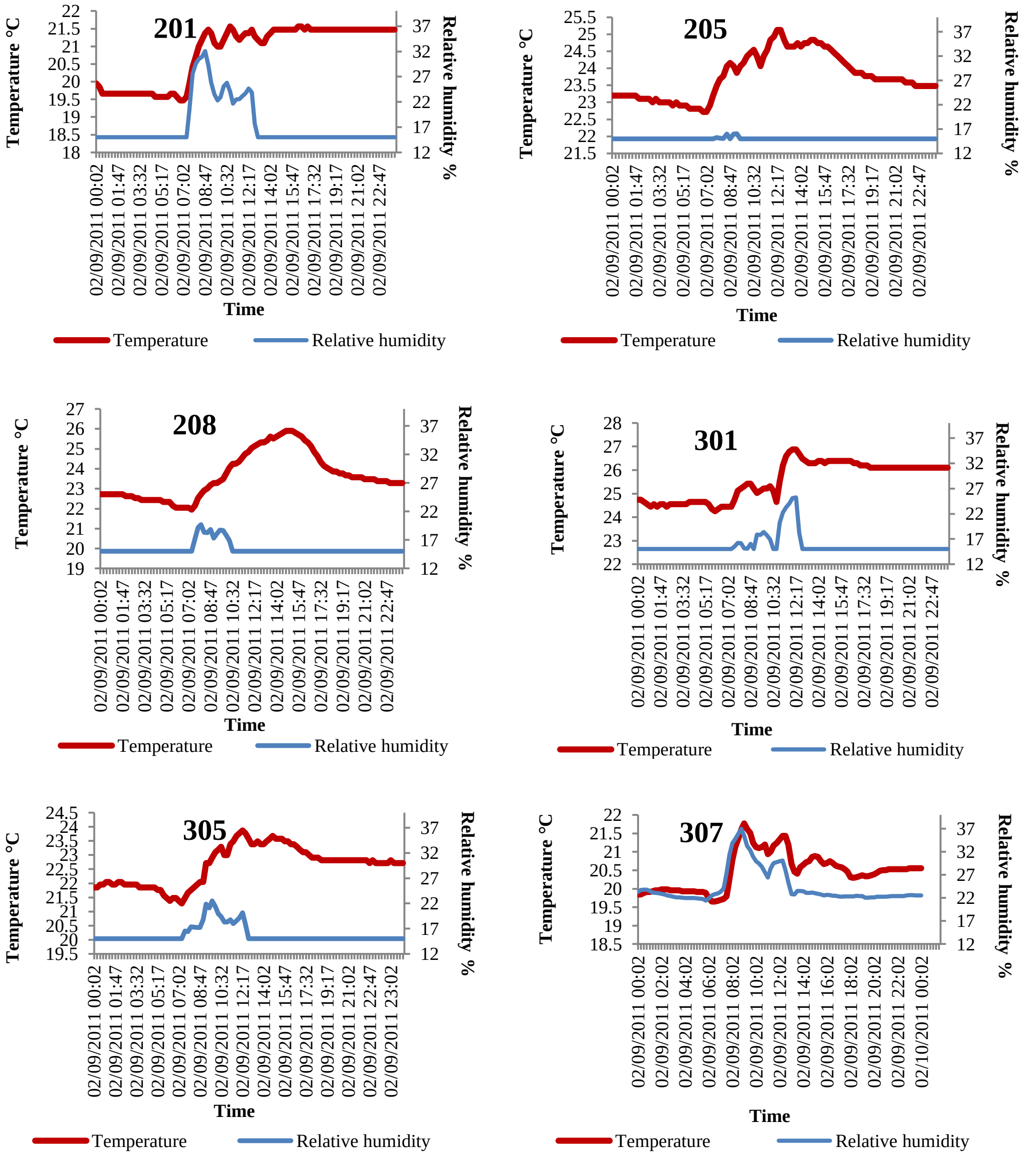


Figure 6.6: Indoor air temperature and relative humidity in all classrooms on 9th February 2011

Generally the indoor air temperatures and the indoor relative humidity levels increased during occupancy, from 7:30am to 12:30pm, in all classrooms. The indoor climatic variable changes were clearly related to the number of occupants, especially relative humidity levels. Unlike the spring survey period measurements, while the indoor air temperature was increasing in all classrooms, the indoor relative humidity increased as well during teaching hours. A comparison of the results shows that environmental variations were related to the number of occupants and the heating and cooling systems of the building during both seasons' measurements.

6.9. Questionnaires

As mentioned before, the assessment of the thermal comfort of the occupants in the classrooms was based on a questionnaire survey. A total number of 459 students from the classrooms located on the first and second floors participated in the survey at noon on 4th May 2010 and 9th February 2011. They answered questions on their perception of thermal sensation in their classrooms, using the 7-point ASHRAE scale. They also chose their indoor thermal preferences, using the 3-point McIntyre scale (McIntyre and Gonzalez, 1976); and answered some questions regarding the sensation of indoor relative humidity and air velocity and their preferences using the 3-point scale.

6.10. Distribution of thermal responses

Based on the questionnaire survey results, the thermal responses of 15 classroom occupants on 4th May 2010 have been analysed and compared to the same classroom's survey results on the 9th February 2011.

6.11. Spring results

During the survey day in spring on 4th May 2010, the questionnaires were filled out by 196 students at 12:00pm in ten classrooms in the morning. In addition, 64 students filled out the questionnaires in five classrooms at 2:30pm during the afternoon.

6.11.1. Thermal sensation

Figure 6.7 shows the overall result of all the thermal sensation responses during the May experiment in both shifts. The results are divided into two categories; the morning and afternoon responses (see Figure 6.8). Figure 6.7 shows that most of the students chose neutral to hot during the spring survey day in both periods and around 35% felt neutral while answering the questionnaires. In addition, around half of the students felt slightly warm to hot in the spring season. However, around 10% felt slightly cool and 5% felt cool in the warm period.

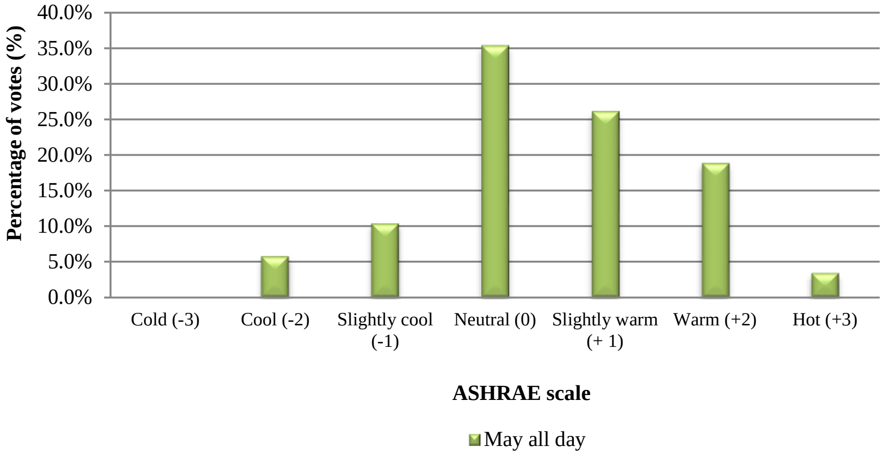


Figure 6.7: Sensation responses in all classrooms on 4th May 2010

Figure 6.8 represents the distribution of thermal sensation votes in the morning and the afternoon shifts separately. Similar to the thermal sensation responses for both shifts, around 35% of the students felt neutral during morning and afternoon classes and most chose neutral to hot in both periods.

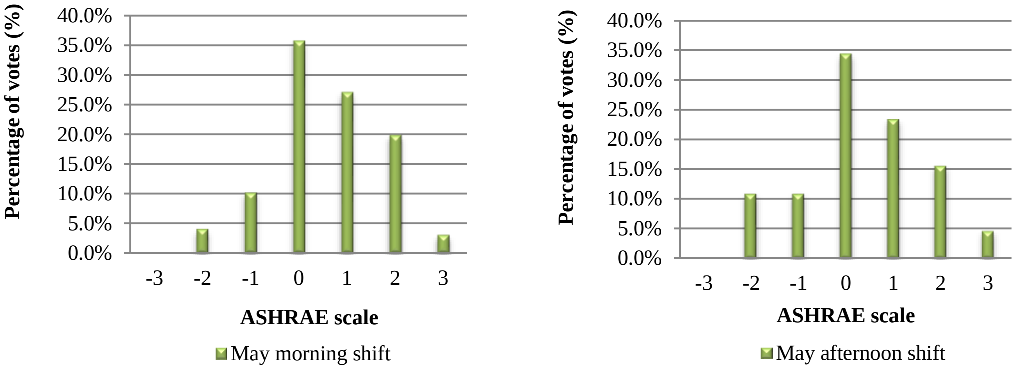


Figure 6.8: Sensation responses on day of survey in spring in morning and afternoon classes

Table 6.11 to 6.13 present the distribution of thermal sensation responses in percentages, and the number of the students during morning and afternoon classes on both floors. The results were separated into first and second floors for the morning shift, as it was not possible to summarise all the results in one table (see Table 6.11 and 6.12). However, for the afternoon shift, as the numbers of the classrooms were limited, all the results are summarised in one table (see Table 6.13).

It can be seen that the most of the students chose between neutral to hot in both periods. The comparison of the sensation responses in each classroom indicates that, in some classrooms and in both shifts, less than 80% of the subjects' responses were in the central three categories of ASHRAE scale, including classrooms 205, 206, and 208 on the first floor, and classrooms 301 and 307 on the second floor. However, in other classrooms more than 80% of the students' responses were in the central three categories. According to ASHRAE Standard 55 (ASHRAE, 2004), a response within the central three categories (-1, 0, +1) of the ASHRAE scale expresses satisfaction or acceptance. In addition, if more than 80% of the responses fall into the central three categories of the ASHRAE scale, from slightly cool to slightly warm, this is enough to consider the indoor environment to be comfortable.

Table 6.11: Thermal sensation responses in morning shift classrooms on first floor in May

Thermal sensation scale (morning -first floor)		201	205	206	207	208
Cold (-3)	**Number**	-	-	-	-	-
	Percentage	-	-	-	-	-
Cool (-2)	**Number**	2	1	1	-	-
	Percentage	10%	4.17%	5.26%	-	-
Slightly Cool (-1)	**Number**	1	4	-	1	1
	Percentage	5%	16.67%	-	11.11%	4.17%
Neutral (0)	**Number**	13	8	6	4	4
	Percentage	65%	33.33%	31.58%	44.44%	16.67%
Slightly Warm (+1)	**Number**	3	7	7	3	4
	Percentage	15%	29.17%	36.84%	33.33%	16.67%
Warm (+2)	**Number**	1	3	5	1	11
	Percentage	5%	12.50%	26.31%	11.11%	45.83%
Hot (+3)	**Number**	-	1	-	-	4
	Percentage	-	4.17%	-	-	16.67%
All	**Number**	20	24	19	9	24
	Percentage	10.21%	12.25%	9.69%	4.59%	12.25%

Table 6.12: Thermal sensation responses in morning shift classrooms on second floor in May

Thermal sensation scale (morning - second floor)		301	305	306	307	308
Cold (-3)	**Number**	-	-	-	-	-
	Percentage	-	-	-	-	-
Cool (-2)	**Number**	-	1	-	-	3
	Percentage	-	7.70%	-	-	13.64%
Slightly Cool (-1)	**Number**	1	3	2	-	7
	Percentage	4.35%	23.98%	9.52%	-	31.81%
Neutral (0)	**Number**	7	6	10	2	10
	Percentage	30.43%	46.15%	47.62%	9.52%	45.45%
Slightly Warm (+1)	**Number**	7	3	9	8	2
	Percentage	30.43%	23.08%	42.86%	38.10%	9.10%
Warm (+2)	**Number**	7	-	-	11	-
	Percentage	30.43%	-	-	52.38%	-
Hot (+3)	**Number**	1	-	-	-	-
	Percentage	4.35%	-	-	-	-
All	**Number**	23	13	21	21	22
	Percentage	11.73%	6.63%	10.71%	10.71%	11.23%

Table 6.13: Thermal sensation responses in afternoon shift classrooms on first and second floors in May

Sensation Scale (Afternoon- all floors)		201	205	208	301	308
Cold (-3)	**Number**	-	-	-	-	-
	Percentage	-	-	-	-	-
Cool (-2)	**Number**	-	1	-	4	2
	Percentage	-	5.26%	-	21.05%	22.22%
Slightly Cool (-1)	**Number**	-	1	2	3	1
	Percentage	-	5.26%	20%	15.79%	11.11%
Neutral (0)	**Number**	6	4	7	3	2
	Percentage	85.71%	21.05%	70%	15.79%	22.22%
Slightly Warm (+1)	**Number**	-	7	1	4	3
	Percentage	-	36.84%	10%	21.05%	33.33%
Warm (+2)	**Number**	1	4	-	4	1
	Percentage	14.29%	21.05%	-	21.05%	11.11%
Hot (+3)	**Number**	-	2	-	1	-
	Percentage	-	10.53%	-	5.26%	-
All	**Number**	7	19	10	19	9
	Percentage	10.94%	29.69%	15.62%	29.69%	14.06%

Table 6.14 present the overall results of thermal sensation responses in both shifts. According to table 6.14, around 73% of the subjects indicated one of the central three categories of the ASHRAE scale in the morning shift and just over 68% of the occupants during the afternoon shift chose responses in the same central categories, which is not enough to satisfy the definition of a comfortable indoor condition, based on ASHRAE 55 (ASHRAE, 2004). However, the score is just below the acceptability level during the spring survey day, which might be increased by a few changes in the indoor conditions of the classrooms, such as ventilation rate, as the difference is very small.

Table 6.14: Overall thermal sensation scores in the morning and the afternoon shift in May

Thermal sensation scale		Morning shift	Afternoon shift
Cold (-3)	**Number**	-	-
	Percentage	-	-
Cool (-2)	**Number**	8	7
	Percentage	4.08%	10.93%
Slightly Cool (-1)	**Number**	20	7
	Percentage	10.20%	10.93%
Neutral (0)	**Number**	70	22
	Percentage	35.72%	34.38%
Slightly Warm (+1)	**Number**	53	15
	Percentage	27.05%	23.44%
Warm (+2)	**Number**	39	10
	Percentage	19.89%	15.63%
Hot (+3)	**Number**	6	3
	Percentage	3.06%	4.69%
All	**Number**	196	64
	Percentage	100%	100%

In addition, comparing the condition of the openings against the thermal sensation scores in central three categories of the ASHRAE scale on the spring survey day indicates that the condition of the doors and windows has a direct effect on occupants' thermal sensation responses (see Table 6.15). The questionnaire results show that all the openings of some classrooms were being kept open during the survey hours. However, in some classrooms the windows were kept open while the doors were kept closed during teaching hours, which resulted in a higher humidity level in the classrooms. Table 6.14 shows that, when the windows and door of the classrooms were open, more than 80% of the votes fell into the central three categories of the ASHRAE scale. However, if the doors of the classrooms were closed, less than 80% of the students were satisfied in terms of the environmental conditions during the survey.

Table 6.15: Condition of openings vs. Thermal sensation responses in all classrooms and in both shifts in May

Classrooms		**201**	**205**	**206**	**207**	**208**	**301**	**305**	**306**	**307**	**308**
Morning shift	**Doors**	Open	Close	Close	Open	Close	Close	Open	Close	Close	Open
	Windows	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
	Central 3 categories	Yes	No	No	Yes	No	No	Yes	No	No	Yes
Afternoon shift	**Doors**	Open	Close	-	-	Open	Close	-	-	-	Close
	Windows	Open	Open	-	-	Open	Open	-	-	-	Open
	Central 3 categories	Yes	No	-	-	Yes	No	-	-	-	No

6.11.2. Preference votes

Figure 6.9 shows the overall result of thermal preference responses on 4th May 2010 in all classrooms. It can be seen that most students wanted to be cooler during the spring survey day on both floors and during both shifts, and that only a small number of the occupants wanted to be warmer or preferred no change in their thermal environment during the questionnaire survey in May.

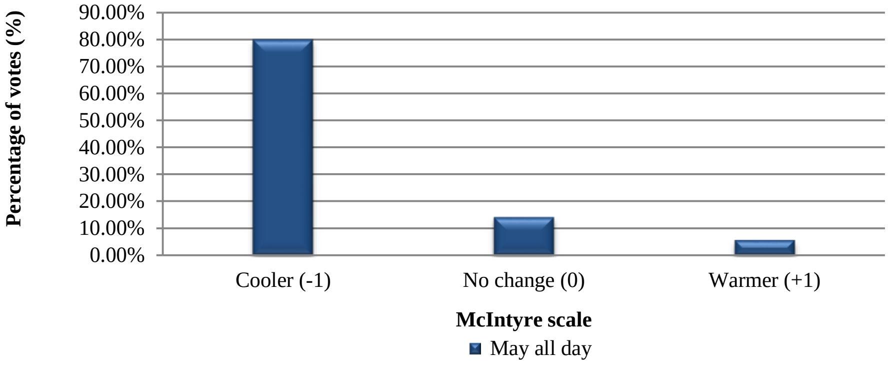


Figure 6.9: Preferences on 4th May 2010 in all classrooms and in both shifts

Comparing the results of the preference responses in the morning to the afternoon also shows that all students in both shifts prefer cooler environments, which indicates that students wanted to be cooler from late morning till early afternoon in May (see Figure 6.10).

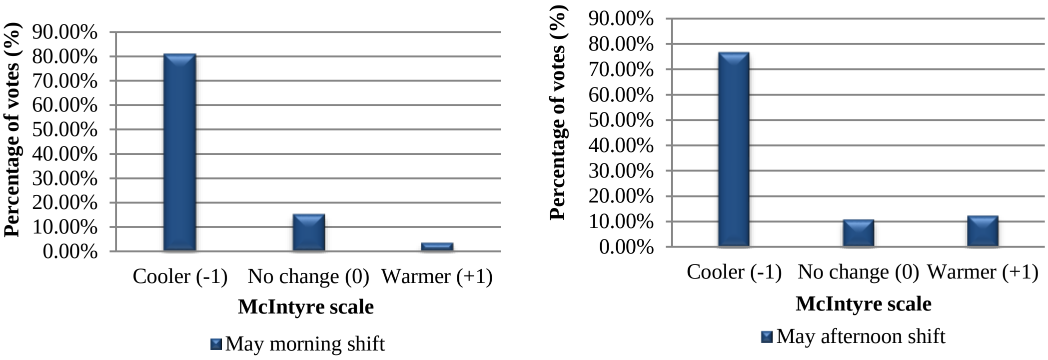


Figure 6.10: Preferences in morning and afternoon shifts separately on 4th May 2010

Tables 6.16 to 6.19 show the distribution of the preference responses on the 3-point McIntyre scale during the morning and the afternoon shifts on the May survey day. The results were categorised into the two floors for the morning periods (see table 6.16 and 6.17). However, as the numbers of classrooms were limited during afternoon, the results are only presented in one table (see Table 6.18).

Table 6.16: Preferences in morning shift classrooms on first floor on 4th May 2010

Preference vote (morning shift-first floor)		**201**	**205**	**206**	**207**	**208**
Cooler (-1)	**Number**	14	7	18	7	23
	Percentage	70%	70.83%	94.73%	77.78%	95.83%
No Changes (0)	**Number**	4	17	1	1	-
	Percentage	20%	29.17%	5.27%	11.11%	-
Warmer (+1)	**Number**	2	-	-	1	1
	Percentage	10%	-	-	11.11%	4.17%
All	**Number**	20	24	19	9	24
	Percentage	10.20%	12.24%	9.70%	4.60%	12.24%

Table 6.17: Preferences in morning shift classrooms on second floor on 4th May 2010

Preference vote (morning shift-second floor)		**301**	**305**	**306**	**307**	**308**
Cooler (-1)	**Number**	22	8	17	21	12
	Percentage	95.65%	61.54%	80.95%	100%	54.54%
No Change (0)	**Number**	1	5	4	-	7
	Percentage	4.35%	38.46%	19.05%	-	31.82%
Warmer (+1)	**Number**	-	-	-	-	3
	Percentage	-	-	-	-	13.64%
All	**Number**	23	13	21	21	22
	Percentage	11.73%	6.63%	10.72%	10.72%	11.22%

Table 6.17: Preferences in afternoon shift classrooms on first and second floors in May

Preference vote (afternoon shift-first and second floor)		201	205	208	301	308
Cooler (-1)	**Number**	7	17	9	16	7
	Percentage	100%	89.48%	90%	84.21%	77.78%
No Changes (0)	**Number**	-	2	1	2	2
	Percentage	-	10.52%	10%	10.53%	22.22%
Warmer (+1)	**Number**	-	-	-	1	-
	Percentage	-	-	-	5.26%	-
All	**Number**	7	19	10	19	9
	Percentage	10.94%	29.69%	15.63%	29.69%	14.05%

It can be seen that the majority of the students wanted to be cooler in both shifts and on both floors and only a small number of the students wanted to be warmer. A few students also preferred no change to their thermal conditions in both periods. However, most wanted their thermal environment to be changed.

Table 6.19 shows that around 76% of the students in the morning shift and more than 87% in the afternoon shift wanted to be cooler. However, around 4% of the students in the morning shift and less than 2% in the afternoon shift wanted to be warmer in the warm spring period. The comparison of the thermal sensation scores and thermal preferences shows that, although around 73% of the students' responses in the morning shift and 68% in the afternoon shift were in the central three categories of the ASHRAE scale (see Table 6.14), expressing thermal satisfaction, just over 75% in the morning shifts and around 87% in the afternoon shifts wanted to be cooler. This illustrates that the majority of students wanted their thermal environment to be changed.

Table 6.18: Overall preferences in morning and afternoon shifts in May

Preference vote		Morning shift	Afternoon shift
Cooler (-1)	**Number**	149	56
	Percentage	76.02%	87.5%
No Changes (0)	**Number**	40	7
	Percentage	20.41%	10.94%
Warmer (+1)	**Number**	7	1
	Percentage	3.57%	1.56%
All	**Number**	196	64
	Percentage	100%	100%

Table 6.20 shows the cross-tabulation of the thermal sensation responses and thermal preference votes in all classrooms and in both shifts on the 4th May 2010. It can be seen that around 77% of the students, who voted neutral in 7-point ASHRAE scale, wanted to be cooler. Moreover, despite feeling cool to hot, most of the occupants wanted to be cooler and only a few of the students wanted to be warmer or preferred no changes during the survey day.

Table 6.20: Sensations and preferences for May

Thermal sensation vote	**Thermal Preference vote**		
	Cooler (-1)	**No change (0)**	**Warmer (+1)**
	Hot	**Hot**	**Hot**
Cold (-3)	-	-	-
Cool (-2)	80%	20%	-
Slightly cool (-1)	55.56%	37.04%	7.40%
Neutral (0)	77.18%	19.56%	3.26%
Slightly warm (+1)	94.12%	5.88%	-
Warm (+2)	93.88%	2.04%	4.08%
Hot (+3)	88.89%	-	11.11%
Total	83.08%	13.85%	3.07%

Comparing the thermal sensation scores on the ASHRAE scale and the thermal preferences on the McIntyre scale shows that neutral sensations were not always the preferred conditions for the secondary school students in this study in Tehran.

6.12. Winter season

During the winter season experiment, the questionnaires were filled out by 199 students at 12:00pm in ten classrooms on 9th February 2011.

6.12.1. Thermal sensation

Figure 6.11 shows the results for thermal sensations of class occupants on 9th February 2011. It can be seen that around 50% of the students chose neutral during the survey in the winter period and nearly 40% chose slightly cool to cold. However, a few of the students felt slightly warm and warm during the survey.

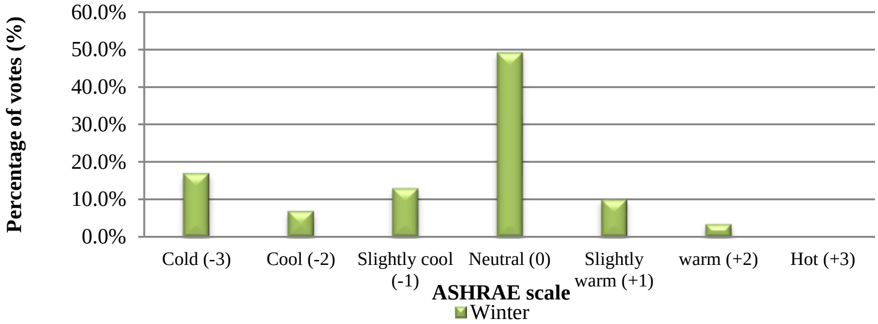


Figure 6.11: Sensation responses on 9th February 2011

Tables 6.21 and 6.22 show the distribution of thermal sensation scores and the number of students surveyed during the winter period survey. The results were categorised by floor.

Table 6.21: Thermal sensation responses on 9th February 2011 on first floor

Thermal sensation vote		201	202	204	205	208
Cold (-3)	Number	-	17	7	-	1
	Percentage	-	85%	38.89%	-	4.35%
Cool (-2)	Number	-	1	-	1	2
	Percentage	-	5%	-	4.76%	8.70%
Slightly Cool (-1)	Number	2	1	2	1	9
	Percentage	10%	5%	11.11%	4.76%	39.13%
Neutral (0)	Number	16	1	6	16	10
	Percentage	80%	5%	33.33%	76.19%	43.48%
Slightly Warm (+1)	Number	1	-	3	1	1
	Percentage	5%	-	16.67%	4.76%	4.35%
Warm (+2)	Number	1	-	0	2	-
	Percentage	5%	-	-	9.52%	-
Hot (+3)	Number	-	-	-	-	-
	Percentage	-	-	-	-	-
All	Number	20	20	18	21	23
	Percentage	10.05%	10.05%	9.04%	10.55%	11.57%

Table 6.9: Thermal sensation responses on 9th February 2011 on second floor

Thermal sensation scale		301	302	305	306	307
Cold (-3)	Number	-	-	4	2	3
	Percentage	-	-	23.53%	10.53%	14.29%
Cool (-2)	Number	-	-	2	1	7
	Percentage	-	-	11.76%	5.26%	33.33%
Slightly Cool (-1)	Number	-	-	6	2	3
	Percentage	-	-	35.29%	10.53%	14.29%
Neutral (0)	Number	14	16	4	8	7
	Percentage	66.67%	84.21%	23.53%	42.11%	33.33%
Slightly Warm (+1)	Number	6	3	-	4	1
	Percentage	28.57%	15.79%	-	21.05%	4.76%
Warm (+2)	Number	1	-	1	2	-
	Percentage	4.76%	-	5.88%	10.53%	-
Hot (+3)	Number	-	-	-	-	-
	Percentage	-	-	-	-	-
All	Number	21	19	17	19	21
	Percentage	10.55%	9.55%	8.54%	9.55%	10.55%

It can be seen that considerable number of the students chose neutral, except in classrooms 202 and 305. In addition, the highest number of responses fell outside the central three categories of the ASHRAE scale. As discussed above, if more than 80% of the votes fall within the three central categories of this scale, the indoor thermal condition is acceptable (ASHRAE, 2004). However, in some classrooms more than 80% of the responses fell within the central three categories including classrooms 201, 205 and 208 on the first floor, and classrooms 301 and 302 on the second floor.

Table 6.23 shows the overall thermal sensation responses in all classrooms during the winter survey day on 9th February 2011. According to Table 6.24, around 72% of the subjects indicated one of the central three categories of the ASHRAE scale, which is not enough to satisfy the criterion for a comfortable condition. As stated previously, a response in the central three categories (-1, 0, 1) of the ASHRAE scale expresses satisfaction or acceptance (ASHRAE, 2004) and more than 80% acceptability in the three central categories of ASHRAE scale, from slightly cool to slightly warm, is enough to consider the indoor environment to be comfortable. However, during the winter period survey only around 72% of the students' responses fell into these categories, similar to the spring period survey, which is just below the acceptability range.

Table 6.23: Overall thermal sensation votes in winter survey day

Thermal sensation scale		All classrooms
Cold (-3)	**Number**	34
	Percentage	17.09%
Cool (-2)	**Number**	14
	Percentage	7.04%
Slightly Cool (-1)	**Number**	26
	Percentage	13.07%
Neutral (0)	**Number**	98
	Percentage	49.23%
Slightly Warm (+1)	**Number**	20
	Percentage	10.05%
Warm (+2)	**Number**	7
	Percentage	3.52%
Hot (+3)	**Number**	-
	Percentage	-
All	**Number**	199
	Percentage	100%

Comparing the condition of the openings in each classroom indicates that, during the survey day in winter the condition of the openings had a direct effect on the occupants' sensation responses (see Table 6.24). The questionnaire results indicate that the openings of some classrooms were being kept closed during the survey. However, in some classrooms the doors were being kept open, while the windows were being kept closed during teaching hours. In most of the classrooms, while the door was open, most of the responses fell within the central three categories of the ASHRAE scale. However, if all the openings, including door and windows, were open, most of the occupants' votes fell out of the central three categories of ASHRAE. Table 6.24 shows that, if the doors of the classrooms were open, more than 80% of the responses fell into the central three categories of ASHRAE scale. However, if the openings were being kept closed, less than 80% of the students were satisfied, in terms of the environmental conditions.

Table 6.24: Condition of openings vs. thermal sensations in all classrooms

Classrooms	201	202	204	205	208	301	302	305	306	307
Doors	Open	Close	Close	Open	Open	Close	Open	Close	Close	Close
Windows	Close	Close	Close	Close	Close	Close	Close	Close	Close	Close
Central 3 categories	Yes	No	No	Yes	Yes	Yes	Yes	No	No	No

6.12.2. Preference votes

Figure 6.12 shows the overall result of the thermal preferences in all classrooms on 9th February 2011. It can be seen that more than 35% of the students wanted to be warmer during in winter season. However, a significant amount of students preferred a cooler or warmer environment.

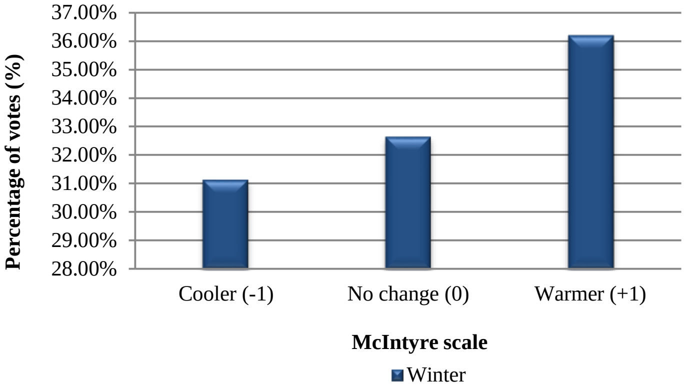


Figure 6.12: Preferences on day of survey in winter during morning shift

Tables 6.25 and 6.26 show the distribution of preference responses made according to the 3-point McIntyre scale in percentages and the number of students in attendance during the winter survey day. Comparing the results illustrates that the percentage of the votes in the three categories of ASHRAE were different in each classroom. In some classrooms, the majority of the occupants wanted to be warmer, such as in classrooms 204 and 202, on the first floor, and in classrooms 305 and 307, on the second floor. However, a considerable number of occupants wanted no change in their thermal environment, while in some classrooms the majority of the students wanted to be cooler. A possible reason might be the heating set point, which might be different in each classroom, as the heating system is a hot water radiator and can be adjusted manually by the occupants. In addition, the infiltration rate of each classroom might be different, which can have an impact on the quality of the indoor environment.

Table 6.25: Preferences on 9th February 2011 on first floor

Preference vote		201	202	204	205	208
Cooler (-1)	**Number**	8	1	7	11	3
	Percentage	40%	5%	37%	52%	13%
No Changes (0)	**Number**	10	-	3	5	14
	Percentage	50%	-	16%	24%	61%
Warmer (+1)	**Number**	2	18	9	5	6
	Percentage	10%	95%	47%	24%	26%
All	**Number**	20	19	19	21	23
	Percentage	10.05%	9.55%	9.55%	10.55%	11.56%

Table 6.26: Preferences on 9th February 2011 on second floor

Preference vote		**301**	**302**	**305**	**306**	**307**
Cooler (-1)	**Number**	11	9	3	7	2
	Percentage	52%	47%	18%	37%	10%
No Changes (0)	**Number**	5	8	3	8	9
	Percentage	24%	42%	18%	42%	43%
Warmer (+1)	**Number**	5	2	11	4	10
	Percentage	24%	11%	64%	21%	47%
All	**Number**	21	19	17	19	21
	Percentage	10.55%	9.55%	8.54%	9.55%	10.55%

Table 6.27 shows the overall thermal preference scores in all classrooms. It can be seen that most of the students wanted to be warmer in all floors, at around 36%. However, nearly the same amount wanted to be cooler or wanted no change in their thermal condition on the winter survey day. According to Table 6.27, around 31% of the students wanted to be cooler and just over 31% of occupants preferred no change on their thermal environment. Based on Table 6.27, we can say that, although 72% of the students' responses were in the central three categories of the ASHRAE scale in winter, just over 36% wanted to be warmer in the winter period.

Table 6.27: Overall thermal preferences in winter survey day

Preference vote		**All classrooms**
Cooler (-1)	**Number**	62
	Percentage	31.15%
No Changes (0)	**Number**	65
	Percentage	32.67%
Warmer (+1)	**Number**	72
	Percentage	36.18%
All	**Number**	199
	Percentage	100%

Table 6.28 shows the cross-tabulation of thermal sensation and preference scores in all classrooms on 9th February 2011. It can be seen that around 85% of the students who gave the response 'slightly warm' on the 7-point ASHRAE scale wanted to be cooler in winter. Moreover, despite feeling cool to hot, most of the occupants wanted to be warmer. However, a similar amount preferred no change in their thermal preferences on the survey day in the winter period.

Table 6.28: Sensation responses and preferences on 9th February 2011

Thermal sensation scale	**% Preference**		
	-1	**0**	**+1**
	Cooler	**No changes**	**Warmer**
Cold (-3)	-	-	100%
Cool (-2)	7.14%	50%	42.86%
Slightly cool (-1)	7.94%	34.62%	57.69%
Neutral (0)	34.94%	47.96%	17.85%
Slightly Warm (+1)	85%	15.5%	-
Warm (+2)	100%	-	-
Hot (+3)	-	-	-
Total	31.15%	32.67%	36.18%

6.13. Thermal sensation and preferences in both seasons

Table 6.29 shows the cross tabulation of thermal sensation and thermal preference scores in all classrooms and in both seasons. It can be seen that around 60% of the students wanted to be cooler in both seasons. Moreover, around 55% of the students who chose ‘neutral’ on the 7-point ASHRAE scale wanted to be cooler. In addition, despite feeling cool to hot, most of the occupants wanted to be cooler. However, the rest of the students wanted to be warmer or wanted no change, with around 5% difference. These results show that the students are not satisfied with their thermal environment.

Table 6.29: Sensation responses and preferences for both seasons

Sensation vote scale	**% Preference**			
	Cooler (-1)	**No change (0)**	**Warmer (+1)**	**Total**
Cold (-3)	-	-	100%	7.40%
Cool (-2)	44.83%	34.48%	20.69%	6.32%
Slightly cool (-1)	32.08%	35.85%	32.07%	11.55%
Neutral (0)	55.26%	34.21%	10.53%	41.40%
Slightly Warm (+1)	92.05%	7.95%	-	19.17%
Warm (+2)	94.64%	1.79%	3.57%	12.20%
Hot (+3)	88.89%	-	11.11%	1.96%
Total	60.35%	22.22%	17.43%	100%

6.14. Air flow and humidity votes

6.14.1. Spring air flow and humidity

The occupants indicated their feeling in terms of indoor air movement and indoor relative humidity on a three category scale, as using more than three categories makes it difficult to be recognised (Heidari, 2000). Figure 6.13 shows all responses on 4th May 2010. It can be seen that most students chose ‘just right’ in terms of humidity and air flow during the survey in both shifts in the spring season. However, considerable amounts of students perceived the conditions to be still and dry in terms of the air flow and relative humidity in most of the classrooms, at around 40%.

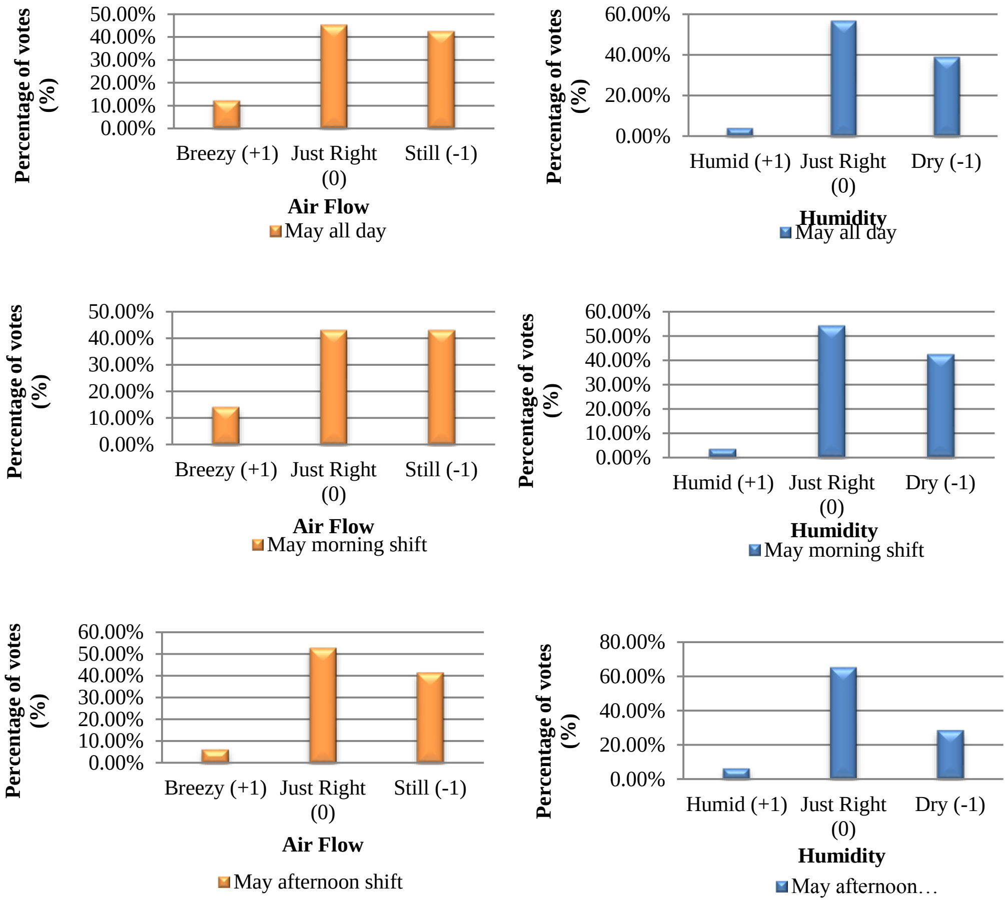


Figure 6.13: Air flow and humidity scores in all classrooms on 4th May 2010

Tables 6.30 to 6.33 presents the tabulation of air movement scores during the spring survey day in all classrooms on the first and second floor. It can be seen that the majority of the occupants chose ‘just right’ in most of the classrooms includes classrooms 201, 205 and 206 on the first floor and classrooms 305 and 306 on the second floor, during the morning period (see Tables 6.30 and 6.31). However, a considerable amount felt the air movement was still. In addition, in the afternoon period most of the occupants voted just right in classrooms 208, 301 and 308 and, similar to the morning period, a considerable number of students gave the response 'still' in terms of air movement within the classrooms (see Table 6.32).

Table 6.30: Air flow responses on 4th May 2010 on the first floor during morning period

Velocity (First floor-morning)		201	205	206	207	208
Still (-1)	**Number**	6	8	5	6	13
	Percentage	30%	33%	26%	67%	54%
Just Right (0)	**Number**	12	13	13	2	10
	Percentage	60%	54%	68%	22%	42%
Breezy (+1)	**Number**	2	3	1	1	1
	Percentage	10%	12.50%	6%	11%	4%
All	**Number**	20	24	19	9	24
	Percentage	10.20%	12.25%	9.69%	4.59%	12.25%

Table 6.31: Air flow responses on 4th May 2010 on the second floor during morning period

Velocity (Second floor-morning shift)		301	305	306	307	308
Still (-1)	**Number**	15	2	9	19	1
	Percentage	65%	15%	43%	90.5%	4.5%
Just Right (0)	**Number**	5	8	12	2	7
	Percentage	22%	61%	57%	9.5%	32%
Breezy (+1)	**Number**	3	3	-	-	14
	Percentage	13%	23%	-	-	63.5%
All	**Number**	23	13	21	21	22
	Percentage	11.73%	6.63%	10.72%	10.72%	11.22%

Table 6. 32: Air flow responses in all classrooms on 4th May 2010 during afternoon period

Velocity (All floors- afternoon shift)		201	205	208	301	308
Still (-1)	**Number**	5	10	-	9	2
	Percentage	71%	56%	-	47%	22%
Just Right (0)	**Number**	2	6	9	10	6
	Percentage	29%	33%	90%	53%	67%
Breezy (+1)	**Number**	-	2	1	-	1
	Percentage	-	11%	10%	-	11%
All	**Number**	7	18	10	19	9
	Percentage	11.11%	28.57%	15.87%	30.16%	14.29%

It can be seen that most of the students felt just right, in terms of air movement, around 43% in the morning shift and 52% in the afternoon shift agreeing with this statement (see Table 6.33). Moreover, nearly the same amount of occupants felt the air was still during the survey day in the spring period, 43% and 41% respectively. Table 6.33 presents the tabulation of the overall air movement on spring survey days in both shifts. It can be seen that most of the students felt just right in the afternoon shift. However, during the morning shift, around 43% of the students chose 'just right' and a similar amount chose 'still'.

Table 6.33: Overall air flow scores in spring survey day during both shifts

Velocity		Morning shift	Afternoon shift
Still (-1)	**Number**	84	26
	Percentage	42.86%	41.27%
Just right (0)	**Number**	84	33
	Percentage	42.86%	52.38%
Breezy (+1)	**Number**	28	4
	Percentage	14.28%	6.35%
All	**Number**	196	63
	Percentage	100%	100%

Tables 6.34 to 6.37 show responses to humidity sensations in the spring period survey day, in the morning and the afternoon shifts. It can be seen that most of the occupants felt just right in terms of the indoor relative humidity in most of the classrooms and the rest mostly felt dry. No one chose ‘humid’ during the morning shift on the first floor. In addition, most of the occupants felt just right in terms of relative humidity in the afternoon shift, while a few perceived conditions to be ‘humid’ in the afternoon shift.

Table 6.34: Humidity perceptions on 4th May 2010 on the first floor during morning shift

Humidity		201	205	206	207	208
Dry (-1)	**Number**	8	7	6	7	12
	Percentage	40%	29%	32%	88%	50%
Just Right (0)	**Number**	12	17	13	2	12
	Percentage	60%	71%	61%	22%	50%
Humid (+1)	**Number**		-	-	-	-
	Percentage	-	-	-	-	-
All	**Number**	20	24	19	9	24
	Percentage	10.20%	12.25%	9.69%	4.59%	12.25%

Table 6.35: Humidity perceptions on 4th May 2010 on second floor during morning shift

Humidity		301	305	306	307	308
Dry (-1)	**Number**	13	2	10	14	4
	Percentage	56%	15%	47.60%	67%	18.19%
Just Right (0)	**Number**	6	11	10	6	17
	Percentage	26%	85%	47.60%	28.30%	77.27%
Humid (+1)	**Number**	4	-	1	1	1
	Percentage	17%	-	4.80%	4.70%	4.54%
All	**Number**	23	13	21	21	22
	Percentage	11.73%	6.63%	10.72%	10.72%	11.22%

Table 6.36 : Humidity perceptions on all floors on 4th May 2010 during afternoon shift

Humidity (afternoon)		201	205	208	301	308
Dry (-1)	**Number**	1	12	1	2	2
	Percentage	14%	63%	10%	12%	22%
Just Right (0)	**Number**	6	7	9	13	6
	Percentage	86%	37%	90%	72%	67%
Humid (+1)	**Number**	-	-	-	3	1
	Percentage	-	-	-	16%	11%
All	**Number**	7	19	10	18	9
	Percentage	11.11%	30.16%	15.87%	28.57%	14.29%

Table 6.37 shows the overall tabulation of the humidity sensation responses in all classrooms and in both shifts during the spring survey day. Around 54% of the occupants in the morning shift and 65% of the afternoon shift felt just right in terms of humidity. However, 42% in the morning shift and around 28% in the afternoon shift felt dry during the survey in spring. As mentioned before, the door and windows were open in some classrooms for ventilation purposes. However, in the other classrooms, the door was usually kept closed while the windows were open during teaching hours, which caused significant numbers of students to feel dry and chose ‘still’, in their perception of airflow.

Table 6.37: Overall humidity votes in spring survey day in both shifts

Humidity		Morning shift	Afternoon shift
Dry (-1)	**Number**	83	18
	Percentage	42.35%	28.57%
Just right (0)	**Number**	106	41
	Percentage	54.08%	65.08%
Humid (+1)	**Number**	7	4
	Percentage	3.57%	6.35%
All	**Number**	196	63
	Percentage	100%	100%

Comparison of the average humidity level in all measured classrooms during the survey day shows that, when the average relative humidity levels in the classrooms were low, students felt dry, and when the humidity was lower, more students felt drier.

6.14.2. Winter air flow and humidity

The occupants indicated their feelings in terms of air velocity and relative humidity on a three category scale on the winter survey day, this scale being used for the reasons given previously (Heidari, 2000). Figure 6.14 shows the result of all the responses on 9th February 2011. It can be seen that most of the students felt just right in terms of humidity and significant numbers considered the conditions to be dry, regarding their humidity sensation. Moreover, many students chose ‘still’ in terms of air flow and considerable number of students felt just right regarding air movement sensation.

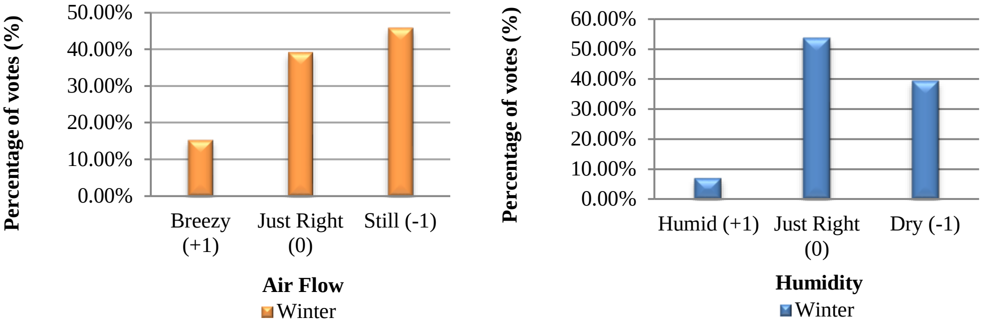


Figure 6.14: Air flow and humidity perceptions in all classrooms on 9th February 2011

Tables 6.38to 6.40 present the results of air movement sensation responses during the winter period.

Table 6.38: Air flow perceptions on 9th February 2011 on first floor

Velocity		**201**	**202**	**204**	**205**	**208**
Still (-1)	**Number**	12	5	7	9	9
	Percentage	64%	25%	37%	42.90%	39.10%
Just Right (0)	**Number**	7	2	9	12	13
	Percentage	36%	10%	47%	57.10%	56.50%
Breezy (+1)	**Number**	-	13	3	-	1
	Percentage	-	65%	16%	-	4.40%
All	**Number**	19	20	19	21	23
	Percentage	9.64%	10.15%	9.64%	10.67%	11.67%

Table 6.39: Air flow perceptions on 9th February 2011 on second floor

Velocity		**301**	**302**	**305**	**306**	**307**
Still (-1)	**Number**	8	10	12	16	2
	Percentage	42%	52.60%	70.60%	84.21%	9.52%
Just Right (0)	**Number**	11	9	2	3	9
	Percentage	58%	47.40%	11.80%	15.79%	42.86%
Breezy (+1)	**Number**	-	-	3	-	10
	Percentage	-	-	17.60%	-	47.62%
All	**Number**	19	19	17	19	21
	Percentage	9.64%	9.64%	8.64%	9.64%	10.67%

It can be seen that most of the students chose ‘still’, especially on the second floor, and that a considerable number of them also felt just right, including in classrooms 204, 205 and 208 on the first floor and classrooms 301, and 307 on the second floor. However, a small number of occupants thought conditions were breezy on both floors.

Table 6.40 show the tabulation of airflow sensation responses in all classrooms during the winter survey day. It can be seen that around 45% of the occupants in all classrooms considered the conditions to be still, while around 39% felt it was just right and a few felt it was breezy.

Table 6.40: Overall air flow sensation responses in all classrooms during winter survey day

Velocity		**All classrooms**
Still (-1)	**Number**	90
	Percentage	45.69%
Just right (0)	**Number**	77
	Percentage	39.08%
Breezy (+1)	**Number**	30
	Percentage	15.23%
All	**Number**	197
	Percentage	100%

Tables 6.41 to 6.43 present the humidity sensation responses on winter survey days in all classrooms. Most of the students felt just right on both floors. However, a considerable number of students felt dry in terms of the humidity sensation and a few thought conditions were humid.

Table 6.41: Humidity perceptions on 9th February 2011 on first floor

Humidity		**201**	**202**	**204**	**205**	**208**
Dry (-1)	**Number**	6	0	4	9	16
	Percentage	30%	0	22%	45%	69.60%
Just Right (0)	**Number**	13	15	12	9	5
	Percentage	65%	75%	63%	45%	21.70%
Humid (+1)	**Number**	1	5	3	2	2
	Percentage	5%	25%	15%	10%	8.70%
All	**Number**	20	20	19	20	23
	Percentage	10.11%	10.11%	9.59%	10.11%	11.61%

Table 6.42: Humidity perceptions on 9th February 2011 on second floor

Humidity		**301**	**302**	**305**	**306**	**307**
Dry (-1)	**Number**	2	7	11	16	7
	Percentage	10%	39.90%	64.70%	84.21%	33.30%
Just Right (0)	**Number**	18	12	6	2	14
	Percentage	90%	63.10%	35.30%	10.53%	66.70%
Humid (+1)	**Number**	-	-	-	1	-
	Percentage	-	-	-	5.26%	-
All	**Number**	20	19	17	19	21
	Percentage	10.11%	9.59%	8.58%	9.59%	10.60%

Table 6.43 shows the overall humidity sensation scores in all classrooms during the winter survey day. It can be seen that most of the occupants felt just right and a significant number thought it was dry, at around 53% and over 39%, respectively.

Table 6.43: Overall humidity sensation responses in all classrooms during winter survey day

Humidity		All classrooms
Dry (-1)	**Number**	78
	Percentage	39.40%
Just right (0)	**Number**	106
	Percentage	53.53%
Humid (+1)	**Number**	14
	Percentage	7.07%
All	**Number**	198
	Percentage	100%

6.15. Metabolic rates and clothing insulation

6.15.1. Spring metabolic rate and clothing insulation

In addition to the sensation and preference responses, personal parameters, such as metabolic rate and clothing insulation should be assessed to predict the thermal comfort of the occupants. In this study, these two personal factors were estimated according to ASHRAE Standard 55 (ASHRAE, 2004). It gives a series of metabolic rates for typical tasks and clothing insulation values for typical ensembles. A clothing section on the questionnaire was designed using checklists of the clothing items which students usually wore in their school environment, namely a combination of a T-shirt or sleeveless blouse, thin trousers, socks, shoes, headwear and a thin long sleeved shirt-dress (manto) during the spring period (Zahiri et al., 2011). Students always wear a manto, trousers and headwear, as this is the typical female school uniform in Iran. However, they adjust their clothing under their uniform according to the heating or cooling seasons. Based on Heidari’s studies (Heidari, 2000), clothing insulation for headwear is usually 0.1 clo in the heating season. Metabolic rate was assumed to be similar to light office activities, with students seated and reading or writing 15 minutes prior to the survey. Table 6.44 shows that the average metabolic rate and clothing insulation value of the occupants in all classrooms and in both shifts during the survey in May 2010 were similar, which indicates that most of the students wore clothes with similar insulation values in the warm months of April and May, whilst undertaking typical classroom activities (Zahiri et al., 2011).

Table 6.44: Average metabolic rate and clothing value of students during lesson hours on 4th May 2010 in morning and afternoon shifts

Number of students	Metabolic heat rate MET	Clothing insulation value (clo)
260	1.0	0.71

6.15.2. Winter metabolic rates and clothing insulation

Personal parameters such as metabolic rate and clothing insulation was assessed, in order to predict the thermal comfort of the occupants during the winter season survey based on ASHRAE Standard 55

(ASHRAE, 2004). A clothing section on the questionnaire was designed using checklists of clothing items which students usually wear in their school environment. Students wore school uniforms which were a combination of a long-sleeved flannel shirt or sweatshirt, thin trousers and sweatpants, socks, shoes, headwear and a thin long-sleeved shirt-dress (manto) during the winter period. . Table 6.45 shows that the average metabolic rate and clothing insulation values for the occupants in all classrooms on the cold season survey day were similar, which indicates that most students wore clothes with similar insulation values in the cold months of January/February whilst taking part in typical classroom.

Table 6.45: Average metabolic rate and clothing value during lesson on 9th February 2011

Number of students	**Metabolic heat rate MET**	**Clothing insulation value (clo)**
198	1.0	1.42

6.16.Questionnaire survey results, based on classrooms locations

6.16.1. Spring: north- and south-facing side classrooms

Figures 6.15 and 6.16 present the overall result of thermal sensation scores on the ASHRAE thermal sensation scale and preference responses on the McIntyre scale on 4th May 2010 in north- and south-facing classrooms during morning and afternoon shifts. The graphs show the overall responses in the morning and the afternoon shifts separately.

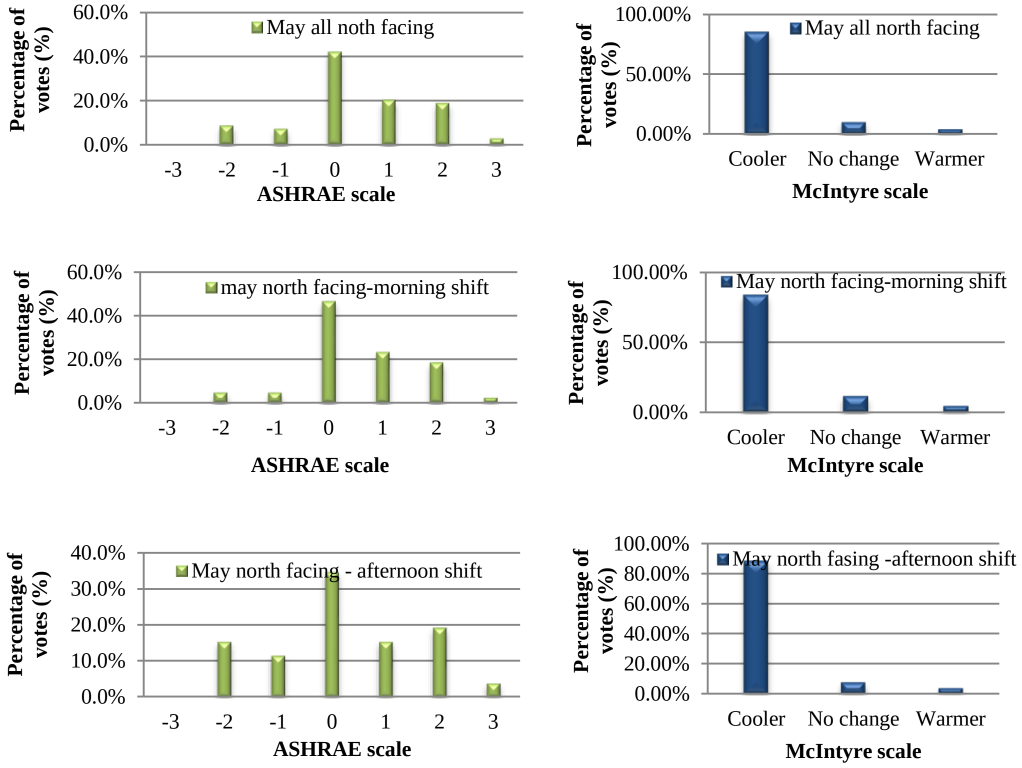


Figure 6.15: Sensations and preferences in north-facing classrooms on 4th May 2010

It can be seen that most occupants in the north-facing classrooms chose ‘neutral to hot’ in all shifts and the majority wanted to be cooler in north-facing classrooms. In addition, similar to the north-facing classrooms, most students felt neutral to hot and preferred to be cooler in south-facing classrooms as well (Figure 6.16).

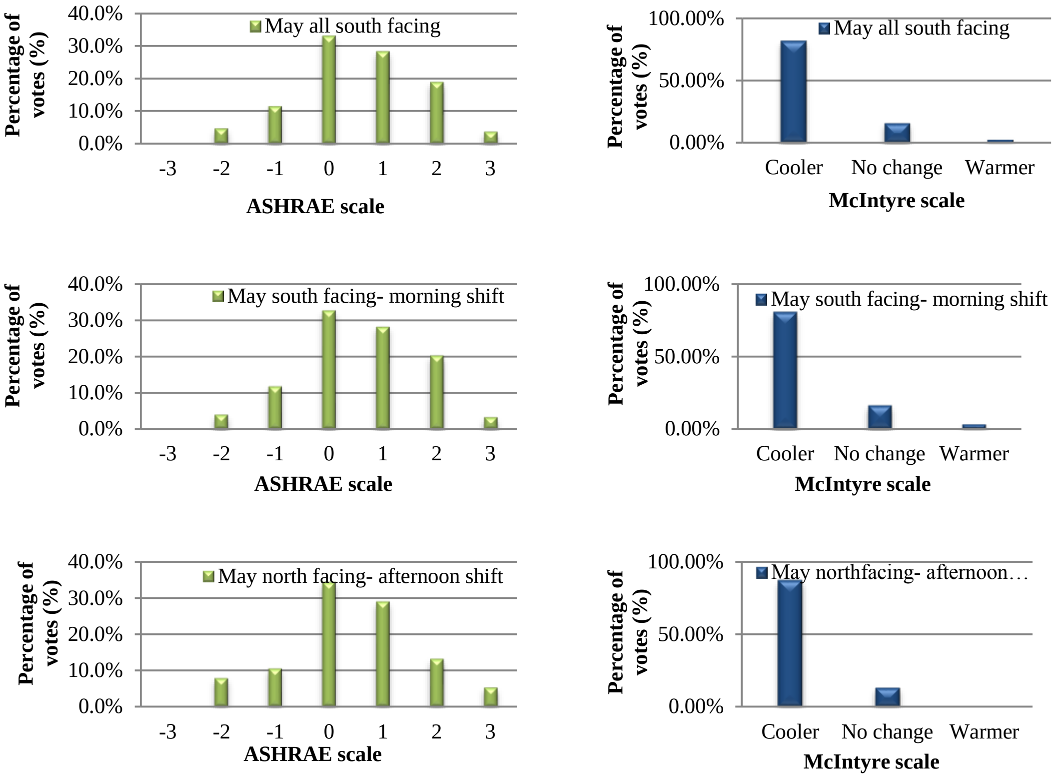


Figure 6.16: Sensations and preferences in south-facing classrooms on 4th May 2010

6.16.2. Spring: first and second floors

Figures 6.17 and 6.18 show the results of thermal sensation responses on the ASHRAE scale and preference responses on the McIntyre scale, on 4th May 2010, on the first and second floors, in the morning and afternoon shifts. Similar to the north- and south-facing side classrooms, most of the responses were in the neutral to hot categories for thermal sensation on both floors and many students wanted to be cooler on the spring survey day. However, during the afternoon shift, and on the second floor, a significant amount of students said they were slightly cool and cool.

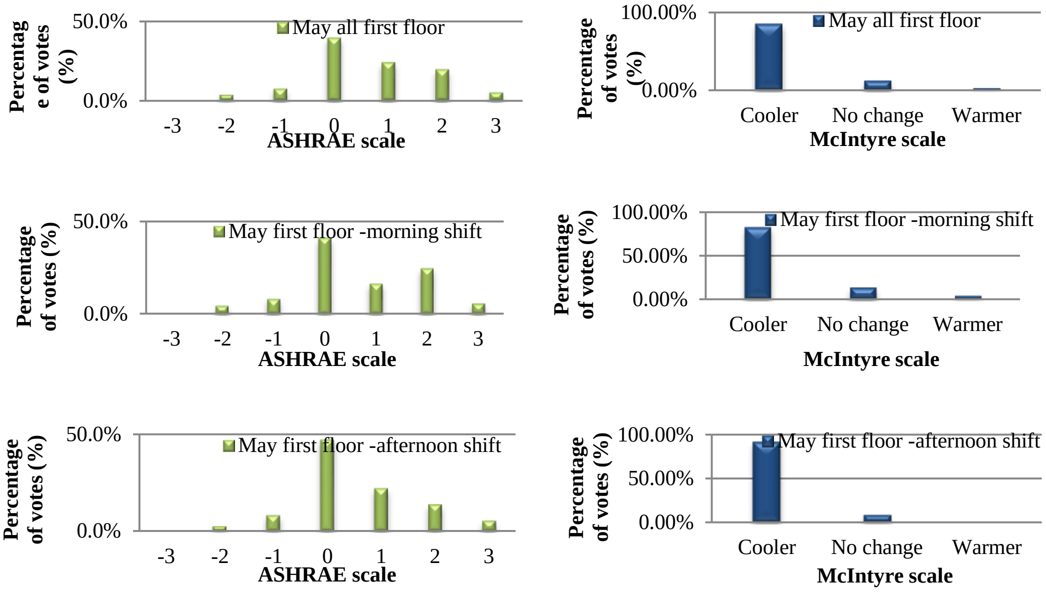


Figure 6. 17: Sensations and preferences in first floor classrooms in both shifts on the 4th May 2010

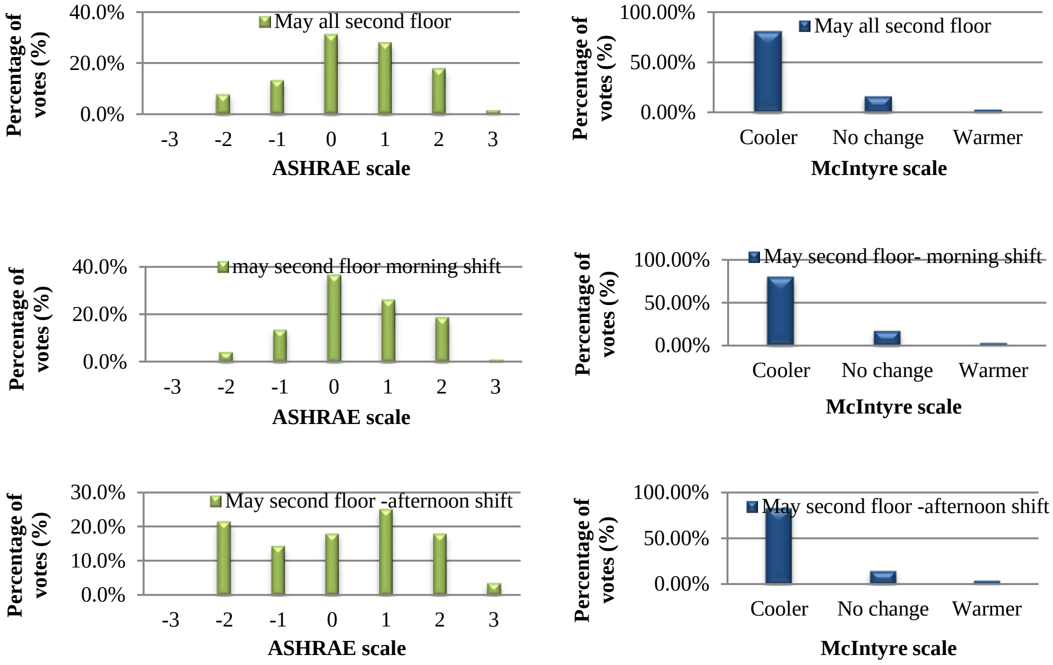


Figure 6.18: Sensations and preferences in second floor classrooms on 4th May 2010

6.16.3. Winter: north-facing and south-facing

Figures 6.19 and 6.20 illustrate the results of thermal sensation votes on the ASHRAE scale and preference responses on the McIntyre scale during 9th February 2011 in north- and south-facing classrooms. It can be seen that the highest percentage of students' responses belonged to the neutral category in the winter period, in terms of thermal sensation experiences, similar to the spring period survey results. In addition, most students in north-facing classrooms felt neutral, at around 70% in the winter period, compared to the south-facing classrooms, which were around 35%. On the other hand, the result for the thermal preference responses is slightly different compared to the spring results. Just less than 50% of the students wanted to be cooler in north-facing classrooms but around 60% wanted to be warmer in south-facing classrooms.

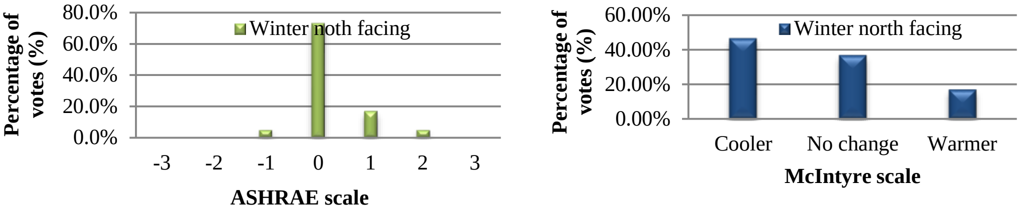


Figure 6.19: Sensations and preferences in north-facing classrooms on 9th February 2011

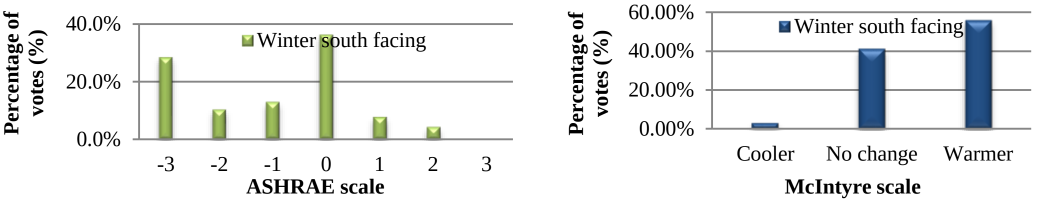


Figure 6.20: Sensations and preferences in south-facing side classrooms on 9th February 2011

A comparison of the indoor air temperature in north- and south-facing side classrooms (see Table 6.8) shows that the mean indoor air temperature in north-facing side classrooms was slightly higher than on the south-facing side, at around 1°C, which caused the students to want a cooler environment in north-facing classrooms. As mentioned before, manually adjusted settings of the heating system in each classroom probably influenced these results.

6.16.4. Winter: first and second floors

Figures 6.21 and 6.22 illustrate the result of the thermal sensation responses on the ASHRAE scale and the preference responses on the McIntyre scale on 9th February 2011 in the first and second floor classrooms. The highest percentage of the students' responses was neutral in the winter day survey in terms of sensations. However, the highest percentage of students wanted to be warmer on the first floor but most on the second floor wanted no change in the winter period.

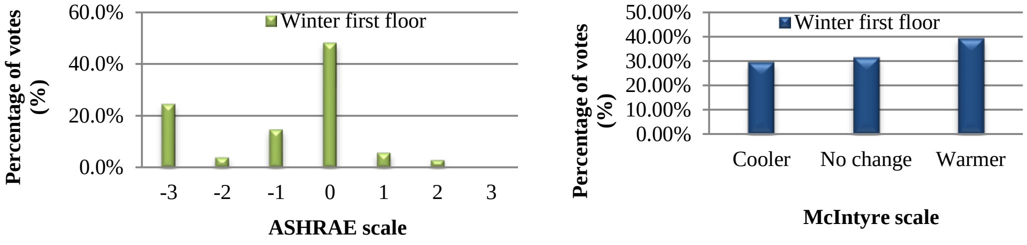


Figure 6.21: Sensations and preferences in first floor classrooms on 9th February 2011

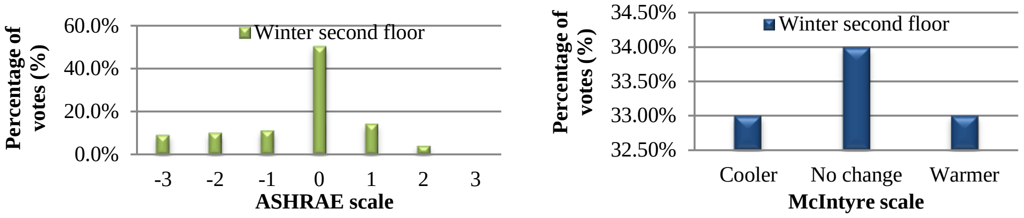


Figure 6.22: Sensations and preferences in second floor classrooms on 9th February 2011

6.17. Airflow and humidity survey results, based on classrooms location

6.17.1. Spring: north- and south-facing sides

The occupants indicated their feelings in terms of air velocity and humidity sensations on a three category scale. Figures 6.23 and 6.24 show the results of all responses on 4th May 2010.

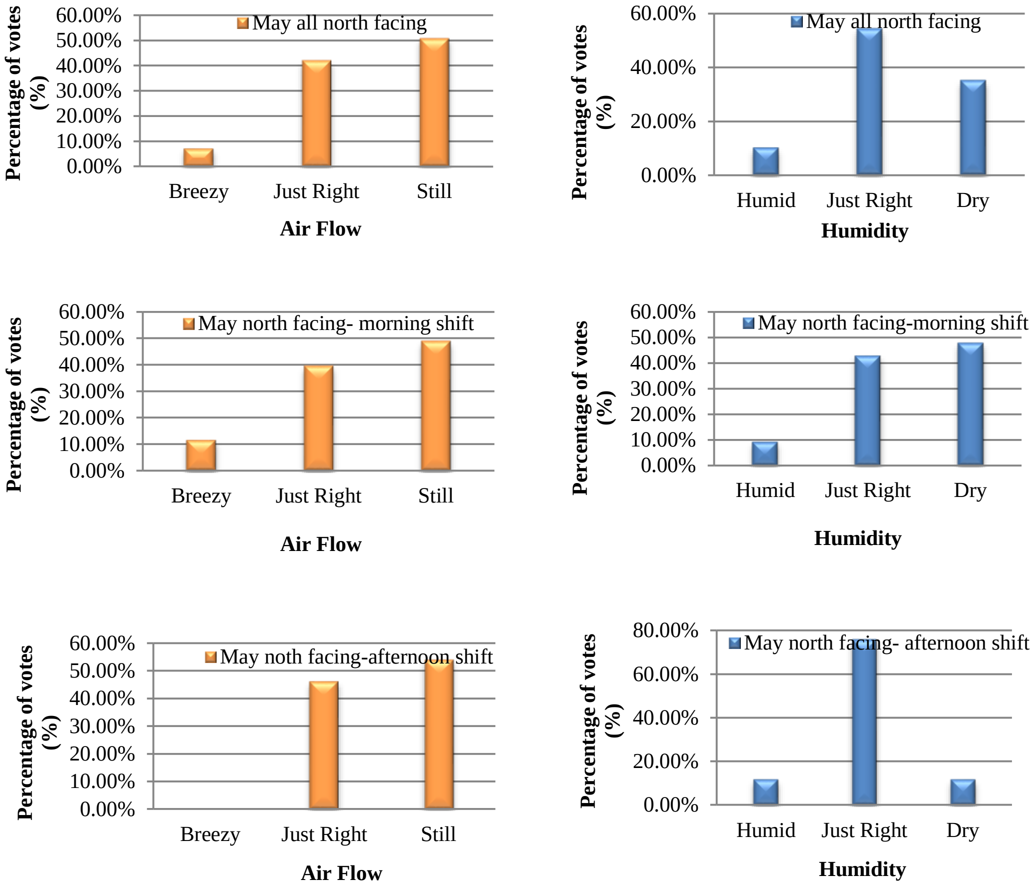


Figure 6. 23: Airflow and humidity responses in north-facing classrooms on 4th May 2010

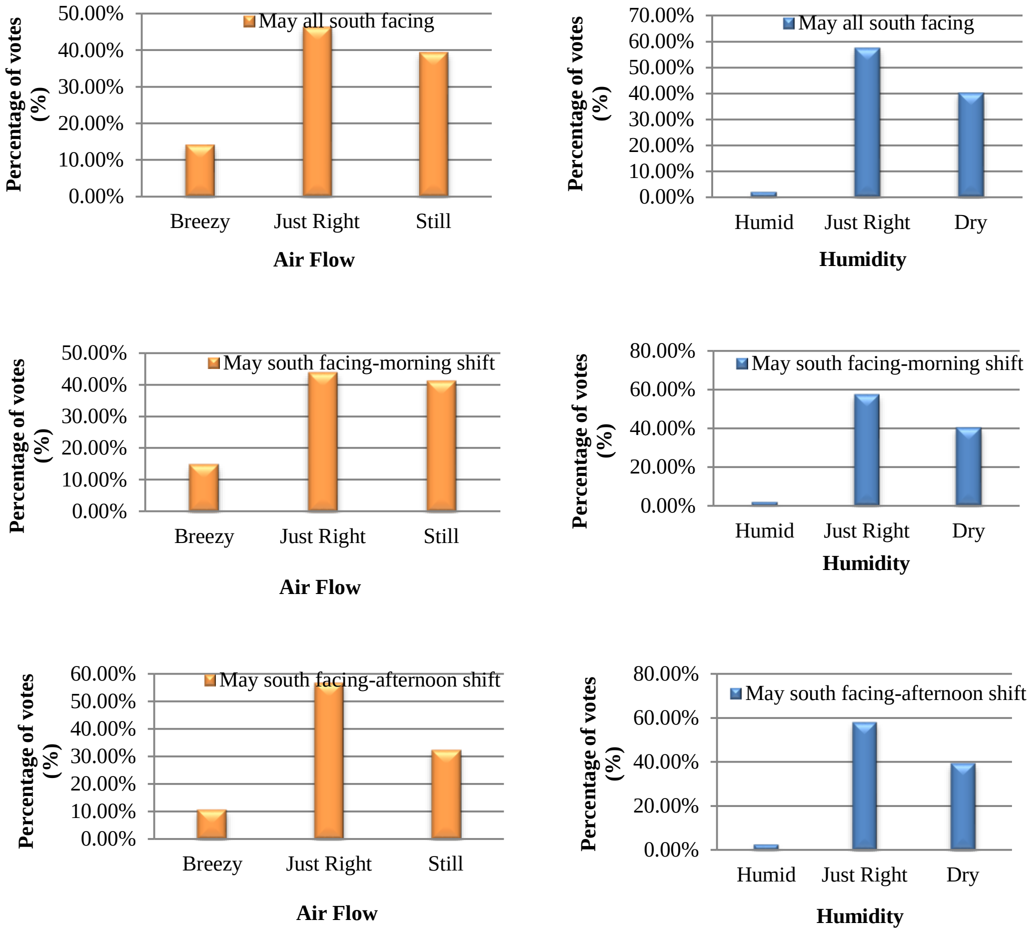


Figure 6.24: Airflow and humidity responses in south-facing classrooms on 4th May 2010

It can be seen that the results are different in north- and south-facing side classrooms. In north-facing side classrooms, the highest percentage of the students felt the air movement was still, but in south-facing classrooms they voted just right. One possible reason could be the outside air flow direction. In addition, in terms of humidity, most of the occupants felt just right in most classrooms and in both directions.

6.17.2. Spring: first and second floors

Figures 6.25and 6.26 show the result of all responses on the 4th May 2010 on the first and second floors. Most of the students on the first floor felt just right in terms of airflow and humidity. However, the considerable amount of them felt the air movement is still on the second floor but they felt the humidity is just right on the second floor.

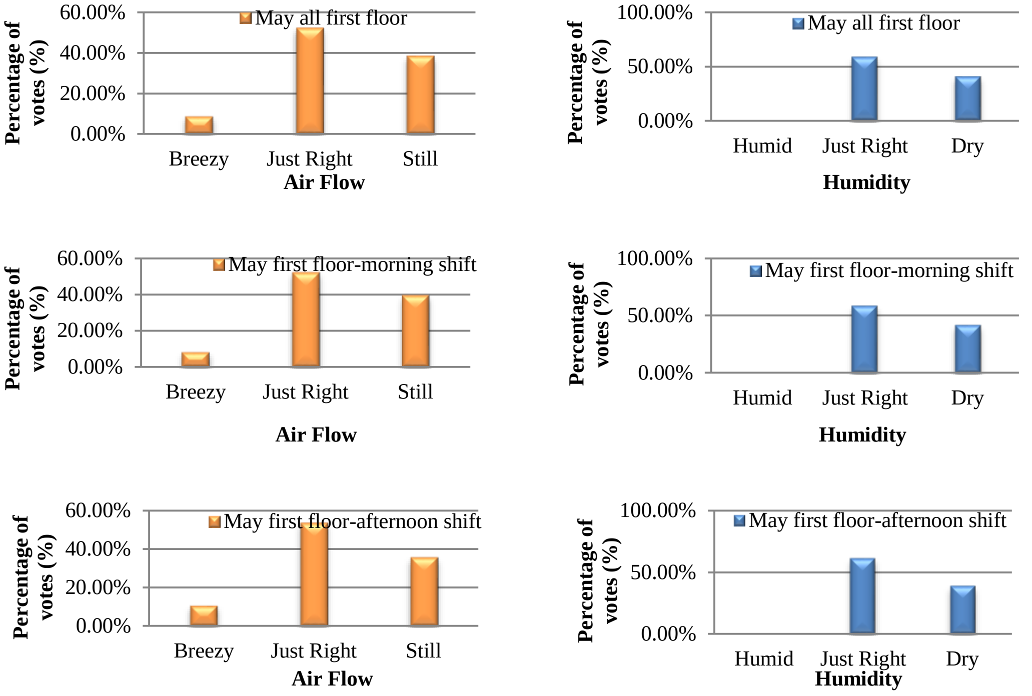


Figure 6. 25: Airflow and humidity responses in first floor classrooms on 4th May 2010

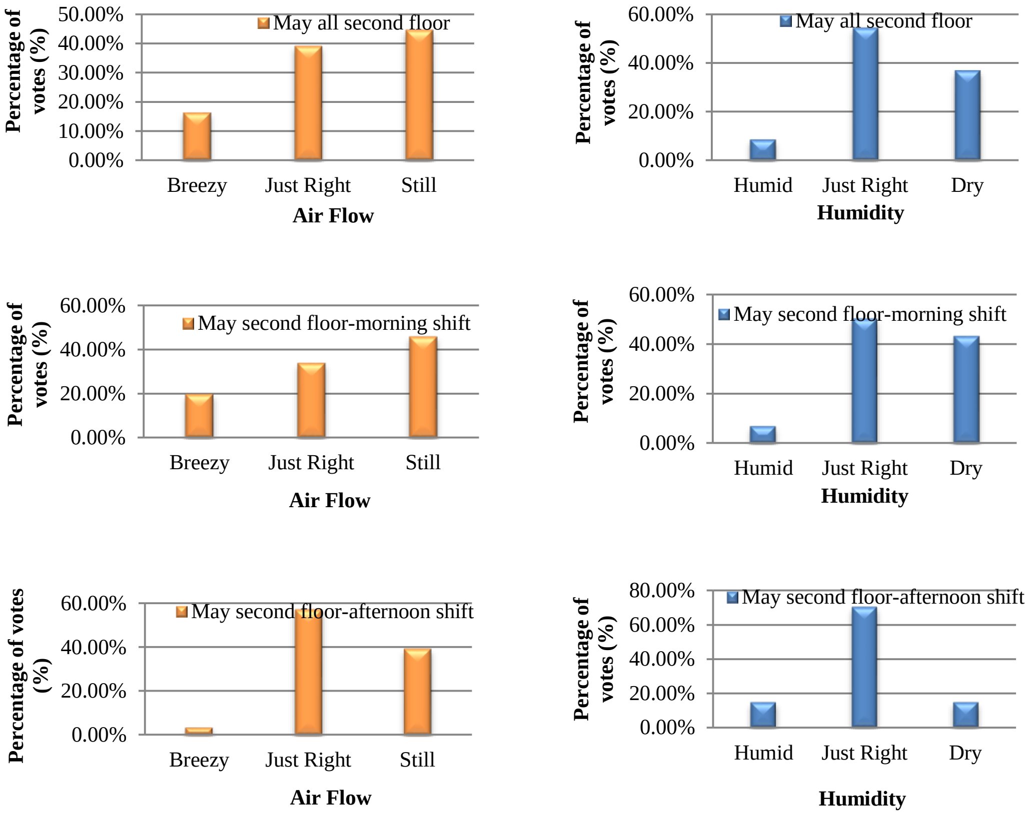


Figure 6.26: Airflow and humidity responses in second floor classrooms on 4th May 2010

6.17.3. Winter: north- and south-facing side

The occupants indicated their feeling in terms of air velocity and humidity on a three category scale in the winter period survey. Figures 6.27 and 6.28 present the result of all responses on 9th February 2011. It can be seen that most students felt the air flow was still on both sides of the school in the winter period. However, they felt just right in terms of humidity in all classrooms.

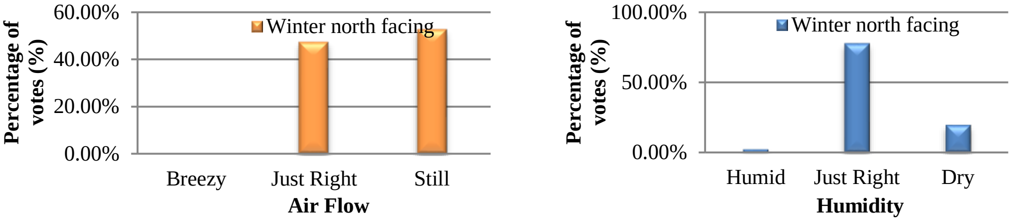


Figure 6.27: Airflow and humidity responses in north-facing classrooms on 9th February 2011

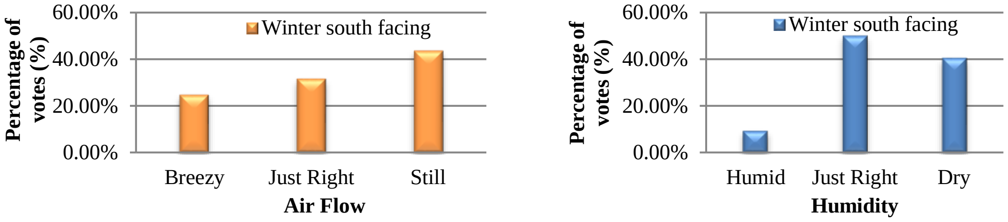


Figure 6.28: Airflow and humidity responses in south-facing classrooms on 9th February 2011

6.17.4. Winter: first and second floors

Figures 6.29 and 6.30 show the result of all responses on the 9th February 2011 on the first and second floors. Most of the students on the first floor felt just right in terms of airflow and humidity. However, the highest percentage felt the air movement was still on the second floor but that the humidity was just right on the second floor, similar to the spring results.

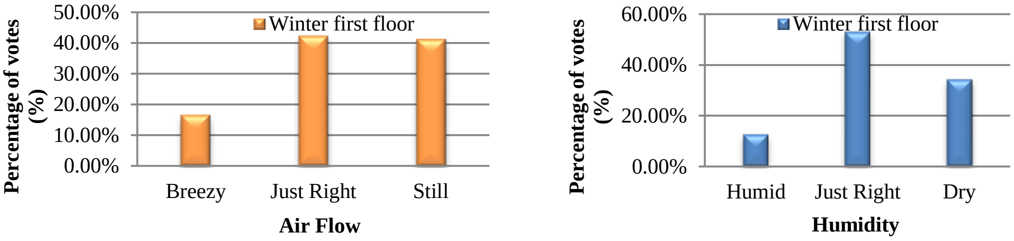


Figure 6.29: Airflow and humidity responses in first floor classrooms on 9th February 2011

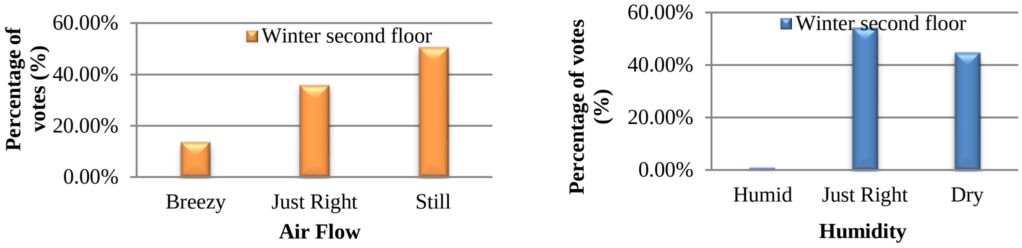


Figure 6.30: Airflow and humidity responses in second floor classrooms on 9th February 2011

6.18. Metabolic heat rate and clothing insulation in all locations in both seasons

The mean value of the clothing insulation and the metabolic heat rate of the occupants in all classrooms on spring survey day were similar, regardless their location. It shows that most students wore clothes with similar insulation values while doing similar activities during the survey period. The result of the winter survey was similar and all the students wore clothes with similar insulation values in the cold season, while doing the similar activities. Personal parameters, such as metabolic rate and clothing insulation, were assessed to predict the thermal comfort of the occupants during the winter and spring season surveys, based on ASHRAE Standard 55 (ASHRAE, 2004). The mean clothing insulation was around 0.71clo in spring and 1.42clo in winter. Metabolic rate was assumed to be light office activities in both seasons, with students seated and reading or writing 15 minutes prior to completing the survey at 1 met.

6.19. Neutral temperature

Neutral temperature is the temperature at which people experience a sensation which is neither slightly warm nor slightly cool. At this temperature the mean response of the subjects is neutral or at the middle point of the seven point ASHRAE scale. According to Heidari’s studies (Heidari, 2009), the indoor comfort neutral temperature (T_n) in Iran depends on the outdoor temperature (To) and can be found from Equation 6.2:

$$T_n = 17.8 + 0.30\,T_{o.} \qquad \text{Eq 6.2}$$

Based on this equation, the neutral temperature in the classrooms in the spring period should have been 24.5°C during the survey period. Although the mean indoor temperature in all classrooms was around 23.5°C in the spring season, only 35% of students in all classrooms felt neutral and around 14% preferred no change on the McIntyre scale. However, most of the occupants wanted to be cooler in the spring period. In addition, the neutral temperature should be around 19°C in the winter period, based on the Heidari equation. The minimum comfort temperature in classroom 201 was around 20°C on the survey day, which is higher than the calculated neutral temperature. However, around 80% of the occupants felt neutral and only 50% wanted no change on their thermal environment. This shows that the neutral temperature for students aged between 15 and 18 is slightly different than the one which was calculated by Heidari (2009) (Zahiri et al., 2011).

6.20. Standard deviation of responses

The standard deviation variable allows us to compare variation among the mean values. Mean and standard deviation of the thermal sensation scores, preference scores, as well as humidity and air movement preferences have been summarised for the cold and warm seasons in Tables 6.46 to 6.49. The mean thermal sensation score was 0.52 in the spring season and -0.61 in winter. The mean indoor air temperature in winter was slightly lower than the spring season, which caused the occupants to feel cooler during winter survey day, compared to the warm spring day. However, the standard deviation of the scores was slightly higher in the winter season than in the spring period (see Table 6.46). In contrast, the mean preference score on the McIntyre scale in the spring period was higher than in the winter season, which shows that more students preferred to be in a cooler environment during the spring than the winter period (see Table 6.47).

In terms of air flow and humidity sensations, most of the mean scores in both categories and all seasons were quite similar. This shows that the students felt similar, regardless of the season. A significant amount of occupants felt dry in both seasons in terms of humidity and also felt that the air movement was still (see Tables 6.48 and 6.49).

Table 6.46: Mean and standard deviation of thermal sensation responses in both seasons

Sensation Votes	Spring	Winter	All
Mean	+0.52	-0.61	+0.03
SD	+1.18	+1.35	+1.38
Min	-2	-3	-3
Max	+3	+2	+3

Table 6 .47: Mean and standard deviation of preferences in both seasons

Preference Vote	Spring	Winter	All
Mean	-0.74	+0.05	-0.40
SD	+0.55	+0.82	+0.79
Min	-1	-1	-1
Max	+1	+1	+1

Table 6.48: Mean and standard deviation of air movement sensation responses in both seasons

Air movement Vote	Spring	Winter	All
Mean	-0.30	-0.30	-0.30
SD	0.68	0.72	0.70
Min	-1	-1	-1
Max	+1	+1	+1

Table 6.49: Mean and standard deviation of humidity sensation responses in both seasons

Humidity Vote	Spring	Winter	All
Mean	-0.35	-0.32	-0.37
SD	+0.56	+0.60	+0.58
Min	-1	-1	-1
Max	+1	+1	+1

6.21. Relationship between environmental variables

6.21.1. Spring period

Figures 6.31 and 6.32 present the scatter diagrams of mean indoor air temperature against the mean thermal sensation scores on the ASHRAE scale in the spring season and in all groups. In addition, Figure 6.32 shows a scatter diagram of the overall means for both shifts. It can be seen that there is a positive relationship between the mean indoor air temperature and the mean sensation scores in both shifts. As the mean air temperature increased, the mean sensation score grows, as the students felt warmer.

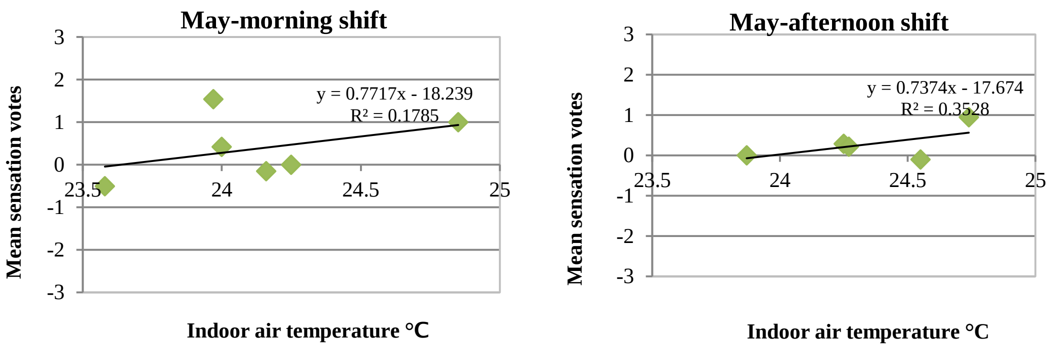


Figure 6.31: Relationship between indoor air temperatures and mean ASHRAE sensation scores on 4th May 2010 in both shifts

The relationship between sensation scores in all groups is positive as well. The mean air temperature was measured from 12pm till 14.45pm, when the questionnaire survey was conducted during both shifts.

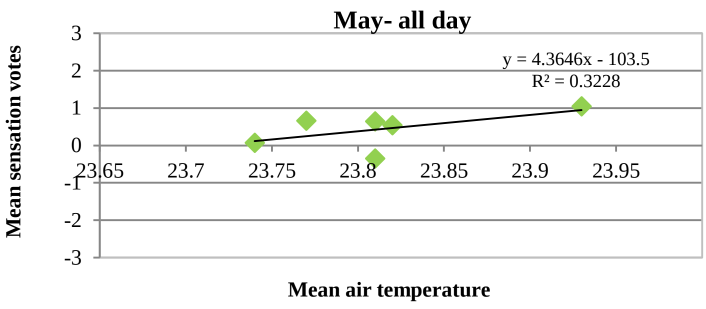


Figure 6.32: Relationship between mean air temperatures and ASHRAE sensation scores on 4th May 2010 in both shifts

Figures 6.33 and 6.34 present the relationship between all thermal sensation scores and the real indoor air temperature in all classrooms during the morning and afternoon shifts. Figure 6.33 presents a scatter diagram of the sensation responses against the indoor air temperature in all classrooms and for both shifts separately. The graphs show that there is a positive relationship between these two variables in both shifts, similar to the mean scatter diagrams in Figures 6.31 and 6.32. Moreover, the relationship between the overall sensation scores and the indoor air temperature in all classrooms was positive as well (see Figure 6.34). As the indoor air temperature increased, the students felt warmer in the classrooms.

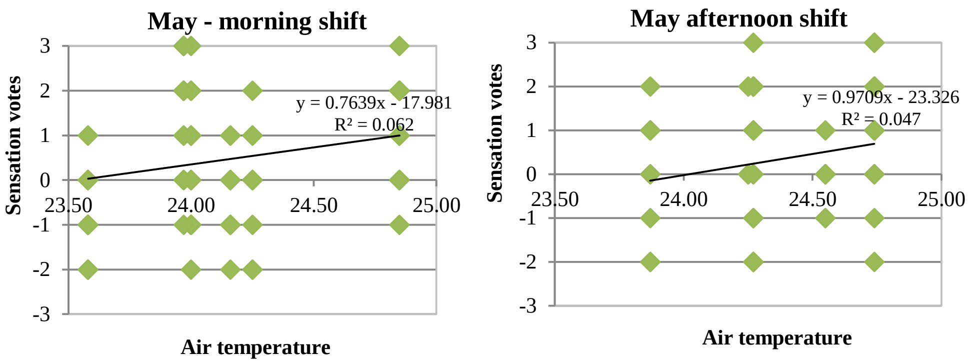


Figure 6.33: Relationship between indoor air temperatures and ASHRAE sensation scores on 4th May 2010 in both shifts separately

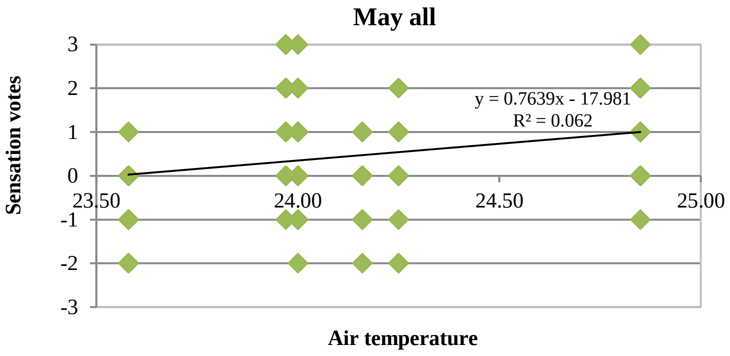


Figure 6.34: Relationship between indoor air temperatures and ASHRAE sensation scores on 4th May 2010 in all groups

Figure 6.35 illustrates the scatter diagrams of the mean indoor air temperatures against the mean preference scores on the McIntyre scale in the spring season in both shifts separately. There is a negative relationship between mean air temperatures and mean preference scores for both shifts. As the mean air temperature increased, the mean preference vote dropped, as the students wanted cooler environments.

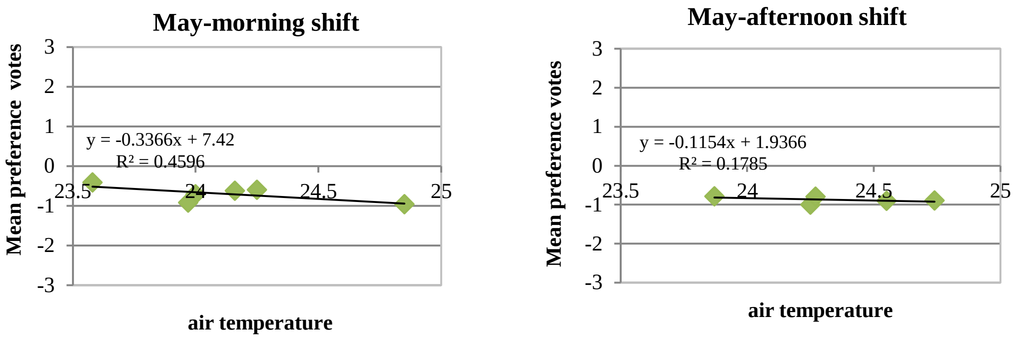


Figure 6.35: Relationship between mean air temperatures and mean preference scores on the McIntyre scale one 4th May 2010 and in both shifts

Figure 6.36 shows the scatter diagram of the all preference scores against the indoor air temperature in all classrooms. The graphs show that there is a negative relationship between these two variables, similar to the mean scatter diagrams in Figure 6.35.

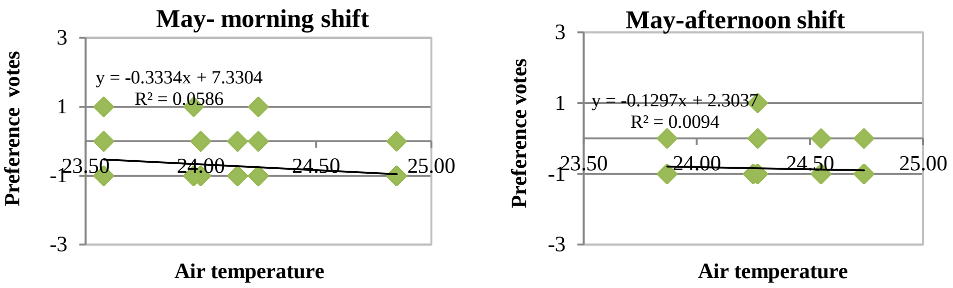


Figure 6.36: Relationship between mean air temperatures and preference scores on the McIntyre scale on 4th May 2010 in all groups

Figure 6.37 shows the scatter diagrams of the mean sensation scores on the ASHRAE scale against the mean preference scores on the McIntyre scale in the spring season survey in the morning and the afternoon shifts separately. There is a negative relationship between mean sensation votes and mean preference votes for both shifts. As the students felt warmer in the classrooms, they preferred a cooler environment.

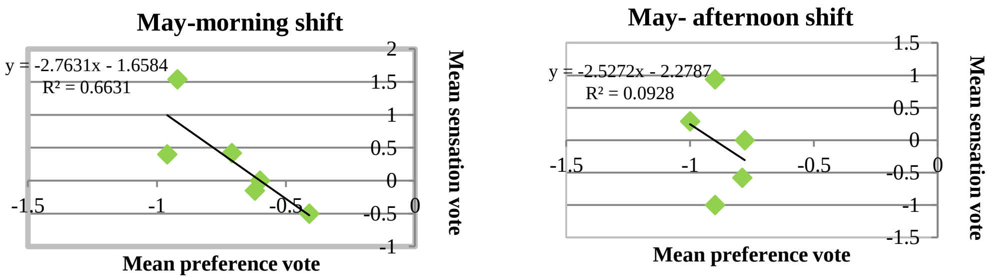


Figure 6.37: Relationship between mean sensation votes and mean preference votes in spring season on the 4th May 2010 and in both shifts

Figure 6.38 shows the scatter diagram of all the preference scores against the sensation scores for all classrooms. The graphs show a negative relationship between these two variables.

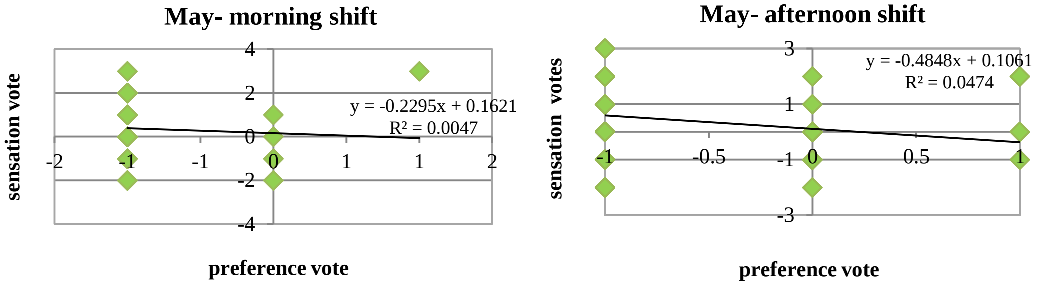


Figure 6.38: Relationship between mean sensation scores and mean preference scores on 4th May 2010 in both shifts

6.21.2. Winter period

Figure 6.39 presents scatter diagrams of mean indoor air temperatures against mean thermal sensation scores on the ASHRAE scale in the winter season. There is a positive relationship between mean air temperatures and mean sensation scores in the winter survey results. As the mean air temperature increased inside the classrooms, the mean sensation vote rises, which means that, at the higher temperatures, the occupants felt warmer, compared to how they felt when temperatures were lower.

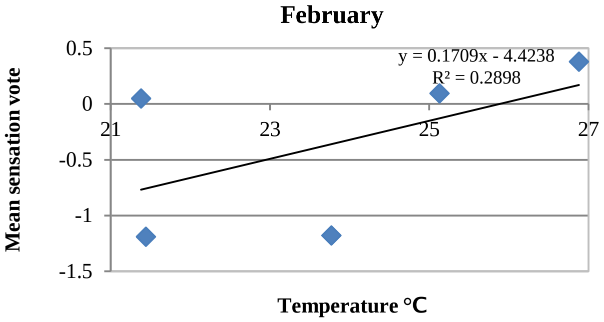


Figure 6.39: Relationship between air temperatures and mean ASHRAE sensation scores on 9th February 2011

Figure 6.40 shows a scatter diagram of indoor air temperatures with all sensation votes in all classrooms during the winter season survey. The graphs show that there is a positive relationship between these two variables, similar to the mean scatter diagrams in Figure 6.36.

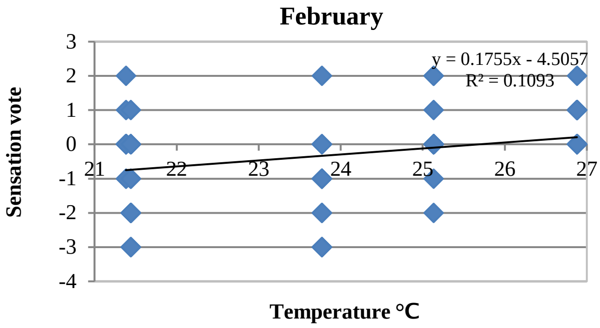


Figure 6.40: Relationship between air temperatures and ASHRAE sensation scores on 9th February 2011

Figure 6.41 shows the scatter diagram of mean indoor air temperatures against mean preference scores on the McIntyre scale in the winter season. There is a negative relationship between mean preference votes and mean sensation votes in the winter survey results. As the mean air temperature increases inside the classrooms, the students showed an increasing preference for a cooler environment.

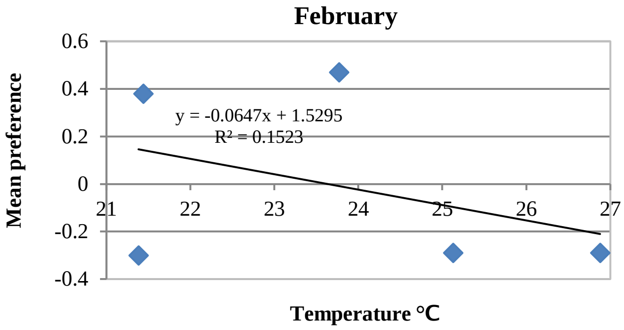


Figure 6.41: Relationship between mean air temperatures and mean preference scores op the McIntyre scale on 9th February 2011

Figure 6.42 shows the scatter diagram of air temperatures with all the preference scores in all classrooms during the winter season survey. The graph shows that there is a negative relationship between these two variables, similar to the mean scatter diagrams in Figures 6.41.

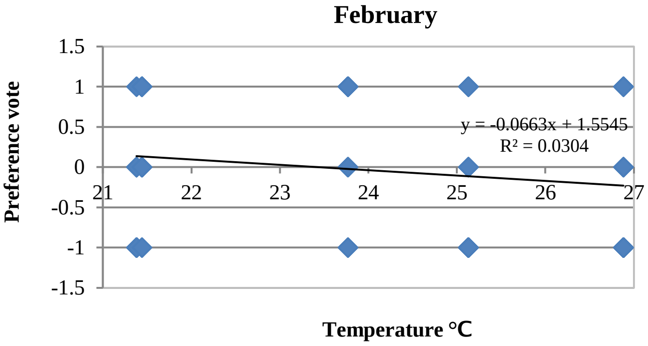


Figure 6.42: Relationship between air temperatures and preference scores on the McIntyre scale on 9th February 2011

Figure 6.43 shows the scatter diagrams of the mean sensation scores against the mean preference scores in the winter season. There is a negative relationship between these two in the winter survey. As the occupants felt warmer in the classrooms, they preferred their environment to be cooler.

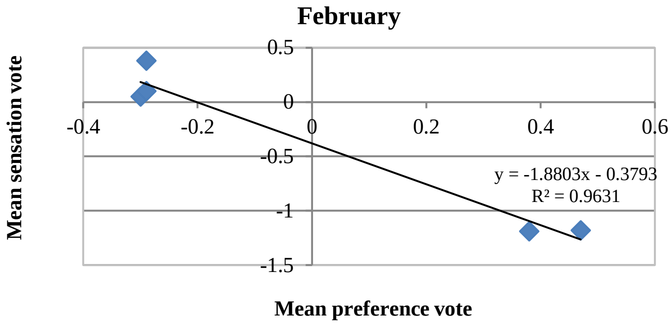


Figure 6.43: Relationship between mean sensation scores and mean preference scores on 9th February 2011

Figure 6.44 shows a scatter diagram of the mean sensation scores against all the preference scores in the winter season. There is a negative relationship between these two in the winter survey. As the occupants felt warmer in the classrooms, they preferred their environment to be cooler.

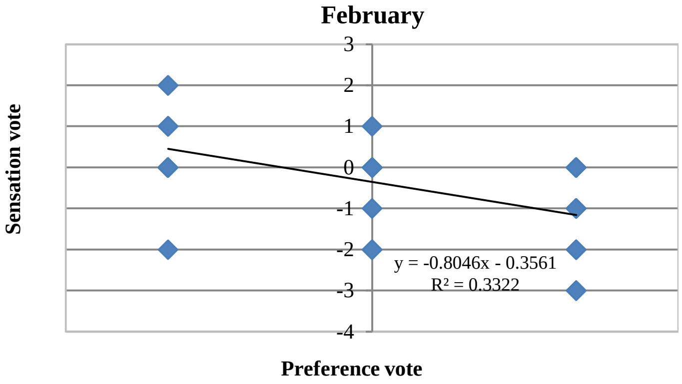


Figure 6.44: Relationship between sensation scores and preference scores on 9th February 2011

6.21.3. Spring and winter period

Figure 6.45 shows the scatter diagram of the mean indoor air temperature with mean sensation votes for both seasons. There is a positive relationship between mean sensation scores and mean temperatures in both seasons. As the mean air temperature increased inside the classrooms, the students felt warmer inside the classrooms, despite the heating and cooling seasons.

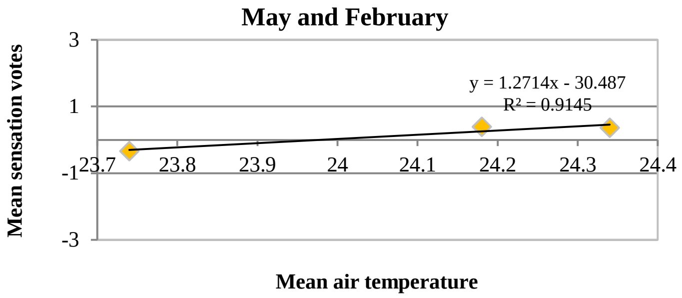


Figure 6.45: Relationship between air temperatures and mean ASHRAE sensation scores in both seasons

Figure 6.46 shows the scatter diagram of the mean indoor air temperature with mean preference scores in both seasons. There is a negative relationship between mean preference scores and mean temperatures in both season survey results. As the mean air temperatures increased inside the classrooms, the students preferred to be in a cooler environment, despite the heating and cooling season.

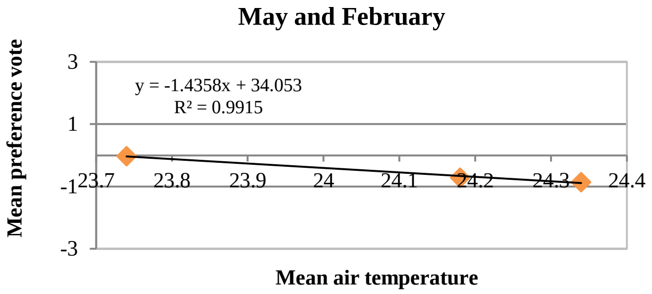


Figure 6.46: Relationship between mean air temperatures and mean preference scores on McIntyre scale in both seasons

Figure 6.47 shows the scatter diagrams of the sensation and mean preference scores in both seasons. There is a negative relationship between mean sensation responses and mean preferences in both season survey results. As the students felt warmer inside the classrooms, they preferred to be in a cooler environment, despite the heating and cooling seasons.

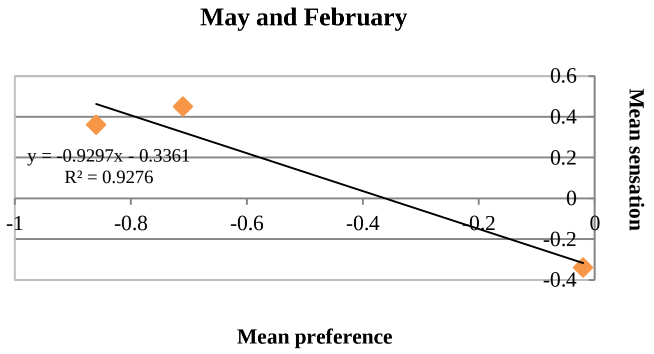


Figure 6.47: Relationship between mean sensation scores and mean preference scores in both seasons

Table 6.50 presents the correlation coefficient between sensation responses and indoor air temperatures, preference responses and indoor air temperatures, as well as sensation responses and preference responses during the questionnaire survey experiment in May and February. It also shows the standard deviation of these performance indicators during the same period.

Table 6.50: Performance indicators showing relationship between sensation response and preference response to indoor air temperature; and sensation response to preference response & standard deviation in May and February

Months	**Performance Indicator**	**Indoor air temperature**		**Preferences vote**	
		R^2	SD	R^2	SD
May morning shift	Sensation vote	0.062	11.90	0.004	1.14
	Preferences vote	0.059	12.46	--	--
May afternoon shift	Sensation vote	0.047	12.10	0.047	1.11
	Preference vote	0.009	12.68	--	--
February morning shift	Sensation vote	0.109	12.20	0.33	1.02
	Preference vote	0.030	12.02	--	--

It can be seen that the standard deviation of the variables were close but the correlation coefficient was different for each relationship in May and February. This shows that the students’ sensation responses and preference responses were different in each classroom. The possible reason for this may be the time and the season of the survey, as well as the location of the classrooms.

6.22. Conclusion

In this chapter, the questionnaire based survey which was conducted in the spring and winter seasons during the field measurement experiment were discussed and the results analyzed. The questionnaire based survey was conducted on one day in each period to evaluate the students’ thermal satisfaction in typical classrooms during the warmest and coldest periods. Although the indoor air temperatures in both seasons were within the comfort band, defined by Heidari (2010) for Iranian people, around 73% of the thermal sensations votes of the students were within the central three categories of the ASHRAE scale. Based on ASHRAE (2004), 80% of the votes in central three categories of the ASHRAE scale shows the thermal satisfaction of the students, and in this case a considerable amount of students were not satisfied with the indoor thermal environment of the classrooms in both seasons. The thermal preference votes confirm the dissatisfaction of the students, as most wanted change in their thermal environment. This study showed that the comfort band calculated by Heidari (2010) is different for female students in a secondary school building and the comfort band is more limited for female students than for occupants living in residential buildings and working in offices. Heidari (2010) stated that Iranian people can achieve comfort at more than 30°C in the hot season and less than 20°C in the cold season but in this study the female students felt uncomfortable when the indoor air temperature exceeded 24.5°C and when it fell below 20°C. It was found that the maximum comfort temperature for female students in a secondary school building in Tehran was 24.5°C in May and the minimum comfort temperature was 20°C in February.

Chapter 7: Evaluation Using Simulation and Validation

7.1. Introduction

In order to improve the physical comfort and learning efficiency of students in classrooms, it is important to evaluate the thermal conditions of the indoor environments in school buildings. Thermal conditions in the classroom have a great effect on academic performance, comfort and attendance of the students in school buildings (CABE, 2010). Therefore, improving the thermal conditions of the classroom increases the physical comfort and learning ability of the students (Hoffman, 2009). Considering the quality of the indoor environment in school building during the design process is an essential factor in order to provide a comfortable environment for students and to control the energy consumption of the school building. The studies show that the condition of the indoor thermal environment and the comfort conditions in the room have a direct relationship with the building’s envelope (Oral et al., 2004). In addition, the outdoor environment, orientation of the building and the thermal properties of the building materials are some of the main factors which have an influence on the building’s envelope design (Oral et al., 2004). In order to assess and improve the thermal condition of the building accurately, it is necessary to validate the thermal simulation software and the weather data files. This chapter presents an evaluation of a building simulation modelling of a female secondary school building in the capital of Iran, Tehran, in the warm spring period of April/May 2010 and cold winter period of January/February 2011, for three and four weeks, respectively. In this chapter the building simulation package, DesignBuilder, and the weather data used in the simulation modelling were validated and the capabilities of the software were reviewed. Moreover, the simulation predictions using the actual weather data and the average weather data were compared against the on-site monitoring results in order to measure the accuracy of the weather data files and DesignBuilder.

7.2. Case study modelling and the simulation package

The thermal performance of six classrooms was evaluated using an environmental analysis software package, known as DesignBuilder (DesignBuilder, 2013a) which will be discussed in detail in the following sections. The simulation tool was used to assess the thermal performance of the classrooms during the warm and cold seasons in order to improve the indoor climatic environments of the typical school building. In this chapter, the difference between the simulation predictions, the field measurements and the parameters that caused uncertainty in the 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. Furthermore, a comparative analysis was performed on the result of the field measurements, as discussed in Chapter 5, and the simulation modelling from the classrooms that were located on first (1) and second (2) floors, facing south (S) and north (N). Moreover, in Chapter 8 various passive design strategies are applied to the simulation model in order to examine and improve the quality of the indoor environment in a typical school building. These strategies include the building materials and thermal properties, orientation of the building, shading devices as well as the building opening types. The indoor climatic variables such as indoor air temperature and relative humidity levels of the classrooms are compared while different passive design options applied to the 3D model.

As stated above, this research is based on the assessment of indoor thermal conditions in a female secondary school building in Tehran using DesignBuilder (DesignBuilder, 2013a) version 2.2.5.2004. DesignBuilder is an environmental analysis tool used for simulating building energy consumption, lighting, comfort performance and CO_2 emissions in early stages of design (DesignBuilder, 2013a). DesignBuilder analyses the comfort performance of the building, based on EnergyPlus data requirement. EnergyPlus (DesignBuilder, 2013a) is developed by the U.S Department of Energy (DOE) and is a building energy simulation programme for modelling the heating, cooling, lighting, ventilating, and other energy flows of the buildings (EnergyPlus, 2013b). DesignBuilder is a user-friendly building simulation package (EnergyPlus, 2013a) that is used in many building simulation experiments. It calculates the thermal and energy performances of various types of buildings which have multiple HVAC types, including naturally ventilated buildings and buildings with double facades (EnergyPlus, 2013b).

7.2.1. Case study school building

The case study school building is a four storey building with the building’s main facade facing south (see Figure 7.1). In order to evaluate and improve the thermal conditions of the classrooms in DesignBuilder, indoor air temperatures and internal relative humidity levels of the classrooms were measured with HOBO data-loggers. The field measurements and the simulation studies were performed in six classrooms facing south (S) and north (N) for three weeks during the spring season and four weeks during the winter season, which included two survey days, on 4th May 2010 and 9th February 2011. The simulation analysis was performed to predict the thermal conditions of the classrooms, with some realistic input assumptions from the field studies, in order to improve the indoor environment. To assess the accuracy of the DesignBuilder simulation tool, indoor air temperatures and relative humidity levels of the classrooms measured by HOBO data loggers were compared to the simulation results which were discussed in this chapter.

Figure 7. 1: Main facade (S) and typical classroom of case study school building

The simulation tool was used to evaluate the thermal conditions of the classrooms with its existing building materials from the field studies. In addition, different building materials and thermal properties were applied to the simulation model in order to examine and improve the quality of the indoor environment in a typical secondary school building which is discussed in Chapter 8. The school building has four storeys, including the basement and the ground floor, and the classrooms are located on the first and second floors (see Figure 7.2). The building's main facade is south-facing in this typical school.

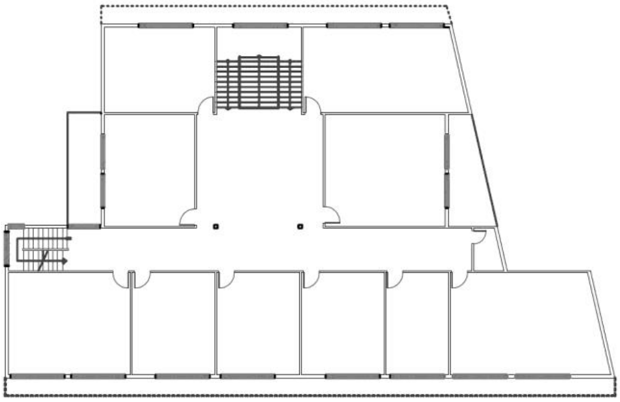


Figure 7. 2: Typical floor plan of school

7.2.2. Construction details

The school building has a masonry structure with brick blocks (see Figure 7.3) which is a commonly used material in masonry buildings in Iran *(National Building Code, 2009a)*. In order to evaluate the indoor thermal conditions with the aid of the simulation tool, the original building materials of the school building used in the external and internal walls, floors, roofs and building openings were defined in DesignBuilder. The case study building's external walls and internal floors have no thermal insulation. The classrooms have single glazed external windows, without any shading devices, and each classroom has a wooden door with an internal window on top. The heating system is a gas powered boiler heating system with radiators in each classroom and corridors that are usually turned on during the months of October to March. In addition, no cooling system operates during the warm season, hence classrooms are naturally ventilated. Table 7.1 summarises the original school building materials in various components and their U-Value, as well as their thickness.

Table 7.1: Materials, thickness and U-value of building components in reference model

Components	Materials	U-value $[W/m^2K]$
Internal walls	Gypsum plastering (2.5 cm) Brick block (10 cm) Gypsum plastering (2.5 cm)	1.831
External walls	Cement sand render (3 cm) Brick block (30 cm) Gypsum plastering (2.5 cm)	1.582
Internal floor	Slate tiles (2cm) Mortar (2.5 cm) Light weight cast concrete (5cm) Clay tile (25 cm) Gypsum and sand render (2 cm) Gypsum plastering (1 cm)	1.342
Roof	Asphalt (3cm) Mortar (2cm) Felt/Bitumen layers (5 cm) Screed (10 cm) Thermal insulation (5 cm) Cast concrete (5cm)Clay tile (25 cm) Gypsum plastering (1 cm)	0.575
External windows	Clear single glaze (6mm)	5.778

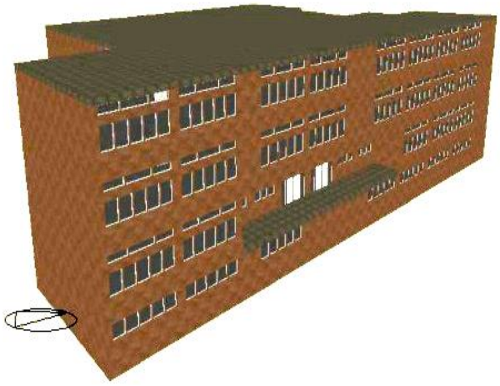


Figure 7.3: Case study school building in DesignBuilder

7.2.3. Schedules for simulation

The occupancy period and the operation of the equipment can be defined in DesignBuilder. In this study the actual schedule of the occupancy and the equipment was adjusted in the simulation tool to represent real user behaviour. The equipment could be adjusted by the occupants at any time. Schedules to be used for the lighting, heating system, natural ventilation demands and occupancy were defined in DesignBuilder separately. Each day of the week had a separate profile in the simulation model. It was considered that the external windows of most classrooms were fully closed during the winter occupancy period and fully open during the spring period. Also, the internal doors were closed, except during break time, in which they were fully open in both seasons. It is important to state that right up to the winter of 2011, where the second semester field study was carried out, the school operated in a two shift format, but since then, and during the second field study, the school moved to a one shift system. In terms of the building occupancy, during the spring semester the school building was occupied from 7:30am to 12:30pm for the morning shift and from 1:30pm to 5:30pm for the afternoon shift. In the winter semester of 2011 the building was occupied from 7:30am to 12:30pm during weekdays. It should be mentioned that the lighting was on during the occupancy period in all classrooms in both seasons. Also weekdays run from Saturday to Thursday in Iran.

7.2.4. Weather data

There are different types of weather data files, ranging from locally recorded weather data to a typical years weather file, which are used in various building simulation engines (Crawley 1998). A weather file is one of the main requirements for performing building simulation analysis. Dynamic simulation and an hourly energy use calculation in some simulation programmes need hourly weather data for a complete year. As the weather conditions change every year, various weather data files have been developed for building simulation, based on the simulation programmes and the analysis requirements (Su et al., 2009). Different weather data sets are developed by various researchers. The most common formats of weather files are the Test Reference Year (TRY), Typical Meteorological Year (TMY, TMY2, TMY3) and International Weather for Energy Calculations (IWEC) (Su et al., 2009). Some of these formats are supported by EnergyPlus and DesignBuilder simulation tools, such as TMY and TRY formats (DesignBuilder, 2013b). TMY is based on an hourly report of the climatic data and has been developed after gathering weather data for several years (Melki and Hayek, 2009). TRY is based on the hourly observation of climatic variables, developed by hourly weather data sets (Crawley 1998). DesignBuilder uses an EnergyPlus EPW format, which is derived from the Typical Meteorological Year 2 (TMY2) weather format (EnergyPlus, 2013c). In this study, it was decided to use the ITMY (Iran Typical Meteorological Year) Data in EnergyPlus Weather format (EPW) provided by the U.S. Department of Energy and derived from the Building and Housing Research Centre (BHRC) of Iran, which records a period of between 30 and 43 years (EnergyPlus, 2013d).

7.2.5. Weather data and simulation package validation

In order to assess the accuracy of DesignBuilder, it is necessary to evaluate the simulation package and validate the weather data file used in the simulation tool. One of the main reasons for validating the typical weather data files for Tehran provided by the U.S. Department of Energy (EnergyPlus, 2013d) is to verify whether it can represent the real weather profile in Tehran, or whether the actual climatic variables obtained from the nearest local weather station in Tehran (Wunderground, 2013) should be employed instead. The nearest local weather station to the school building is located in Mehrabad Airport, just around three Kilometres away from the school building (see Figure 7.4), the advantage of being that the weather readings captured outside of the school building are as accurate and eligible as they can possibly be.

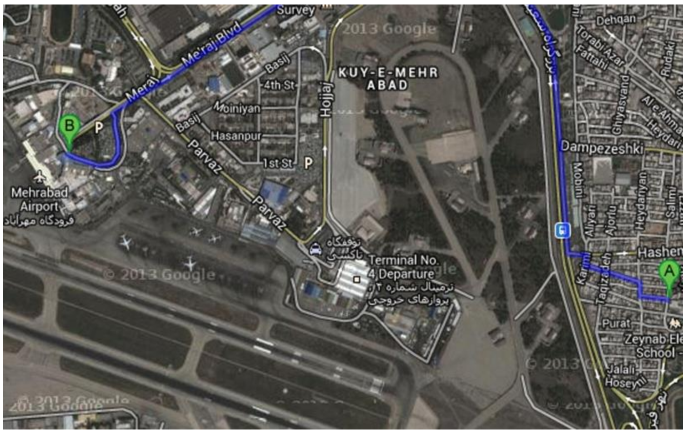


Figure 7.4 : Location of School Building (A) and Local Weather Station (B) (Google map, 2013)

In this study, the building simulation tool, DesignBuilder, employed the default (typical) EPW file from the EnergyPlus and the actual weather data records for Tehran from the local weather station (Wunderground, 2013, Irimo, 2011) separately, in order to predict indoor environmental conditions. The predicted climatic variables by DesignBuilder software, which employed the actual and the typical weather files (EPW) separately, were then compared to the measured climatic variables recorded by HOBO data-loggers to ensure the accuracy of the simulation package and to validate the weather data files.

The first weather file in the EPW format for Tehran which was obtained from the EnergyPlus website (EnergyPlus, 2013c) was employed in DesignBuilder as a base for the weather file. The EPW file from EnergyPlus represents a typical meteorological year in Tehran, and in this case it is the averages of a period of record from 30 to 43 years (EnergyPlus, 2013d). Next, the modified EPW file which used the actual weather variables was employed in DesignBuilder to run the simulation. In order to use the actual weather data, the climatic variables of the default EPW file for Tehran were modified and the actual data gained from the local weather station applied to the weather file, instead of the average typical year. The aim was to modify the weather file as much as possible to represent local conditions most accurately. However, some weather data in the default EPW file were not available on the actual daily records of the weather data from the local weather station. The only available data were temperature, relative humidity, wind speed and wind direction, as well as sky condition. These data were updated in the default EPW file to the actual daily assumption and a new EPW file was then generated, using the actual data for the whole period of the field measurements for three weeks in spring and four weeks in winter seasons. To modify the EPW file, the following steps were undertaken using an EnergyPlus converter:

- Running the weather converter on the original file and converting the file to EnergyPlus CSV.
- Opening the EnergyPlus CSV file in Excel spreadsheet.

- Making the modifications and then saving the amended document as a CSV in the spreadsheet programme.
- Running the weather converter again; this time selecting the CSV and making sure the File type was "EnergyPlus CSV", in order to convert it to the EPW format.

The actual climatic variables were recorded sub-hourly by Iran’s Meteorological Organisation. However, the typical weather data was recorded hourly and the HOBO data-loggers measured indoor air temperatures and relative humidity levels at 15 minutes interval. In order to adjust the quarterly and sub-hourly data to the hourly basis, the average hourly measurements of sub-hourly and quarterly readings were calculated.

7.3. Spring season validation

The indoor air temperature and the internal relative humidity levels were measured by HOBO data-loggers and predicted by DesignBuilder in six classrooms during the spring season experiment, from 23rd April 2010 to 13th May 2010. These days represented the warmest weeks during the academic year and the time before the summer vacation closure. The classrooms were located on the first (1) and second (2) floors, facing north (N) and south (S). The simulation tool employed actual and typical weather data files separately. Using the actual and average weather data in the simulation tool produced various indoor air temperature ranges and different relative humidity levels in each classroom, the prediction by DesignBuilder. A comparison was carried out to assess the agreement of the measured results against the predicted simulation results of DesignBuilder from the classrooms detailed above.

7.3.1. Indoor air temperature

Figures 7.5 and 7.6 illustrate the indoor air temperature ranges measured by HOBO data-loggers and calculated by DesignBuilder (DB) using actual and average outdoor weather variables. The blue boxes in the graphs present the survey day on 4th May 2010.

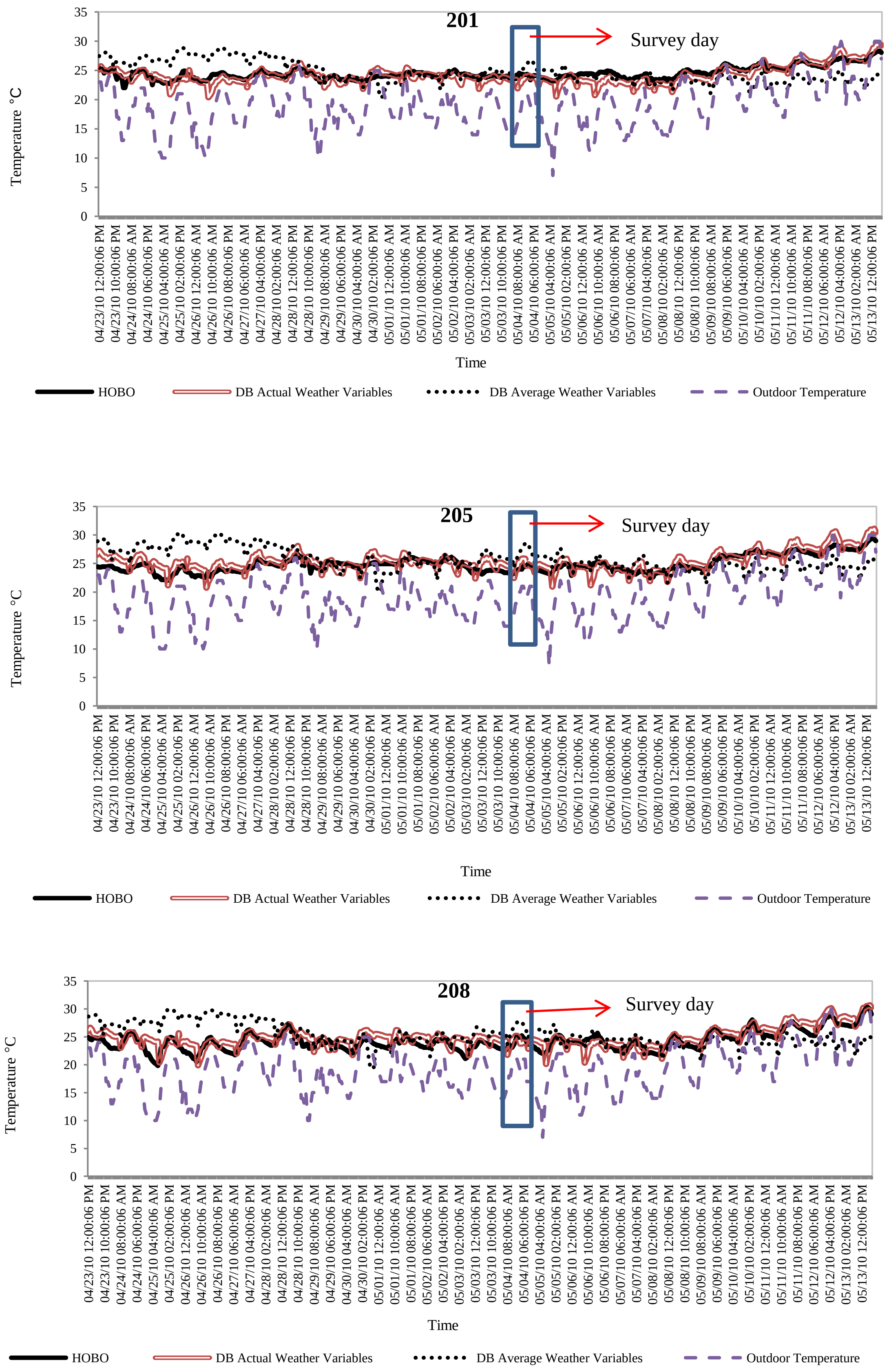


Figure 7.5 : Simulated indoor air temperature profiles against measured indoor temperature profiles for classrooms 201, 205 and 208 during spring season

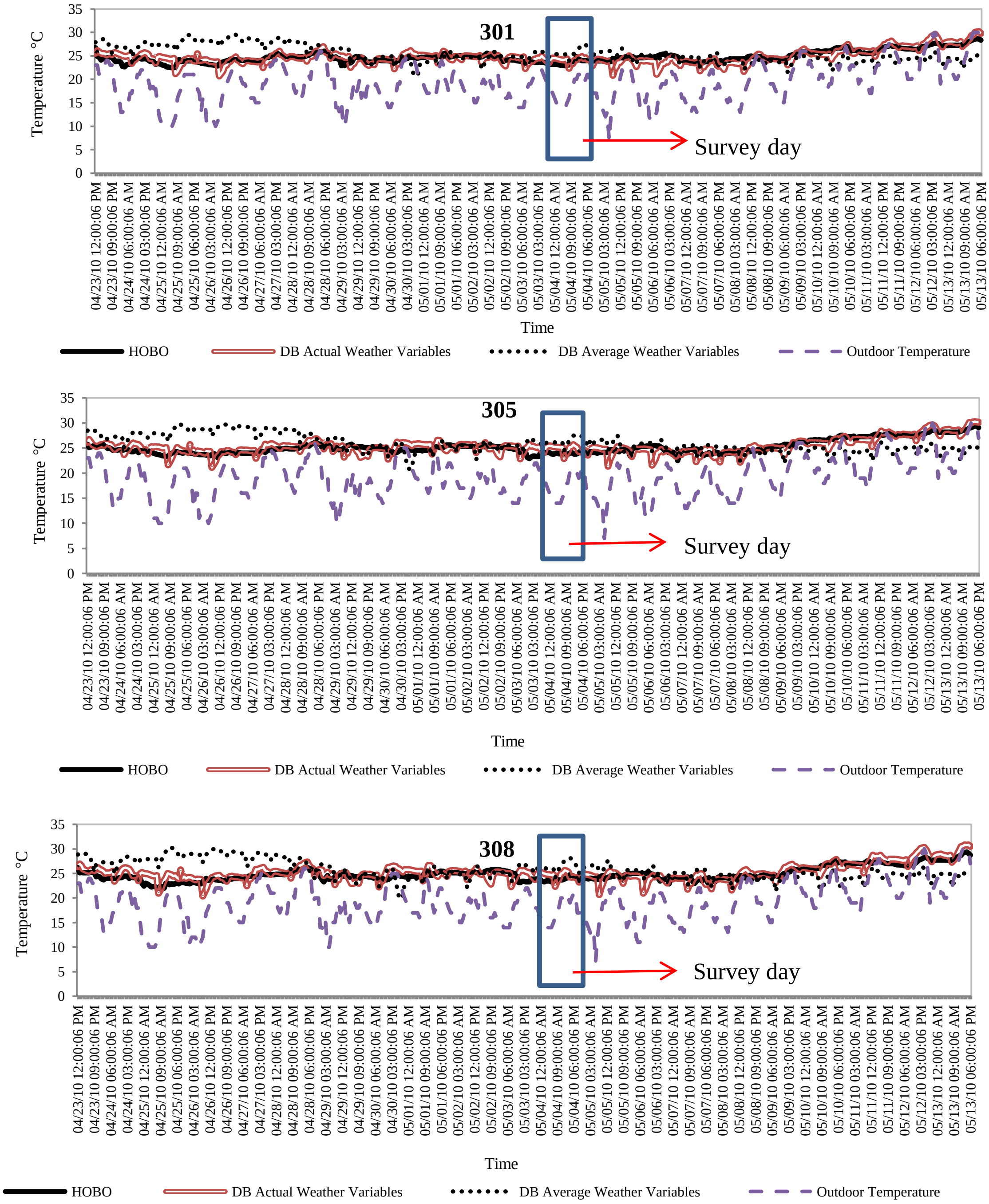


Figure 7.6 : Simulated indoor air temperature profiles against measured indoor temperature profiles for classrooms 301, 305 and 308 during spring season

The results of the simulation analysis and the field measurements show that they usually followed a similar pattern in all classrooms, especially when the actual weather data was applied to the simulation tool during the survey day on 4th May 2010. However, the measured and the predicted internal air temperatures, found using the average weather data files by the simulation tool, sometimes did not follow the same pattern. A possible reason could be the use of the average outdoor air temperature, which is not exactly the same as the actual weather variable, which complies with the average climatic variable, but in the different range.

7.3.2. Indoor relative humidity

In addition, the relative humidity levels measured by HOBO data-loggers and predicted by DesignBuilder during the spring season for three weeks were compared using the actual and the typical weather data files in DesignBuilder (see Figure 7.7 and 7.8). The blue boxes present the survey day in May.

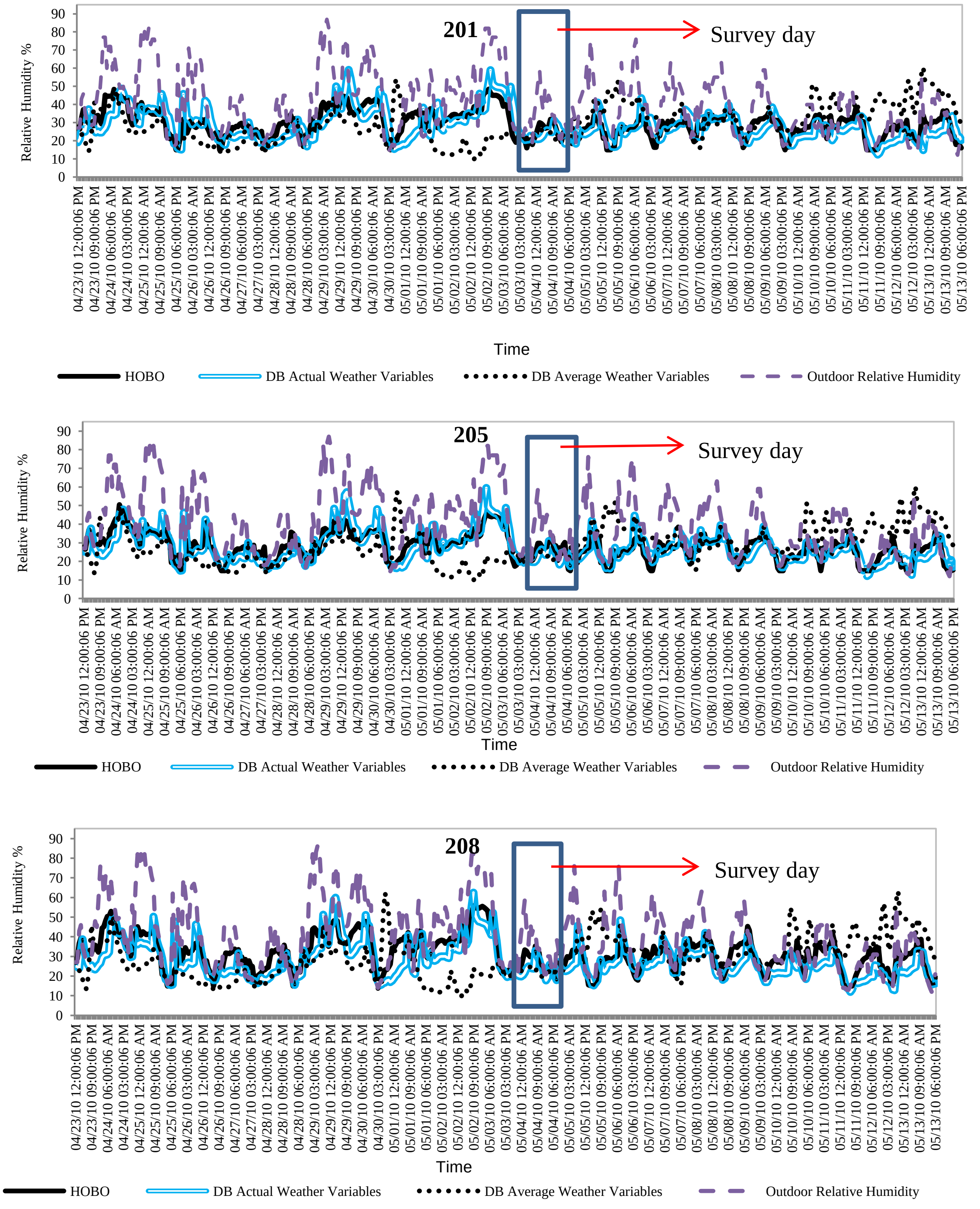


Figure 7. 7: Simulated indoor relative humidity profiles against measured indoor relative humidity profiles for classrooms 201, 205 and 208 during the spring season

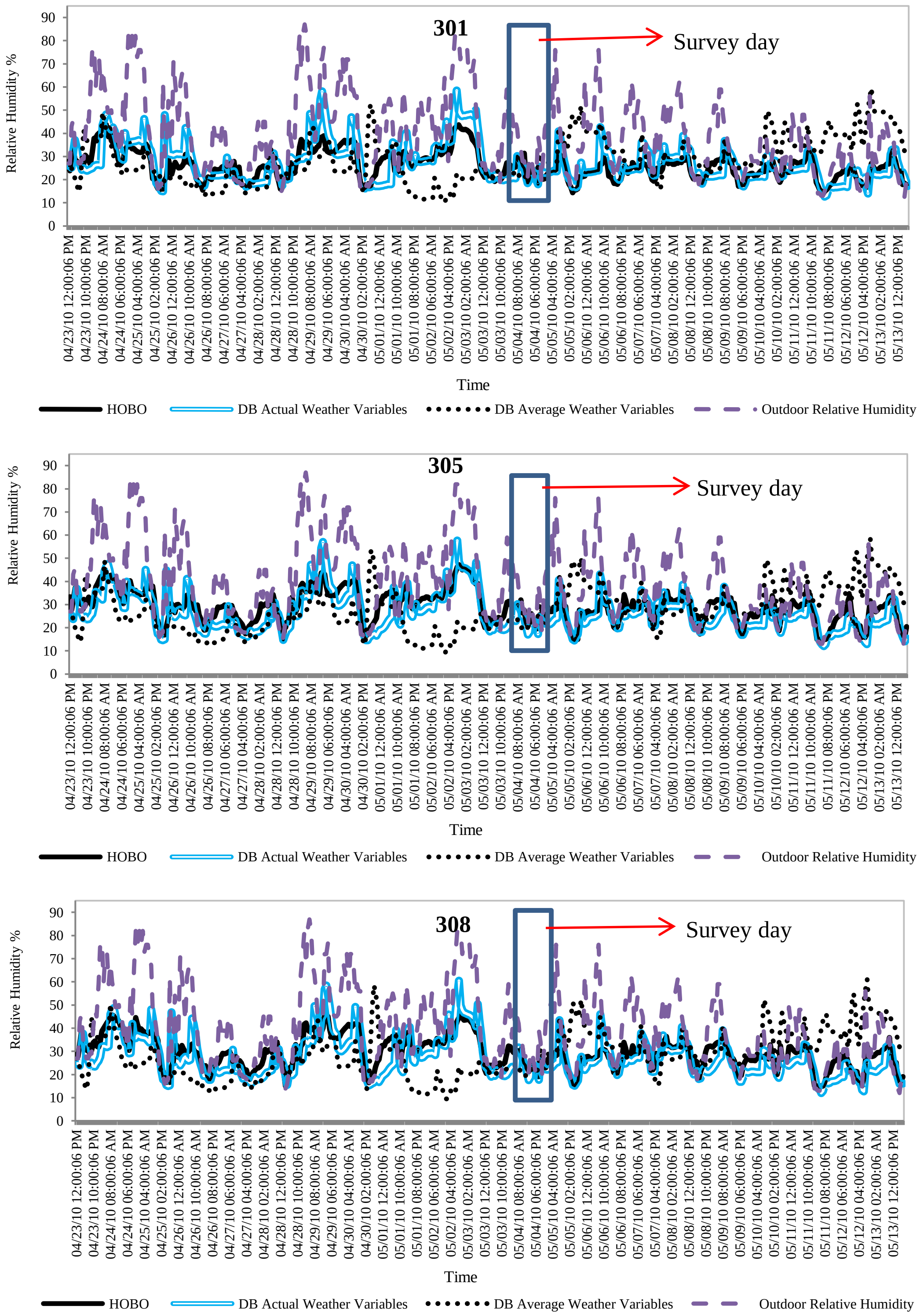


Figure 7.8: Simulated indoor relative humidity profiles against measured indoor relative humidity profiles for classrooms 301, 305and 308 in spring season

Similar to the indoor air temperature, the measured internal relative humidity levels were in close parallel with the predicted indoor relative humidity levels produced by DesignBuilder, when the actual weather data file was employed. However, the relative humidity levels using the average weather data file were usually under- and over-estimated. Generally, defining indoor relative humidity is more complicated than defining indoor air temperature, as relative humidity can easily be affected by the outdoor weather conditions and the number of the occupants of specific rooms, especially if the building has a poor construction, and as a result the rain and snow may enter the buildings through leaks in the buildings' envelope. For example, if the outdoor weather condition is rainy or it snow, the humidity level increases quickly; and if the number of occupants rises, the humidity level goes up (Center Point Energy, 2008), as breathing produces moisture, which increases the level of humidity inside a room (Whitmyrea and Pandianb, 2004). In addition, if the airflow rate increases, it can decrease the humidity level inside a classroom. If the classrooms is naturally ventilated or even if it has a poor construction, increasing the air flow rate will decrease the humidity level in indoor spaces (Kasmai, 2008). Figures 7.5 to 7.8 show that both indoor relative humidity levels and internal air temperature ranges followed the outdoor relative humidity levels and the outdoor air temperatures during the warm season, as the classrooms were naturally ventilated.

7.3.3. The effect of outdoor climatic variables

The results show that using the actual weather data files in the simulation analysis produces more accurate results and the indoor air temperatures and the internal relative humidity levels are more similar to the climatic variables measured by the HOBO data-loggers, in comparison to the results of simulation modelling using average climatic data. Figure 7.9 and 7.10 present the actual outdoor air temperatures and outdoor humidity levels in comparison to the average outdoor variables. It can be seen that both the actual and the average climatic variables usually followed similar patterns but in different ranges. The average and actual outdoor air temperatures had a close range during the survey day of 4th May 2010 but the outdoor relative humidity level was different on the same day, so it is better to use the actual weather variables in the simulation analysis, in order to get a more accurate result.

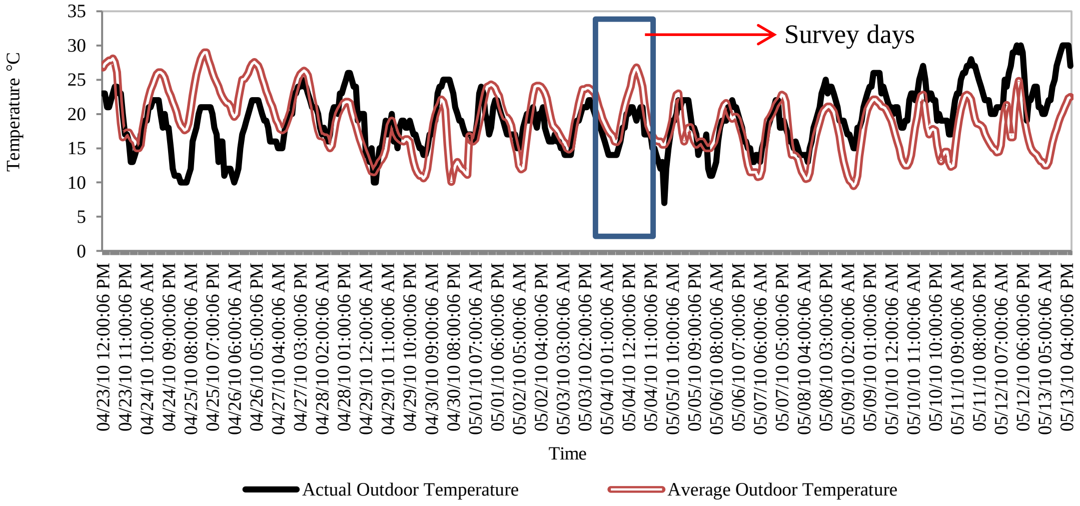


Figure 7.9: Comparison of actual and average outdoor air temperatures during spring season experiment

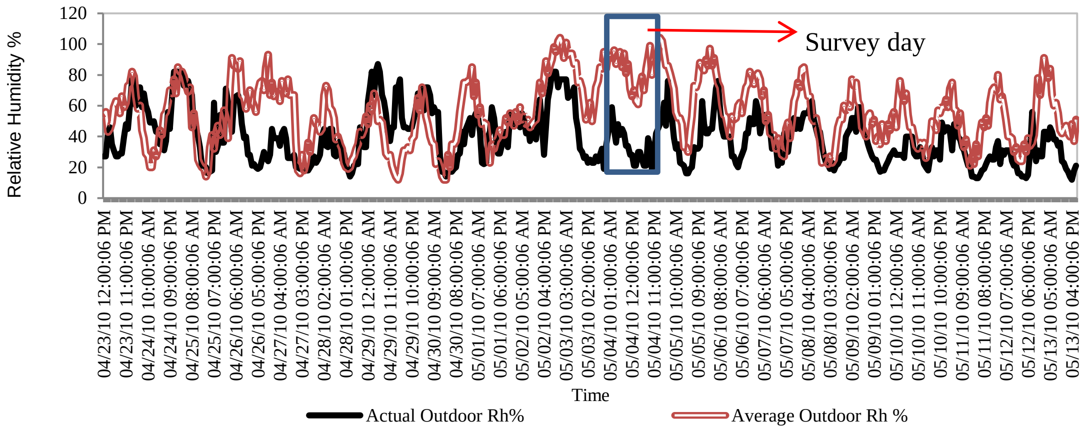


Figure 7.10: Comparison of actual and average outdoor relative humidity levels during spring season experiment

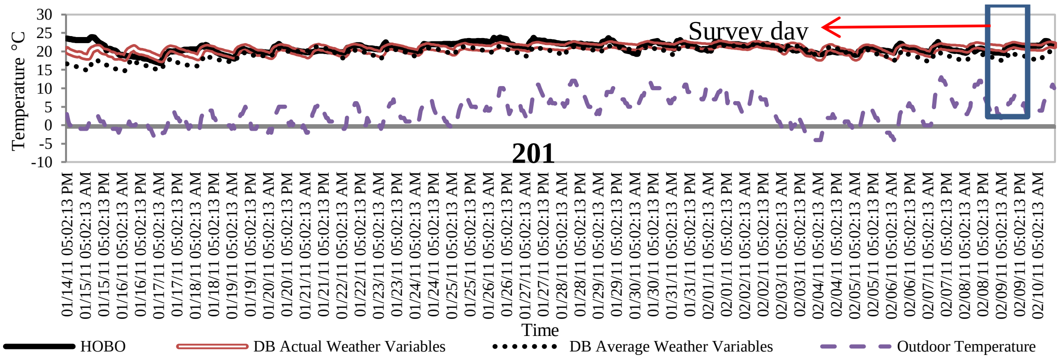
Moreover, the results of the simulation analysis were very close to the measured results during the survey day, made using the actual weather variables. As the survey results were directly employed to simulate modelling in terms of the occupancy, equipment schedules, clothing and metabolic heat rates, the indoor air temperatures and relative humidity levels measured by the HOBO data-loggers were very close to the simulation results. The results show that the measured indoor air temperatures in all classrooms had a maximum of 8.5% difference with the results of the simulation modelling using the actual weather data file on the survey day, but in terms of relative humidity levels the percentage of difference was sometimes much higher and reached even more than 32%. As discussed before, the prediction of relative humidity levels is much more complicated and uncertain than predictions of air temperatures, as it is influenced by more factors (Whitmyrea and Pandianb, 2004).One possible reason for this can be the number of the occupants in the classrooms during teaching hours, which might vary, and also the production of moisture through breathing, as mentioned above (Center Point Energy, 2008). As the number of students in the classrooms decreased or increased, the humidity level dropped or rose accordingly. In addition, air flow and ventilation rates, which can have a direct influence on the level of relative humidity, are other uncertainties and unmeasured factors in this study.

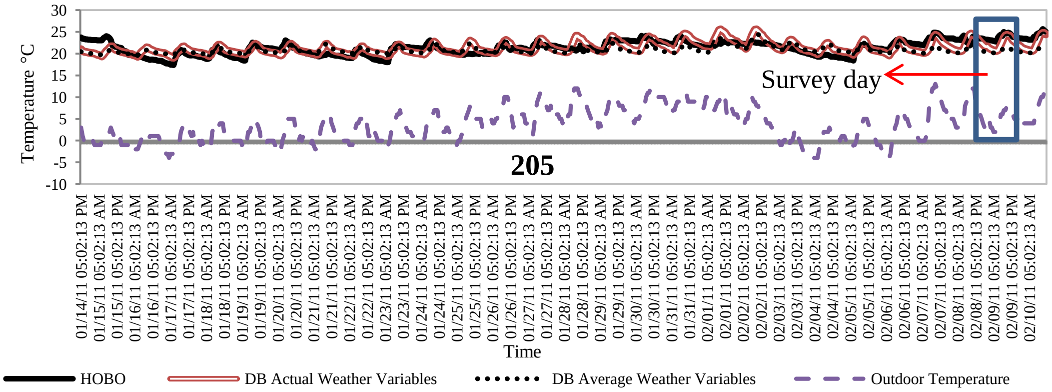
7.4. Winter season validation

Indoor air temperatures and internal relative humidity levels were measured by the HOBO data-loggers and predicted by DesignBuilder in six classrooms during the winter season experiment, from 14th January 2011 to 10th February 2011. These four weeks represented the coldest weeks of the year (Kasmai, 1994). This experiment was conducted in the same classrooms used for the spring season experiment, except for one classroom, Classroom 308, as it was not occupied during the winter season due to a decrease in the number of students, compared to the previous academic year. However, the classroom next door was selected as a sixth classroom in the winter season study, Classroom307. The simulation tool employed actual and typical weather data files separately, in order to compare the difference between the indoor climatic variables.

7.4.1. Indoor air temperature

Figures 7.11 and 7.12 show indoor air temperature measured by HOBO data loggers and predicted by the simulation tool, DesighBuilder, in six classrooms during the winter season experiment. It can be seen that, using actual and average weather data in the simulation tool produced various indoor air temperature ranges in each classroom, which was predicted by DesignBuilder. A comparative analysis was carried out to estimate the agreement of the measured result with HOBO data-loggers against the predicted simulation results by DesignBuilder from the classrooms which are located on the first and second floors, facing south and north.





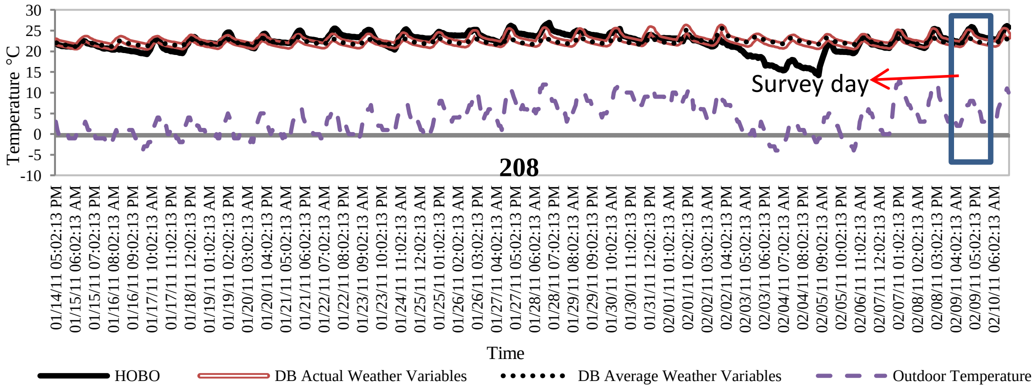


Figure 7.11: Simulated indoor temperature profiles against measured indoor temperature profiles for classrooms 201, 205 and 208 during winter season

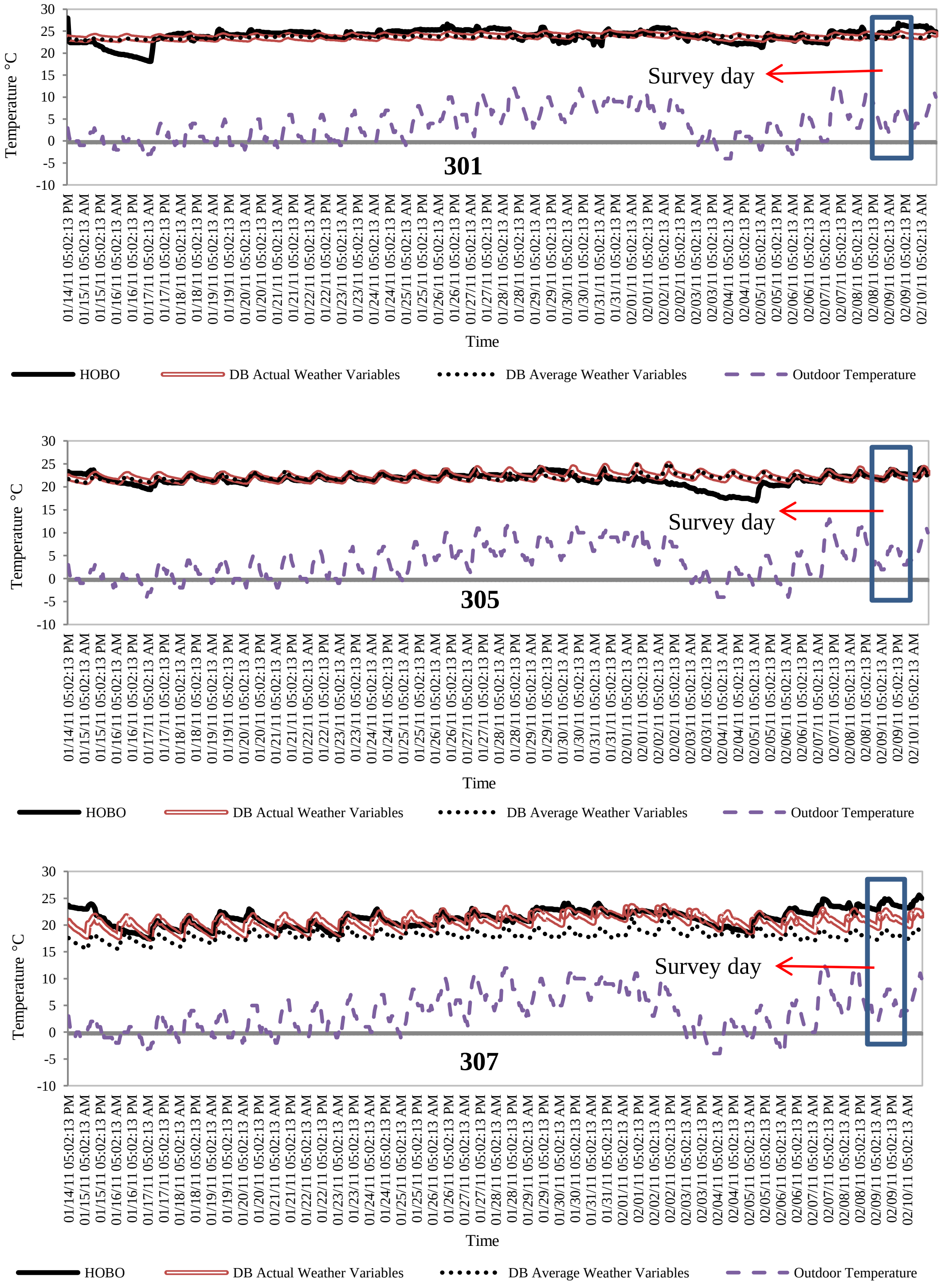


Figure 7.12: Simulated indoor temperature profiles against measured indoor temperature profiles for classrooms 301, 305 and 307 during winter season

The ranges of the measured and the calculated indoor air temperature using the actual outdoor weather variables usually followed a similar pattern in all classrooms, especially during the 9th Feb 2011 survey day. Moreover, the indoor air temperatures, calculated using the average weather data file as well as the actual weather data file, also followed the measured indoor air temperatures in most of the classrooms, unlike in the spring season experiment. As the classrooms had a heating system during the winter season, the indoor air temperature results using the actual and the average weather variables had similar ranges and the predicted indoor air temperatures, using the actual and the average weather files, were usually in parallel with actual outdoor air temperatures. However, calculating indoor air temperature through the simulation modelling is more complicated in the winter season than the spring season, as the classrooms were heated by manually adjustable hot water radiators, as previously stated. As a result, the heating set point was various in each classroom and was possibly changed several times during the field experiment resulting in different temperature ranges in each classroom, as well as under- and over-estimated results. In addition, it was found that the measured temperature in some classrooms suddenly dropped during certain days, as if no heating system was in operation. For example, the indoor air temperature in classrooms 208 and 301 dropped by about 5K on 5th February 2011. The sudden decrease in room temperatures shows that it had snowed heavily during these days and most classes were cancelled, except for the final year courses, and the heating system in those classrooms were shut down.

7.4.2. Indoor relative humidity levels

In addition, the relative humidity levels measured by HOBO data-loggers and predicted by DesignBuilder during the winter season for four weeks were compared using actual and typical weather data files in the simulation tool. As with the indoor air temperature, the measured internal relative humidity levels were usually in close parallel with those predicted by DesignBuilder which employed the actual weather data file. However, the calculated relative humidity levels, generated through using the average weather data file, were sometimes under- and sometimes over-estimated (see Figures 7.13 and 7.14).

In addition, the graphs illustrate that the minimum indoor relative humidity levels measured by HOBO data-loggers in all classrooms was 15% but the relative humidity levels calculated by the simulation tool were lower, at around 10%. As discussed in Chapter 5, this percentage of difference is related to the HOBO data-loggers' limit, which did not record relative humidity levels below 15%. However, relative humidity level lower than 30% is considered to involve low humidity conditions (Mporg, 2006), which do not have an effect on the results of this study as it is still considered low.

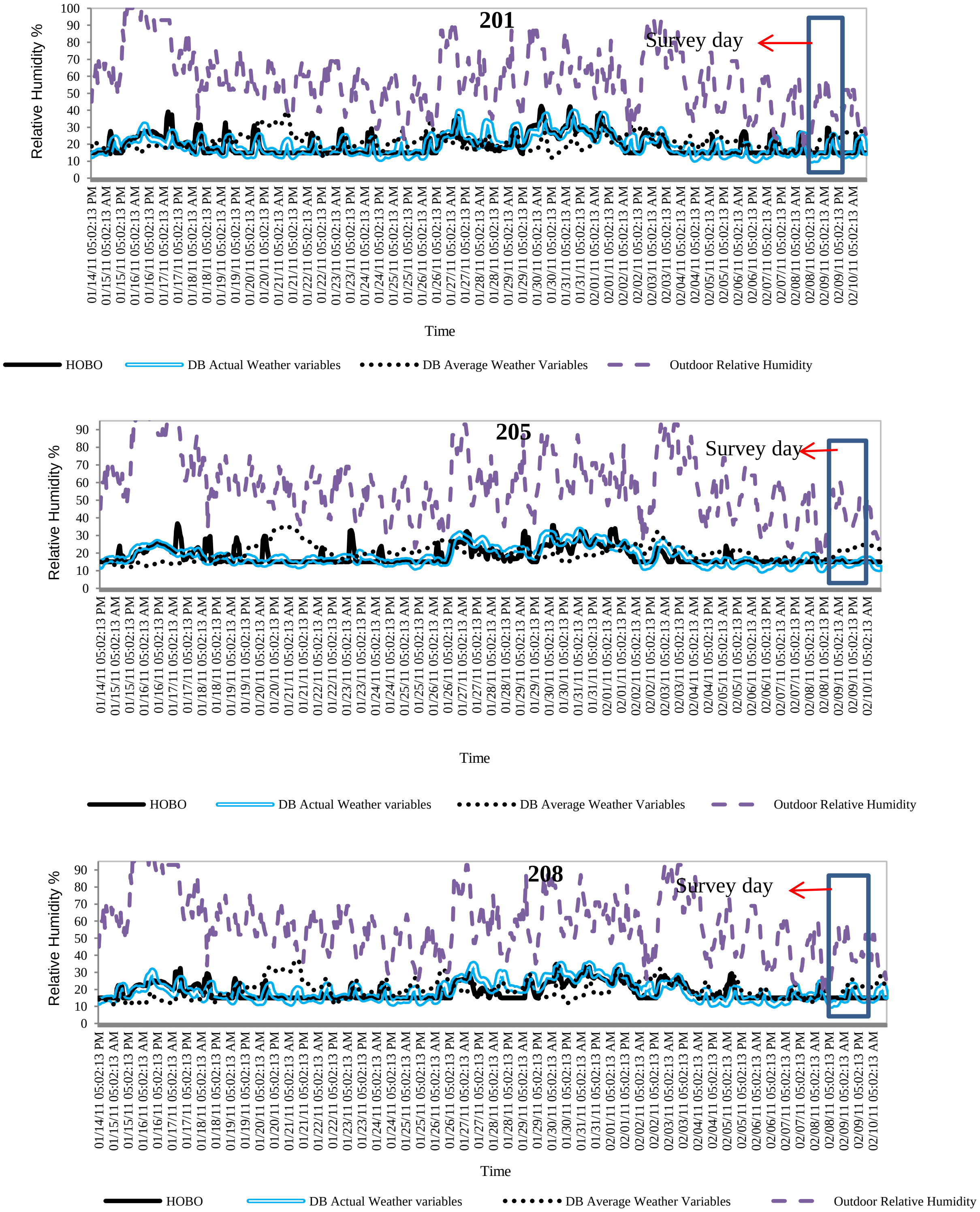


Figure 7. 13: Simulated indoor relative humidity profiles against measured indoor relative humidity profiles of classrooms 201, 205 and 208 during winter season

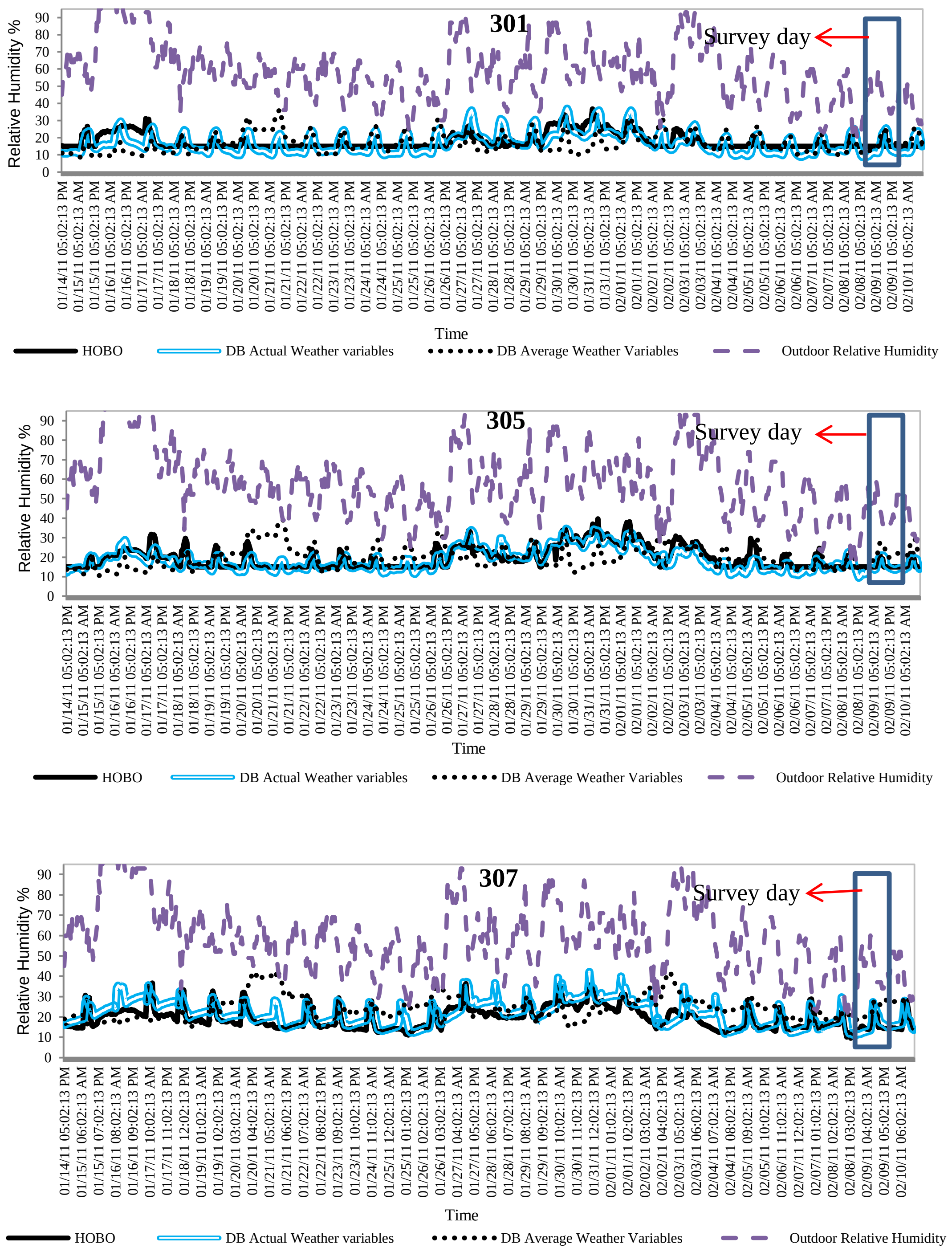


Figure 7.14: Simulated indoor relative humidity profiles against measured indoor relative humidity profiles of classrooms 301, 305 and 307 during winter season

In general both relative humidity levels and indoor air temperature ranges followed the outdoor air temperature and relative humidity levels in the cold season, although all the openings were shut in most of the classrooms during occupancy. One possible reason could be the construction of the building, which is considered poor and medium in most of the classrooms. In addition, results show that using the actual weather data files in the simulation analysis produced more accurate predicted results and the indoor air temperatures and internal relative humidity levels were more similar to the measured climatic variables generated by the HOBO data-loggers, in comparison to the result of simulation analysis using average climatic data.

7.4.3. The effect of outdoor climatic variables

Figures 7.15 and 7.16 present the actual outdoor air temperatures and outdoor humidity levels in comparison to the average outdoor variables. It can be seen that the actual and average climatic variables usually follow a similar pattern but in different ranges. It can be seen that the average and the actual outdoor air temperatures and relative humidity levels were different during the survey day on the 9th Feb 2011 but had a similar pattern.

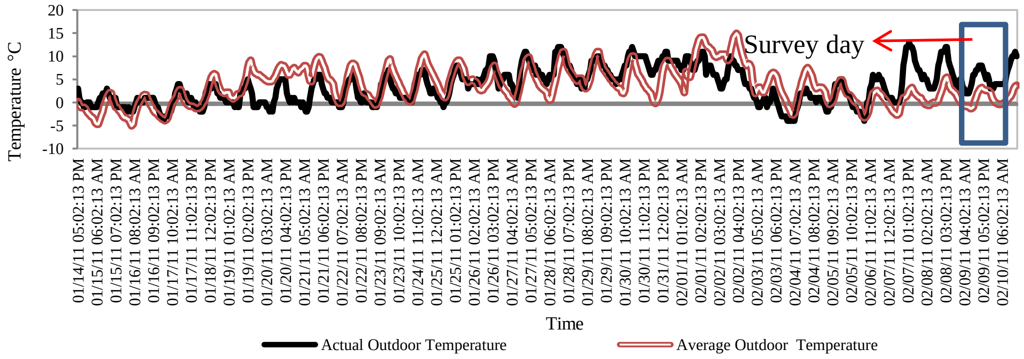


Figure 7 15: Actual and average outdoor air temperatures during winter season experiment

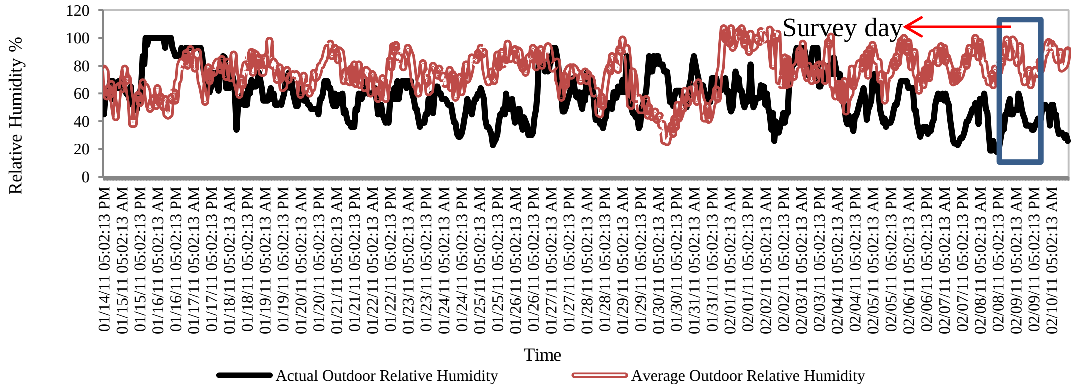


Figure 7.16: Actual and average outdoor relative humidity levels during winter season experiment

In addition, predicting indoor air temperature by employing the actual weather data file was easier than calculating the indoor relative humidity levels during the winter season, as with the spring season experiment. Moreover, the results generated by the simulation tool were more similar to the survey day measured results, as these employed to simulation modelling directly, in terms of occupancy, opening schedule and lighting, clothing and metabolic heat rate. Furthermore, the results show that the measured indoor air temperature in all classrooms had a maximum of 14% difference with the result from simulation modelling, using the actual weather data file on the survey day, but in terms of relative humidity levels the percentage difference was sometimes much higher. The prediction of relative humidity levels was much more complicated and uncertain than the air temperature as it was influenced by a larger number of factors. A possible reason for this is the number of occupants, air flow and ventilation rate, all of which have a direct influence on the levels of relative humidity.

7.5. Percentage difference in spring and winter seasons

To validate the accuracy of the simulation analysis, the results calculated by DesignBuilder were compared to the monitoring data by calculating the percentage of differences between the measurements during the teaching hours in the survey days in both seasons. The teaching hours for the spring season were from 7:30am to 12:30pm for the morning shift and from 1:30pm to 5:30pm for the afternoon shift. However, during the winter semester the school had only one shift, which ran from 7:30am to 1:30pm. As mentioned in section 7.4, average weather variables and actual weather variable files were applied to the simulation tool separately and the results compared to the field measurement results. The Percentage of Difference (PD) between the DesignBuilder measurements, using the actual (DAC) and the average (DAV) weather variables and Field Measurements (FM), for both indoor air temperatures and indoor relative humidity levels, were calculated by using the equations below:

$$PD = ((DAC - FM) / FM) \times 100 \quad \text{Eq. 7. 1}$$

$$PD = ((DAV - FM) / FM) \times 100 \quad \text{Eq. 7. 2}$$

The PD between the simulation results and monitoring results for both internal humidity levels and indoor air temperatures during the spring season survey day are shown in Tables 7.2 and 7.3. As can be seen in Table 7.2, the PD between the monitoring and simulation results for indoor air temperatures using the actual weather data was around 8.5% in Classroom 201. However, the PD using the average weather variables was also not much significant and the maximum difference was around 16.62% in classroom 205.

Table 7.2: Maximum PD between measured indoor air temperatures and simulated indoor air temperatures using actual and average weather data on survey day in spring

Classrooms	PD using actual weather data	PD using the average weather data
201	8.51%	14.25%
205	7.79%	16.62%
208	7.44%	13.80%
301	6.23%	14.78%
305	7.47%	15.77%
308	7.28%	16.48%

Table 7.3: Maximum PD between measured indoor relative humidity levels and simulated indoor relative humidity levels using actual and average weather data on survey day in spring

Classrooms	PD using actual weather data	PD using average weather data
201	29.51%	30.92%
205	32.93%	38.70%
208	23.21%	37.30%
301	21.14%	35.04%
305	21.25%	38.04%
308	23.37%	37.78%

On the other hand, the PD for indoor relative humidity between the monitoring and the simulation results using the actual and average weather data files was significantly higher than the PD of indoor air temperatures (see Table 7.3). The maximum PD using actual weather data files was around 33% in classroom 205 and around 39% using the average weather variables in the same classroom. Increasing the number of occupants results in increasing the level of humidity, as breathing produces moisture. In addition, opening and closing the openings results in varied air flow rates in the room, which have an effect on humidity levels. Tables 7.4 and 7.5 present the PD between the monitoring and the simulation results using the actual and average weather data file on the survey day and during teaching hours in the winter season experiment. It can be seen that the maximum PD between the indoor air temperature measured by the HOBO data-loggers and the predicted indoor air temperature by DesignBuilder, using the actual weather data file, was just over 13% in classroom 307. In addition, the maximum PD between field measurement results and simulation results using the average weather variables was around 24.57% in the same classroom. Generally, the PD that exists using the actual weather file is lower than that found when using the average weather variable, in terms of indoor air temperatures, which is reasonable, as the average weather data file is the mean of variables for the previous few years.

Table 7.4: Maximum PD between measured indoor air temperatures and simulated indoor air temperature using actual and average weather data on survey day in winter

Classrooms	PD using actual weather data	PD using average weather data
201	5.93%	13.31%
205	12.26%	14.99%
208	3.46%	8.39%
301	9.25%	11.02%
305	2.57%	4.56%
307	13.88%	24.57%

However, like the spring season results, the PD between the monitoring results and the simulation results using the actual and average weather data files for indoor relative humidity levels was much higher than the indoor air temperature results. The PD between the measured and predicted indoor relative humidity levels was around 32.20% in classroom 201, using the actual weather data file, and more than 70% in the same classroom using the average weather file. The possible reason could be the number of occupants and the users’ behaviour, as discussed before as well as sky condition.

Table 7. 5: Maximum PD between measured indoor relative humidity levels and simulated indoor relative humidity levels using actual and average weather data on survey day in winter

Classrooms	PD using actual weather data	PD using average weather data
201	32.20%	70.11%
205	11.37%	44.08%
208	16.88%	38.32%
301	20.34%	38.47%
305	14.46%	42.56%
307	21.16%	48.69%

However, the maximum PD between the monitoring result and the simulation result using the actual and average weather variables during the field measurement for the three and four week periods during the spring and winter seasons, respectively, was much higher than the result of the survey days, and the possible reason is users’ behaviours in indoor spaces. To get more accurate results, in terms of PD between the field measurement and the simulation result, it was decided to focus on occupancy hours during the survey days, as all the results of the survey days had been defined through simulation modelling.

7.6. Conclusion

School design in Iran has been improved considerably in recent years but the comfort of the occupants and the climatic characteristics of the building have not been considered appropriately (Iravani, 2010a). Therefore, in order to create high quality indoor environments and to increase the learning performance of students, it is necessary to evaluate the thermal condition of the classrooms in terms of the simulation tool. Studying the thermal conditions of the school building in this study shows that the greatest difference between the measurements and the simulation results caused by users’ behaviour and 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 indicated that DesignBuilder is a satisfactory simulation tool which can be used for building environmental simulation analysis. In addition, predicting indoor air temperatures, by employing the actual weather data file, is easier than calculating indoor relative humidity levels as relative humidity can easily be affected by various factors, for reasons given above. The fact that students in this case were able to manage the opening condition and able to move out of and back into the room during teaching hours could have influenced relative humidity levels during the field experiment.

Chapter 8: Simulation Analysis and Discussion

8.1. Introduction

This chapter investigates the effect of passive design strategies on indoor thermal performance of classrooms using a building thermal simulation tool, in this case DesignBuilder, as discussed in Chapter 7 in detail. The main aim is to improve the indoor thermal comfort of the classrooms with regards to the students’ thermal satisfaction and the climatic conditions of the city of Tehran using passive design strategies. The simulation analysis was carried out for two classrooms facing north and south, located on the first and second floors of the school building. In order to evaluate the building simulation tool and validate the weather data file, the simulation analysis was performed as explained in Chapter 7 for six classrooms on the first and second floors and during the spring and winter seasons. The result of analysis confirmed that DesignBuilder is a suitable building simulation tool for this study using the actual weather data file. After the confirmation of the suitability of DesignBuilder as an appropriate simulation tool, more advanced simulation analysis was carried out in two of the classrooms, which were then used as a baseline model. By applying various passive design strategies, which were reviewed in Chapter 4, the impact of orientation, solar shading devices, glazing, thermal mass and cavity external walls, as well as external wall and roof insulation, on indoor air temperature in spring and winter seasons was analysed by revising the case study building model in order to identify the optimal solution for each parameter. Following this, the optimum design solutions were defined for the case study building, by combining all the optimal design solutions for each parameter.

8.2. The layout of the simulation analysis

The aim of applying the passive design strategies to the prototype school building is to achieve thermal comfort in the classrooms with respect to the students’ thermal satisfaction and with minimum heating and cooling loads in the school building, to reduce the energy costs of the building. The simulation analysis were primarily performed during the survey days in May and February, in order to define a comfort temperature for the classrooms, based on the students’ responses to their thermal sensations and thermal preferences, as discussed in Chapter 6. The main aim of the simulation analysis is to study the effect of passive design strategies on indoor air temperatures for north- and south-facing classrooms in the typical school building in the city of Tehran, in order to establish an optimum design solution for improving the indoor thermal conditions of the secondary school building with respect to the students’ thermal satisfaction. The passive design strategies were employed individually to the case study building model in DesignBuilder, without changing the original condition of the base case, except for applying each of proposed passive design strategy separately to get more accurate results. Firstly, the orientation of the building, glazing, ventilation strategies, shading devices, thermal mass and cavity walls, as well as roof and wall insulation were considered as a series of proposed passive design strategies. Optimal design solutions were selected for each strategy and then were employed altogether to the case study building in order to establish the best design solution for the typical building by comparing the result to the base case condition in both survey days (see Figure 8.1). At the next stage, to confirm whether the proposed design solution for the survey days was an appropriate solution for the warmest and coldest periods, suggested optimum solutions were employed and analysed for the whole period of the field study in the spring (23rd April to 13th May 2010) and winter seasons (14th January to 10th February 2011). Finally, a series of design guidelines were defined for the typical secondary school building in Tehran, based on passive design strategies and with respect to students' thermal satisfaction. Figure 8.1 illustrates the modelling process of the simulation studies, using passive design strategies. An appropriate output assumption can be generated by making changes in input assumption (Input e) for each passive design strategy until achieving the optimum output result. For each stage of thermal simulation, only one input value is replaced and the remaining inputs are kept fixed. After performing the thermal simulation analysis, the predicted parameter using an input assumption (Pe) will be compared to the predicted base case value (PB) to discover whether it is acceptable or not. Otherwise, the thermal simulation will be repeated with a new value for the input parameter until the optimum parameter is achieved. This procedure will continue for each input parameter until all the output results are satisfactory. Afterwards, a new input parameter, using all of the optimum solutions (Input opts), will be applied to the thermal simulation model and the result will be compared to the predicted base case value (PB).

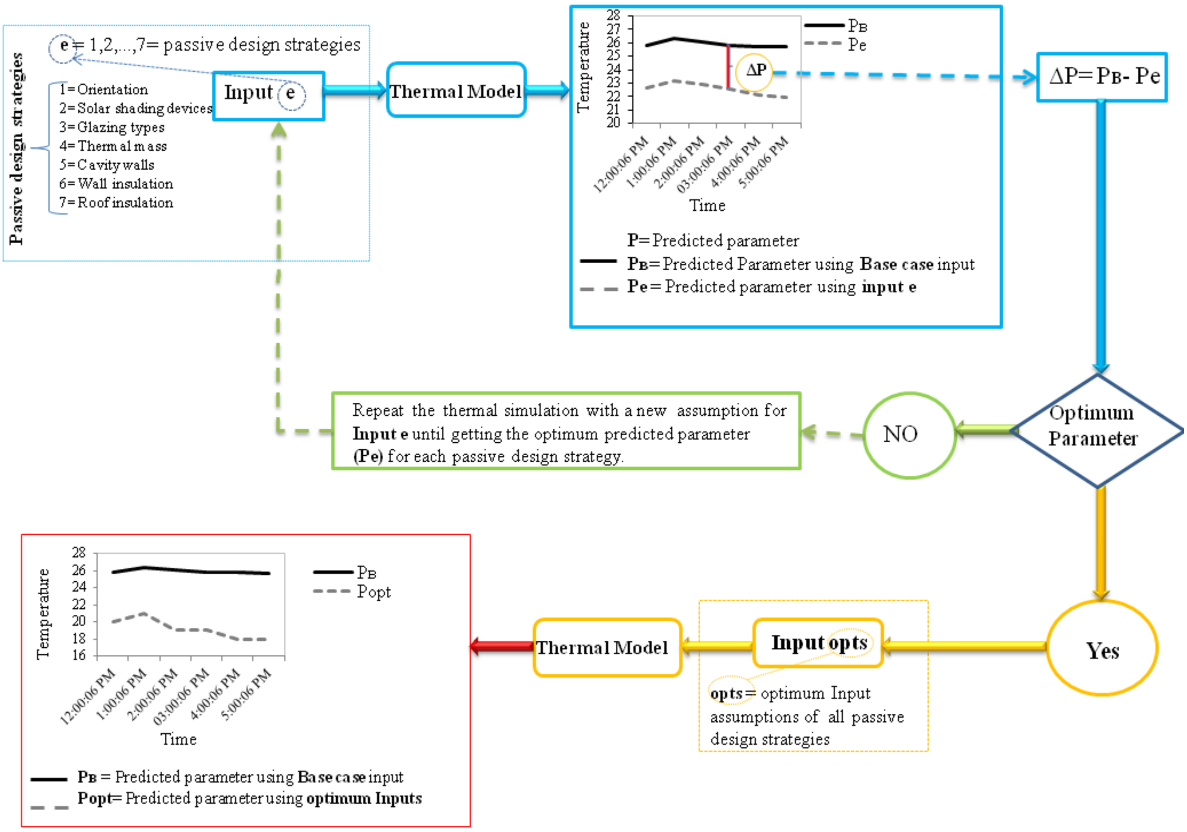


Figure 8.1: Procedure for experimental study

8.3. The case study building

The original school building is a female secondary school building in the city of Tehran. The building is a four storey building, including the basement and the ground floor, with a masonry structure, as previously discussed in Chapter 7. The offices and laboratories are located on the basement and ground floors. However, all classrooms were located on the first and second floors. The main building facades faced north and south and the long axis of the building was extended from east to west. For the simulation analysis purpose in this chapter, two classrooms were selected for indoor thermal studies that represented all classrooms facing north and all classrooms facing south. Figure 8.2 further clarifies the orientation of the selected classrooms. It should be said that the field measurements and the questionnaire based survey were conducted in these two classrooms along with another four classrooms on the same floors. As discussed in Chapter 7, the real climatic conditions obtained from the Iranian meteorological station (Irimo, 2013) were mapped on to modified weather data files from EnergyPlus, which then employed to the simulation software to get more accurate results. Figure 8.2 also illustrates the typical floor of the case study building that was used in the simulation software and also presents the simulated classrooms on the north and south faces of the building, classrooms 208 and 301.

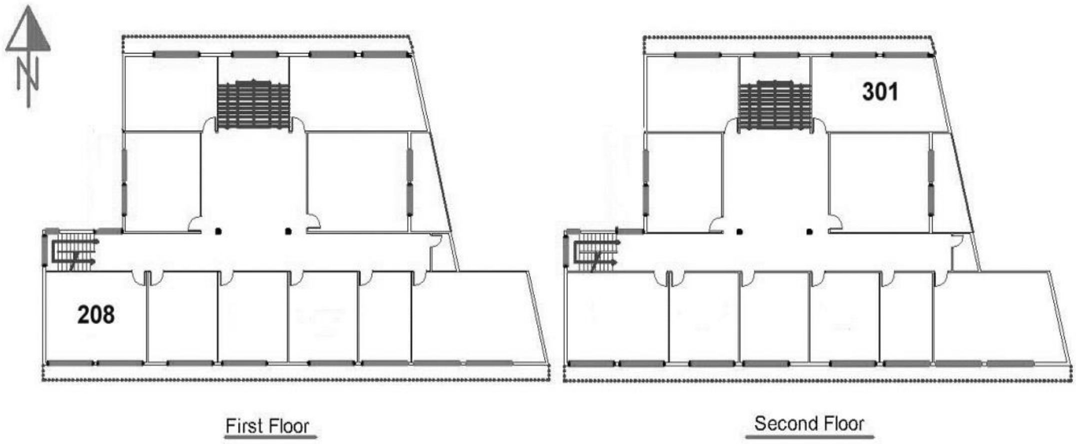


Figure 8.2: Typical floor plan of school building showing proposed selected classrooms for simulation analysis

The construction materials and thermal properties of the secondary school building are the typical building materials used for masonry buildings in Tehran. The real materials and thermal properties were employed in the simulation model in DesignBuilder in order to obtain accurate results. Table 8.1 summarises the materials of the secondary school building's components, with their U-values and thicknesses.

Table 8. 1: Materials, thickness and U-value of building components in case study school building

Components	**Materials**	**U-Value $[W/m^2K]$**
Internal Walls	Gypsum plastering (2.5 cm) Brick block (10 cm) Gypsum plastering (2.5 cm)	1.831
External Walls	Cement sand render (3 cm) Brick block (30 cm) Gypsum plastering (2.5 cm)	1.582
Internal Floor	Slate tiles (2cm) Mortar (2.5 cm) Light weight cast concrete (5cm) Gypsum plastering (1 cm)	1.342
Roof	Asphalt (3cm) Mortar (2cm) Felt/Bitumen layers (5 cm) Screed (10 cm) Thermal insulation(Glass wool) (5 cm) Cast concrete (5 cm) Clay Tile (25 cm) Gypsum plastering and render(1 cm)	0.575
External Windows	Clear single glaze (6 mm)	5.778

Table 8.2 presents the proposed schedules for occupancy, ventilation and heating systems of the case study building, based on the real schedules of the school building.

Table 8.2 : Building operation schedules of base case building model

Building operation	**Schedules**	
	Spring	**Winter**
Natural ventilation	On (7:00am-9:00pm)	Off
Heating system	Off	On (all day)
Occupancy period	7:30am-12:30pm/ 1:30pm-5:30pm	7:30am/12:30pm

According to the original school building timetable, the school had two shifts during the spring semester and one during the winter semester of the following academic year, when the field study experiments were conducted. The morning shift was from 7:30am to 12:30pm and the afternoon shift was from 1:30pm till 5:30pm. In addition, the windows were opened in all classrooms from 7:00am and were closed after the cleaning up period at around 9:00pm in the spring season. It should be mentioned that the heating system was turned on all-day during the cold period.

8.4. Selected classrooms for the simulation

As previously mentioned for the simulation analysis purpose, two classrooms have been selected from the case study building out of the overall six monitored classrooms. The thermal climatic variables were measured in both classrooms and all the students in those classrooms filled out the questionnaire survey in both seasons. Classroom 208 and Classroom 301 were selected as the case study classrooms, which are located on the first and second floors, respectively. Classroom 208 faces south and classroom 301 faces north. Both classrooms had the largest number of students during the field studies in both seasons compared to the other monitored classrooms (see Table 8.3). The mean indoor air temperature in both classrooms in the spring season was around 23°C, which is very similar to the overall mean indoor air temperature, as discussed in Chapter 5.

During the winter season, the classrooms were heated by hot water radiators, which are manually adjustable; this resulted in different mean indoor temperatures in each classroom. Classroom 208 was around 23°C and 301 showed an average temperature of around 26°C. Further to this, the average temperature in all classrooms was around 23°C on the day that the survey was carried out. Coincidently this is just under the average indoor temperature in the spring season, which was 24°C. It should be stated that the simulation analysis was performed in similar classrooms in both seasons for the purpose of comparison. Based on the validation analysis in Chapter 7, it was found that Classroom 208 was poorly constructed, with a high infiltration rate, whereas Classroom 301 was classified as a good construction. This proves that construction quality and material had an effect on the indoor air temperatures in both classrooms.

Table 8.3: Summary of selected classrooms for simulation analysis

Classroom	**208**		**301**	
Seasons	Spring	Winter	Spring	Winter
Number of the Students	24	23	23	21

8.5. Comfort temperature in the case study building

In order to identify the indoor comfort temperature (Tc) or neutral temperature (Tn) in the case study school building and to predict the initial comfort temperature ranges in the secondary school building in Tehran, the following equation was used, based on Heidari's (2010) predictions with regards to all residential and office buildings, with varied heating and cooling systems and with respect to the religion and culture. Tmo is the monthly mean outdoor temperature.

$$T\boldsymbol{c}=17.80+0.30\ T\boldsymbol{mo} \quad \text{(Heidari, 2010)} \qquad \text{Eq. 8. 1}$$

Equation 8.1 was identified by Heidari (Heidari, 2010), based on a decade of thermal comfort field studies on Iranian people in fifteen cities and in four various climatic regions of Iran. In this study people were free to adjust the indoor condition to make themselves comfortable. This study showed that the occupants were able to tolerate a wide range of temperatures, covering more than 14K in the hot season and 7K in the cool season. The findings show that people can obtain comfort at higher indoor air temperatures compared to previous international standard recommendations. Also, there is a strong relationship between clothing insulation and indoor air temperature. For instance, a lower temperature results in more clothing insulation.

In addition, Iranian people can achieve comfort at more than 30°C in the hot period and less than 20°C in the cool season (Heidari, 2010). He also cited that, in the hot and dry climate of Iran, people can make themselves comfortable between 16.5°C and 22°C in the cold season and between 28°C and 34°C in hot seasons, by adjusting their clothes, activity and air velocity (Heidari, 2010). However, based on ASHRAE Standard 55 (2004), the thermal comfort boundaries were defined for 90% of the occupants' acceptance at 5K (2,5°C on either side of the neutral temperature) and for 80% of the occupants' acceptance at 7K (3.5°C on either side of the neutral temperature) in a free-running building. On the other hand, Nicol and Humphreys (2001), state that the range of acceptable conditions at any one time is in the region of ±2K if they have no control of the condition, in order to make themselves comfortable. However, giving free control over the conditions will increase this range.

The Heidari's (2010) equation 8.1 is very close to Auliciems' (1986) equation (Eq. 8.2), which is for all buildings and depends on the relationship between comfort temperature and outdoor mean temperature. The comfort temperature is related to the outdoor mean monthly temperature for $5°C<Tmo<30°C$:

$$T\boldsymbol{n}= 17.6+0.31 \text{ Tm outside} \qquad \text{Eq. 8. 2}$$

In this research, Heidari's equation (Eq. 8.1) has been used to define comfort temperature in the classrooms and the initial comfort temperature boundaries is based on his finding (Heidari, 2010), which covers more than 14K in the hot season and 7K in the cool season. The appropriate thermal comfort temperatures will be discussed later in section 8.7, based on the analysis of the thermal simulation and survey results.

8.6. The application of passive strategies

Passive design strategies including orientation, glazing and shading devices, insulation materials as well as thermal mass were employed in the prototype school building separately. The simulation analysis was performed on classrooms 208 and 301 during the survey days on 4th May 2010 and 9th February 2011. Classroom 208 was located on the first floor, facing south, and Classroom 301 on the second floor, facing north. The main aim of selecting these two classrooms was to analyse the effect of passive strategies on indoor air temperatures in various floors and different directions. In addition, the simulation analysis was conducted in both classrooms for an extended period, which covers the whole period of the field experiment in both seasons to identify if the result of the analysis on the survey days was similar during the extended period.

8.6.1. Orientation

Building orientation can affect the needs for mechanical energy systems in the buildings. An appropriate building orientation can decrease the use of mechanical heating and cooling systems and, as a result, reduce the energy bills of the building. It is important to consider the connection between the geographical features of the site and the building itself in order to create an accurate passive building (Light House Sustainable Building Centre and Guido, 2009). Building orientation has an impact on the heat gains of the building, as a result of the variety of solar radiation at different angles (Givoni, 1998a). To analyse the impact of the orientation on the indoor environment of the case study school building, a simulation analysis have been performed on the various directions. The eight main directions (N, NW, W, SW, S, SE, E and NE) have been considered for the prototype school building, from 0 ° to 315 ° (see Figure 8.3). It should be mentioned that the base case main facade is oriented south/north.

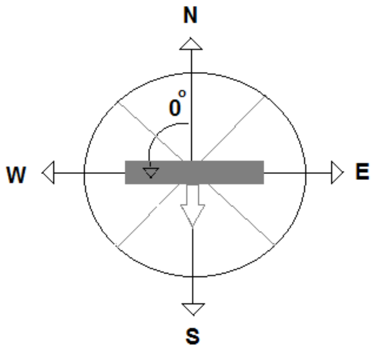


Figure 8.3 : Orientation experiment of case study building in simulation tool

The building was rotated anti-clockwise for eight primary directions, starting with 0° in the North. Figures 8.4 and 8.5 show the hourly variations in indoor air temperatures in classrooms 208 and 301, based on the eight main geographic directions on the 4th May 2010 and 9th February 2011, when the questionnaire surveys were carried out.

Figure 8.4 shows the hourly indoor air temperature in classroom 208 and 301 on the 4th May 2010. It can be seen that the indoor air temperature was in the highest range when the south facade faced west and south-west respectively in Classroom 208 but when the facade faced north and north-east, the indoor air temperature dropped, compared to the other side. However, the indoor air temperature in Classroom 301 was increased in all directions. This is because the main facade of the classroom faced north in the base case and it received the minimum solar radiation, compared to the other directions.

On the other hand, the result of the simulation study in both classrooms during the winter season shows that the indoor air temperature decreased in any direction in Classroom 208 but it increased in Classroom 301 as the building was rotated anti-clockwise, based on the direction of the base case (see Figure 8.5).

Figures 8.4 and 8.5 confirm that the south-west and west directions caused maximum indoor air temperatures, and the north direction resulted in minimum indoor air temperatures.

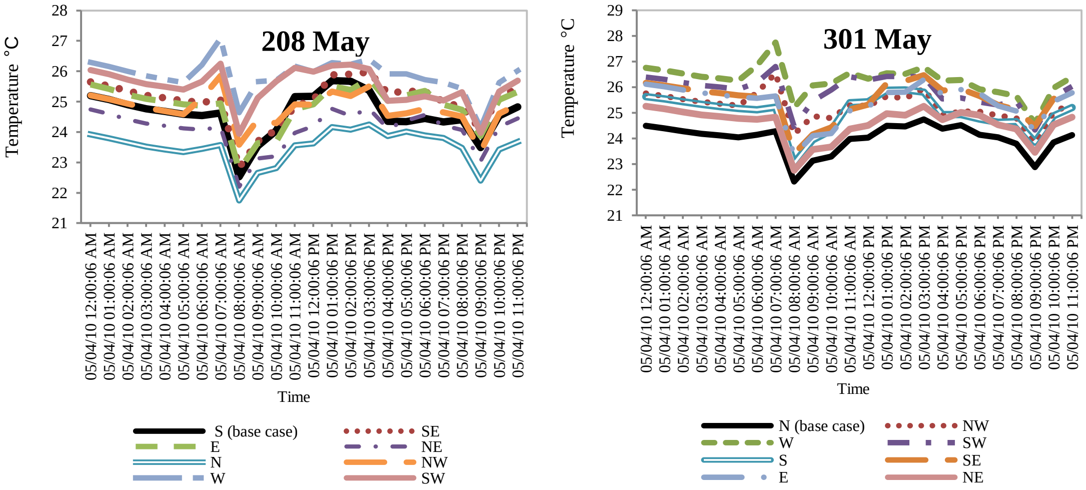


Figure 8.4: Indoor temperature profile for eight primary directions in classrooms 208 and 301 on 4th May 2010

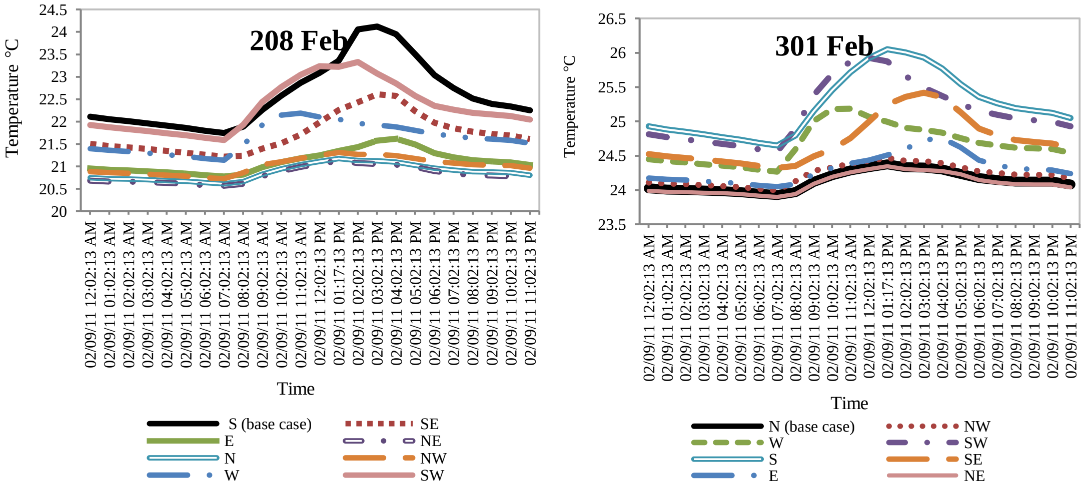


Figure 8.5: Indoor temperature profile for eight primary directions in classrooms 208 and 301 on 9th Feb 2011

Based on Kasmai (2008), the southern walls gain direct solar radiation for around 8 hours a day in summer and 10 hours a day in winter in the city of Tehran at 35° N latitude. However, the northern walls receive no solar radiation in the winter season but gets at least 6 hours of sunlight a day during the summer period. The east and west walls gain the maximum amount of solar radiation in summer, at least 7 hours a day, but this amount reduces considerably in the winter season and to around 4 hours a day of sunshine.

It should be mentioned that, in this study, the indoor air temperature was highest in south-facing classrooms in winter but in the spring period the west and south west directions caused maximum indoor air temperatures. This is because the southern walls received considerable amounts of sunlight in summer, after the east- and west-facing walls, but it received the maximum amount in winter, based on Kasmai's study (Kasmai, 2008). The comparison of indoor air temperature variations in the spring and winter seasons in all directions shows that, when the classrooms faced west, east or south, the indoor air temperature increased, especially in warm spring period. However, when it faced north, it had the minimum internal air temperature, either in warm or cold seasons, compared to the other directions.

Moreover, the maximum and the minimum indoor air temperature in both seasons' experiments (4th May 2010 and 9th February 2011) are presented in Tables 8.4 and 8.5 in all directions, including the base case. It can be seen that the minimum indoor air temperatures were in northerly and north-easterly directions in both classrooms, in both seasons. The maximum indoor air temperatures were in the westerly and south-westerly directions in both classrooms in the spring season. However, during the winter season, the south and south west directions had the maximum indoor air temperatures in both classroom experiments, which confirms Kasmai's study (Kasmai, 2008) regarding having maximum solar radiation in a southerly direction in winter and in a westerly direction in the warm season.

Table 8.4: Maximum and minimum indoor air temperatures in various primary directions for Classroom 208 on 4th May 2010 and 9th February 2011

Directions		**North**	**North East**	**East**	**South East**	**South (Base case)**	**South West**	**West**	**North West**
4thMay	Max °C	24.6	24.8	25.7	26	25.7	26.3	27.1	25.9
	Min °C	21.7	22.2	22.7	22.8	22.5	23.9	24.1	23.4
9th Feb	Max °C	21.2	21.1	21.6	22.6	24.1	23.3	22.2	21.3
	Min °C	20.6	20.6	20.8	21.2	21.7	21.6	21.1	20.7

Table 8. 5: Maximum and minimum indoor air temperatures in various primary directions for Classroom 301 on 4th May 2010 and 9th February 2011

Directions		**North (Base case)**	**North East**	**East**	**South East**	**South**	**South West**	**West**	**North West**
4th May	Max °C	24.7	25.3	26.3	26.5	25.9	26.8	27.7	26.5
	Min °C	22.3	22.8	23.4	23.4	23	24.3	24.6	23.8
9th Feb	Max °C	24.4	24.6	24.8	25.4	26.1	25.9	25.2	24.5
	Min °C	23.9	23.9	24.1	24.3	24.7	24.7	24.3	24

Moreover, the simulation analysis was conducted for all periods of the field experiment by applying the orientation strategy to the case study school building in both classrooms to identify if the simulation analysis result on the survey days was similar to the extended periods of the study. Figures 8.6 and 8.7 illustrate indoor air temperatures over this extended period and in various geographic directions in classrooms 208 and 301 during the monitoring period in warm and cold seasons. It can be seen that the result of the whole periods in both seasons was usually similar to the result of the survey days in May and February. The maximum indoor air temperature was usually in W and SW directions in the warm period in both classrooms but it was in S and SW directions in the winter period.

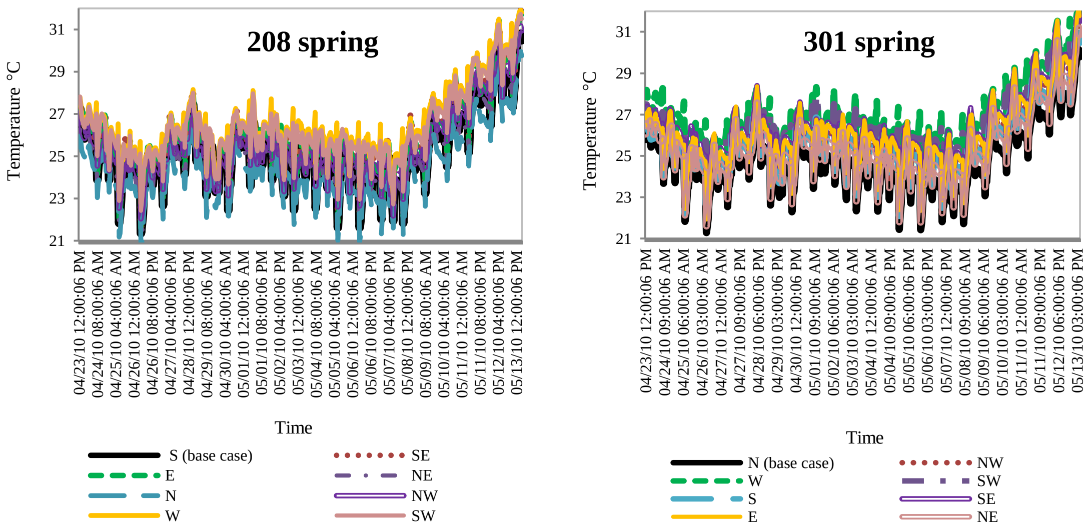


Figure 8.6: Indoor temperature profile for eight primary directions in classrooms 208 and 301 in April/May 2010

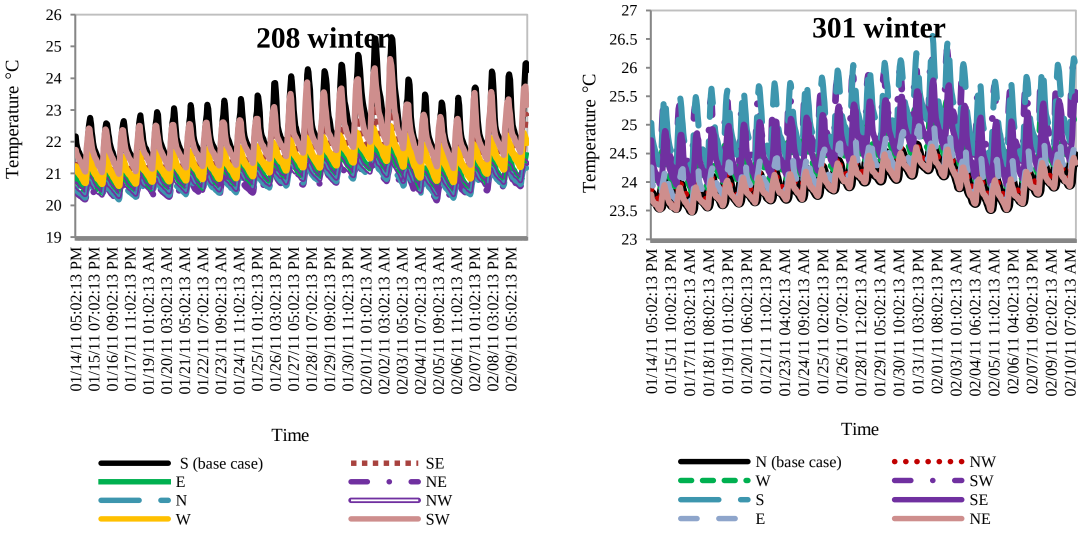


Figure 8.7: Indoor temperature profile for eight primary directions in classrooms 208 and 301 in Jan/Feb 2011

In addition, Tables 8.6 and 8.7 present the maximum and minimum indoor air temperatures in both classrooms and in both seasons. Similar to the survey day results, the minimum indoor air temperatures were in northerly or north-easterly directions in both seasons. The maximum indoor air temperatures were in a southerly and south-westerly direction in winter similar to the survey day results. However, during the spring period the maximum indoor air temperatures were in east- and west-facing classrooms, after the south-west direction.

Table 8.6: Maximum and minimum indoor air temperatures in various primary directions for Classroom 208 on April/May 2010 and January/ February 2011

Directions		North	North East	East	South East	South (Base case)	South West	West	North West
April/May	Max °C	30	31.1	32.1	31.9	30.8	31.7	31.9	31.2
	Min °C	20.9	21	21.5	21.6	21.4	22.4	22.8	22
Jan/Feb	Max °C	21.4	21.4	21.9	23.6	25.3	24.6	22.5	21.6
	Min °C	20.2	20.1	20.3	20.7	21.1	21	20.6	20.3

Table 8.7: Maximum and minimum indoor air temperatures in various primary directions for Classroom 301 on April/ May 2010 and January/ February 2011

Directions		North (Base case)	North East	East	South East	South	South West	West	North West
April/ May	Max °C	30.1	31.2	32.2	32	30.9	31.7	32	31.3
	Min °C	21.3	21.6	21.9	22.1	21.8	22.8	23.4	22.5
Jan/Feb	Max °C	24.6	24.6	25	25.8	26.6	26.3	25.4	24.7
	Min °C	23.5	23.5	23.6	23.9	24.2	24.1	23.8	23.6

8.6.2. Glazing (Heat gains and heat losses of windows)

Improving the insulation of windows has a significant impact on heating in buildings but it has no effect on cooling. To reduce the heating demands of a building, it is suggested that the U-value of the glazing area should be decreased (Ford et al., 2007). The thermal characteristics of the glazing area are an important part of the window design, which has a considerable effect on thermal performance of indoor spaces. Thermal characteristics include U-values and insulation of the windows, the framing type and the overall area of the windows (Mikler et al., 2009). To improve the thermal insulation performance of the glazing area, it is suggested that the number of panes should be increased, up to triple glazing, which results in reducing the U-value of the windows, as well as decreasing heating during the warm season (Ford et al., 2007). The effect of the windows on the indoor air temperature was investigated by applying various glazing types to the windows, such as double glazed and triple glazed windows. Figures 8.8 and 8.9 show the impact of various glazing type on indoor air temperature. The actual glazing type for the given building was a 6 mm single glazing clear window. Two various double glazing windows were selected for the simulation analysis. The first double glazing type was a window with 3 mm and 6 mm panes and the air as a window gas material between two panes. The next double glazing window had 6 mm and 13 mm panes with air as a gas between them. The last glazing type was triple glazing windows with 3 mm and 13 mm panes with air as a gas material.

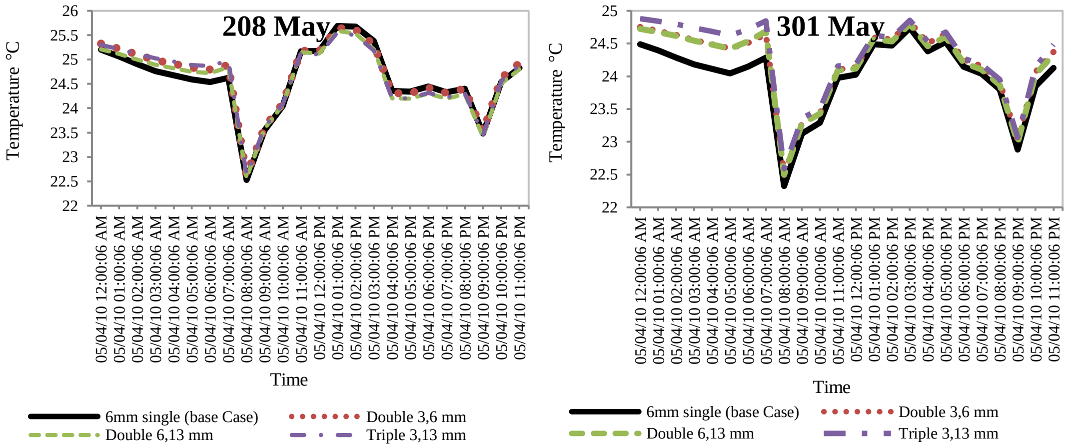


Figure 8.8: Indoor temperature profile for various glazing type in classrooms 208 and 301 on 4th May 2010

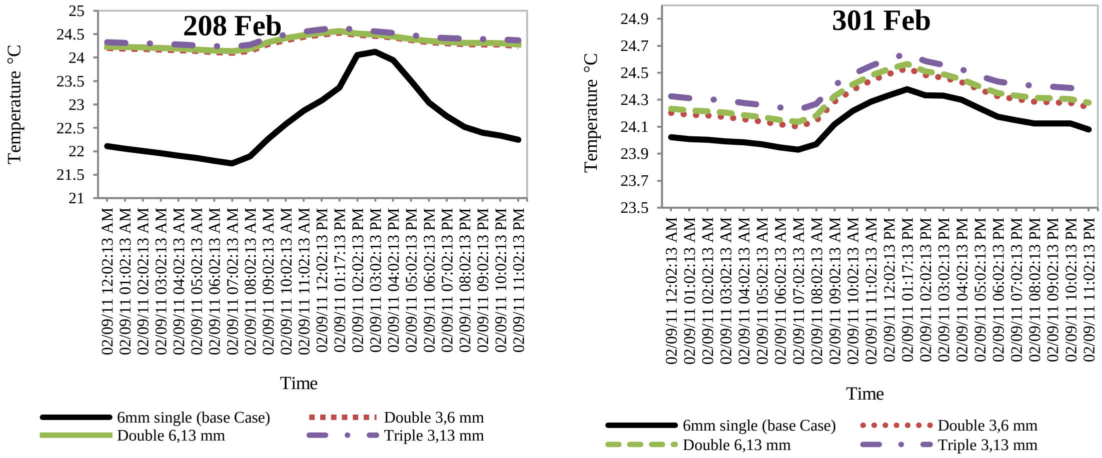


Figure 8. 9 : Indoor temperature profile for various glazing types in classrooms 208 and 301 on 9th Feb 2011

As can be seen in Figures 8.8 and 8.9, using double and triple glazing windows had almost no effect during 4th May 2010 on north- and south-facing classrooms, except when the windows were closed in Classroom 301 during the unoccupied period before 7:00am. However, during the cold winter day, the use of double and triple glazing had a considerable effect on the indoor air temperatures. In Classroom 208 the indoor air temperatures increased up to a maximum of 2.5°C during the winter season. However, in midday it had only increased by about 0.5°C. A possible explanation for this is the existence of solar radiation at midday in south-facing classrooms, which increased the indoor air temperature. In addition, the internal air temperature in Classroom 301 increased less than in Classroom 208, only rising by around 0.5°C maximum. However, the temperature increase in Classroom 301 during the survey day in winter was more constant than in Classroom 208. A possible explanation for this may be poor construction and poor airtightness level in Classroom 208, as well as the effect of solar radiation on increasing the temperature on south-facing classrooms. As can be seen in Figures 8.8 and 8.9, using double glazing and triple glazing windows have almost the same effect on indoor air temperature in both seasons.

Tables 8.8 and 8.9 present the maximum and minimum indoor air temperatures in classrooms 208 and 301 during the survey days, in the spring and winter seasons. It can be seen that applying triple glazing caused the maximum indoor air temperature in both seasons and in both classrooms. However, single glazed windows resulted in having minimum indoor air temperatures in both classrooms and in both seasons.

Table 8 8: Maximum and minimum indoor air temperature with various glazing types for Classroom 208 on 4th May 2010 and 9th February 2011

Glazing Type		Single 6mm (base case)	Double 3,6 air	Double 6,13 air	Triple 3,13 air
4th May	Max °C	25.6	25.7	25.6	25.7
	Min °C	22.5	22.6	22.6	22.6
9th Feb	Max °C	24.1	24.5	24.6	24.6
	Min °C	21.7	24.1	24.1	24.2

Table 8.9: Maximum and minimum indoor air temperature with various glazing types for Classroom 301 on 4th May 2010 and 9th February 2011

Glazing Type		Single 6mm (base case)	Double 3,6 air	Double 6,13 air	Triple 3,13 air
4th May	Max °C	24.7	24.8	24.8	24.9
	Min °C	22.3	22.5	22.5	22.6
9th Feb	Max °C	24.4	24.5	24.6	24.6
	Min °C	23.9	24.1	24.1	24.2

Figures 8.10 and 8.11 illustrate the effect of glazing type on indoor air temperatures during the whole period of the field studies. It can be seen that this impact is similar to that found in the field experiment periods in both seasons. Indoor air temperature saw no significant change in south and north-facing classrooms during the spring period.

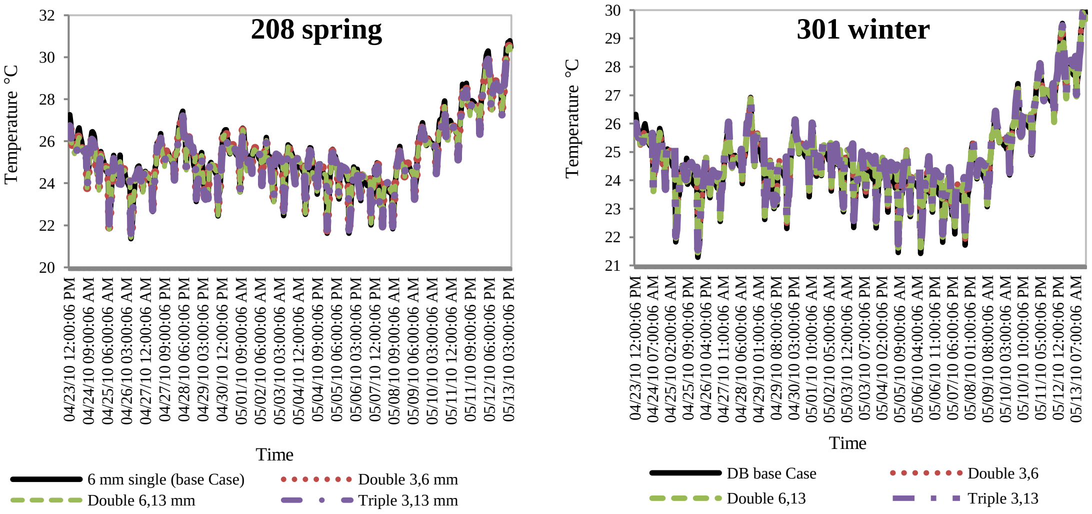


Figure 8.10: Indoor temperature profile for various glazing types in classrooms 208 and 301 in April/May 2010

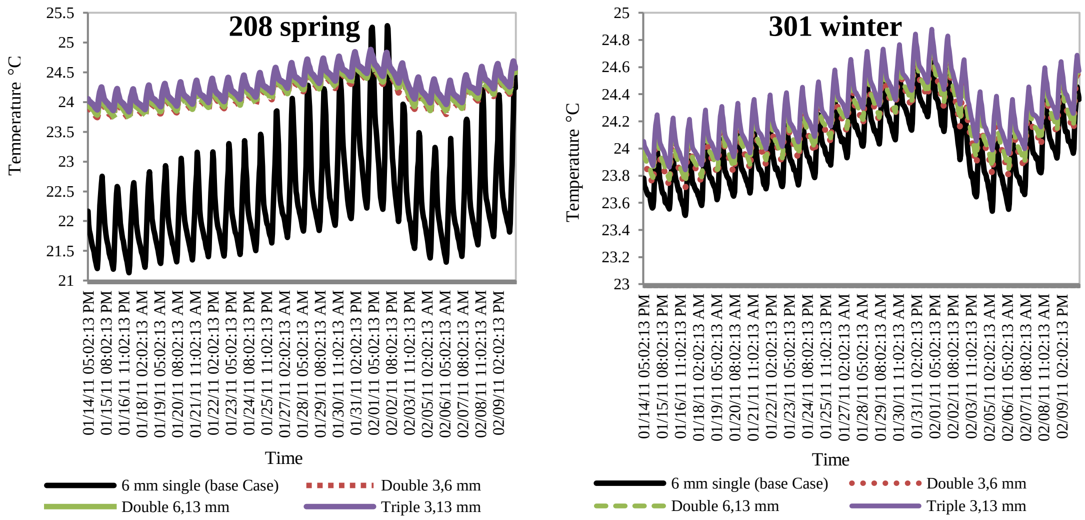


Figure 8. 11 : Indoor temperature profile for various glazing types in classrooms 208 and 301 in Jan/Feb 2011

However, during the winter season study, the indoor air temperature in both classrooms increased when double and triple glazing was used in windows but the result was much more significant in classroom 208 than 301. A possible explanation for this is the poor construction of Classroom 208. Tables 8.10 and 8.11 present the maximum and minimum indoor air temperature in both classrooms during the warm and cold seasons experiment, after employing the different glazing types to the case study school building. It can be seen that, similar to the survey days experiment, employing the triple glazed windows resulted in the maximum indoor air temperature in warm and cold seasons. However, single glazed windows caused the minimum indoor air temperatures in both seasons in classrooms 208 and 301.

Table 8.10: Maximum and minimum indoor air temperature with various glazing types for Classroom 208 on April/May 2010 and January/ February 2011

Glazing Type		**Single 6mm (base case)**	**Double 3,6 air**	**Double 6,3 air**	**Triple 3,13 air**
April/May	Max °C	30.5	30.7	30.5	30.8
	Min °C	21.4	21.5	21.4	21.5
Jan/Feb	Max °C	24.9	24.8	24.8	25.3
	Min °C	21.1	23.7	23.8	23.8

Table 8.11: Maximum and minimum indoor air temperature with various glazing types for Classroom 301 on April/ May 2010 and January/ February 2011

Glazing Type		**Single 6mm (base case)**	**Double 3,6 air**	**Double 6,3 air**	**Triple 3,13 air**
April/ May	Max °C	30.1	30.1	30	30.1
	Min °C	21.3	21.4	21.5	21.6
Jan/Feb	Max °C	24.6	24.8	24.8	24.9
	Min °C	23.5	23.7	23.8	23.8

8.6.3. Shading devices

The main purpose of using shading devices is to prevent direct solar radiation reaching external walls. There are various kinds of shading: shading of the building over itself; shading of near obstacles, such as overhangs; fins and blinds; as well as shading of surrounding buildings and far obstacles (Ford et al., 2007). In this study, the effect of near obstacle shading on the indoor environment was examined. Five various types of shading devices were examined, including vertical overhangs with different lengths, a combination of side fins and overhangs, as well as window blinds. The aim is to find the best strategies for decreasing indoor air temperatures during the warm period while making the most of solar radiation during the winter season.

- **Sizing of overhangs and fins**

To find the starting dimensions for a shading devices' shadow, including overhangs and fins, the following equation have been used, based on a range of literature (Kasmai, 2008, O'Connor et al., 1997):

For Overhangs: $$\boldsymbol{H = \frac{D * \tan A}{\cos\,(Z - N)}} \qquad \text{Eq. 8. 3}$$

For Fins: $$\boldsymbol{W = D * \tan\,(Z - N)} \qquad \text{Eq. 8. 4}$$

Where H is the depth of the overhang's shadow on the window and W is the depth of the side fin's shadow over the window. Moreover, D stands for shading device projection and A is the angle of the shadow, which describes the length of shadow on the wall. In addition, Z is the solar azimuth and N the window azimuth. Figure 8.12 presents the geometry and components for vertical and horizontal shading devices. The initially proposed lengths for the overhangs and fins (see Table 8.12) are based on Iranian national building energy regulations (Ministry of Housing and Urban Development, 2009).

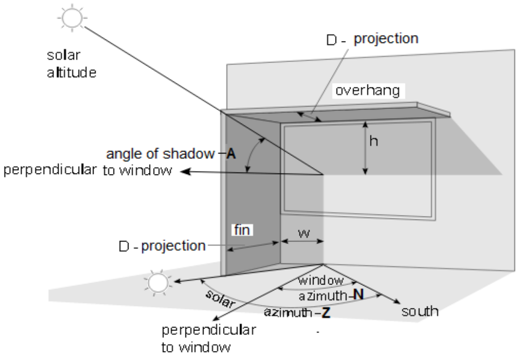


Figure 8.12: Geometry and components of shading devices (O'Connor et al., 1997)

Table 8.12 summarised the proposed shadow angles for overhangs and fins for windows facing in various directions in the city of Tehran, with the latitude of 35° 41'.

Table 8.12: Suggested shadow angle of shading devices for windows facing various direction in Tehran (Ministry of Housing and Urban Development, 2009)

Windows Direction	**S**	**N**	**E**	**W**	**30° NE**	**60° NE**	**30° SE**	**60° SE**	**30° NW**	**60° NW**	**30° SW**	**60° SW**
Horizontal Shading	60°	-	50°	-	70°	55°	60°	55°	-	-	50°	-
Vertical Shading	-	75° west	-	Movable shadings	60° east	35° east	-	-	45° west	Movable shadings	30° west	Movable shadings

According to Kasmai (2008), during the hottest period, the maximum energy of the sun radiated on the south-facing walls is around 12:00pm. However, it is at 6:30am and 5:30pm in summer for north-facing walls, and there is no radiation during the winter in this direction. Considering that the school would close for final exams in May, 12:00pm in May was chosen as the appropriate solar azimuth to calculate the projection of shading devices based on the suggestion of Kasmai (2008), stated below:

$$\boldsymbol{D} = \frac{\boldsymbol{H} * \boldsymbol{cos}\,(\boldsymbol{Z}-\boldsymbol{N})}{\boldsymbol{tan}\,\boldsymbol{A}} \qquad \text{Eq. 8. 5}$$

Based on the information in Table 8.12 and using Equations 8.5, it was decided to choose the initial length of 30 cm for the vertical and horizontal projections, which creates a shadow over the whole window in warmest period. Although Iranian building regulations (2009) suggest not using any horizontal shading devices on the north side of buildings in Tehran, in this study both vertical and horizontal shading devices were used for comparing their effect on indoor air temperatures. As the building's main axis lay in an east-to-west direction, and the main facade faced south, the angle of the window azimuth was 0°. The window azimuth is the angle between the perpendicular to the window and the real south (Ministry of Housing and Urban Development, 2009). Table 8.13 summarises the proposed design strategies for shading devices and the length of the projections for each strategy in a base case building, as well as the blind dimensions. Each strategy was added to the base case model in DesignBuilder separately and the effect on indoor air temperature was compared afterwards.

Table 8. 13: Types of shading devices used in the simulation analysis and their dimensions

Shading device type	**Size of projection and blind**
Overhangs	30 cm
Overhangs	60cm
Overhangs and side fins	30cm and 30cm
Overhangs and side fins	60cm and 60cm
Inside Blinds-Medium slate	Cover whole window (100*70 cm^2)

As discussed above, various design strategies for shading devices were employed in the simulation model in order to examine the indoor air temperature variations during the warm and cold seasons, which included the survey days. The primary suggestion for choosing the type and size of shading devices was based on Iranian building regulations (Ministry of Housing and Urban Development, 2009).

However, various dimensions for overhangs and side fins were employed to the base case model for comparison. In addition, although these regulations suggested not to use side fins in south-facing windows or overhangs in north-facing windows, in this study both shading devices types were employed in both classrooms to compare their effect on internal air temperatures. Later, the optimum solution will be selected, based on the simulation result.

- **Overhangs**

The primary projection depth for overhangs is 60 cm for south-facing windows, based on Iranian building regulations. However, an additional length was considered, in order to compare the difference between impacts on internal temperatures. The additional length for the overhangs was 30 cm depth, half the dimension suggested by the regulations. The vertical offset of the overhangs from the top of the windows was zero, as suggested by Iranian building regulations (2009) and the width of overhangs was equal to the window's width. Although Iranian building regulations suggest not to use overhangs for north-facing windows (see Table 8.12), in this study a similar sized overhang and side fins were employed, as for south-facing windows in northern windows during the warm and cold seasons, in order to compare the impact of each strategy on internal temperature.

- **Combinations of side fins and overhangs**

The initial depth considered for the side fins was based on Iranian building regulations, which is 30 cm for north-facing windows west of the opening (see Table 8.12). However, it was decided to use side fins in both north- and south-facing windows, in order to examine the results. Moreover, an additional depth, double the initial one, of 60 cm, was used, in order to compare their effect on indoor air temperatures. The offset of the side fins from right and left of the windows were zero and the height of the fins were equal to the window's height, based on Iranian building regulations. The side fins were employed in the openings along with the overhangs in north- and south-facing classrooms.

- **Window blinds**

Although Iranian building regulations does not suggest using window blinds as shading devices, in this study a blind with a medium slate was employed inside the windows to examine the effect of it on indoor air temperatures. As the survey result showed in Chapter 6, no curtain was employed in most of the classrooms. Even if a curtain was available, they were never used; so it was decided to examine the effect of the blinds on indoor air temperatures, especially in the warm season.

- **Result of the analysis**

As discussed before in this section, a range of shading devices with various dimensions were employed in the base case model, including overhangs and blinds, as well as a combination of overhangs and side fins, in order to analyse the effect of them on indoor air temperature. Figures 8.13 and 8.14 show the hourly variations on indoor air temperature by which resulted from applying various shading devices in classrooms 208 and 301 on 4th May 2010 and 9th February 201, when the questionnaire survey was carried out. As can be seen in Figure 8.13 to 8.14, employing 30 cm overhangs and side fins together at the openings reduced the indoor air temperature in both classrooms on 4th May 2010. The indoor air temperature in Classroom 208 was reduced by a maximum of 2.5°C but in Classroom 301 it only dropped by around 0.5°C maximum.

Moreover, employing 30 cm overhangs reduced the indoor temperatures as well, but the effect of overhangs on indoor air temperatures is less than the when it used in combination with side fins. The indoor air temperatures were reduced by a maximum 2°C in the south-facing classroom, while in the north-facing classroom, it only dropped by approximately 0.3°C. It was expected that applying deeper overhangs and side fins would result in lower temperature, as the external walls around the shading devices received less solar radiation, but the result shows almost no effect when applying the 60 cm overhangs and side fins, compared to using the 30 cm overhangs and side fins (figure 8.13 and 8.14). The same result was found for 30 cm overhangs against 60 cm ones. A possible reason is the solar altitude in the periods of April/May and January/February. In April/May this is between 62° and 73° and in January/February it is between 33° and 39° (Kasmai, 2008). In addition, using a medium slate blind inside the windows also helped to reduce indoor air temperatures, as it prevented the sun's radiation reaching the room. However, the effect of this type of shading device is less than that of overhangs and side fins, and the combination of both, but it can be used as an additional item to be used when it is needed.

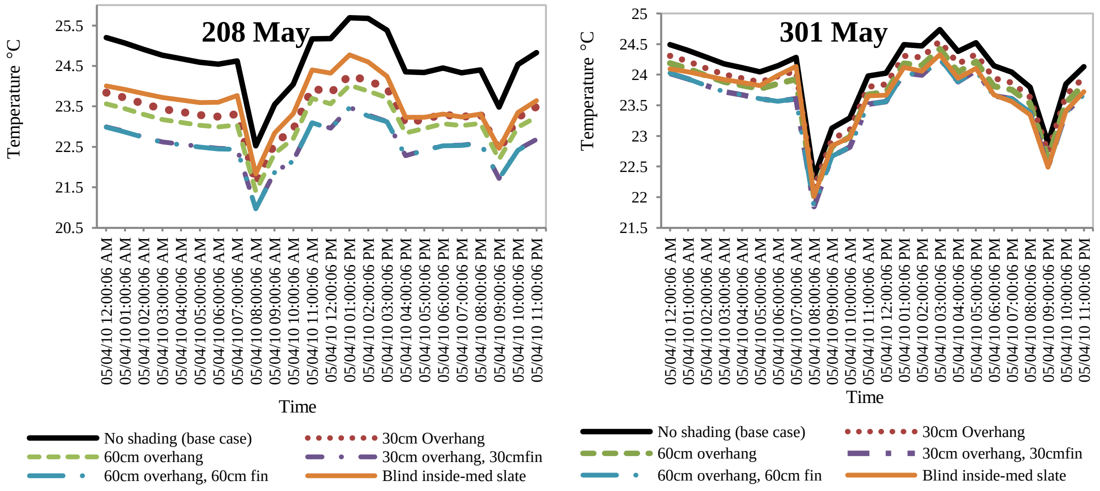


Figure 8. 13: Indoor temperature profile with different shading devices in classrooms 208 and 301 on 4th May 2010

Moreover, it was expected that the indoor air temperature with all combinations of shading devices between sunset and sunrise would be equal to the base case result, as the sun is absent during this period, but it can be seen that the indoor air temperatures were lowered all day in both classrooms through the use of various shading devices. A possible reason might be the effect of the thermal mass of the wall, which was 30 cm brick. As the shading devices prevented the sun reaching some part of the windows and interior spaces, as well as the surrounding external walls, the amount of energy which was released during the night decreased and, as a result, the indoor air temperature was lower than expected.

However, the result of the study on the cold winter day was different. The indoor air temperature were decreased with the use all combinations of shading devices. However, they had a small effect on indoor air temperatures on 9th February 2011, especially on the north-facing classroom, as there was no solar radiation in that room in winter. Using all combinations of shading devices had no effect on indoor air temperatures in Classroom 301, except medium slate blinds which increased the indoor air temperature by up to 0.3°C. A possible explanation for this might be increased airtightness levels in Classroom 301. However, the indoor air temperature in south-facing side classroom decreased by the application of any shading devices including internal blind. As the shading devices prevent the sun reaches to some part of the external walls, including windows, it resulted in decreasing the air temperatures during the cold winter day. In addition, internal blinds caused another drop in indoor air temperatures, compared to the other shading devices, as it restricted the solar radiation from reaching the indoor space. The indoor air temperature decreased by about 1.5°C maximum during the afternoon period after applying all combinations of side fins and overhangs, as well as internal blinds.

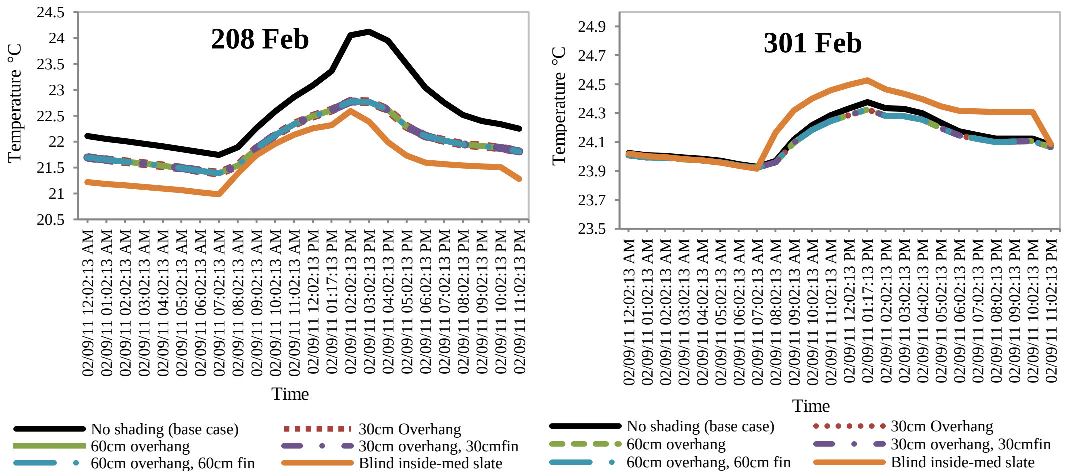


Figure 8.14: Indoor temperature profile with different shading devices in classrooms 208 and 301on 9th Feb 2011

Tables 8.14 and 8.15 present the maximum and minimum indoor air temperature, after employing various shading devices to the base case building on the survey days in May and February. It can be seen that the indoor air temperature is maximum in both classrooms and in both seasons when no shading devices were applied to the building. Using a combination of side fins and overhangs resulted in a minimum indoor air temperature during the spring survey day in both classrooms and during the winter season survey day, all combinations of shading devices resulted in a minimum air temperature in both classrooms, which is reasonable, as the shading devices prevents the sun reaching the indoor environment.

Table 8.14: Maximum and minimum indoor air temperatures with various shading devices for Classroom 208 on 4th May 2010 and 9th February 2011

Shading Device		No shading device (base case)	30cm over hangs	60cm overhangs	30cm fin-30cm overhangs	60cm fin,60cm overhangs	Blind inside med slate
4th May	Max°C	25.7	24.3	24	23.5	23.5	24.8
	Min °C	22.5	21.6	21.4	21	21	21.8
9th Feb	Max °C	24.1	22.8	22.8	22.8	22.8	22.6
	Min °C	21.7	21.4	21.4	21.4	21.4	21

Table 8.15: Maximum and minimum indoor air temperatures with various shading devices for Classroom 301 on 4th May 2010 and 9th February 2011

Shading Device		No shading device (base case)	30cm over hangs	60cm overhangs	30cm fin-30cm overhangs	60cm fin,60cm overhangs	Blind inside med slate
4th May	Max °C	24.7	24.6	24.4	24.3	24.3	24.3
	Min °C	22.3	22.1	22	21.9	21.9	22
9th Feb	Max °C	24.4	24.3	24.3	24.3	24.3	24.5
	Min °C	23.9	23.9	23.9	23.9	23.9	23.9

Figures 8.15 and 8.16 illustrate the indoor temperature ranges after the application of shading devices in classrooms 208 and 301 and during the whole period of field study experiment in April/May and January/February. The effect of applying various shading devices on indoor air temperatures in a whole period of field study was similar to the survey days' results. Using all combinations of shading devices caused lower temperatures in north- and south-facing classrooms in April/May 2010. In addition, the indoor air temperature was decreased in winter by the application of any type of shading device in classroom 208, but in classroom 301 it had hardly has any effect, as the sun did not radiate to the north side of the building.

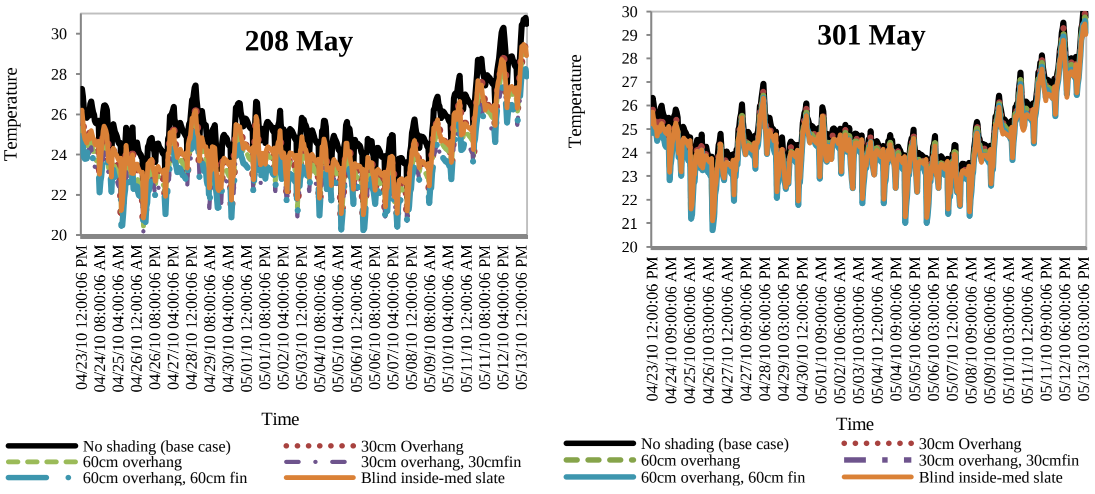


Figure 8.15: Indoor temperature profile with different shading devices in classrooms 208 and 301 in April/May 2010

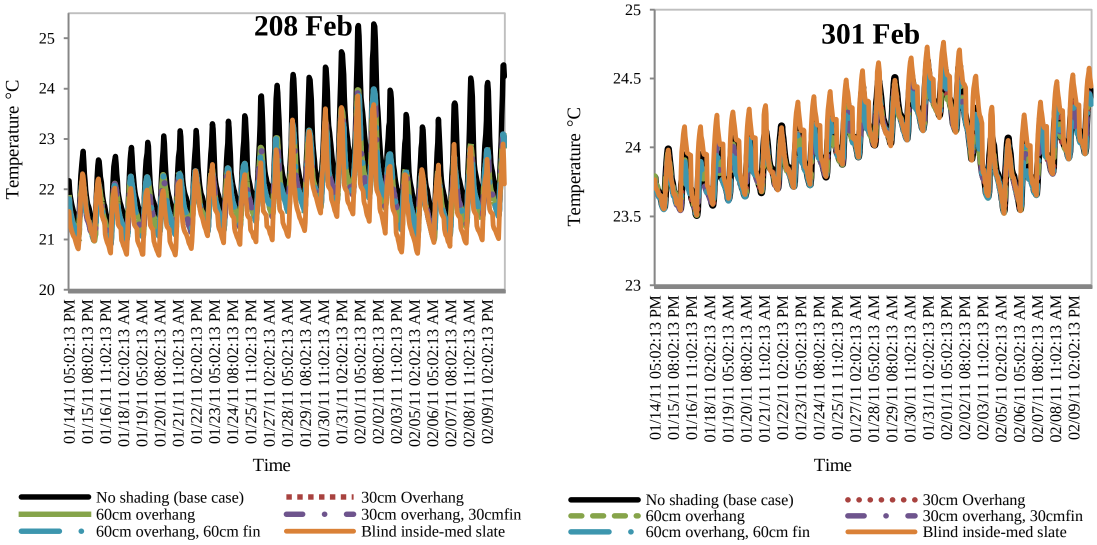


Figure 8.16: Indoor temperature profile with different shading devices in classrooms 208 and 301 in Jan/Feb 2011

Tables 8.16 and 8.17 present the minimum and maximum indoor air temperatures in classrooms 208 and 301, after applying different shading device types. If the building had no shading devices, the classrooms had the maximum indoor air temperatures, compared to the other types of shading devices, in both seasons. However, other types of shading devices decreased the indoor air temperature in both seasons, similar to the survey day results.

Table 8.16: Maximum and minimum indoor air temperature with various shading devices for Classroom 208 on April/May 2010 and January/ February 2011

Shading Device		No shading device (base case)	30cm overhangs	60cm overhangs	30cm fin 30cm overhangs	60cm fin 60cm overhangs	Blind inside med slate
April/May	Max °C	30.79	29.5	29.1	28.3	28.3	29.5
	Min °C	21.35	20.7	20.5	20.1	20.1	20.8
Jan/Feb	Max °C	25.29	24	24	24	24	23.9
	Min °C	21.13	20.9	20.9	20.9	20.9	20.7

Table 8.17: Maximum and minimum indoor air temperature with various shading devices for Classroom 301 on April/ May 2010 and January/ February 2011

Shading Device		No shading device (base case)	30cm overhangs	60cm overhangs	30cm fin 30cm overhangs	60cm fin 60cm overhangs	Blind inside med slate
April/May	Max °C	30.13	29.9	29.8	29.6	29.6	29.5
	Min °C	21.29	21	20.8	20.7	20.7	21.1
Jan/Feb	Max °C	24.64	24.6	24.6	24.6	24.6	24.8
	Min °C	23.51	23.5	23.5	23.5	23.5	23.5

8.6.4. Ventilation

Increasing the air movement rate in indoor spaces increases the cooling efficiency in hot and warm seasons. Natural ventilation is one of the passive design strategies which enhance indoor air quality in hot and dry regions by providing fresh air. Night ventilation and evaporate cooling are some of the important ventilation strategies used to decrease the indoor air temperature in hot and dry regions (Ford et al., 2007). In this study the focus is on night time ventilation during the warm spring season of April/May for cooling purposes, and the results, compared to the base case building results. During the field study experiment the windows always opened at around 7:00am and closed usually at around 9:00pm, after the cleaning up period. Night ventilation reduces indoor air temperatures in hot climates, as the outdoor temperature drops after sunset (Sheta, 2012). As can be seen in Table 8.18, four different ventilation strategies were considered for the simulation analysis. These strategies included, the base case practice; and all day ventilation, which included night ventilation with two various opening ratios, of 40% and 60%. Moreover, for the last strategy no ventilation mode was applied in the base case model in order to compare indoor air temperatures when ventilation is absent for a whole day.

Table 8.18: Different ventilation strategies applied to simulation modelling

Ventilation Strategy	Window Opened	Window Closed	Duration of ventilation (hours)	Opening ratio
Base case practice	7:00	21:00	14	40%
All day and night ventilation	00:00	23:59	24	40%
All day and night ventilation	00:00	23:59	24	60%
No ventilation	Never	Whole day	0	0%

Figure 8.17 presents indoor air temperatures in classroom 208 and 301 on 4th May 2010. It can be seen that the lack of ventilation in both classrooms clearly increased the indoor air temperature during the survey day. The indoor air temperature in the south-facing classroom increased to around 5°C, compared to the base case result, but it only increased by up to 3°C in the north-facing classroom as less solar radiation reached this room.

However, applying the all-day ventilation mode to simulation modelling results in reducing the indoor air temperature in both classrooms, compared to the base case. The indoor air temperature decreased by around 3°C in classroom 208 during the occupancy period, though it only dropped by around 2°C in classrooms 301. It can be seen that the indoor air temperature was much lower during the non-occupancy period in the night, as the windows were open all day, which had an effect on indoor air temperatures during the daytime, especially on south-facing rooms, and decreased the temperature by around 2°C to 3°C. As it is illustrated in Table 8.18, two various opening ratios were considered for all day ventilation strategies, 40% and 60%. However, it can be seen that 20% difference in opening ratios has little effect on indoor air temperatures, which followed a similar pattern with a very small difference. A possible reason may be minimal air movement in outdoor environments and high air temperatures during the hot and warm period.

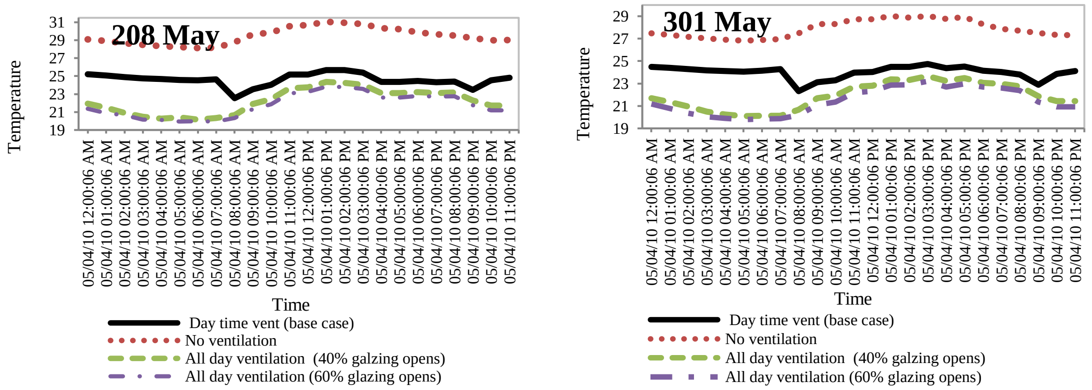


Figure 8.17: Indoor temperature profile with different ventilation strategies in classrooms 208 and 301 on 4th May 2010

Tables 8.19 and 8.20 present the maximum and minimum indoor air temperatures in classrooms 208 and 301 during the spring survey day. The indoor air temperature was at a maximum level in both classrooms when no ventilation system was operating. However, all day ventilation resulted in minimum indoor air temperatures in both classrooms, especially when the ratio of opening was 60%.

Table 8.19: Maximum and minimum indoor air temperature with various ventilation strategies for Classroom 208 on 4th May 2010

Ventilation		Day time (base case)	No vent	All day vent 40% glazing opens	All day vent 60% glazing opens
4th May	Max°C	25.7	31.1	24.3	23.8
	Min°C	22.5	28.1	20.2	19.9

Table 8.20: Maximum and minimum indoor air temperature with various ventilation strategies for Classroom 301 on 4th May 2010

Ventilation		Day time (base case)	No vent	All day vent 40% glazing opens	All day vent 60% glazing opens
4th May	Max°C	24.7	29	23.7	23.2
	Min°C	22.3	26.8	20.1	19.8

Figure 8.18 illustrates the effect of various ventilation strategies on indoor air temperature in classrooms 208 and 301during the field study periods in April/May 2010. It can be seen that the results of whole period were similar to the survey day in May 2010. An all-day ventilation strategy resulted in reducing day time air temperatures more than a day time ventilation strategy.

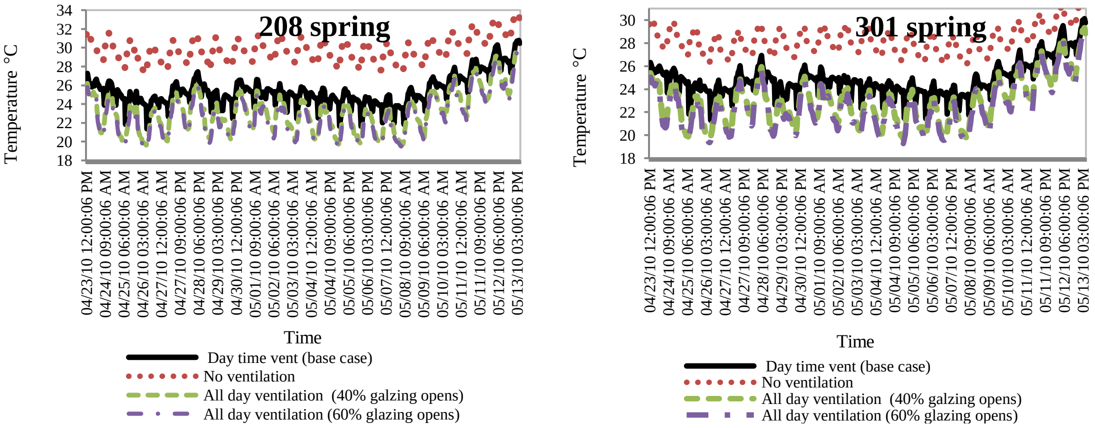


Figure 8.18: Indoor temperature profile with different ventilation strategies in classrooms 208 and 301 in April/May 2010

Tables 8.21 and 8.22 show the maximum and minimum indoor air temperatures in both classrooms during the whole period of the field study in the spring season. In both classrooms using no ventilation resulted in maximum indoor air temperatures. However, all day ventilation caused reductions in indoor air temperatures, especially with a 60% ratio for the openings.

Table 8. 21: Maximum and minimum indoor air temperature with various ventilation strategies for Classroom 208 on April/May 2010

Ventilation		**Day time (base case)**	**No vent**	**All day vent 40% glazing opens**	**All day vent 60% glazing opens**
April/May	Max°C	30.8	33.7	29.8	29.6
	Min°C	21.4	27.3	19.6	19.1

Table 8. 22: Maximum and minimum indoor air temperature with various ventilation strategies for Classroom 301 on April/ May 2010

Ventilation		**Day time (base case)**	**No vent**	**All day vent 40% glazing opens**	**All day vent 60% glazing opens**
April/ May	Max°C	30.1	31.9	29.3	29.1
	Min°C	21.3	26.1	19.7	19.3

8.6.5. Thermal insulation

Appropriate insulation material helps to reduce undesirable heat loss or heat gain through the building envelope. It decreases the heat flow rate through the wall, roof, floors and openings, whether outward or inward, and, as a result, reduces the energy consumption of the building (Autodesk Ecotect Analysis, 2013, Light House Sustainable Building Centre and Guido, 2009). Thermal insulation materials have an impact on the indoor air temperatures of the buildings. A well-insulated building results in lower conductivity through the building envelope fabrics, which decrease the heat flow, as well as providing a comfortable indoor environment. The amount of heat loss from building components is measured by U-values or thermal transmittance. A lower U-value means lower heat loss thorough the building fabrics and better insulation of the buildings. In addition, R-values or thermal resistance is a measure of a material's resistance to heat flow, and therefore an indicator of a material's insulation properties. It is the inverse of the U-value (Light House Sustainable Building Centre and Guido, 2009). In this study, different insulation types, with various thicknesses, were employed for the external walls, as well as the roof, separately, to examine their effects on the U-value of the building and, as a result, on the indoor air temperature. The thermal insulation materials used in the simulation modelling were based on Iranian national building regulation recommendations and are the typical insulation materials currently used in Iran (Ministry of Housing and Urban Development, 2009, IFCO, 2012, Irima, 2012).

- **Thermal insulation in external walls**

The original school building does not include any thermal insulation materials on the external walls. Three various type of insulation materials have been employed in the external walls, including glass wool, extruded polystyrene (XPS) and expanded polystyrene (EPS). They have been applied to the walls separately, with various thicknesses, between 5 cm and 10 cm. Also they have been applied to the outer and inner sides of the external walls, in order to investigate the effect of the positioning of the insulation materials on the indoor air temperatures. Table 8.23 summarises the insulation materials as well as their thicknesses, which were applied to the external walls and used in the simulation analysis. These materials are one of the most common thermal insulation materials used in Iran.

Table 8.23: Insulation types, thicknesses and positions in simulation modelling

Thermal Insulation	Glass wool	XPS	EPS
Thickness (cm)	5-10	5-10	5-10
Position	In-Out	In-Out	In-Out

Figures 8.19 and 8.20 illustrate the result of the simulation analysis with regards to insulation types, thicknesses and positions, on the survey day in May 2010, in south- and north-facing classrooms.

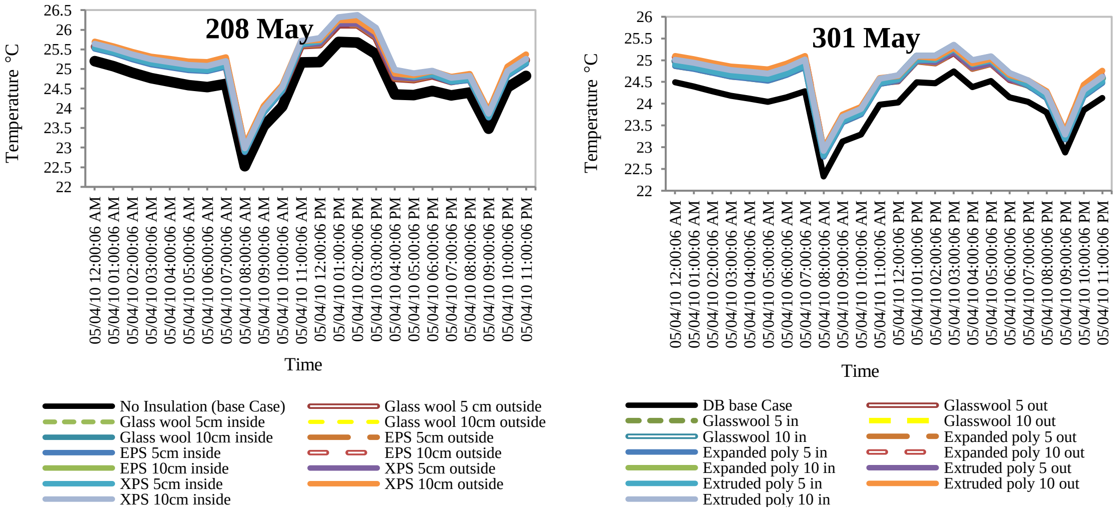


Figure 8.19: Indoor air temperature profile with different wall insulation in classrooms 208 and 301 on 4th May 2010

It can be seen that the application of all types of thermal insulation with 5 cm and 10 cm thicknesses resulted in higher indoor air temperatures in both classrooms. It should be mentioned that the windows were open during the occupancy period in the base case building till the cleaning up period at around 9:00pm in the warm period. As the application of tight fitting thermal insulation materials can improve airtightness levels of a building and limit air leakage through the buildings envelope, less air infiltration occurred in the building (Light House Sustainable Building Centre and Guido, 2009) and as a result the indoor air temperature increased in both classrooms, regardless the location. The indoor air temperatures increased by around 0.6K in both classrooms during the survey day in May.

On the other hand, the application of thermal insulation on the external walls during the winter season survey on the 9th February 2011 had a considerable effect on indoor air temperatures in Classroom 208, which increased significantly in the south-facing classroom. Although applying the insulation material increased the indoor air temperature in north-facing classroom also, the increase in temperature was not as significant as with the south-facing classroom, only increasing by about 0.8K maximum. A possible reason for this might be the airtightness of the classrooms' envelope, which was poor in Classroom 208 but was good in Classroom 301. After the application of insulation to the external wall, the infiltration decreased in Classroom 208, which had a poor construction in a base case building and caused higher temperature increases, compared to the north-facing classroom.

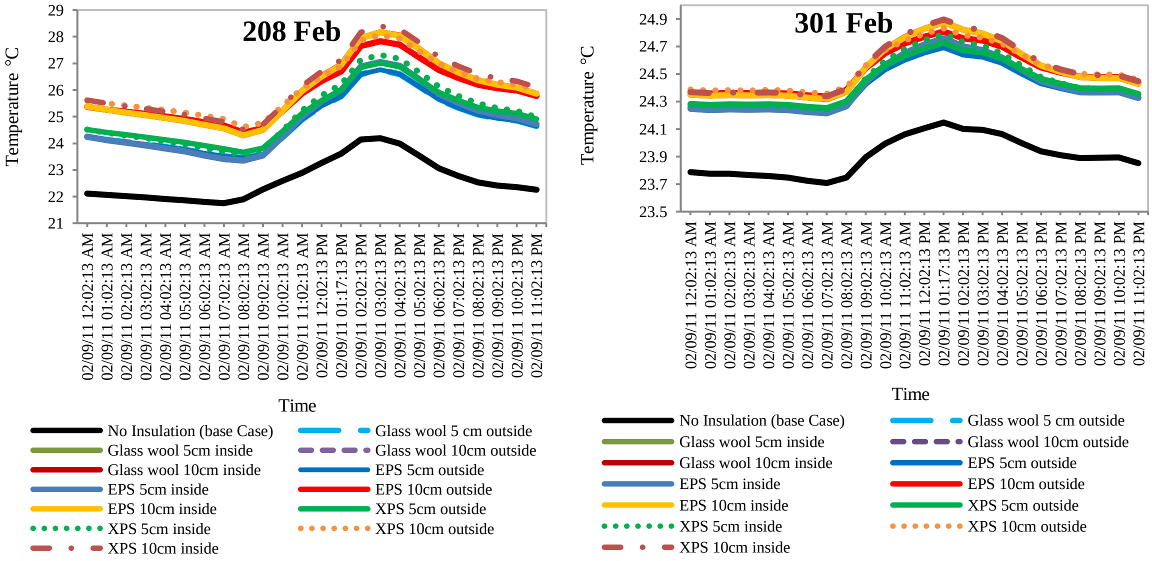


Figure 8.20: Indoor air temperature profile with different wall insulation in classrooms 208 and 301 on 9th Feb 2011

In addition, adding 10 cm of insulation material resulted in a higher increase in temperature than the 5 cm thermal insulation in both classrooms. For example, 10 cm of extruded polystyrene increased the indoor air temperatures by about 4.3K during the hottest time of the day in Classroom 208, but 5 cm of the same thermal insulation increased the indoor air temperatures by about 3.3K in the same classroom and at the same period.

Tables 8.24 and 8.25 summarise the results of the simulation analysis, based on the minimum and maximum indoor air temperatures in both classrooms on both survey days during the warm spring period and cold winter season. It can be seen that employing 10 cm of insulation material has more effect on the increase in indoor air temperature in both seasons and in both classrooms, compared to the 5 cm thickness of the same insulation type. The indoor air temperatures increased by about 0.1K in Classrooms 301 in both seasons after, 10 cm of any insulation materials were applied, compared to the

5 cm of the same type of thermal insulation material. In Classroom 208, the indoor air temperatures increased by about 1K more during the winter survey day through the application of 10 cm of the insulation material, compare to 5 cm of the same insulation type. However, during the May survey day it only increased by 0.1K, compared to the 10 cm thickness of the thermal insulation material, similar to Classroom 301. A possible reason for increasing the indoor air temperature could be the improvement in airtightness level in the classrooms as discussed in this section. Moreover, if the thermal insulation materials were applied to the inner side of the external walls, the indoor air temperatures usually increased during the hottest period of the day in both seasons and in both classrooms. However, during the cold period of the day, if the thermal insulation materials were applied to the outer side of the walls, the indoor air temperatures increased in all classrooms. The reason is the benefit of the mass, as the insulation placed on the outer side of the wall and the wall is constructed with 30 cm bricks in the base case building. However, the increasing in temperature was not very significant.

Table 8.24: Maximum and minimum indoor air temperatures with various insulations for exterior walls for Classroom 208 on 4th May 2010 and 9th February 2011

Ex-Wall Insulation		**No insulation (base case)**	**Glass wool**	**Glass wool**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**EPS**	**EPS**	**XPS**	**XPS**	**XPS**	**XPS**
Thickness (cm)		-	5	5	10	10	5	5	10	10	5	5	10	10
Position		-	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
4th May	Max °C	25.69	26.1	26.3	26.2	26.4	26.1	26.2	26.2	26.4	26.2	26.3	26.3	26.4
	Min °C	22.53	22.9	22.9	23	23	22.9	22.9	23	23	23	22.9	23.1	23
9th Feb	Max °C	24.19	26.8	27.1	27.8	28.2	26.8	27.1	27.8	28.2	27	27	28.1	28.4
	Min °C	21.75	23.4	23.4	24.4	24.3	23.4	23.4	24.4	24.3	23.7	23.6	24.6	24.5

Table 8.25: Maximum and minimum indoor air temperatures with various insulations for exterior walls for Classroom 301 on 4th May 2010 and 9th February 2011

Ex-Wall Insulation		**No insulation (base case)**	**Glass wool**	**Glass wool**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**EPS**	**EPS**	**XPS**	**XPS**	**XPS**	**XPS**
Thickness (cm)		-	5	5	10	10	5	5	10	10	5	5	10	10
Position		-	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
4th May	Max °C	24.74	25.2	25.2	25.3	25.3	25.2	25.2	25.3	25.3	25.2	25.3	25.3	25.4
	Min °C	22.33	22.8	22.8	22.9	22.9	22.8	22.8	22.9	22.9	22.9	22.8	23	22.9
9th Feb	Max °C	24.15	24.7	24.8	24.8	24.9	24.7	24.8	24.8	24.9	24.7	24.8	24.8	24.9
	Min °C	23.71	24.2	24.2	24.3	24.3	24.2	24.2	24.3	24.3	24.3	24.2	24.4	24.3

Figures 8.21 and 8.22 show the results of the simulation analysis using various types of thermal insulation with different thicknesses in north- and south-facing classrooms during the field study periods in warm and cold seasons, which is an extension of the survey experiment. The results of the whole periods were nearly the same as survey day results. It can be seen that adding any type of insulation material increased the indoor air temperatures in north- and south-facing classrooms in both seasons but the increase was more significant in Classroom 208 during the winter period, as it was poorly constructed, compared to Classroom 301, just similar to the one day survey results in May and February. Adding insulation materials to the exterior walls increased the indoor air temperature by around 0.5°C maximum in the spring period in both classrooms but during the winter season the maximum indoor

temperature was 0.7K more than the base case in Classroom 301. However, the maximum temperature difference in Classroom 208 was 4.5K, which is significant. Adding thermal insulation material improved the airtightness of the building and resulted in increasing the indoor air temperature in the winter season in Classroom 208 which had poor construction.

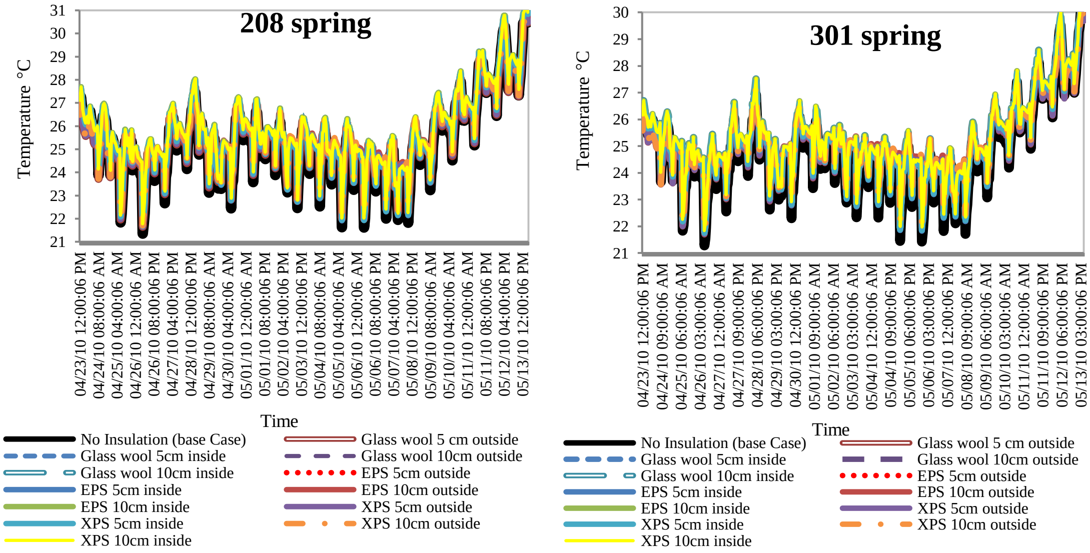


Figure 8.21: Indoor temperature profile with different wall insulation in classrooms 208 and 301 in April/May 2010

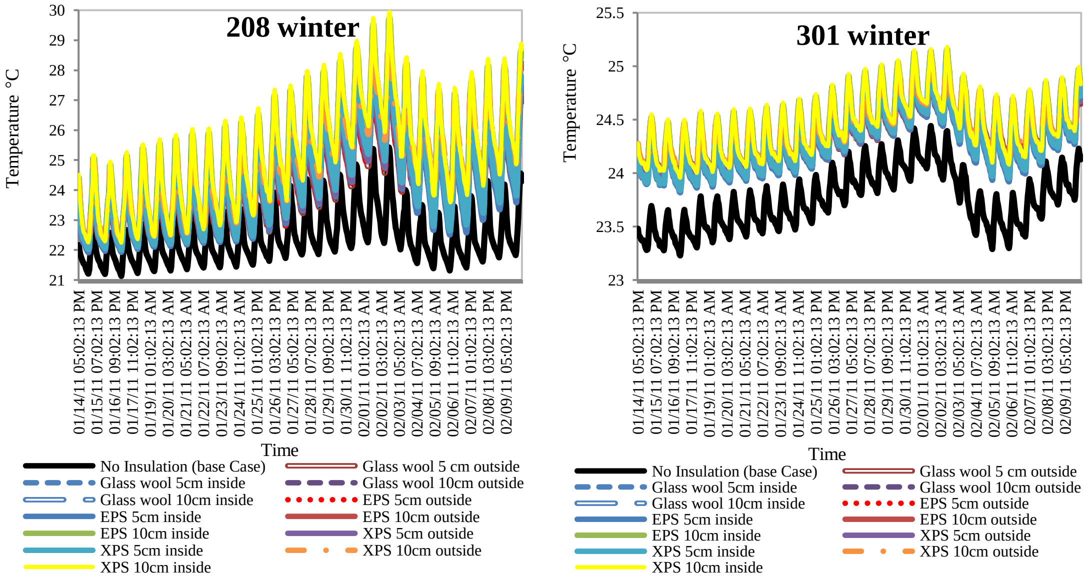


Figure 8.22 : Indoor temperature profile with different wall insulation in classrooms 208 and 301 in Jan/Feb 2011

Tables 8.26 and 8.27 present the minimum and maximum indoor air temperatures caused by various thermal insulation materials with different thicknesses in classrooms 208 and 301 in both warm and cold seasons. The overall results was similar to the survey days' results in May and February, as adding insulation material to the outer side of the exterior wall during the cold periods of the day resulted in higher indoor air temperatures, whether in winter or spring. However, if the insulation materials were applied to the inner side of the wall, it caused a bigger increase in indoor air temperatures during the warmest times of the days, regardless of the season. In addition, as discussed above, the increase in indoor air temperatures was more considerable during the winter period in Classroom 208 when using thicker insulation material, due to its poor construction.

Table 8.26: Maximum and minimum indoor air temperature with various insulation materials for exterior walls for Classroom 208 on April/May 2010 and January/February 2011

Ex-Wall Insulation		**No insulation (base case)**	**Glass wool**	**Glass wool**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**EPS**	**EPS**	**XPS**	**XPS**	**XPS**	**XPS**
Thickness (cm)		-	5	5	10	10	5	5	10	10	5	5	10	10
Position		-	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
April/May	Max °C	30.79	30.8	31.2	30.8	31.2	30.8	31.2	30.8	31.2	30.8	31.2	30.8	31.3
	Min °C	21.35	21.6	21.7	21.7	21.8	21.6	21.7	21.7	21.8	21.6	21.7	21.7	21.8
Jan/Feb	Max °C	25.43	28.1	28.7	29	29.7	28.1	28.7	29	29.7	28.4	29	29.2	29.9
	Min °C	21.13	22	21.9	22.3	22.2	22	21.9	22.7	22.2	22	22	22.3	22.3

Table 8.27: Maximum and minimum indoor air temperature with various insulation materials for exterior walls for Classroom 301 on April/May 2010 and January/February 2011

Ex-Wall Insulation		**No insulation (base case)**	**Glass wool**	**Glass wool**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**EPS**	**EPS**	**XPS**	**XPS**	**XPS**	**XPS**
Thickness (cm)		-	5	5	10	10	5	5	10	10	5	5	10	10
Position		-	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In
April/May	Max °C	30.13	30.1	30.5	30.1	30.5	30.1	30.5	30.1	30.5	30.1	30.5	30.1	30.5
	Min °C	21.29	21.7	21.7	21.7	21.8	21.7	21.7	21.7	21.8	21.7	21.8	21.8	21.8
Jan/Feb	Max °C	24.44	25	25	25.1	25.2	25	25	25.1	25.2	25	25.1	25.1	25.2
	Min °C	23.23	23.9	23.8	24	23.9	23.9	23.8	24	23.9	23.9	23.8	24	

In general, adding insulation to the external wall had the effect of increasing temperatures in all rooms and in both seasons but it was more significant during the winter and in the room with poor construction. Also, putting insulation on the outer side of the walls had almost same effect on indoor air temperatures as when it was put on the inner side during the cold period of the day in all classrooms and in both seasons. In addition, thicker insulation materials had more effect on increasing indoor air temperature than thinner insulation in the room with poor construction and in cold days (see Tables 8.26 and 8.27). Based on the simulation results, it is suggested that the use of thicker insulation material on the outer surfaces of walls with mass construction will give the advantage of greater thermal mass in the winter period in rooms with poor construction. However, it is suggested that insulation is also required in the rooms with good construction, but with less thickness, which has the effect of increasing temperatures in winter. All types of insulation materials have almost the same effect. The important factor on increasing or decreasing indoor air temperatures is the thickness of the thermal insulation.

Table 8.28 presents how the insulation types and their thicknesses have an impact on the U-value of the external walls. All the thermal insulation materials were selected based on Iranian national building regulations (Ministry of Housing and Urban Development, 2009). The U-value of the non-insulated external wall in the case study school building was 1.61 W/m^{2}K. The tested variations of thermal insulation included glass wool, extruded polystyrene (XPS) and expanded polystyrene (EPS), with 5 cm of thickness reduced the U-vale of the base case building to 0.54, 0.48 and 0.36 W/m^{2}k, respectively. As can be seen, using 5 cm of extruded polystyrene (XPS) reduced the overall U-value of the external wall more than other types of thermal insulation with similar thickness.

Table 8.28: Effect of thickness of insulation materials on overall U-value of external wall

Thermal Insulation	Thickness (cm)	U-value w/m^{2}k
Base Case	-	1.614
Glass wool	5	0.535
Glass wool	10	0.321
XPS	5	0.478
XPS	10	0.281
EPS	5	0.535
EPS	10	0.321

However, increasing the thickness of the insulation materials to 10 cm had more impact on decreasing the U-value of the external wall, which decreased to 0.32, 0.28 and 0.32 W/m^{2}K when using glass wool, extruded polystyrene (XPS) and expanded polystyrene (EPS). XPS thermal insulation results in lower U-values compared to other types of thermal insulation and caused higher indoor air temperature in all classrooms and in both seasons (see Tables 8.24 to 8.27) but the difference was very minimal.

- **Thermal insulation in roof**

The base case building had only 5 cm of glass wool installed in the roof layer as a thermal insulation material. Three various type of insulation materials were employed in the roof layer, in a similar way to the external wall experiment of thermal insulation. The applied insulation materials included glass wool, extruded polystyrene (XPS) and expanded polystyrene (EPS). They were applied to the roof individually, with 10 cm of thickness. The reason for using 10 cm of thickness for the thermal insulation materials was the result of the external wall's thermal insulation practice, which had more effect on increasing the indoor air temperature in the winter period. As mentioned above, the base case building had 5cm of glass wool as the thermal insulation. Based on the external wall insulation experiment, using various types of thermal insulation materials with similar thicknesses had a very similar effect on indoor air temperatures. Therefore, in this experiment 10cm was selected for XPS, EPS and glass wool as the roof thermal insulation. In addition, the thermal insulation materials were applied to the outer side of the roof as well as the inner side, in order to investigate the effect of the positioning of the insulation materials on the indoor air temperature. The insulation materials were applied to the roof only and the floors has no thermal insulation, just similar to the base case building. Moreover, the ground floor was below the general offices and laboratories. As the roof and ground floors were the most complex parts of the building compared to the middle floors and there were no classrooms on the ground floor and the basement; so no thermal insulation was installed in the middle floors in this study. In this research the effect of the building’s envelope on the indoor thermal performance of the classrooms was investigated. Table 8.29 summarises the thermal insulation materials as well as their thicknesses, which were applied to the roof layers in the base case model in the simulation analysis.

Table 8.29: Insulation types, their thicknesses and positions used in the roof layers in the simulation modelling

Insulation	Glass wool	XPS	EPS
Thickness (cm)	10	10	10
Position	In-Out	In-Out	In-Out

Figures 8.23 and 8.24 present the effects of various thermal insulation materials, installed to the outer side and inner side of the roof, on indoor air temperatures in the north- and south-facing classrooms. It can be seen that the application of all types of thermal insulation with 10cm of thickness caused lower indoor air temperatures on the May survey day in a north-facing classroom on the top floor when the windows were kept closed from 9:00pm to 7:00am during a non-occupancy period. The indoor air temperatures decreased by around 0.5K only in this classroom. Also during the occupancy period and during peak temperatures, the thicker insulation material caused a minimal increase in indoor air temperatures in the classrooms located on the top floor, 301. However, obviously the change in insulation thickness had no effect on Classroom 208 located on the first floor (see Figure 8.23).

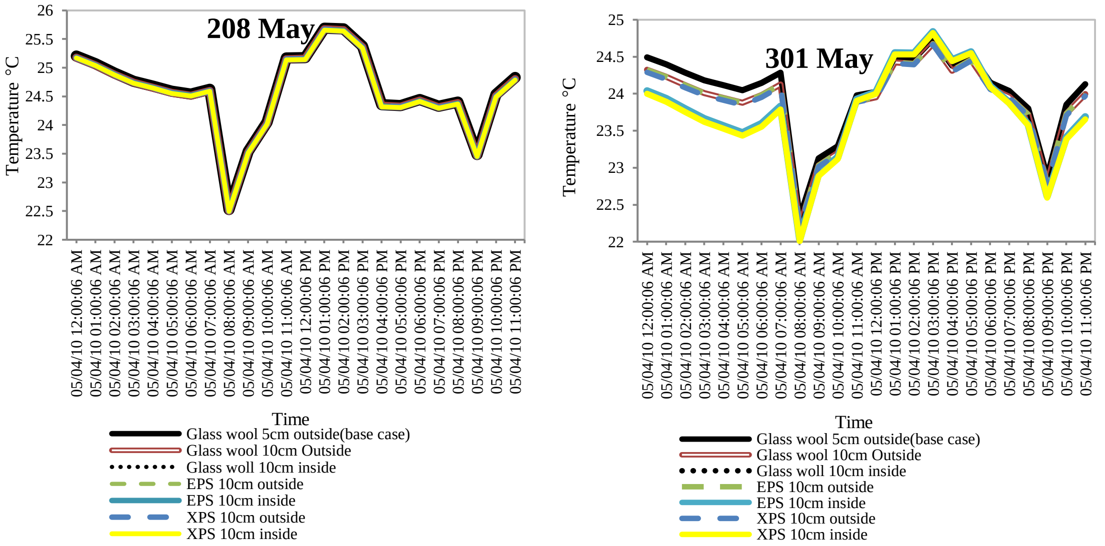


Figure 8.23 : Indoor temperature profile with different roof insulation in classrooms 208 and 301 on 4th May 2010

On the other hand, the application of thicker thermal insulation on the roof during the winter season survey slightly increased indoor air temperatures in Classroom 301 during the hottest time of the day. This was very minor at less than 0.3K. Although increasing the thickness of the insulation material decreased the indoor air temperatures during the warm period and increased the indoor air temperatures during the cold season on the last floor, the changes were not very significant, which shows that the current thickness for thermal insulation in the roof can be used for typical buildings, which was recommended by Iranian national building regulations (National Building Code, 2009a). In addition, as Classroom 208 was located on the first floor, the thickness of the thermal insulation materials had no effect on indoor air temperature in that classroom.

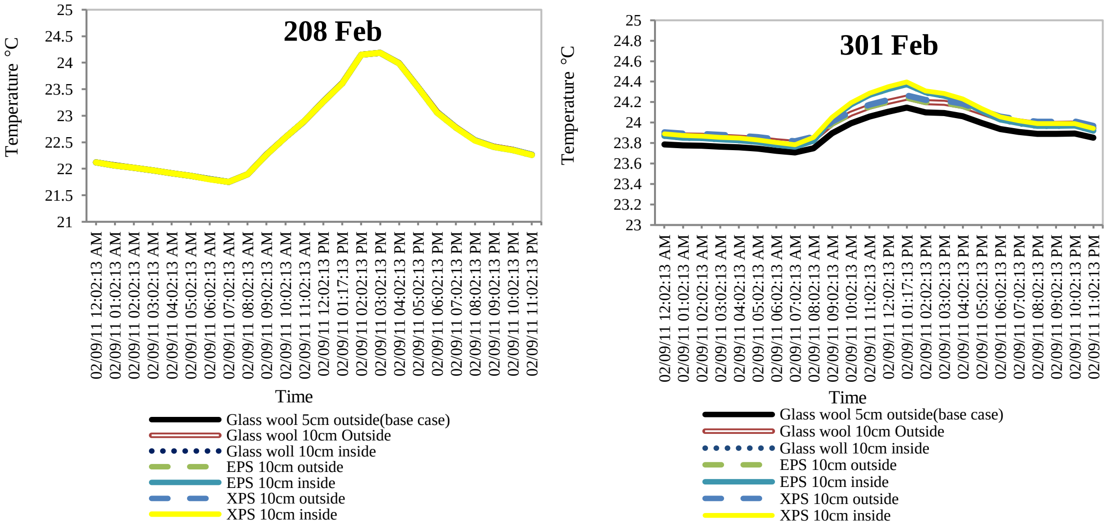


Figure 8.24 : Indoor temperature profile with different roof insulation in classrooms 208 and 301 on 9th Feb 2011

Tables 8.30 and 8.31 summarise the result of the simulation analysis based on the minimum and maximum indoor air temperature in both classrooms and in both survey days during the warm spring period and cold winter season. It can be seen that employing 10 cm of the insulation material obviously has no effect on the change of indoor air temperature in the classroom 208 which is located on the First floor. Although the indoor air temperature had some changes in Classroom 301 which is located on the top floor, these changes are not very significant. Moreover, the application of thermal insulation of the roof in outer side and inner side of the roof layers has very similar effect on indoor air temperature. Also all type of recommended insulations types has similar impact on the changes of indoor air temperature in the classroom.

Table 8.30: Maximum and minimum indoor air temperature with various roof insulation materials for Classroom 208 on 4th May 2010 and 9th February 2011

Roof insulation		**Glass wool (base case)**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**XPS**	**XPS**
Thickness (cm)		**5**	**10**	**10**	**10**	**10**	**10**	**10**
Position		**out**	**out**	**in**	**out**	**in**	**out**	**in**
4th May	Max °C	25.7	25.7	25.7	25.7	25.7	25.7	25.7
	Min °C	22.5	22.5	22.5	22.5	22.5	22.5	22.5
9th Feb	Max °C	24.2	24.2	24.2	24.2	24.2	24.2	24.2
	Min °C	21.8	21.8	21.8	21.8	21.8	21.8	21.8

Table 8.31: Maximum and minimum indoor air temperature with various roof insulation materials for Classroom 301 on 4th May 2010 and 9th February 2011

Roof insulation		**Glass wool (base case)**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**XPS**	**XPS**
Thickness (cm)		**5**	**10**	**10**	**10**	**10**	**10**	**10**
Position		**out**	**out**	**in**	**out**	**in**	**out**	**in**
4th May	Max °C	24.7	24.7	24.8	24.7	24.8	24.7	24.8
	Min °C	22.3	22.2	22	22.2	22.2	22.2	22.2
9th Feb	Max °C	24.2	24.2	24.4	24.2	24.4	24.3	24.4
	Min °C	23.7	23.8	23.8	23.8	23.8	23.8	23.8

Figures 8.25 and 8.26 present the results of various types of thermal insulation installed in the roof layers on indoor air temperatures during the whole period of the field studies in the warm and cold seasons. The result is very similar to the survey days' results and the indoor air temperatures decreased very little during the non-occupancy period in April/May in Classroom 301 and slightly increased during January/ February.

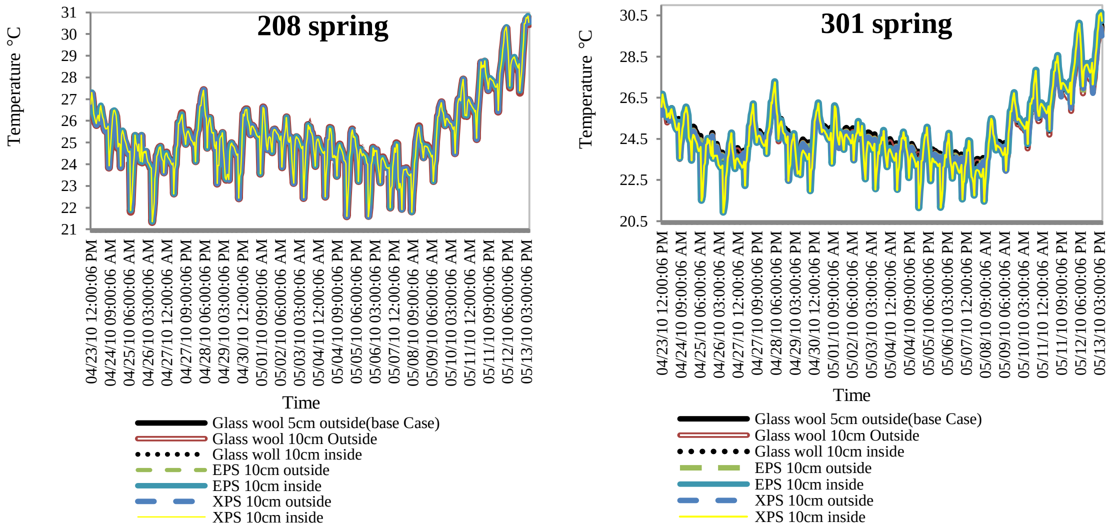


Figure 8.25: Indoor temperature profile with different roof insulation materials in classrooms 208 and 301 in April/May 2010

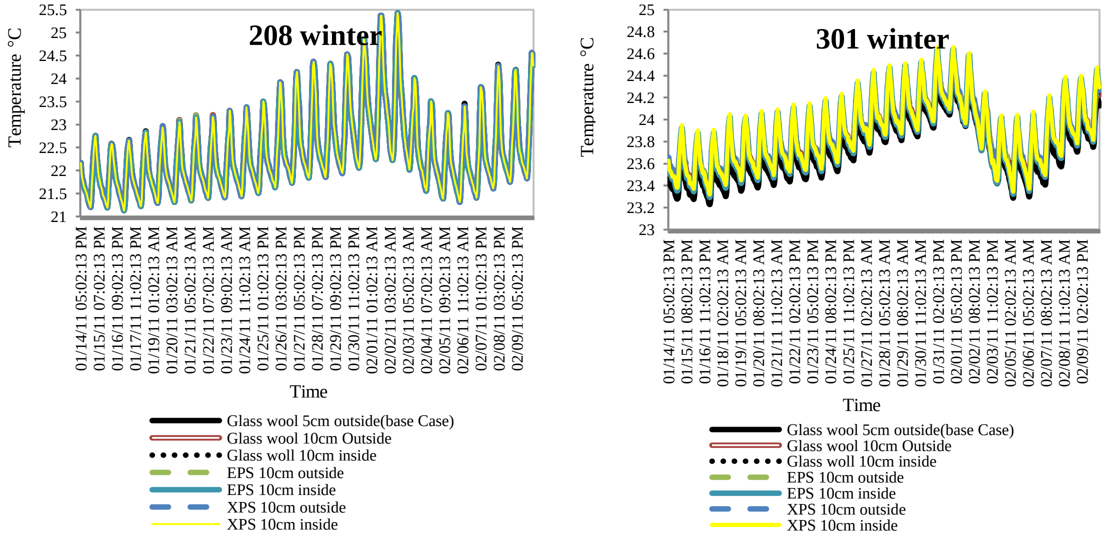


Figure 8.26: Indoor temperature profile with different roof insulation materials in classrooms 208 and 301 in Jan/Feb 2011

Table 8.32 and 8.33 present the minimum and maximum indoor air temperatures caused by applying various insulation materials with 10 cm of thickness to the roof layers in both seasons. Overall, the result is very similar to the survey days' results. Like the survey days, adding insulation material to the outer side and the inner side of the roof during the warm period had a similar impact on indoor air temperatures which only changed by less than 0.3K. Also the application of all types of thermal insulation materials had very similar effects on changes in indoor air temperatures.

Table 8.32: Maximum and minimum indoor air temperatures with various insulation materials for roofs for Classroom 208 on April/ May 2010 and January/February 2011

Roof insulation		**Glass wool (base case)**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**XPS**	**XPS**
Thickness (cm)		**5**	**10**	**10**	**10**	**10**	**10**	**10**
Position		**out**	**out**	**in**	**out**	**in**	**out**	**in**
4th May	Max °C	30.8	30.7	30.8	30.8	30.8	30.8	30.8
	Min °C	21.4	21.3	21.4	21.3	21.4	21.3	21.4
9th Feb	Max °C	25.4	25.4	25.4	25.4	25.4	25.4	25.4
	Min °C	21.1	21.1	21.1	21.1	21.1	21.1	21.1

Table 8.33: Maximum and minimum indoor air temperature with various insulation materials for roofs for Classroom 301 on April/ May 2010 and January/February 2011

Roof insulation		**Glass wool (base case)**	**Glass wool**	**Glass wool**	**EPS**	**EPS**	**XPS**	**XPS**
Thickness (cm)		**5**	**10**	**10**	**10**	**10**	**10**	**10**
Position		**out**	**out**	**in**	**out**	**in**	**out**	**in**
4th May	Max °C	30.1	29.9	30.6	29.9	30.6	29.9	30.6
	Min °C	21.3	21.2	20.9	21.2	20.9	21.2	20.9
9th Feb	Max °C	24.4	24.5	24.6	24.5	24.6	24.5	24.7
	Min °C	23.2	23.4	23.3	23.4	23.3	23.4	23.3

Table 8.34 presents the impact of various insulation types with various thicknesses on the U-value of the roof. All the thermal insulation materials were selected based on Iranian national building regulations (Ministry of Housing and Urban Development, 2009). The U-value of the roof for the base case building was 0.53 W/m^{2}K. The tested variations of thermal insulation materials including glass wool, XPS and EPS, reduced the U-value of the base case building to 0.32, 0.28 and 0.32 W/m^{2}K respectively. As can be seen, using 10 cm of extruded polystyrene (XPS) reduced the overall U-value of the roof more than the other types of thermal insulations, with similar thickness.

Table 8.34: Effect of thermal insulation materials and their thicknesses on U-value of the roof

Insulation	**Thickness (cm)**	**U-value (W/m^{2}K)**
Base Case	5	0.527
Glass wool	10	0.318
XPS	10	0.279
EPS	10	0.318

8.6.6. Thermal mass in walls

Thermal mass is the capability of fabrics to save heat. It can be integrated into a building as part of the buildings components in the walls and floor. High thermal mass materials, such as concrete, brick, stone and earth, can absorb and hold heat and release it slowly later on when there is a temperature difference between the material and the surroundings (Light House Sustainable Building Centre and Guido, 2009). It is suggested that high thermal mass materials should be used in building components in hot regions, as this provides a comfortable indoor environment by reducing indoor air temperatures and avoiding overheating (Kasmai, 2008). Based on Givoni and Kruger (2008), using high thermal mass materials in external walls reduces indoor air temperatures, especially when considering night ventilation for the room. In this study various thermal mass materials with different thicknesses were applied to the simulation model. Table 8.35 shows the materials used in external wall components in the base case building.

Table 8.35 : Thermal mass materials using different thicknesses in external wall components

Thermal Mass	Brick (base case)	Brick	Heavy concrete	Heavy concrete	Medium concrete	Medium concrete	Light concrete	Light concrete
Thickness (cm)	30	20	25	40	25	40	25	40

Figure 8.27 and 8.28 illustrates the effect of various thermal mass materials on indoor air temperature on the survey day on 4th May 2010 in classrooms 208 and 301, facing south and north.

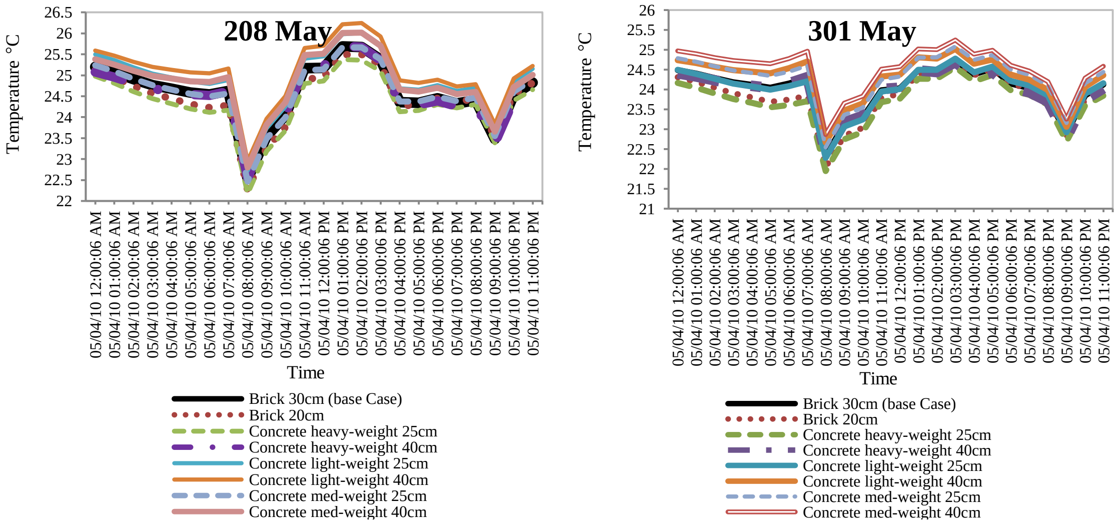


Figure 8.27: Indoor temperature profile with different thermal mass materials in classrooms 208 and 301 on 4th May 2010

It can be seen that the indoor air temperature increased when using low thermal mass materials. However, using high thermal mass materials decreases indoor air temperatures on warm spring days. For instance, applying 40 cm of lightweight concrete increased the indoor air temperature by around 0.7K in peak periods in both classrooms and using 25 cm heavyweight concrete reduced the temperature by around 0.3K in peak periods, but this was not very significant in spring, compared to the base case. The reason is the current material of the base case which included the thermal mass of a 30 cm brick wall. Moreover, during the field study on the 9th February 2011, the application of high thermal mass materials also resulted in reducing the indoor air temperature, in a way which was very similar to the spring season experiment (see Figure 8.28). The temperature difference between the base case and low thermal mass material (lightweight concrete) was around 3K at the peak time in Classroom 208 but only around 1K in Classroom 301. Possible reasons can be direct solar gain in Classroom 208 and also lower radiator temperatures in Classroom 301. However, the temperature difference between the base case and high thermal mass materials during the peak period in both classrooms was around 1K at most.

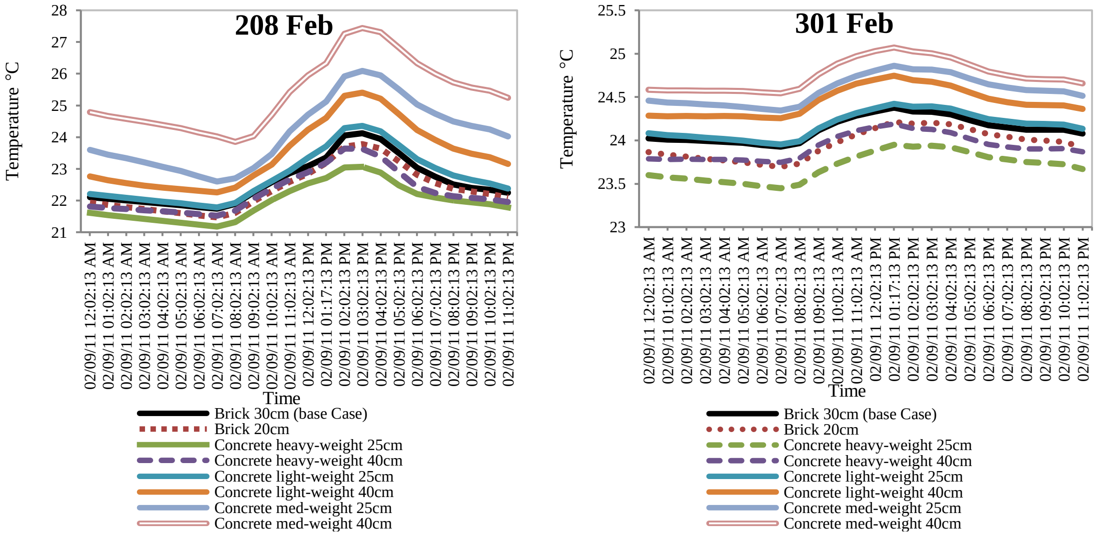


Figure 8.28: Indoor temperature profile with different thermal mass materials in classrooms 208 and 301 on 9th Feb 2011

Considering Figures 8.27 and 8.28, it can be seen that the application of thicker materials usually resulted in lower reduction in indoor air temperatures in both seasons and in both classrooms. For example, using 40 cm heavyweight concrete blocks in the external walls caused less reduction in indoor air temperatures than 25 cm heavyweight concrete blocks. Based on the literature, the impact of thermal mass is increased by increasing thermal density and decreasing the thickness of the material which causes more constant heat capacity. A thinner density of mass material responds faster to surface temperature fluctuations and consequently will store excess heat gains and dampen interior air temperatures more effectively (Byrne and Ritschard, 1985, Autodesk Sustainability Workshop, 2011, Fehr, 2009). It is also essential to locate thermal mass in direct solar radiation, for it to have more impact on indoor air temperatures, although indirect sunlight has an effect on the overall performance of the building, as the walls will be heated by air convection (Autodesk Sustainability Workshop, 2011, Nasrollahi, 2009).

In addition, it can be seen that using lightweight concrete increases indoor air temperatures in both classrooms and in both seasons. However, the effect was more considerable in the winter survey day. Based on Rise and Holm (2004), using lightweight concrete in a building’s envelope cause longer time lags. In addition, Vangeem et al (2013) reported that reducing the density of the concrete masonry walls results in increasing thermal lag. They cited that for external uninsulated concrete walls, the beneficial effects of thermal mass are increased as density is reduced from 2400 kg/m³ to 800 kg/m³ (Figure 8.29), which might be a possible reason for the higher temperatures seen when using lightweight concrete masonry walls compared to heavyweight concrete.

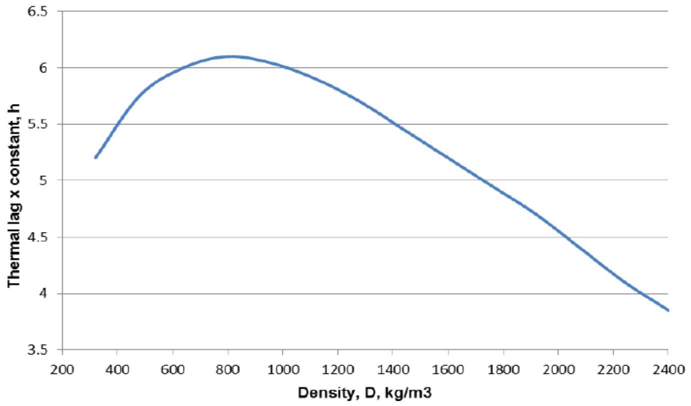


Figure 8.29: Optimum concrete density for maximum thermal lag (Vangeem et al., 2013)

Tables 8.36 and 8.37 present the minimum and maximum indoor air temperatures in classrooms 208 and 301 caused by applying various thermal mass materials to the external wall layers of the base case building during the survey days experiment. It can be seen that the medium-weight and lightweight concrete resulted in maximum indoor temperatures and heavyweight concrete and brick materials resulted in minimum indoor air temperatures in both classrooms and in both seasons.

Table 8.36: Maximum and minimum indoor air temperatures with various thermal mass materials for Classroom 208 on 4th May 2010 and 9th February 2011

Thermal mass		**Brick (base case)**	**Brick**	**Heavy concrete**	**Heavy concrete**	**Med concrete**	**Med concrete**	**Light concrete**	**Light concrete**
Thickness (cm)		**30**	**20**	**25**	**40**	**25**	**40**	**25**	**40**
4th May	Max°C	25.69	25.5	25.4	25.7	26	26.3	25.7	26
	Min°C	22.53	22.3	22.2	22.6	22	23	22.5	22.8
9th Feb	Max°C	24.12	23.8	23.1	23.6	24.4	25.4	26.1	27.5
	Min°C	21.74	21.5	21.2	21.5	21.8	22.3	22.6	23.9

Table 8.37: Maximum and minimum indoor air temperatures with various thermal mass materials for Classroom 301 on 4th May 2010 and 9th February 2011

Thermal mass		**Brick (base case)**	**Brick**	**Heavy concrete**	**Heavy concrete**	**Med concrete**	**Med concrete**	**Light concrete**	**Light concrete**
Thickness (cm)		**30**	**20**	**25**	**40**	**25**	**40**	**25**	**40**
4th May	Max°C	24.7	24.7	24.6	24.7	24.8	25	25.1	25.3
	Min°C	22.3	22.1	22	22.4	22.3	22.7	22.6	22.7
9th Feb	Max°C	24.4	24.2	24	24.2	24.4	24.8	24.7	25.1
	Min°C	23.9	23.7	23.5	23.8	24	24.3	24.4	24.6

Figures 8.30 and 8.31 present the impact of thermal mass on indoor air temperatures in south- and north-facing classrooms during the field study experiments in April/May 2010 and January/February 2011. Similar to previous simulation results, the result of whole period experiment in both seasons was similar

to the survey days' experiments in May 2010 and February 2011. The heavyweight concrete blocks, with 25 cm thickness, reduced the indoor air temperatures more than the other thermal mass elements with various thicknesses. In addition, lightweight concrete, with 40 cm thickness, increased the indoor air temperatures significantly more, compared to other thermal mass materials. As was discussed previously, a thin mass is more useful than a thick mass, especially in direct solar radiation. A thicker mass is generally ineffective, as the heat is removed from the surface and lost (Autodesk Sustainability Workshop, 2011).

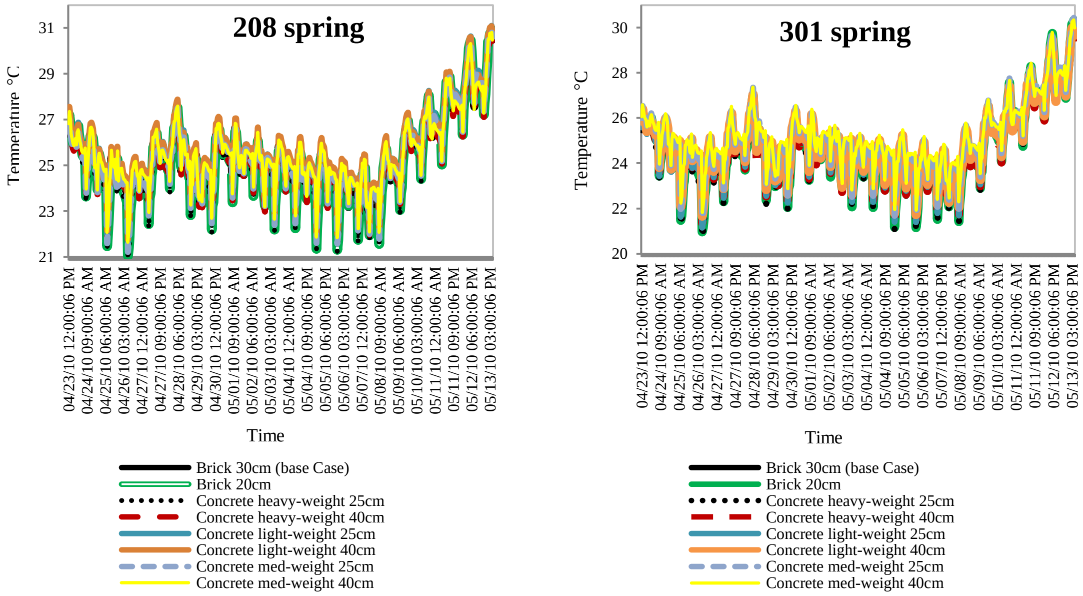


Figure 8.30: Indoor temperature profile with different thermal mass materials in classrooms 208 and 301 in April/May 2010

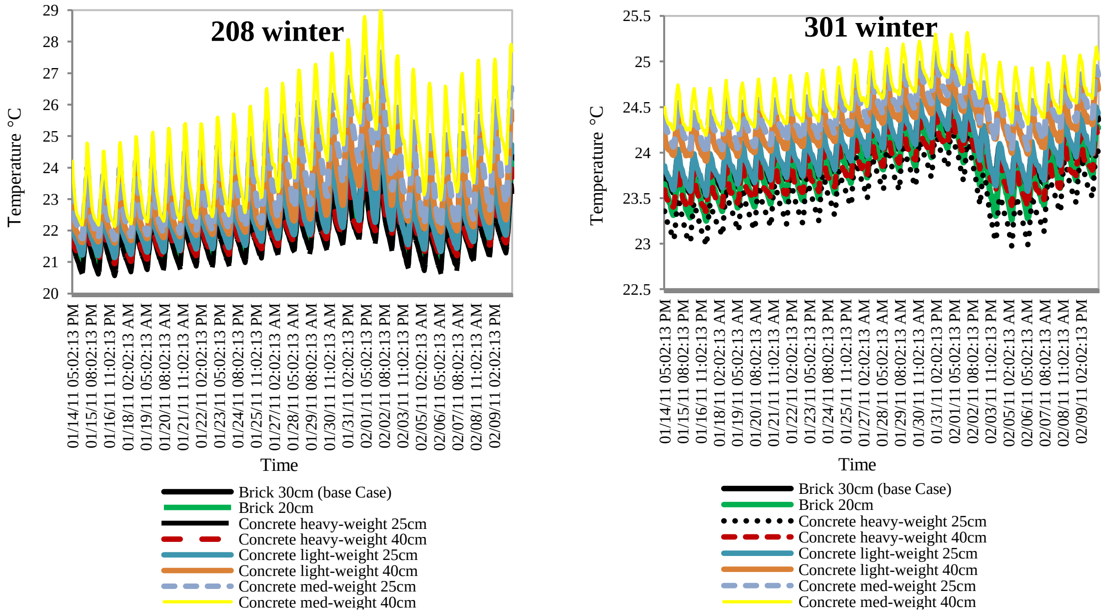


Figure 8.31: Indoor temperature profile with different thermal mass materials in classrooms 208 and 301 in Jan/Feb 2011

Tables 8.38 and 8.39 show the minimum and maximum indoor air temperatures in classrooms 208 and 301 after employing different thermal mass materials to the external wall layers of the base case building during the field study experiment in April/May and January/February. It can be seen that the medium-weight and lightweight concrete resulted in the maximum indoor temperature and heavyweight concrete and brick materials resulted in minimum indoor air temperatures in both classrooms and in both seasons, similar to the survey days' results.

Table 8.38: Maximum and minimum indoor air temperature with various thermal mass materials for Classroom 208 on April/May 2010 and January/February 2011

Thermal mass		**Brick (base case)**	**Brick**	**Heavy concrete**	**Heavy concrete**	**Med concrete**	**Med concrete**	**Light concrete**	**Light concrete**
Thickness (cm)		**30**	**20**	**25**	**40**	**25**	**40**	**25**	**40**
4th May	Max°C	30.79	30.9	30.8	30.6	31.1	31.1	30.9	30.8
	Min°C	21.36	21.1	20.9	21.4	21.6	21.8	21.2	21.7
9th Feb	Max°C	25.29	25	24.3	25	25.6	26.9	27.7	29
	Min°C	21.13	20.9	20.6	21	21.2	21.6	21.7	22.1

Table 8.39: Maximum and minimum indoor air temperature with various thermal mass materials for Classroom 301 on April/May 2010 and January/February 2011

Thermal mass		**Brick (base case)**	**Brick**	**Heavy concrete**	**Heavy concrete**	**Med concrete**	**Med concrete**	**Light concrete**	**Light concrete**
Thickness (cm)		**30**	**20**	**25**	**40**	**25**	**40**	**25**	**40**
4th May	Max°C	30.13	30.3	30.2	29.8	30.3	30.1	30.4	30.4
	Min°C	21.29	21	20.8	21.3	21.2	21.7	21.5	21.8
9th Feb	Max°C	24.64	24.5	24.3	24.5	24.7	25	25.1	25.3
	Min°C	23.51	23.3	23	23.4	23.5	23.9	24	24.2

8.6.7. Cavity walls

Cavity walls (see Figure 8.32) include two skins or two wythes of masonry, such as brick or concrete blocks, which are separated by a cavity. The cavity between two walls ranges from 5 cm to 10 cm maximum and can include insulation, as it may improve the indoor thermal performance of the building (Masonry Advisory Council, 2002). Applying cavity walls to the building envelope has several advantages compared to solid walls:

- Increasing resistance to moisture penetration.
- Providing high thermal energy efficiency in the building and reducing heat loss and heat gain.
- Increasing fire resistance.
- Can be used as load bearing material, as its capacity is excellent (Masonry Advisory Council, 2002).

In addition, cavity walls provide a high thermal mass within the building envelope, especially when insulated (Butcher, 2009). The insulated cavity wall can supply higher thermal mass if the interior surface of the wall is exposed (Walsh et al., 2006).

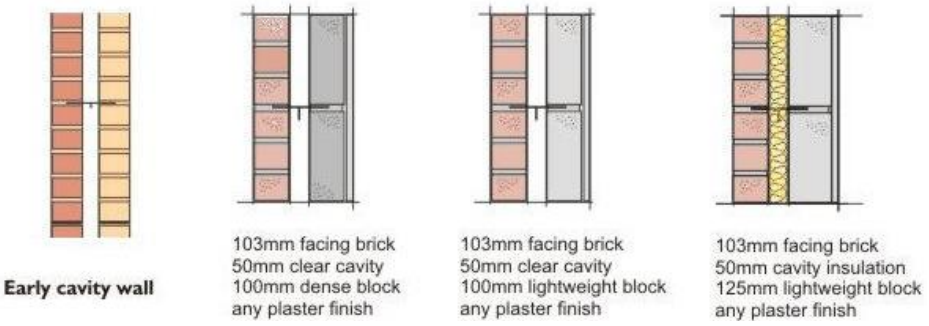


Figure 8.32: Example of various cavity walls (University of the West of England, 2006)

In this study, the aim of applying the cavity walls to the simulation modelling is to analyse the effect of cavity walls on indoor air temperatures, as they provide high thermal mass. In cavity walls, the separation of both walls by the air space allows considerable amounts of heat absorb and scatter in the outer wall and cavity before getting into the inner wall and indoor environment. Generally, cavity walls have a productive impact on the heating and cooling loads of the building (Masonry Advisory Council, 2002).

Figure 8.33 presents the impact of external cavity walls on indoor air temperatures in south- and north-facing classrooms on the survey day, May 2010. The dimensions and materials used for this simulation modelling are based on the recommendations of the Iranian Building Codes (Mporg, 2006). It can be seen that using various kinds of materials, such as masonry elements with different thicknesses in cavity walls made a small change to indoor air temperatures in both classrooms on the survey day in May, since they increased in all classrooms using cavity walls, but it was a very small change, of about 0.5K at most (see Figure 8.33). However, lightweight concrete resulted in higher indoor air temperatures than heavyweight concrete.

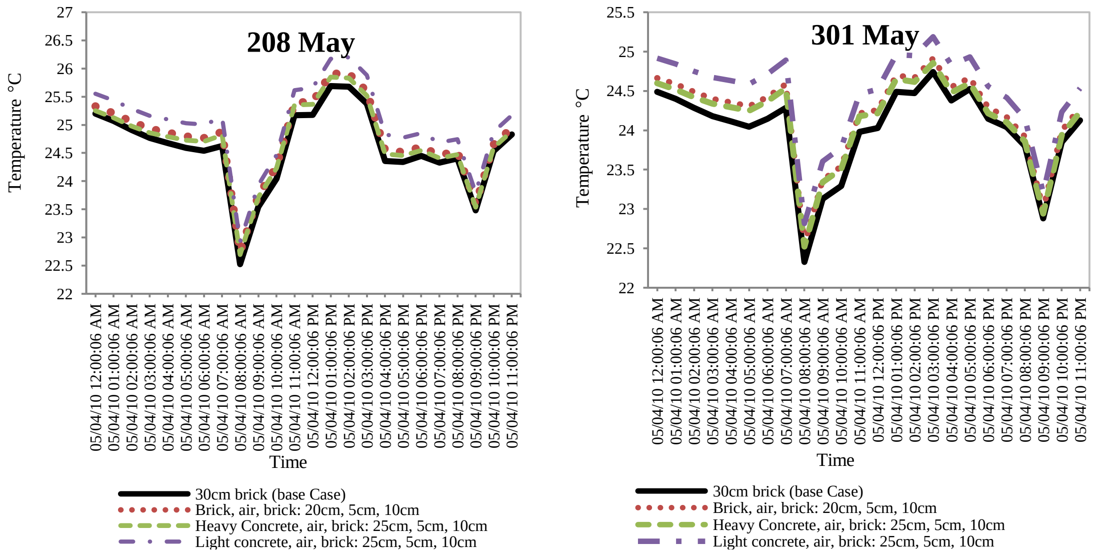


Figure 8.33: Indoor temperature profile with different cavity wall strategies in classrooms 208 and 301 on 4th May 2010

Figure 8.34 illustrates the effect of cavity walls on indoor air temperatures in both classrooms on the survey day in February. Likewise in May, applying lightweight concrete had more impact on increasing indoor air temperatures but this change was considerably higher in Classroom 208 than the north-facing classroom, Classroom 301, in the winter.

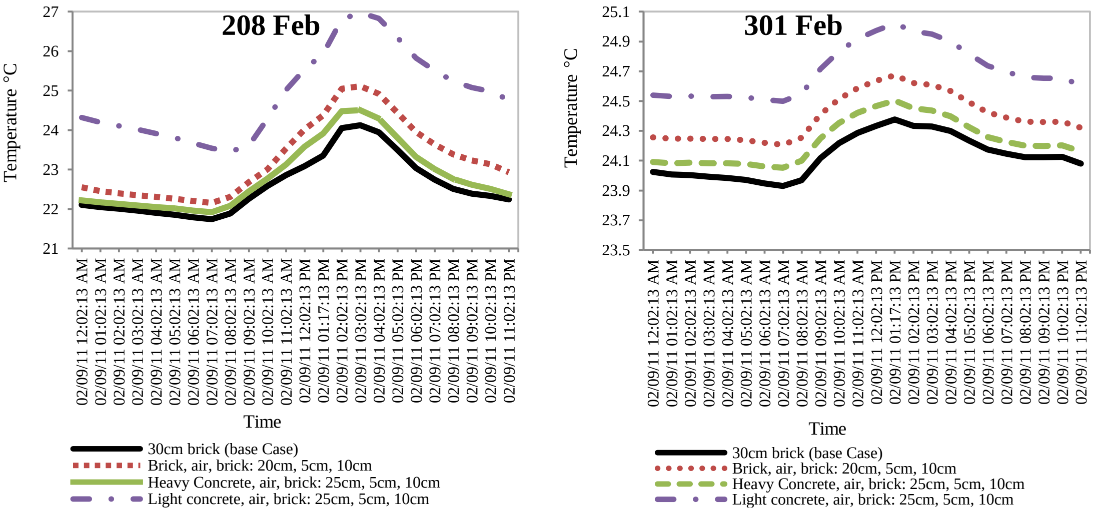


Figure 8.34: Indoor temperature profile with different cavity wall strategies in classrooms 208 and 301 on 9th Feb 2011

The indoor air temperature in Classroom 208 increased by about 2.5K maximum, but this change was only 0.5K in Classroom 301, like May's result. A possible reason might be the good construction of Classroom 301, which helped to reduce temperature fluctuations and the poor construction of the Classroom 208, which was improved by applying cavity walls. Also Classroom 208 faced south- and cavity walls could act as thermal mass and store solar radiation during the daytime and release it at night. In addition, lightweight concrete caused greater increases in indoor air temperatures. As discussed previously in this section, using lightweight concrete in a building's envelope causes longer thermal lags, which might bring higher temperatures, when using lightweight concrete blocks compared to heavyweight ones (Ries and Holm, 2004, Vangeem et al., 2013).

Tables 8.40 and 8.41 shows the minimum and maximum indoor air temperatures caused by employing cavity walls in the base case building. Lightweight concrete resulted in having maximum indoor air temperatures and the base case model had the minimum indoor air temperatures in both classrooms and in both seasons, though the difference was not very significant.

Table 8.40 : Maximum and minimum indoor air temperatures with various cavity walls for Classroom 208 on 4th May 2010 and 9th February 2011

Cavity walls		**Brick (base case)**	**Brick air brick**	**Con heavy air brick**	**Con light air brick**
4th May	Max°C	25.69	25.9	25.9	26.2
	Min°C	22.53	22.7	22.7	22.9
9th Feb	Max°C	24.12	25.1	24.5	27
	Min°C	21.74	22.2	21.9	23.5

Table 8.41 : Maximum and minimum indoor air temperature with various thermal mass materials for Classroom 301 on 4th May 2010 and 9th February 2011

Cavity walls		Brick (base case)	Brick air brick	Con heavy air brick	Con light air brick
4th May	Max°C	24.74	24.9	24.9	25.2
	Min°C	22.33	22.6	22.5	22.8
9th Feb	Max°C	24.38	24.7	24.5	25
	Min°C	23.93	24.2	24.1	24.5

Figures 8.35 and 8.36 present the effect of applying cavity walls to the base case building on indoor air temperatures in both classrooms during the field studies experiment in April/May 2010 and January/February 2011.

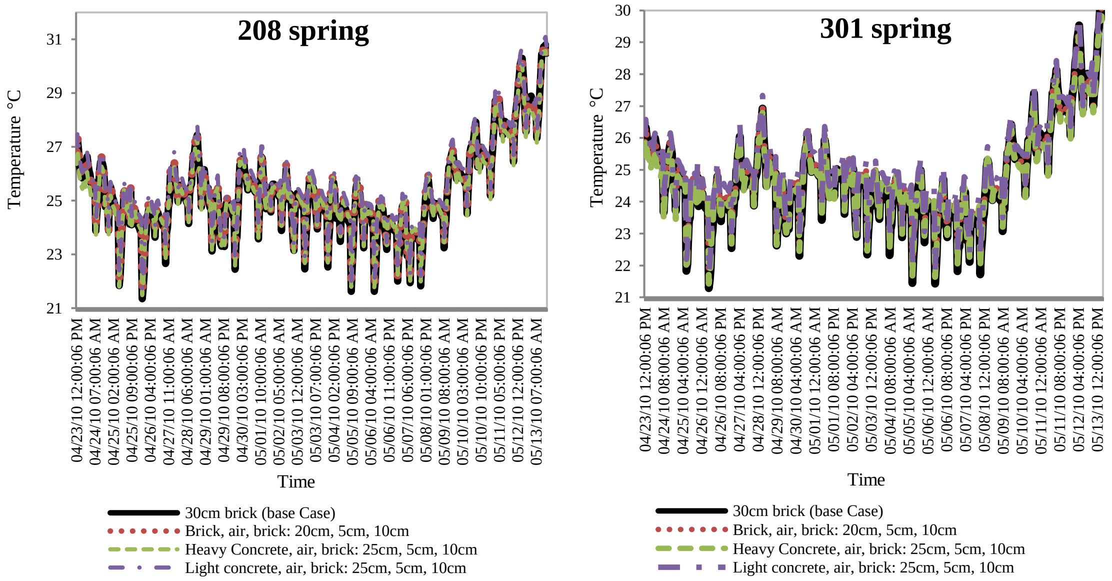


Figure 8. 35: Indoor temperature profile with different cavity wall strategies in classrooms 208 and 301 in April/May 2010

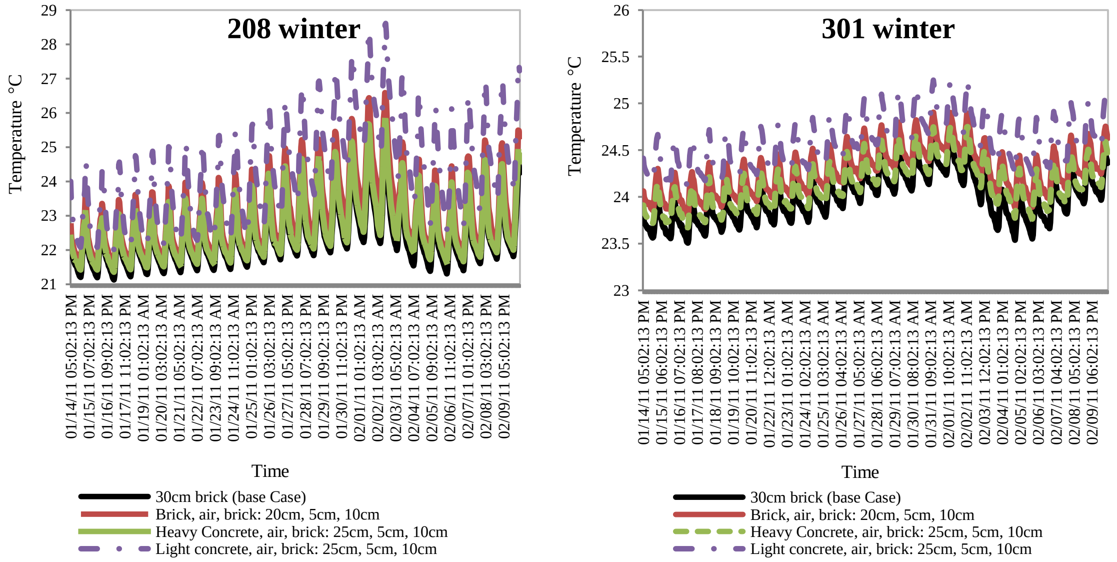


Figure 8.36 : Indoor temperature profile with different cavity wall strategies in classrooms 208 and 301 in Jan/Feb 2011

It can be seen that the whole period in both classrooms and in both seasons had similar changes as on the survey days in May and February. The lightweight concrete had more impact on increasing indoor air temperatures than heavyweight concrete, in both seasons. The increase in air temperatures was significantly high in Classroom 208, using lightweight concrete in the winter season. As the classroom faced south, the mass of the cavity walls could store heat during the day and release it overnight. In addition, lightweight concrete reduces thermal lag (Ries and Holm, 2004, Vangeem et al., 2013), which might be a reason for having higher temperatures in Classroom 208 in winter. Tables 8.42 and 8.43 show that the lightweight concrete resulted in the maximum indoor air temperatures and the base case had the minimum indoor air temperatures in both seasons and in both classrooms.

Table 8.42: Maximum and minimum indoor air temperatures with various cavity walls for Classroom 208 on April/May 2010 and January/February 2011

Cavity walls		Brick (base case)	Brick air brick	Con heavy air brick	Con light air brick
4th May	Max°C	30.8	30.8	30.6	31.1
	Min°C	21.4	21.6	21.5	21.7
9th Feb	Max°C	25.3	26.6	25.9	28.6
	Min°C	21.1	21.5	21.4	22

Table 8.43: Maximum and minimum indoor air temperatures with various thermal mass materials for Classroom 301 on April/May 2010 and January/February 2011

Cavity walls		Brick (base case)	Brick air brick	Con heavy air brick	Con light air brick
4th May	Max°C	30.13	30.1	29.8	30.4
	Min°C	21.29	21.6	21.4	21.8
9th Feb	Max°C	24.64	24.9	24.8	25.3
	Min°C	23.51	23.8	23.7	24.1

8.7. Discussion of field studies and optimum solutions

A field study experiment was conducted in order to assess the students' thermal satisfaction as well as indoor thermal conditions in the warm spring period and cold winter season. It included a thermal comfort survey and field measurement on the climatic variables, indoor air temperature and relative humidity levels. Later, the passive design strategies were examined using simulation-based analysis to improve the indoor thermal performance of the female secondary school building in Tehran. The optimum design solution will be based on the field studies' results in May and February as well as the result of simulation analysis in employing the passive design strategies. From the result of the field study the students' preferences in the classrooms in terms of the climatic variables were observed and with the help of the simulation analysis the optimal design solution will be defined.

8.7.1. Field study

The field study includes field measurements of the climatic variable in six classrooms for 3 weeks in April/May 2010 and 4 weeks in January/February 2011. During the field measurement, a questionnaire based survey was conducted for one day in May and one day in February to examine the students' thermal expectations in warm and cold seasons in the classrooms facing north and south and located on the first and second floors. As discussed before in Chapter 6, May is the warmest period during the academic year before the final exams and summer holiday and February is the coldest period before the winter holiday (Kasmai, 1994). The field study was not conducted during the summer as the school was closed after final exams for the summer vacation.

8.7.2. Field measurement

Filed measurement included the measurement of indoor air temperature and relative humidity levels during the field study experiment, covering the survey days in spring and winter seasons. The initial comfort temperature in the base case building is defined based on Heidari's equation (Eq.8.1) and his suggested range for the comfort temperature in indoor environments. The comfort temperatures for the classrooms during May and February are 24.46°C and 19.60°C respectively with the range of ±7K and ±3.5K from the comfort temperature in spring and winter seasons. As the results of survey have an effect on the choice of optimum design solution, the primary focus of the field measurements during the simulation analysis will be on the survey days in both seasons. As perceived before (Section 8.6), the results of a one day survey in cold and warm seasons is similarly changed, compared to the whole period of field measurements in each classroom, and the trends changed almost exactly in parallel with specific design solutions. Table 8.44 presents the maximum, minimum and mean indoor air temperatures in classrooms 208 and 301 during the survey days. Based on the field measurement results, the mean indoor air temperature in both classrooms was around 23.5°C during the May survey day, which falls within the comfort temperature zone. During the winter survey day, the indoor air temperature was more than 23°C in Classroom 208 and less than 26°C in Classroom 301. The internal temperature was still in the comfort zone in Classroom 208, just below the maximum comfort temperature in winter, but in Classroom 301 it was warmer than the maximum comfort temperature in the cold season. A reason for this temperature difference might be the different infiltration rates in both classrooms, as well as various adjustable heating settings in both classrooms.

Table 8.44 : Mean, maximum and minimum indoor air temperature in classroom 208 and 301 on 4th May 2010 and 9th February 2011

Classroom	**208**		**301**	
	May	**Feb**	**May**	**Feb**
Mean T °C	23.70	23.66	23.69	25.55
Min T °C	22.62	21.95	22.92	24.25
Max T °C	25.42	25.90	24.94	26.88

8.7.3. Questionnaire survey

The results of the questionnaire survey indicated that just less than 73% of the students' responses on the morning of the May survey day fell into the central three categories of the ASHRAE scale (slightly cool, neutral, and slightly warm) and more than 83% of the students who voted in these categories preferred a cooler environment. As mentioned in Section 8.7.2, the indoor comfort temperature in the two classrooms during the May survey day fell within Hedari's comfort zone (Eq.8.1) but the students wanted to be in cooler classrooms. On the other hand, during the winter survey day, 73% of the students' responses fell into the central three categories of the ASHRAE scale, similar to the warm spring results. However, around 36% wanted a warmer environment and 33% wanted no change in the indoor air temperature, while surprisingly, more than 30% wanted a cooler environment in the winter season. A possible reason for this could be the higher indoor air temperatures around the radiators in the classrooms, which made some of the students feel too warm. It should be noted that the indoor air temperature in Classroom 208 fell within the comfort zone in winter but was slightly higher than the maximum comfort temperature in Classroom 301 during the same day.

It should be remembered that, based on the ASHRAE (2004), if 80% of the occupants vote in the central three categories of the ASHRAE scale, it shows their thermal satisfaction with the indoor thermal conditions. In this study the thermal sensation votes was slightly below 80% in both seasons. Also thermal preference votes confirm the view that the students wanted their thermal environment to be changed in both seasons. During the spring season they wanted a cooler environment but the result of preference votes is a little complex during the winter because the heating system, which had various set points in different classrooms, could be adjusted manually by the occupants. In addition, the scatter diagrams of the mean indoor air temperature and the thermal sensation responses had a positive relationship in May and February. However, the scatter diagram of the mean indoor air temperature and mean preference response had a negative relationship during the same seasons, which shows that, as the indoor air temperature increased, students preferred to be in cooler environment. These results show the validity of the survey results in both seasons (see Figures 6.31 to 6.44 in Chapter 6).

Moreover, occupants indicated their feeling regarding air flow and the humidity in both seasons. The results showed that most students felt 'just right' in terms of humidity in both the spring and winter seasons, as around 54% of the students voted 'just right', although the indoor relative humidity was below standard, which is 30% (Chegeni, 2011), in all classrooms and in both seasons. A possible reason might be a misunderstanding of a considerable number of the young students regarding humidity sensation. Although a low humidity level makes them uncomfortable, they might not be aware that this dissatisfaction is the result of low relative humidity levels and might believe that the indoor air temperature was not acceptable instead. However, a significant amount of the occupants felt 'dry', at around 42% in spring and 30% during the winter survey day.

In terms of air flow, considerable number of the occupants felt ‘just right’ in all classrooms during the spring season, at about 45%, but the same amount of occupants felt it was ‘still’ in the winter season. However, a large number of the students felt ‘still’ after choosing ‘just right’ in May survey day, at around 40%, and the same amount felt ‘just right’ in winter. As the windows were open during the warm season and closed during the winter, the air flow rate was higher in spring and, as a result, more students felt higher air flow rate than in the winter season.

These results illustrate that there should be some changes in the design of the building to bring the temperature to a lower level in the warm period and to keep the temperature higher in cold seasons, with the minimum use of energy in winter (during the winter the heating was always on and, in some classrooms, students felt warm in winter). In addition, the results show that the defined comfort temperature, based on Heidari’s equation (Eq. 8.1), as well as the comfort temperature range for the students in secondary schools for girls in Tehran, is different from the one defined by Heidari’s equation. The comfort temperature should be lower in warm seasons and higher in cold seasons. A possible reason is related to religious and culture grounds. As the female students needed to wear a special uniform and cover up their head in the school building on religious grounds, the neutral temperature was slightly different in school for girls in Tehran. Moreover, in the school building the students had less control in make themselves comfortable, compared to residential buildings, and they needed to wear the school uniform at all time. As a result, the range of the comfort temperature is more limited than Heidari’s defined range. The comfort range is more similar to Nicol and Humphrey (Nicol and Humphrey, 2001), ±2K of the comfort temperature range. Based on the questionnaire studies in this research, the maximum comfort temperature in May was 24.5˚C and the minimum in February was 20˚C, as most of the students wanted a cooler environment when the indoor air temperature was more than 24.5˚C and a warmer environment when the indoor air temperature was below 20˚C.

8.8. Recommended optimum solution

Based on the field study experiment and the simulation analysis results, the initial optimum design solution for the base case building was defined using passive design strategies. The optimum factors were taken from the analysed passive design strategies, including orientation, glazing, shading devices, thermal mass, ventilation and insulation. The result was developed to improve indoor thermal comfort and thermal performance in the classrooms. They were updated, based on the suggested comfort zone in the classrooms and the primary optimum design combination, which included suggested building orientation in the Iranian building regulations, double glazing windows for improving the airtightness of the room, a combination of 30cm of the overhangs and side fins for south and north-facing side classrooms, external thermal insulation material with the U-value between 0.28 and 0.32w/m^{2}k for the external walls, 25 cm high density concrete blocks as a thermal mass for the exterior facade and all day natural ventilation strategies during the warm season. In addition, two more strategies were employed on the external walls to compare the overall results of the suggested optimum solution: 30 cm brick as thermal mass material and cavity walls with external insulation. To estimate the effect of the optimum solution, the real base case building was compared to the optimum design solution. Table 8.45 summarises the initial optimum solution.

Table 8.45 : Initial optimum design solution based on passive design strategies

Passive Design Strategy	Optimum Design Solution
Orientation	Main axis extended east west
Glazing	Double glazing
Shading Devices	30 cm overhangs and side fins
Ventilation	All day ventilation in warm season
Thermal Mass in external walls	Option 1. Brick Option 2.High dense concrete blocks Option 3.Cavity walls: 10cm brick, 10cm insulation 25cm high dense concrete
Insulation	10 cm EXP or glass wool in either side of the external walls and 5cm in roof
Heating system	off

8.8.1. Spring optimum solution

Figures 8.37 and 8.38 illustrate the indoor air temperature of the real base case and the optimum solutions in classrooms 208 and 301 with respect to outdoor temperature and the comfort temperature on the 4th May 2010. The peak indoor air temperature is decreased by approximately 3K by the applications of optimum solutions during the survey day on 4th May 2010 in Classroom 208. It should be noted that peak indoor air temperature was during the occupied period in midday while the windows were open. In addition, the indoor air temperature reduced by about 5.5K during the unoccupied period which is still a significant amount.

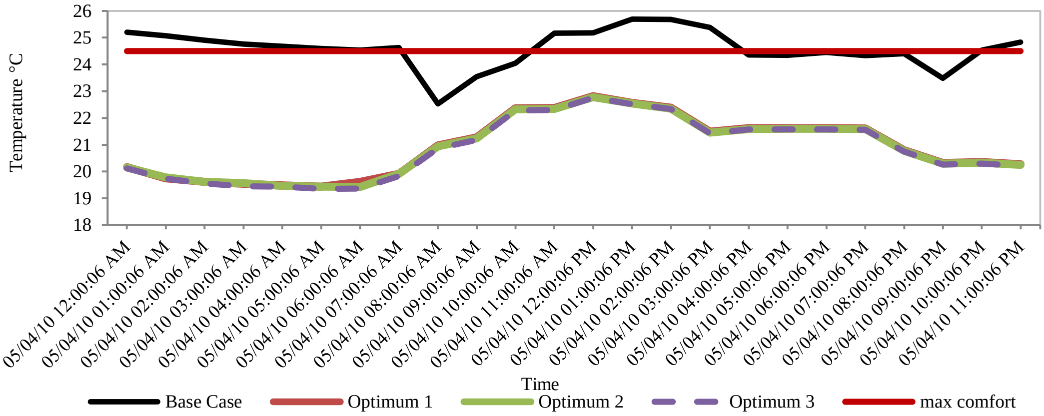


Figure 8. 37 : Optimum design solution in Classroom 208 on the 4th May 2010

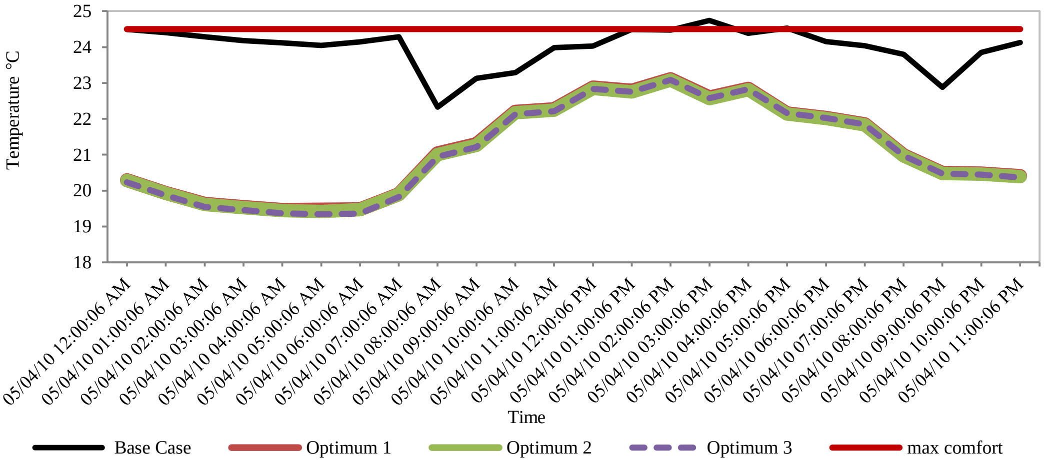


Figure 8.38 : Optimum design solution in Classrooms 301 on the 4th May 201

The reduction of the peak indoor air temperature during the occupied period in Classroom 301 was less than Classroom 208, around 2K which is considerable. Also the reduction of maximum indoor air temperature during the unoccupied period was around 4.5K. After the application of the optimum solutions the whole profile of the indoor air temperature was around proposed comfort temperature in both classrooms. Table 8.46 presents the temperature difference between the minimum, maximum and mean indoor air temperature before and after the application of optimum solutions. It can be seen that by applying all the proposed solutions the indoor air temperature in both classrooms reduced significantly and the temperature difference between each optimum solution and the base case temperature is approximately similar during the 4th May 2010.

Table 8.46 : Difference between minimum, maximum and mean indoor air temperature before and after application of optimum solutions in May 2010

Indoor air temperature °C	**Mean**		**Max**		**Min**	
	208	**301**	**208**	**301**	**208**	**301**
Real base case	24.60	24.01	25.69	24.74	22.53	22.33
Optimum solution 1	20.92	21.13	22.82	23.10	19.44	19.47
Optimum solution 2	20.89	21.11	22.78	23.08	19.42	19.42
Optimum solution 3	20.85	21.08	22.76	23.08	19.35	19.34

8.8.2. Winter optimum solution

Figures 8.39 and 8.40 illustrate the indoor air temperature of the real base case and the optimum solutions in classrooms 208 and 301 with respect to outdoor temperature and the comfort temperature on the 9th February 2011. During the application of the optimum solutions, the heating system was turned off to compare the maximum indoor air temperature caused by the optimum solutions to the base case indoor air temperature, while the radiators were turned on.

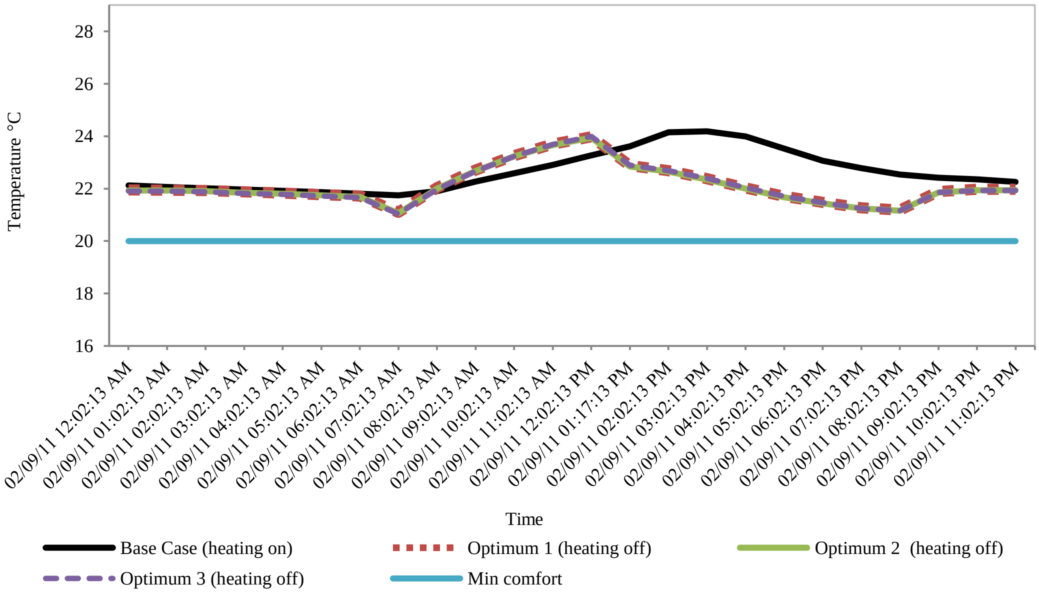


Figure 8.39 : Optimum design solution in Classrooms 208 on 9th Feb 2011

By the application of the all optimum design solutions, the maximum indoor air temperature was decreased by approximately 2K during the survey day on 9th February 2011 in Classroom 208. It should be noted that the heating system was turned off during the application of the optimum solutions. As a considerable amount of the students preferred to be in the cooler environment, at around 52%, and the indoor air temperature reduced by about 2K by the optimum solutions, more comfortable indoor environment could be provided with the minimum building energy use and while the indoor air temperature was around the proposed comfort temperature. In addition, by the application of the optimum solutions, the indoor air temperature was reduced by about 2.5K to 4K in Classroom 301. Similar to Classroom 208, a considerable number of the students wanted their environment to be cooler in this classroom. After the application of the optimum solutions the indoor air temperature reduced significantly and as a result the students might feel more comfortable in the classroom.

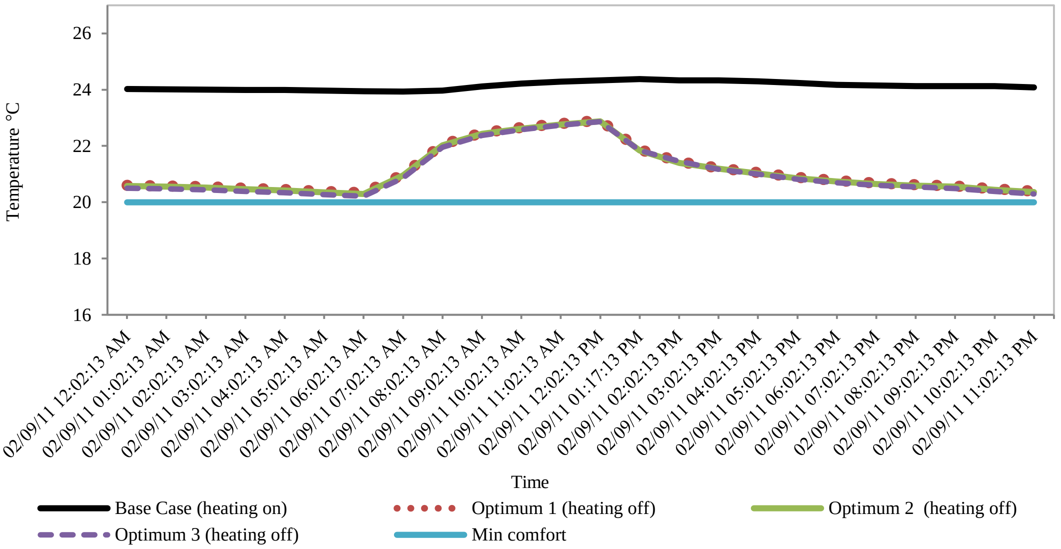


Figure 8.40 : Optimum design solution in Classrooms 301 on 9th Feb 2011

Table 8.47 presents the temperature difference between the minimum, maximum and mean indoor air temperatures before and after the application of optimum solutions in winter. It can be seen that, by applying all the proposed solutions, the indoor air temperature in both classrooms reduced while the heating system is set to be off. The temperature difference between each optimum solution and the base case temperature was approximately similar during the 9th February 2011.

Table 8.47 : Difference between minimum, maximum and mean indoor air temperature before and after application of optimum solution on 9th February 2011

Indoor air temperature °C	**Mean**		**Max**		**Min**	
	208	**301**	**208**	**301**	**208**	**301**
Real base case	22.64	24.13	24.19	24.38	21.75	23.93
Optimum solution 1	22.14	21.14	23.98	22.91	21.10	20.34
Optimum solution 2	22.11	21.10	23.94	22.87	21.07	20.30
Optimum solution 3	22.11	21.05	23.99	22.87	21.04	20.21

8.9. Overview of the whole period

To get an overview of the application of the optimum solutions during the whole period of the field study and compare the results in spring and winter seasons in south- and north-facing side classrooms, a simulation analysis was performed for 3 weeks in the warm spring season of April/May from 23rd

April to 13th May in 2010; and for 4 weeks in the cold period of January /February from 14th January to 10th February in 2011, by applying the proposed optimum solutions. The selected periods for the field study in spring and winter represent the warmest and coldest periods throughout the year and while the schools are open before the exams and winter and summer holidays. The minimum, maximum and the average indoor air temperatures of the base case during the whole period of were compared to the results of the optimum solutions, in order to identify whether the internal temperatures were in the proposed comfort band during the whole period of studies.

8.9.1. Spring season

Figure 8.41 and 8.42 presents the based case indoor air temperature profile, as well as the optimum solutions temperature profile, during the warm spring period of April/May 2010 in north- and south-facing side classrooms, 301 and 208 respectively. It should be noted that, in the base case building, the windows were open from 7:00am till 9:00pm during the occupancy, until the cleaning up period.

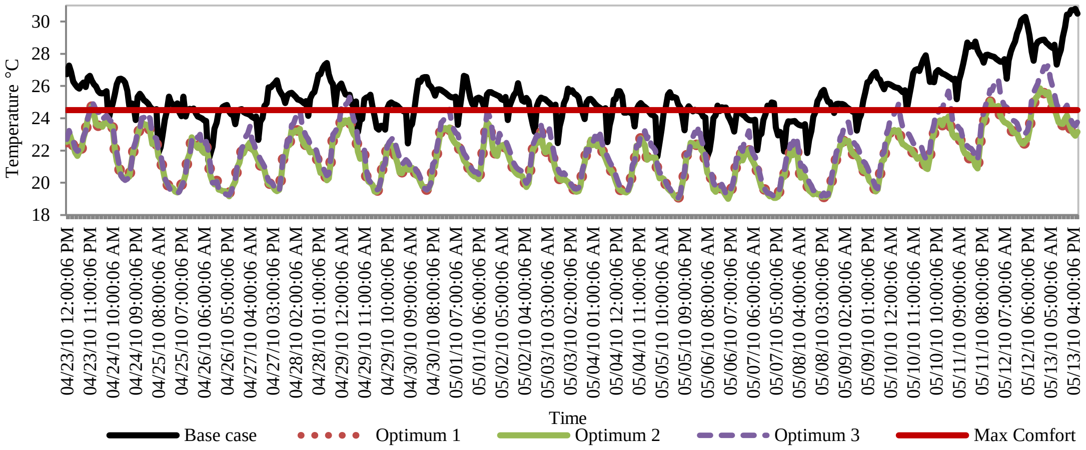


Figure 8.41 : Optimum design solution in Classrooms 208 in April/May 2010

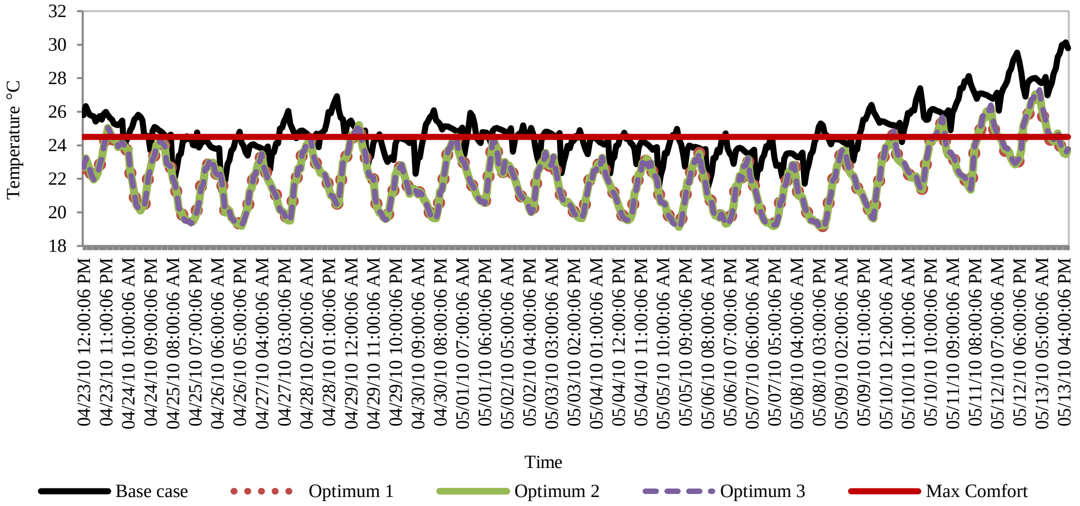


Figure 8.42 : Optimum design solution in Classrooms 301 in April/May 201

It can be seen that after the employment of all optimum solutions the indoor air temperature mostly decreased considerably during the warm spring period. The maximum and minimum temperatures were mostly within the proposed comfort band in both classrooms, except from midnight till early morning, before the occupancy period. The reason was the use of thermal mass in the external walls, which kept the heat of the solar radiations inside during the daytime and released it during the night and early mornings, just before the sunrise. However, during the night-time, while the heating was releasing by the mass of the external walls, the rooms were not occupied and, as a result, the increase in indoor air temperatures was not a concern. Table 8.48 confirms that the mean indoor air temperatures as well as minimum indoor air temperatures were within the proposed comfort band in both classrooms, by employing all optimum solutions. On the other hand, the maximum indoor air temperature was not within the comfort band in classrooms 208 and 301 but as mentioned above, it usually increased beyond the comfort band while the classrooms were not occupied. In addition, the application of all optimum solutions resulted in the reduction of the average internal temperatures from about 4K in Classroom 208 to less than 3K in Classroom 301, which is significant.

Table 8.48 : Difference between minimum, maximum and mean indoor air temperature before and after application of optimum solution from 23rd April 2010 to 13th May 2010 in classrooms 208 and 301

Indoor air temperature °C	**Mean**		**Max**		**Min**	
	208	**301**	**208**	**301**	**208**	**301**
Real base case	25.35	24.81	30.79	30.13	21.35	21.29
Optimum solution 1	21.62	22.04	25.82	26.99	19.04	19.18
Optimum solution 2	21.61	22.04	25.87	27.12	18.10	19.13
Optimum solution 3	22.06	22.06	27.31	27.31	19.06	19.06

8.9.2. Winter Season

Figures 8.43 and 8.44 present the base case indoor air temperature profile as well as the optimum solutions temperature profile during the cold winter period of January/February 2011 in classrooms 208 and 301, facing south and north respectively. It should be noted that, in the base case building, the heating system was on all day and the significant number of students in classrooms 208 and 301 wanted their classrooms to be cooler, as the heating was set at a high level. However, during the application of the optimum solutions it was turned off in order to compare the results to the base case, with the minimum heating loads. After applying all the optimum solutions, the indoor air temperature was reduced during the cold period, compared to the base case indoor air temperature.

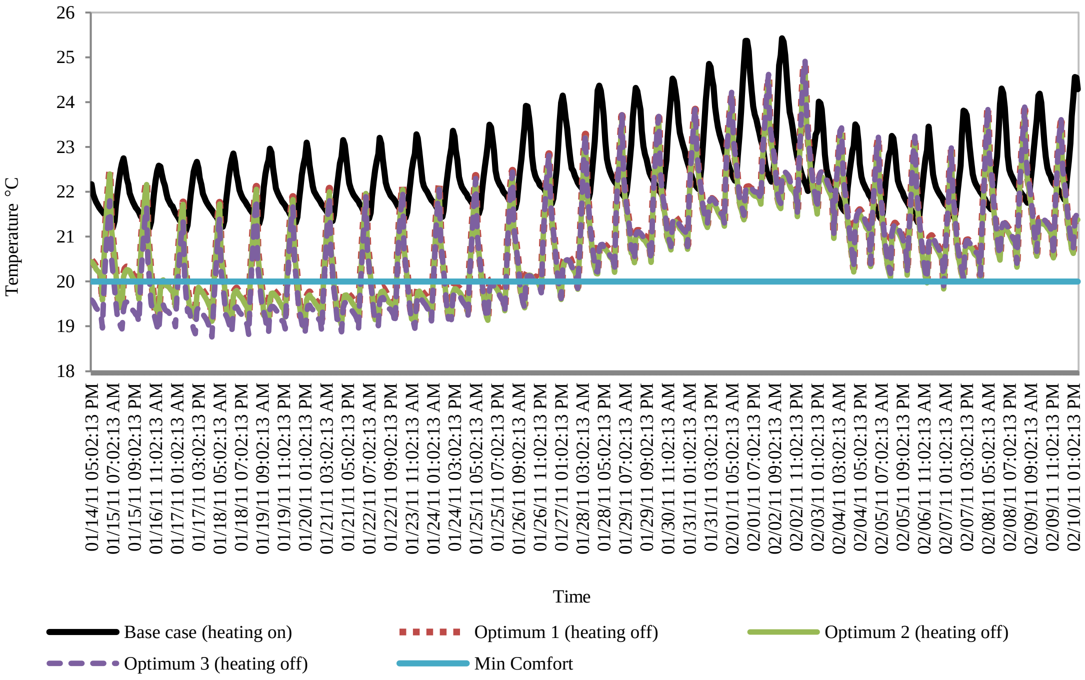


Figure 8.43: Optimum 208 Jan/Feb 2011

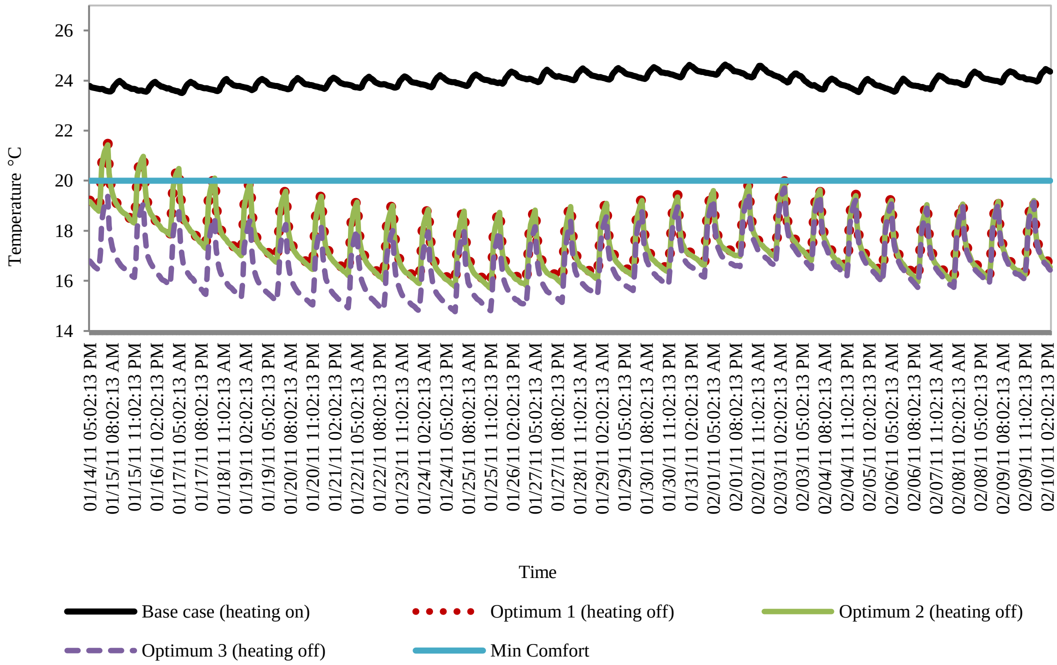


Figure 8.44: Optimum 301 Jan/Feb 2011

Moreover, after the application of the optimum solutions, and while the heating system was turned off, the indoor air temperature usually fell within the acceptable range especially in Classroom 208. With the minimum heating set point, the indoor air temperature can be always kept in a comfort band. Also the clo value of the occupant can be increased instead, when the temperature is less than the lower comfort band, which helps to reduce the heating load of the building. In addition, the indoor air temperature was usually within the proposed comfort band in Classroom 208 but the mean indoor air temperatures in Classroom 301 were sometimes below the proposed comfort band. However, this difference was not significant and, as stated above, with a low heating set point, the indoor air temperature could be increased to the comfort temperature.

Table 8.49 confirms that the maximum indoor air temperature was within the proposed comfort band in both classrooms, by employing all the optimum solutions. The average and minimum indoor air temperatures were slightly below the comfort band but this difference was not significant and could reach the comfort temperature with a minor increase in the heating set point or by increasing the clo value. In general, the application of all optimum solutions resulted in reductions in average internal temperatures from about 1.5K in Classroom 208 to about 7.5K in Classroom 301 while the heating system was off in winter.

Table 8.49: Difference between minimum, maximum and mean indoor air temperature before and after application of optimum solutions from 14th January 2011 to 10th February 2011 in classrooms 208 and 301

Indoor air temperature °C	**Mean**		**Max**		**Min**	
	208	**301**	**208**	**301**	**208**	**301**
Real base case	22.41	24.00	25.43	24.64	21.13	23.51
Optimum solution 1	20.93	17.57	24.85	21.48	19.03	15.82
Optimum solution 2	20.86	17.48	24.76	21.43	19.00	15.71
Optimum solution 3	20.80	16.64	24.93	19.71	18.76	14.77

8.10. Final discussion

A simulation analysis was performed to compare the result of the optimum solution against the base case, after the application of passive design strategies. The aim was to reduce the indoor air temperature in the warm season and to keep the internal temperature in an acceptable range in the cold season, with the minimum energy use. The result of the simulation analysis indicated that all day natural ventilation and the application of the shading devices to the window areas helped significantly in reducing the indoor air temperature in warm spring season. Employing the 30 cm overhang and side fins on the windows is the suggested optimal projection. Solar shading devices reduced the indoor air temperature in winter but this reduction can be overcome by using moveable shading devices. In addition, adding the insulation materials to the external layers of the external walls, and using double glazing windows helped increasing the indoor air temperature in winter, as it reduced the building's infiltration rate. Although adding the double glazed windows and insulation materials to the external wall increased the indoor air temperature in spring, they had a small impact on increasing the temperatures, which was overcome by applying the shading devices and an all-day natural ventilation strategy. It should be noted that all-day ventilation has no cost at all and only obtains by keeping the windows open all day. The installation of thermal insulation and double glazed windows, as well as shading devices, needs installation costs, but using these strategies will reduce the buildings energy costs over the years. Table 8.50 shows the suggested optimum solution for the female secondary school building with respect to the thermal satisfaction of the occupants and passive design strategies for climatic condition of the city of Tehran. The passive design strategies include orientation, glazing, solar shading devices, ventilation, thermal mass and insulation for roof and external walls.

Table 8.50 : Proposed passive design strategies for the female secondary school building in Tehran

Passive Strategies	Solution	Current Practice in a base case
Orientation	South-South East	South
Glazing	Double, with air in between	6 mm Single glazing
Solar Shading	30 cm overhangs and side fins (can be movable to get the effect of sun in winter) Blind and slate can be used in warm season	No solar shading
Ventilation	All day ventilation in hot and warm seasons	Ventilation from 7:00am to 21:00 in spring
Wall Insulation	10 cm common thermal insulation material on external side of external walls layers	No wall insulation
Roof Insulation	5 cm common thermal insulation materials on internal side of roof layers	5 cm insulation on the external layers of roof
Thermal Mass	25 cm high-density concrete blocks or 30 cm outer bricks in external walls	30 cm brick in external walls

The cost of passive design strategies needs to be assessed to evaluate the benefits of passive design strategies in saving energy and reducing building energy costs, against the installation and maintenance of the passive techniques in the city of Tehran and for secondary school buildings.

8.11. Conclusions

This chapter presented the thermal simulation analysis for the female secondary school building in the city of Tehran, using passive design strategies. The base case building was modelled on a building thermal simulation tool, which in this case was DesignBuilder. Based on the passive design strategies and the students' thermal preferences within the classrooms, the optimum design solutions were defined for the secondary school buildings to improve the indoor thermal conditions by comparing the effect of each passive design strategy to the base case building. The suggested optimum solution includes all day ventilation, installation of overhangs and side fins, the use of thermal mass and thermal insulation in external walls and roof. The primary simulation study was performed during a survey day in the spring and winter seasons separately. To confirm the results of the survey days, the extended simulation analysis was consequently performed during the whole period of the field study in spring and winter seasons.

Chapter 9: Environmental Design Guidelines for Schools in Tehran

9.1. Introduction

Creating comfortable and healthy indoor study space is one of the essential purposes of climatic design of school buildings. Environmental design guidelines help to reduce electrical and mechanical energy consumption in buildings by getting the benefits of natural energy sources. In this section, the environmental design guidelines for the female secondary school buildings in the city of Tehran have been introduced, based on the results of this research. In Chapter 8 the effects of various passive design strategies, including orientation, solar shading devices, glazing, thermal mass and cavity walls, as well as external walls and roof insulation on indoor air temperature in spring and winter seasons, were studied, and the final recommendations are summarised in this chapter as the climatic design guidelines, with regards to female students thermal satisfaction in the secondary school building. Using climatic design in buildings can save energy and also protect the environment. The guidelines consist of the thermal conditions of the classrooms; indoor temperatures in cold and warm seasons; building orientation; thermal insulation; thermal mass, glazing and shading devices; and ventilation strategies. These guidelines can be used in most hot and dry climatic regions in Iran.

9.2. Climate of Tehran

In relation to the environmental design purpose, the city of Tehran is classified as a hot and dry climatic region. Generally, Tehran has hot summers with low humidity levels and cold winters (Kasmai, 2008). Annual precipitation is low and average rainfall on the plain is about 218mm. The average temperature during the hottest period is 29.6˚C in July/August and during the coldest period is 3.1˚C in January/February (Irimo, 2011). In general, the coldest period is in December, January and February and the hottest period is from June to August. However, May is the warmest period during the academic year, as the schools are usually closed during the summer season. The design recommendations in this chapter can be used for similar climatic regions. Figure 9.1 shows the geographic location of Tehran.

Figure 9.1: Geographic location of Tehran

9.3. Thermal condition

The thermal conditions of the classrooms within the female school building in Tehran should be suitable for the activities and clothing of the students, so the metabolic heat rate and clothing insulation of the students needs to be considered during the design process, in order to achieve thermal comfort. The activities of the students in the classrooms are light office activities, such as reading and writing, with a typical metabolic heat rate of 1 met. However, their clothing insulation is generally higher than male students and the female students need to wear a specific uniform, as explained previously. Clothing insulation is 0.71 clo in the warm spring period and 1.42 clo in the cold winter season. Thermal comfort can be gained when there is a balance between body heat and its loss to the surroundings. The rate of heat loss is related to clothing insulation and the temperature of the air and surrounding surfaces. The heat produced by the students' activities is lost to the surroundings by the normal processes of convection, conduction, radiation and evaporation (DfES, 2003a). Hence, it is important for the architects and the designers to consider the activities and clothing of female students during teaching hours, in order to create comfortable study spaces.

9.4. Preferred Temperature

The preferred indoor air temperature in the classrooms during the teaching hours is another important factor which needs to be considered, in order to produce a comfortable space for the occupants. Based on this study, female students felt uncomfortable when the indoor air temperature was more than 24.5˚C in the warm season and less than 20˚C in the cold season.

In addition, by applying appropriate passive design solutions to the school buildings, the peak indoor air temperature can be decreased by around 2K in north-facing classrooms and by 4K in south-facing classrooms in spring during teaching hours. Also, the internal air temperature in north- and south- facing classrooms can be held in an acceptable condition in winter with the minimum use of the heating system, which results in reducing the heating loads of the building. The indoor air temperature can be stable between 19°C and 25°C in south-facing classrooms and varied from 16°C to 21.5°C in north-facing classrooms during the occupancy period with the no heating system, where the outdoor air temperature is between 0°C and 8°C. When the students feel cold, the heating system can be turned on with the minimum heating load or clo value of the clothing insulation can be increased instead in cold seasons.

9.5. Recommendations for architectural features

In order to apply environmental design features in secondary school buildings in the city of Tehran, appropriate passive design strategies, including orientation, glazing and shading devices, thermal mass, insulation materials, as well as natural ventilation, with respect to the female students' thermal preferences, needs to be considered during the design process by architects and designers. For the climatic design of school buildings in Tehran, the main aims are outlined below:

- Preventing solar radiation in warm periods and provide it in cold seasons.
- Providing shade in hot and warm seasons.
- Providing natural ventilation in hot and warm seasons.
- Keeping indoor air temperatures at a desirable and stable level in warm and cold seasons.

9.5.1. Orientation

For school building orientation in the city of Tehran, it is necessary to consider solar radiation to get the benefits of the sun during the cold season and prevent it penetrating into classrooms during the hot and warm season which help to overcome the overheating during teaching hours. To minimise the amount of solar radiation penetrating into the indoor spaces in warm seasons, and to maximise it in cold seasons, the best orientation for the main facades of school buildings in Tehran is south to south-east, which is also recommended by Iranian building regulations; the worst is west and south-west.

9.5.2. Glazing

This study proves that using double glazed and triple glazed windows has a considerable effect on indoor air temperature during the winter period, as it improves the infiltration rate of the building and, as a result, increases the indoor air temperature in winter and reduces the need to the heating systems. However, it is suggested to use double glazed rather than triple glazed windows, for economic reasons. The maximum glazed area of 30-40% suggested by Iranian building regulations for heat loss purposes is acceptable, as it provides good daylight design.

9.5.3. Shading devices

Protecting the indoor environment from solar radiation during the hot seasons is one of the main purposes of the climatic design in the city of Tehran. All the openings facing east, south and west should have some means of shading device. There should be no windows on the east and west side of the classrooms though, as these directions get the maximum sunlight during the hot season, and may cause overheating. Thermal simulation in this study shows that installing 30cm overhangs and side fins in combination for south- and north-facing classrooms has a considerable effect on reducing indoor air temperatures during the warm season. The simulation results also prove that using internal blinds during the spring season decreases indoor air temperatures, as it reduces the amount of solar radiation entering the room.

9.5.4. Thermal mass

The simulation analysis suggested using 30cm of brick blocks or 25cm of heavyweight concrete blocks as the appropriate thermal mass materials for the school building in Tehran. The heavyweight concrete blocks have a similar impact as 30cm bricks on indoor air temperatures. They both cause reduction on indoor air temperatures in warm seasons. Appropriate use of thermal mass with a suitable shading device and a natural ventilation strategy can limit overheating in the hot and warm seasons. In addition, installing thermal insulation materials on the outside layer of an external wall with high thermal mass will increase the positive effect of mass on indoor thermal conditions.

9.5.5. Thermal Insulation

An appropriate thermal insulation material for roof and walls is important for reducing heat loss, and making the indoor environment of the building warmer in cold seasons. The thermal insulation material should be selected from the materials recommended by the Iran National Building Code. The common type of insulation materials used in Iran are glass wool, extruded polystyrene (XPS) and expanded polystyrene (EPS). The thickness of the insulation material has a great influence on indoor air temperatures. All common types of thermal insulation materials used in Iran have a very similar effect on the indoor air temperature. However, glass wool insulation material has the best impact on improving indoor thermal condition.

Based on this research, the roof layers should have 5cm of glass wool on the inside of the roof layers, as a thermal insulation material. Also 10cm of the thermal insulation materials should be installed on the outside of the external walls, in order to achieve a U-value between 0.28 and $0.32\mathrm{W/m^2K}$. This range of U-values is good enough to keep the indoor temperatures quite stable. Using the recommended thermal insulation in the roof and external walls increases the indoor air temperature in winter. It also has a small effect in increasing the indoor air temperature during the spring season but this effect can be overcome by an appropriate natural ventilation strategy.

9.5.6. Natural ventilation

The indoor air temperature can be increased undesirably during warm seasons, which can be caused by solar radiation or by the high density of the occupants. However, the use of natural ventilation can decrease indoor air temperatures considerably, reduce the need for mechanical ventilation and, as a result, reduce energy consumption of the school building.

The main aim of natural ventilation is to provide good air quality in indoor environments. The building regulations suggest providing 8 litres per second per person (l/s/p) of fresh external air to meet the need for odour control and adequate indoor air quality (DfES, 2003a). In the summer, this amount can be increased to remove extra heat gains that reduce overheating. However, in winter, lower ventilation rates are usual.

This study shows that using an all-day ventilation strategy during the warm and hot seasons in the city of Tehran has a significant impact on the reduction of indoor air temperatures in classrooms. In the city of Tehran, during the months from May to August, the wind direction is usually from the south-east, so the windows can be faced to this direction on southern side of the building in order to get the advantage of natural ventilation in hot and warm seasons. It is also suggested that control of the windows should be given to the occupants, so they have the ability to adjust the indoor thermal conditions, as far as possible.

9.6. Recommended environmental design guidelines

The application of all suggested passive design strategies in the case study building proves that the combination of all environmental design strategies have a considerable effect on indoor air temperatures in hot and warm seasons. The suggested strategies are summarised in Table 9.1. It should be mentioned that using these strategies will keep the indoor air temperature in an acceptable condition for students in female secondary school buildings in Tehran during teaching hours, in warm and cold seasons, without any mechanical cooling and heating systems being required, which keeps the energy loads to a minimum level and, as a result, will reduce energy use in the building, while keeping the indoor environment in an acceptable condition.

Table 9.1: Suggested passive design strategies for female secondary school buildings in hot and dry climate of Tehran

Passive design strategies	Solution
Orientation	South-South East.
Glazing	Double, with air in between
Solar Shading	Moveable 30cm overhangs and side fin combination.
Ventilation	All day ventilation in hot and warm seasons.
Wall Insulation	10cm common thermal insulation on external sides of external wall layers.
Roof Insulation	5cm common thermal insulation on internal sides of roof layers.
Thermal Mass	25cm high-density concrete blocks or 30cm outer bricks in external walls.

It should be stated that all-day ventilation strategies and the installation of shading devices has a maximum effect in reducing the indoor air temperature during the spring season. Double glazed windows and external wall insulation also have a considerable effect on keeping the indoor temperature in an acceptable condition, while the heating system is off in winter.

9.7. Conclusion

In this chapter the environmental design guidelines for female secondary school buildings were introduced for the city of Tehran based on a thermal simulation analysis, as shown in Chapter 8, using passive design strategies, including orientation, insulation, glazing and solar shading, ventilation strategy, as well as thermal mass, with respect to the female students' thermal preferences. The application of passive design strategies has a considerable impact on indoor air temperatures both in warm and cold seasons in hot and dry climatic regions. This climatic design guideline can be used for female school buildings in the city of Tehran or other regions with similar climates, in order to create a comfortable study space for students, with the minimum energy consumption. By applying these strategies, the indoor air temperature can be kept at an acceptable level, with the minimum heating and cooling loads, which would provide low energy thermal comfort and reduce building maintenance costs in the hot and dry regions of Iran.

Chapter 10: Conclusions

10.1. Conclusions

The current thesis was carried out to investigate the thermal performance of a typical female secondary school building in Tehran during the warm spring period and cold winter season. It also examined the thermal behaviour of typical classrooms using field studies and computer simulations to propose an optimum design solution for the school building, in order to keep the indoor air temperature in a comfort band with minimum heating and cooling loads. The field studies included a questionnaire based survey regarding the students' thermal comfort and on-site measurements of the climatic variables, such as indoor air temperatures and relative humidity levels for six classrooms in spring 2010 and winter 2011. The main aim was achieved by answering the research questions.

10.1.1. On-site monitoring

The field measurements was carried out in two periods, the warm spring period of April/May 2010, and the cold winter season of January/February 2011, just before the exam periods and the summer and winter holidays. The indoor air temperatures and relative humidity levels were recorded for three weeks in the warmest period of the spring season, and for four weeks during the coldest period in winter season. The results showed that the maximum and minimum indoor air temperatures were mostly within the comfort bands defined by Heidari (2010) for Iranian people in both seasons.

10. 1. 2. Questionnaire survey

The questionnaire based survey was conducted on one day in each proposed season to evaluate the students' thermal satisfaction in typical classrooms during the warmest and coldest periods. Although the indoor air temperatures in both seasons were within the comfort band defined by Heidari (2010) for Iranian people, around 73% of the thermal sensation responses of the students were within the central three categories of the ASHRAE scale. Based on ASHRAE (2004), 80% of the votes in central three categories of the ASHRAE scale showed the thermal satisfaction of the students and, in this case, the considerable amount of students were not satisfied with the indoor thermal environment of their classrooms in both seasons. The thermal preferences confirm the dissatisfaction of the students, as most wanted to change in their thermal environments, either to make them cooler or warmer. This study showed that the comfort band calculated by Heidari (2010) was different for the female students in a secondary school building and the comfort band was much more limited for female students than the other occupants living in residential buildings and working in offices. Heidari (2010) stated that Iranian people can achieve comfort in temperatures higher than 30˚C in the hot season and lower than 20˚C in the cold season, but in this study the female students felt uncomfortable when the indoor air temperature exceed 24.5˚C and when it fell below 20˚C. It was found that the maximum comfort temperature for female students in a secondary school building in Tehran was 24.5˚C in May and the minimum comfort temperature was 20˚C in February.

10. 1.3. Thermal simulation

Thermal simulation analysis was performed to examine the effect of passive design strategies, including orientation, insulation, glazing and solar shading, ventilation strategy as well as thermal mass on indoor air temperature of the classrooms with respect to the students' thermal preferences. Passive design strategies were applied to the case study school building separately and later the optimum strategies were applied together to the case study building to compare their impact on indoor air temperatures. After applying the appropriate optimum solution to the case study building, the mean indoor air temperature decreased by approximately 4K in south-facing classroom and 2K in north- facing classroom during the field study experiment in April/May. Also, the mean indoor air temperature in the winter season was between 19°C and 25°C in south-facing classrooms, while it was between 16°C and 21.5°C in north-facing classroom after the application of an optimum design solution, with no heating system in operation. When the students felt cold, the heating system could be turned on, with the minimum heating load, or clo value of the clothing insulation could be increased to keep the heating system off in cold seasons and reduce the energy load of the building.

10.1.4. Recommended guidelines for passive school building design

The results illustrate that the application of optimum passive design strategies has a considerable impact on indoor air temperatures in warm and cold seasons and usually keeps the environment within the comfort band. The suggested strategies are summarised in Table 10.1.

Table 10.1: Suggested passive design strategies for female secondary school buildings in Tehran

Passive Strategies	Solution	Current Practice in a base case
Orientation	South-South East	South
Glazing	Double, with air in between	6 mm Single glazing
Solar Shading	Moveable 30cm overhangs and side fins combination	No solar shading
Ventilation	All-day ventilation in hot and warm seasons	Ventilation from 7:00am to 21:00 up to cleaning period in spring
Wall Insulation	10cm common thermal insulation on external sides of external wall layers	No wall insulation
Roof Insulation	5cm common thermal insulation on internal side of roof layers	5cm thermal insulation on external layers of roof
Thermal Mass	25cm High-density concrete blocks or 30cm outer bricks in external walls	30cm brick in external walls

It should be mentioned that using these strategies will keep the indoor air temperature in an acceptable condition in the female secondary school buildings in Tehran during the teaching hours both in warm and cold seasons without any cooling and heating mechanical systems' operation, and as a result will reduce the energy use of the building. Moreover, an all-day ventilation strategy and the installation of shading devices have the maximum effect in reducing indoor air temperatures during the spring season. Double glazed windows and external wall insulation also have a considerable effect on keeping the indoor temperatures within acceptable limits, while the heating system is turned off in winter. The findings of this study shows that, with the use of passive design strategies in the female secondary school building in Tehran, the indoor air temperatures can be kept in an acceptable condition, with minimum energy loads, which would not only result in providing low energy thermal comfort, but also reducing building maintenance costs in hot and dry regions of Iran.

10.2. Limitation of the study

The present study was limited to the following areas which can be covered in further studies:

- The current investigation is limited to the region of Tehran, with its particular climate.
- The thermal simulation study is limited to the knowledge of DesignBuilder simulation software.
- The primary input assumptions for the thermal simulation model in the female secondary school building in Tehran are limited to the field study results including measurement of indoor air temperature and relative humidity levels as well as questionnaire based survey results regarding to the number of the students, the classrooms thermal condition and the school building's construction materials. The measurement of daylighting and electrical lighting levels and applying the result to DesignBuilder may have an effect on the prediction of indoor climatic variables.
- This study was restricted to female students in Tehran. Male students may have had different thermal responses in the city.
- This research has only examined thermal behaviour of north-facing and south-facing classrooms in Tehran. Other orientations may have created different thermal conditions in the secondary school building.

10.3. Recommendations for further research

It is proposed that further studies might be carried out in the following areas:

- The field studies and the simulation analysis were undertaken in two periods only during the warm spring season and cold winter. It is recommended to extend the research across all seasons, to cover the whole year.
- It is advisable to examine similar studies on other types of buildings, such as commercial, residential and municipal ones, as well as in primary schools and nursery schools.
- The research was conducted in a female secondary school only. It is suggested that further research might be carried out in male schools, in order to compare male and female students' expectations of the indoor thermal environment, for a similar age group.
- It is suggested that the energy consumption of such buildings should be evaluated, in order to investigate how much energy can be saved after the application of passive design strategies.
- The research was conducted in the hot and dry climate of Tehran. Similar studies can be undertaken in other climatic regions of Iran, including hot and humid and cold and moderate climatic regions.

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Appendices

Appendix 1: Survey forms

- **Questionnaire survey form in English**

Date: Place: Time: Classroom's number:

1. How do you feel at the moment?

   Cold ☐ Cool ☐ Slightly cool ☐ Neutral ☐ Slightly warm ☐ Warm ☐ Hot ☐

2. Would you like to be

   A bit cooler ☐ No changes ☐ A bit warmer ☐

3. How do you feel at the moment in terms of air flow?

   Still ☐ Just right ☐ Breezy☐

4. How do you feel at the moment in terms of relative humidity?

   Dry ☐ Just right ☐ Humid ☐

5. How do you feel at the moment in terms of lighting?

   Bright ☐ Just right ☐ Dark ☐

6. Would you like classroom to be

   Lighter ☐ No changes ☐ Darker ☐

7. What clothes are you wearing at the moment?

8. What activity did you do in the last 15 minutes?

9. What is your general impression of the classroom in terms of thermal comfort?

   Hot ☐ just right ☐ cold ☐

10. Do you have any other comments about the environment in your class?

- **Questionnaire survey form in Farsi**

با سلام و احترام

پرسشنامه‌اي كه اكنون در اختيار داريد به منظور بررسی آسایش حرارتی کلاسها در مدارس ایرانی و بهبود آن تهیه شده است .از آنجا كه اطلاعات صحيح و درست مي‌تواند رهنمون محقق به سمت يك استنتاج منطقي و نتيجه گيري درست باشد، لذا خواهشمند است اينجانب را در اجراي تحقيق ياري نماييد و به كلية سؤالات با دقت كامل پاسخ دهيد. از همكاري صميمانه شما كمال تشكر و قدر داني را دارم.

تاریخ: .... ساعت: .... شماره کلاس و مقطع تحصیلی: ....

1) به نظر شما در حال حاضر درجه حرارت هوای داخل کلا س چگونه می با شد؟

سرد☐ خنک☐ کمی خنک☐ معمولی☐ کمی گرم☐ گرم☐ د اغ ☐

2) می خواهید که د مای هوای د اخل کلاس شما در حال حاضر چگونه باشد؟

کمی خنک تر☐ بدون تغيير ☐ کمی گرم تر ☐

3) به نظر شما در حال حاضر جریان هوای داخل کلا س چگونه می با شد؟

راکد☐ مناسب☐ دارای وزش باد ☐

4) به نظر شما در حال حاضر رطوبت نسبی داخل کلا س چگونه می با شد؟

مرطوب☐ مناسب☐ خشک☐

5) به نظر شما در حال حاضر روشنایی داخل کلا س چگونه می با شد؟

درخشان☐ مناسب☐ تاریک☐

6) می خواهید که نور د اخل کلاس شما در حال حاضر چگونه باشد؟

روشن تر☐ بدون تغيير☐ تاریک تر☐

7) در حال حاضر چه نوع لباسها یی پوشیده اید؟ (لطفا گزینه های مناسب را علامت بزنید.)

چادر☐ مانتو☐ مقنعه☐ کاپشن☐ کت☐ ژاکت☐ شلوار پارچه ای☐ شلوار جین☐ روسری☐
کفش ورزشی☐ کفش معمولی ☐ جوراب☐ تی شرت ☐ پلور☐ پیراهن☐

8) در پانزده دقیقه گذشته چه نوع فعالیتی از قبیل درس خواندن ,راه رفتن , ورزش کردن, نشستن وغیره انجام داده اید؟ لطفا نام ببرید.

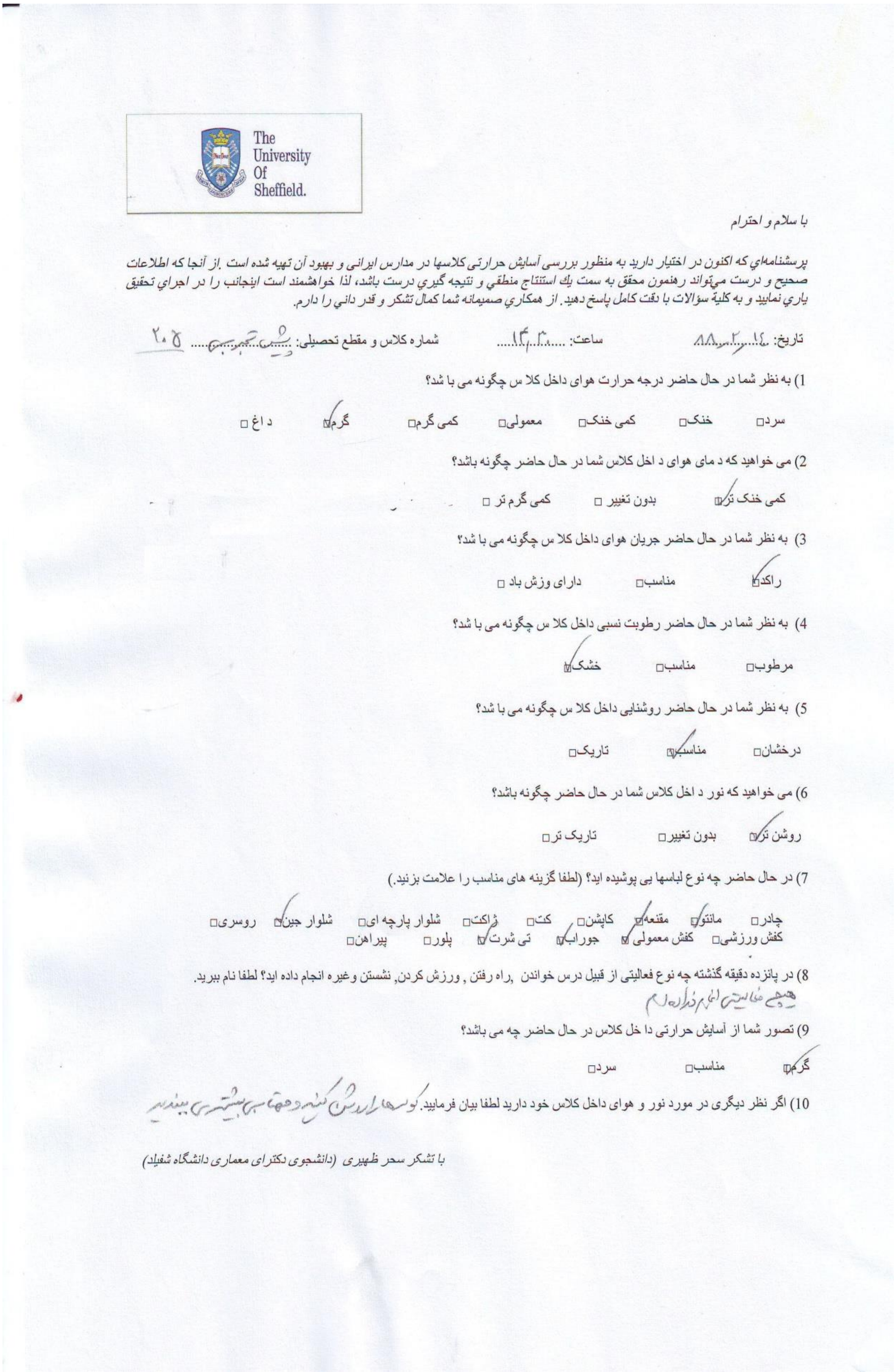
9) تصور شما از آسایش حرارتی دا خل کلاس در حال حاضر چه می باشد؟

گرم☐ مناسب☐ سرد☐

10) اگر نظر دیگری در مورد نور و هوای داخل کلاس خود دارید لطفا بیان فرمایید

با تشکر سحر ظهیری (دانشجوی دکترای معماری دانشگاه شفیلد)

- **Sample of original questionnaire survey form in Farsi**



The University Of Sheffield.

با سلام و احترام

پرسشنامه‌اي كه اكنون در اختيار داريد به منظور بررسی آسايش حرارتی كلاسها در مدارس ايرانی و بهبود آن تهيه شده است .از آنجا كه اطلاعات صحيح و درست مي‌تواند رهنمون محقق به سمت يك استنتاج منطقي و نتيجه گيري درست باشد، لذا خواهشمند است اينجانب را در اجراي تحقيق ياري نماييد و به كلية سؤالات با دقت كامل پاسخ دهيد. از همكاري صميمانه شما كمال تشكر و قدر داني را دارم.

تاریخ: ۱٤/۲/۸۸ ساعت: ۱۴/۲۰ شماره کلاس و مقطع تحصیلی: پیش تجربی ۲۰۵

1) به نظر شما در حال حاضر درجه حرارت هوای داخل کلا س چگونه می با شد؟

سرد☐ خنک☐ کمی خنک☐ معمولی☐ کمی گرم☐ گرم☑ د اغ ☐

2) می خواهید که د مای هوای د اخل کلاس شما در حال حاضر چگونه باشد؟

کمی خنک تر☑ بدون تغییر ☐ کمی گرم تر ☐

3) به نظر شما در حال حاضر جریان هوای داخل کلا س چگونه می با شد؟

را کد☑ مناسب☐ دارای وزش باد ☐

4) به نظر شما در حال حاضر رطوبت نسبی داخل کلا س چگونه می با شد؟

مرطوب☐ مناسب☐ خشک☑

5) به نظر شما در حال حاضر روشنایی داخل کلا س چگونه می با شد؟

درخشان☐ مناسب☑ تاریک☐

6) می خواهید که نور د اخل کلاس شما در حال حاضر چگونه باشد؟

روشن تر☑ بدون تغییر☐ تاریک تر☐

7) در حال حاضر چه نوع لباسها یی پوشیده اید؟ (لطفا گزینه های مناسب را علامت بزنید.)

چادر☐ مانتو☑ مقنعه☑ کاپشن☐ کت☐ ژاکت☐ شلوار پارچه ای☐ شلوار جین☑ روسری☐
کفش ورزشی☐ کفش معمولی ☑ جوراب☑ تی شرت ☑ پلور☐ پیراهن☐

8) در پانزده دقیقه گذشته چه نوع فعالیتی از قبیل درس خواندن ,راه رفتن , ورزش کردن, نشستن وغیره انجام داده اید؟ لطفا نام ببرید.
هیچ فعالیتی انجام نداده ام

9) تصور شما از آسایش حرارتی دا خل کلاس در حال حاضر چه می باشد؟

گرم☑ مناسب☐ سرد☐

10) اگر نظر دیگری در مورد نور و هوای داخل کلاس خود دارید لطفا بیان فرمایید. کولرها را روشن کنند و [illegible] بیشتری بیندازند

با تشکر سحر ظهیری (دانشجوی دکترای معماری دانشگاه شفیلد)

- Site Record Form in English

Date: Place: Time: Number of the students:

1. Electrical lighting:
   On ☐ Off ☐
2. Air conditioner:
   On ☐ Off ☐
3. Mechanical heating:
   On ☐ Off ☐
4. Windows:
   Open ☐ Close ☐
5. Blinds:
   Open ☐ Close ☐
6. Door:
   Open ☐ Close ☐

- **Site record form in Farsi**

با سلام و احترام

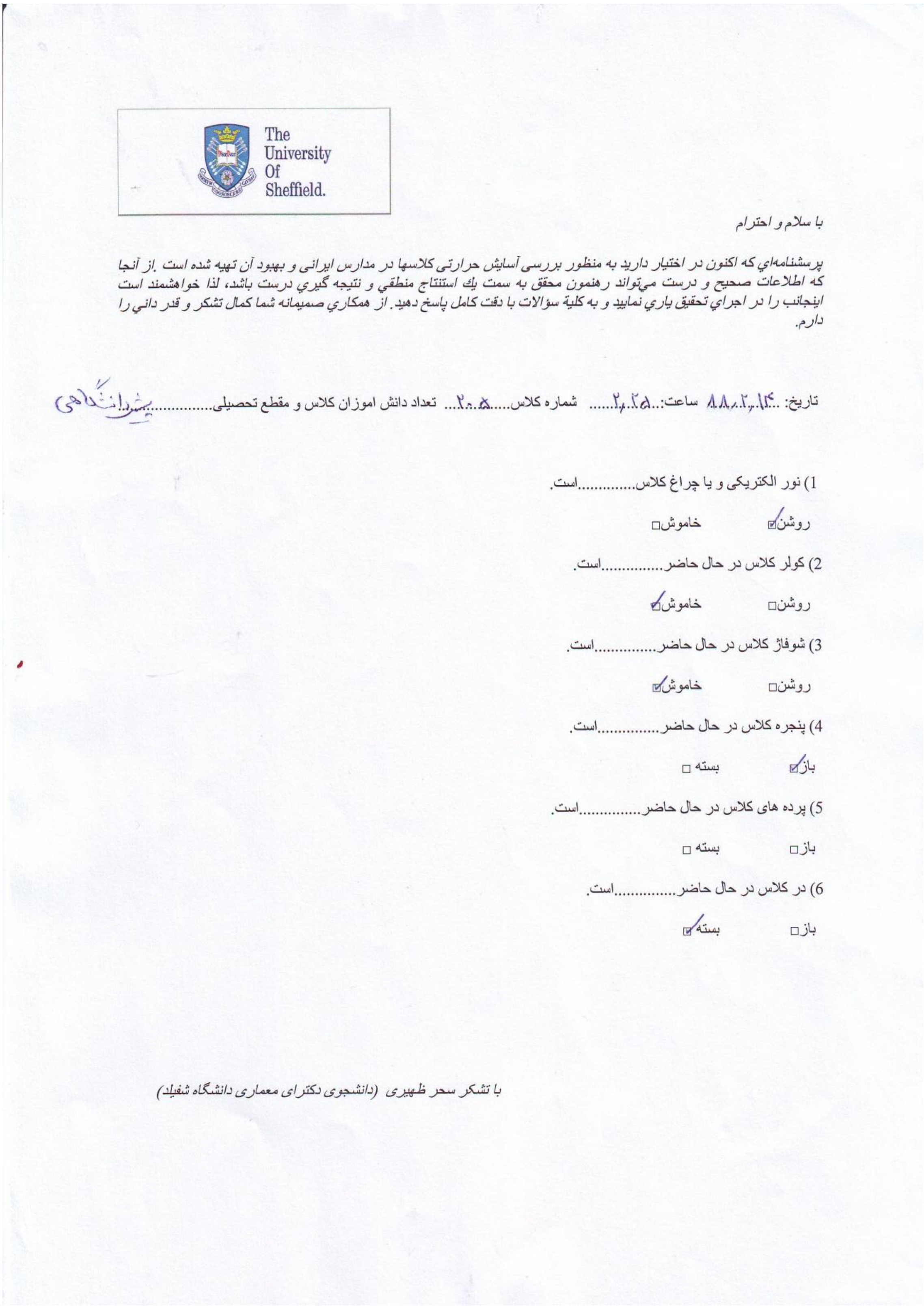
پرسشنامه‌اي كه اكنون در اختیار دارید به منظور بررسی آسایش حرارتی كلاسها در مدارس ایرانی و بهبود آن تهیه شده است. از آنجا كه اطلاعات صحیح و درست مي‌تواند رهنمون محقق به سمت يك استنتاج منطقي و نتيجه گيري درست باشد، لذا خواهشمند است اينجانب را در اجراي تحقيق ياري نماييد و به كلية سؤالات با دقت كامل پاسخ دهيد. از همكاري صميمانه شما كمال تشكر و قدر داني را دارم.

تاریخ: .... ساعت:.......... شماره کلاس........ تعداد دانش اموزان کلاس و مقطع تحصیلی.............

1) نور الکتریکی و یا چراغ کلاس.............است.
روشن☐ خاموش☐
2) کولر کلاس در حال حاضر..............است.
روشن☐ خاموش☐
3) شوفاژ کلاس در حال حاضر..............است.
روشن☐ خاموش☐
4) پنجره کلاس در حال حاضر..............است.
باز☐ بسته ☐
5) پرده های کلاس در حال حاضر..............است.
باز☐ بسته ☐
6) در کلاس در حال حاضر..............است.
باز☐ بسته ☐

با تشکر سحر ظهیری (دانشجوی دکترای معماری دانشگاه شفیلد)

- Original site record form in Farsi



The University Of Sheffield.

با سلام و احترام

پرسشنامه‌اي که اکنون در اختیار دارید به منظور بررسی آسایش حرارتی کلاسها در مدارس ایرانی و بهبود آن تهیه شده است. از آنجا که اطلاعات صحیح و درست مي‌تواند رهنمون محقق به سمت يك استنتاج منطقي و نتيجه گيري درست باشد، لذا خواهشمند است اینجانب را در اجراي تحقيق ياري نماييد و به كلية سؤالات با دقت كامل پاسخ دهيد. از همكاري صميمانه شما كمال تشكر و قدر داني را دارم.

تاریخ: ...۸۸/۲/۱۴ ساعت:...۲،۲۵...... شماره کلاس.....۲۰۵... تعداد دانش اموزان کلاس و مقطع تحصیلی................پیش دانشگاهی

1) نور الکتریکی و یا چراغ کلاس............است.

روشن☑ خاموش☐

2) کولر کلاس در حال حاضر..............است.

روشن☐ خاموش☑

3) شوفاژ کلاس در حال حاضر..............است.

روشن☐ خاموش☑

4) پنجره کلاس در حال حاضر..............است.

باز☑ بسته ☐

5) پرده های کلاس در حال حاضر..............است.

باز☐ بسته ☐

6) در کلاس در حال حاضر.............است.

باز☐ بسته☑

با تشکر سحر ظهیری (دانشجوی دکترای معماری دانشگاه شفیلد)