Thermal Comfort Prediction, Conditions and Air Quality for Younger and Older Children in Kuwait Schools

by

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Doctoral Thesis

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To the soul of my

mother

To my father

To my family

To my wife

To my beloved children:

Reem, Dima, Shama,

Nour and Walid

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Abstract

The thesis presents the field and laboratory work conducted to investigate the applicability of different thermal comfort indices and equations to assess the thermal sensation of very young children (6-10 years) and older children (11-17 years) in Kuwait classrooms under different ventilation modes (hybrid, natural and air-conditioned), in addition to investigating the quality of the air inside the classrooms. Few thermal comfort and indoor air quality studies have been conducted to determine the thermal comfort and indoor air quality situation inside the classrooms (especially where the young children are presents) in comparison to that for adults in other building environments such as offices or vehicles. The aim of this thesis was to provide baseline data and expand the knowledge for young children's thermal comfort (as well as older children) and the effects of the indoor air quality inside classrooms on them throughout different ventilation modes (hybrid, natural and air-conditioned). The work was achieved by conducting both laboratory and field experiments, as follows:

Laboratory tests were conducted to measure the insulation value of the different schoolwear ensembles used in Kuwait classrooms. Three methods were used to indicate and compare the thermal insulation values of different schoolwear ensembles worn by girls and boys in Kuwait classrooms during summer and winter seasons. Results suggest that the clothing insulation values found from the measured and adapted data were similar to the adult's data in standards tables for the same summer and winter seasons ensembles. In addition, the temperature ratings of the clothing are close to, and in agreement with, the scholars' comfort temperature.

A new thermal comfort questionnaire has been designed for gathering thermal sensation and reflected data from younger children. The questionnaire has been designed employing learning and educational techniques for very young people, and was statistically tested against the standard questionnaire and with old age groups to ensure no bias was introduced. The results show that the new designed thermal comfort questionnaire can help children to assess their sensation in a better manner than that of the standard questionnaire, and that it can be considered as a new subjective assessment tool that can support the thermal comfort standard by investigating the thermal comfort sensations of younger children age groups.

A large scale field study was then conducted to investigate the applicability of different thermal comfort indices for Kuwait classrooms along the academic year and under different ventilation modes to assess the thermal sensations for younger (6-10 years) and older (11-17 years) students' age group during the school day. The newly designed thermal comfort questionnaire and the clothing insulation values mentioned previously were used to collect the subjects' responses for comparison with a range of thermal comfort indices (PMV, ePMV, PMV_{10} and adaptive, and various comfort equations).

Results show that no difference in the neutral temperature between both age groups during the different ventilation modes and the PMV model is the most appropriate model to predict the thermal sensations of the younger subjects during the different ventilation modes, including the natural ventilation mode, since Kuwait' classrooms largely considered as air-conditioned spaces. This work provides knowledge of thermal comfort and comfort conditions in Kuwait classrooms.

The final part of the field study was conducted to investigate the adequacy of the ventilation rates during naturally and air-conditioned ventilation modes inside 10 elementary classrooms in Kuwait occupied by 6-10 year old children by measuring the CO_2 concentration levels inside these classrooms. The findings showed that naturally ventilated classrooms have lower average CO_2 concentration levels (708 ppm) than air-conditioned classrooms (1596 ppm). The main reason for the high CO_2 concentration in air-conditioned classrooms is attributed to the possibly inappropriate selection of ventilation system type (wall-mounted split units) inside the classrooms. This type of ventilation system cools recirculated room air provides no outside air (fresh air), which is may not be appreciated for high occupancy zones like classrooms. Suitable means for fresh air provision must be made for this mode of operation.

Some remedial solutions are theoretically suggested to reduce the high CO_2 levels in air-conditioned classrooms which may enhance the students' and staffs' performance. The latter data on CO_2 levels being above recommended values have been communicated to Kuwaiti government.

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Chapter 1

Thesis Aims, Objectives and Structure

1.1 Chapter Summary

This chapter introduces the work covered in this thesis and addresses the limited information found in the literature regarding the thermal comfort and indoor air quality issues inside classrooms with respect to younger children (6-10 years old) as well as older children (11-17 years old). The aims and objectives of this thesis to address this lack of information and the methodology used to achieve these aims and objectives are clarified in this chapter. The thesis structure is in accordance with the work conducted, where each chapter represents a part of this work in addition to a literature review about the thermal comfort and the indoor air quality issues.

1.2 Introduction

In the last few decades, the thermal comfort and the indoor air quality issues have become a global point of interest and caught a great interest by many researchers around the world. This interest is due to the impacts of nowadays life style, where people spend most of their life (more than 90%) in artificial climate controlled environments, on the occupant's health, performance and productivity which may have detrimental consequences on people's and the society's future by increasing the health care expenses and decreasing the work productivity, which may affect the national economy.

Extensive researches were conducted worldwide to investigate the occupants' thermal comfort and indoor air quality conditions in different buildings types to improve the indoor thermal and environment conditions that can provides healthy environments and improves the occupant's performance and productivity. Throughout the literature review of the thermal comfort and indoor air quality issues, some lack of information was found. These lacks of information can be summarized as follows;

- Few of these researches were conducted in classrooms, where most of these few studies conducted in classrooms were in tropical or subtropical climatic zones where no studies conducted in hot and dry climate, i.e. desert climate, such as Kuwait climate.
- Most of these thermal comfort studies in these classrooms were conducted to investigate the thermal sensations of adults' occupants or occupants with developed writing and reading skills, where the thermal sensations of the very young children (6-10 years old), who's their writing and reading skills are still developing, are not covered.
- The insulation values of the different clothing worn by children in these studies were roughly estimated from the standard tables which is originally base on adult's measurements and do not practically adopted to fit the children sizes, which if applied to children's clothing, the use of these data to assess the children's thermal comfort sensation may result in errors.
- The metabolic rate of the children in these studies were roughly estimated from the standard tables which is originally based on adult's measurements and do not practically measured to fit the children sizes, which if applied to younger children, the use of these data to assess the children's thermal comfort sensation may introduce errors.
- No indoor air quality investigations were conducted in Kuwait classrooms to investigate the quality of the inside classrooms air and it is impacts on the student's and staff's health, performance and productivity.

1.3 Thesis Aims and Objectives

The main objectives of this thesis reported here, which apply to students between the ages of 6 to 17 years old in Kuwait classrooms are:

- Designing a new thermal comfort questionnaire which is applicable to younger ages that helps to assess their thermal sensation in order to indicate their thermal comfort situation and satisfaction. This should help to provide better thermal and health conditions which can improve their learning, performance and productivity. As a result from this study, additional benefits may occur by improving the energy consumption.
- Investigating the applicability of the use of the clothing insulation values presented in the standard tables (ISO 7730, ISO 9920 and ASHRAE 55), which are based on adult measurements, for estimating the clothing insulation values for children's schoolwear by comparing a number of alternative methods for determining clothing insulation values applied to children's clothing.
- Examining the applicability of different thermal comfort indices (PMV, ePMV, PMV_{10} and adaptive model, and various comfort equations) for Kuwait classrooms under three different ventilation modes; hybrid, natural and air-conditioned ventilation modes, and to determine whether one model is more appropriate than the others for thermal comfort prediction in such situations.
- Investigating the effect of reducing the standard adult's metabolic rate data to fit young children by determining the neutral temperature (t_n) for both younger (6-10 years) and older (11-17 years) in the classrooms during different ventilation modes along the academic year and comparininingthe findings with similar studies conducted elsewhere and reported in the literature.
- Determining the comfort zone for Kuwaitis' students on ASHRAE psychrometric chart and investigating the preferred temperature (t_p) for both age groups in the classrooms during the different ventilation modes and along the academic year and its impacts of the students' neutral and preferred temperature on energy consumption.
- Measuring and comparing the indoor CO_2 concentrations in classrooms located in different regions in Kuwait with two different types of ventilation modes (air-

conditioned and natural ventilation modes) and comparing these measurements with that found in ASHRAE standard 62 for classrooms and similar studies conducted elsewhere and reported in the literature. The impact of the CO_2 measurements on the student's performance and productivity will be investigated according to the existing literature studies and some remedial solution will be suggested to enhance the IAQ inside the classroom environment to enhance the students' and staff's performance.

1.4 Thesis Methodologies and structure

In this thesis a comprehensive review of the previously work done by other researchers regarding to the human thermal comfort and indoor air quality (IAQ) issues in classrooms was done. In this revision a specific attention to young children in classrooms, and the effects of the indoor thermal and air quality conditions on the student's and staff's health, performance and productivity inside the classroom. A literature review of the thermal comfort (chapter 2) and indoor air quality (chapter 3) issues in classrooms some lack of information was found.

These lacks of information were discussed and covered during the work of this thesis as follows:

Although the first elementary years represented about 40% of the academic levels around the world, it was found through the literature review of the thermal comfort issue in classrooms (chapter 2) a lack of information of investigating the thermal comfort conditions of the young children especially from 6 to 10 year. The reason of this lack of information can be attributed to the difficulties that may face the children in understanding the concept of thermal comfort issue and the influences of the different thermal comfort variables on their thermal sensation. Regarding to the indoor air quality issue in classrooms (chapter 3) it found that a few studies that investigated the quality of the indoor air inside classrooms, where no similar studies conducted in Kuwait classrooms where the use of the air-conditioned systems are essential during most of the academic year.

This lack of information was treated in this thesis by designing and evaluating a new thermal comfort questionnaire (chapter 4) for gathering reported thermal comfort sensations from young children including children of age group from 6 to 10 years old. The idea of the new questionnaire is to design a thermal comfort questionnaire that can help the children from 6 to 10 years old to assess their thermal sensations but at the same it must have no effects or bias on the understanding of older age groups (11+).

Another point of lack arises through the literature, that all the researchers were roughly estimated two of the basic thermal comfort variables for children measurements, the metabolic rate and clothing insulation value, from the standard tables which originally based for adult's measurements. This estimation may lead to some uncertainty of using the standard tables to fit the children measurements. In this thesis the work was extended to investigate the applicability of using the standard tables to estimate the clothing insulation values for different children schoolwear used in Kuwait classrooms (chapter 5).

This work was done by comparing different measurements methods, using thermal manikin; McCullough et al. (1985) regression equation and McCullough et al. (1985) regression equation with a correction, as proposed by Havenith (2007). Additional procedure was followed in this thesis to investigate the effect of the insulation values on the different scholars' age groups were investigated using the clothing temperature rating using McCullough et al. (2009) technique and compared to the scholars' comfort temperature found in recent field studies.

The metabolic rate of children in sedentary activity was investigated in this thesis by comparing effect of estimating it from the standard tables, based on adult's measurements, and that based on findings of Havenith (2007) and Parsons (2003) on the prediction of the thermal comfort sensation of children (PMV and PMV_{10}) during the field studies conducted in Kuwait classrooms among different ventilation modes (chapter 6).

All the pervious studies found in the literature investigated the thermal comfort conditions in classrooms in tropical or hot humid climatic environments where no studies done in classrooms in hot dry (desert) climatic environment like Kuwait classrooms. The thermal sensations of the younger and older children were combined in these studies.

After covering all the lack of information regarding the thermal comfort issue in classrooms, the results found (chapter 4 and 5) were used to conduct the thermal comfort study done in the thesis (chapter 6) to investigate the applicability of the different thermal comfort indices and equations to assess the younger students' thermal sensations in Kuwait classrooms during different ventilation modes, hybrid; natural and air conditioned.

Regarding to the literature review of the indoor air quality in classrooms (chapter 3) and due to the lack of indoor air quality investigations in Kuwait classrooms, the work was extended to investigate the indoor air quality status in classrooms (chapter 7) by measuring the CO_2 concentrations levels in different ventilation modes and compare it to that found in the standards. This indoor pollutant was chosen because the indoor concentration of CO_2 has often been used as a surrogate for the ventilation rate per occupant. The impacts of these CO_2 levels on the student's performance and productivity were investigated according to the existing literature studies. Some remedial solutions were suggested to enhance the IAQ inside the classroom environment in order to enhance the students' and staff's performance.

Finally, a detailed description about the methodologies used throughout can be found in the related chapters.

Chapter 2

Thermal Comfort Literature Review

2.1 Chapter Summary

This chapter introduces the literature review concerning the thermal comfort issues related to students in classrooms. It considers the worldwide thermal comfort research on the effect of the different environmental and personal thermal comfort variables that have a major effect on students in classroom environments. It clarifies that more research and investigations are needed to provide greater understandings of how students in Kuwait classrooms react to such environments.

2.2 Introduction

People's nowadays life style is that they spend most of their life (more than 90%) in artificial climate controlled environments. This fact has caused a great interest in investigating the occupants' thermal comfort by many researchers to improve the indoor thermal environment conditions. ASHRAE 55 standard (2004), defines the thermal comfort for a person as "that condition of mind which express satisfaction with the thermal environment". Most of these research works have dealt with the thermal sensations of adults' occupants, or occupants with developed writing and reading skills, exposed to different environments such as classrooms and different ventilation modes.

The number of investigations into young children's thermal comfort, especially who's writing and reading skills are still developing, in classrooms living in hot and arid climate, i.e. desert climate, such as Kuwait climate are limited. The aim of this thesis is to investigate the issue of thermal comfort in classroom environments, with particular reference to young children age groups, which causes considerable discomfort to the occupants.

This chapter reviews the previous work done, regarding the human thermal comfort fields and with specific reference to classrooms and young children thermal sensations; environmental and personal variables measured, human thermoregulations, in addition to the thermal comfort models and indices. Information about the thermal conditions inside classrooms and its physical, physiological and psychological effects on the classroom occupants is provided, with consideration to current assessment and evaluation methods for classrooms and models used of human thermoregulations and thermal comfort.

2.3 Thermal Comfort Variables

The basic thermal comfort variables that directly affect the human perception of thermal comfort can be divided into 4 basic environmental variables and 2 personal parameters. These are defined and described as;

2.3.1 Environmental Variables

Air Temperature (t_a)

Air temperature is most often defined as "the temperature of the air surrounding the person", ASHRAE 55 (2004), and which is a representative of its surroundings. The air temperature close to the clothed person skin does not represent the surrounding air temperature because of the influence of clothing which acts as a boundary between the person and the actual air temperature of the surrounding.

Mean Radiant Temperature ($\bar{t}_r$)

Radiation is one of the heat exchange means between bodies as well as conduction and convection. Mean radiant temperature is defined as 'the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation as in the actual non uniform environment ', ASHRAE 55 (2004). According to ISO 7726 (2001), There are many methods to calculate the mean radiant temperature. Some of these methods are by using the plane radiant temperature (t_{pr}) which is defines as "the uniform temperature of an enclosure where the radiance on one side of a small plane element is the same as in the non-uniform actual environment", ISO 7726 (2001). This quantity describes radiation from one side only and $\bar{t}_r$ can be calculated using the following equation:

$$\bar{t}_r = \frac{0.18(t_{pr}[up] + t_{pr}[down]) + 0.22(t_{pr}[right] + t_{pr}[left]) + 0.33(t_{pr}[front] + t_{pr}[back])}{2(0.18 + 0.22 + 0.33)} \quad \text{(Eq. 2.1)}$$

Where,

t_r = mean radiant temperature, ^oC

t_{pr} = plane temperature, ^oC

This equation is based on a seated person. Mean radiant temperature can also be calculated by obtaining the globe temperature (t_g), air temperature and air velocity for the environment using the following equation:

$$\bar{t}_r = \left[\left(t_g + 273\right)^4 + \frac{0.25 \times 10^8}{\varepsilon_g} \left(\frac{\left|t_g - t_a\right|}{D} \right)^{\frac{1}{4}} \times \left(t_g - t_a\right) \right]^{\frac{1}{4}} - 273 \quad \text{(Eq. 2.2)}$$

Where,

t_r = mean radiant temperature, ^oC

t_a = ambient temperature, ^oC

t_g = globe temperature, K

ε_g = emissivity of the globe

D = diameter of the globe (mm)

Air Velocity (v_a)

Air velocity can be expressed by the air movement across or against a body. This quantity is a vector quantity which has a magnitude and direction and fluctuated with time in space. For practical purposes in the case of thermal environments, where velocity is not constant with time, the air flow can be described by the mean air velocity (v_a). The definition of the mean air speed is "the average of the instantaneous air velocity over an interval of time", ASHRAE 55 (2004).

Humidity

Absolute humidity (water vapour density) can be described as the ratio of the actual mass of water vapour contained in the air to the total volume of the air sample. Relative humidity (Φ), gives the ratio of actual amount of water vapour in the air to the saturated amount of water vapour at the same temperature and pressure. Another definition of the relative humidity can be expressed as "the ratio of partial pressure of water vapour in air to the saturation pressure of water vapour at the same temperature and pressure" ASHRAE 55 (2004). Since this quantity is a ratio, it is often expressed as a percentage.

2.3.2 Personal Parameters

Metabolic Heat Production

Metabolism is the oxidation process done by our body to get the energy needed from the food and store it as chemical energy. This process is very important for human to practice their life which starts from the human birth time and last to the end of the person life. If a person does any type of work or physical activity, the body transforms the chemical energy stored in it to heat and mechanical work. The rate of this transformation per unit of skin surface area is called the "metabolic rate" which increases when tasks are performed to provide the energy required for the various physical activates. This parameter is usually expressed in "Wm^{-2}" or "met" units, and can be measured (such as Calorimetry) or estimated from the standard tables, i.e. ASHRAE 55 (2004) and ISO 7730 (2005).

ASHRAE (2009) and ISO 8996 (2004) standards presents well determined estimations tables of metabolic rates for different tasks. With respect to ISO 8996 (2004), the metabolic rate depends upon the person's age, sex, body dimensions (height and weight) and health. The data in the standards were measured and tabulated based on the amount of energy (heat) produced by an average sized 30 years old healthy adult with a body surface area of $1.8m^2$ and $1.6m^2$, for male and female individuals respectively, and with reference to seated, quite activity (1 met or 58.1 Wm^{-2}). In using the standard tables, more attention and appropriate corrections are needed when dealing with special group of people such as children; elderly persons; people with physical problems; pregnant ladies … etc, (ISO 8996, 2004 and Parsons, 2003). Some few examples of metabolic rate values for different activities are shown in Table 2.1.

Table 2.1: Summary of estimated metabolic rates, (ASHRAE 55, 2004)

Activity	Wm^{-2}	Met
Resting		
Seated, quite	60	1.0
Standing relaxed	70	1.2
Walking (on level surface)		
0.9 m/s, 3.2 km/h, 2.0 mph	115	2.0
1.2 m/s, 4.3 km/h, 2.7 mph	150	2.6
1.8 m/s, 6.8 km/h, 4.2 mph	220	3.8
Office Activities		
Seated, reading, or writing	60	1.0
Walking about	100	1.7
Driving		
Automobile	60-115	1.0-2.0
Aircraft, routine	70	1.2
Miscellaneous Occupational Activities		
Cooking	95-115	1.6-2.0
House cleaning	115-200	2.0-3.4
Pick and shovel work	235-280	4.0-4.8
Miscellaneous Leisure Activities		
Dancing, social	140-255	2.4-3.4
Tennis, single	210-270	3.6-4.0
Wrestling, competitive	410-505	7.0-8.7

Clothing

Clothing affected the convective, conductive and radiant heat loss from the body skin to the environment by providing a thermal resistance between the body and the environment. Its main function is to maintain a static layer next to the skin, (Hardy *et* *al*. 1953), to maintain the body thermal state. Clothing worn by people is often modified and adapted according to the changes in seasons and outdoor weather conditions. The unit for measuring the clothing's insulation values is the clo unit, which is proposed by Gagge *et al*. (1971), who defined the clo unit as, one clo is the amount of insulation necessary to maintain comfort and mean skin temperature of 33^{o}C in a room temperature of 21^{o}C, with air movement not over 0.1 m/s, humidity not over 50% and a metabolism of 1 met (resting condition). For more technical use, another type of units (m^2°C/W) is used in measuring the clothing insulation values, where 1 clo is equivalent to 0.155 m^2°C/W.

Many researches have been conducted to investigate the insulation values of the different types of indoor and outdoor clothing. The types of clothing used in these investigations were varied from a single layer garment to multiple layers ensemble. ASHRAE and ISO organizations supported some of these research and established standard tables containing the insulation values for the most commonly clothing ensembles worn indoors (ASHRAE, 2009 and ISO 9920, 2007). The data of these tables was based on adult size (surface area = 1.8 m^2) measurements by using adult sized thermal manikins (McCullough and Jones, 1984, and Olesen and Nielsen, 1983) or adult active subjects (Nishi *et al*. 1975).

From these tables, the naked person clo value is equal to 0, while a person wearing a typical business suit has a clo value of 1.0. The clo value can be calculated using different methods. The simplest method to calculate the insulation value of an ensemble is to estimate the insulation value of each individual garment that consists the ensemble and then sum them together. Table 2.2 shows the clo values for some selected clothing items, (ISO 9920, 2007).

Using the standard tables to estimate the clo value for an ensemble normally gives sufficient accuracy if the tables are used carefully, ASHRAE (2009). If exact clo values are required for certain ensembles or that not included in the tables, using thermal manikins is better to measure the insulation values.

Table 2.2: Summary of clothing insulation values for some selective garments (ISO 9920, 2007)

Clothing item	I_{clu}	Clo value
T-shirt	0.09	0.014
Short sleeve shirt	0.09	0.029
Normal, long sleeves	0.25	0.039
Flannel shirt, long sleeves	0.3	0.047
Light-weight trousers	0.2	0.031
Overalls	0.28	0.043
Thin sweater	0.2	0.031
Jacket	0.35	0.054
Fabric-covered, cushioned, swivel chair	0.1	0.016

2.4 Thermoregulation and Heat Balance

Human being needs to maintain a constant body temperature of 37^{o}C, where any change of few degrees in this temperature represents a threat to his health and life. In order to maintain this temperature within the appropriate limits for the human life, human has a complex system to regulate his body temperature by determining the temperature of different parts of the body, and then take the appropriate action to modify it to ensure maintaining a homotherm state in the body.

Human body interacts with its environment by generating and exchanging its internal heat with surrounding environments via evaporation, radiation and conduction to maintain a constant temperature for the body, in a heat balance process described as steady state, Fanger (1972). In fact, the human body maintains its temperature in a constant temperature range rather than a specific single temperature, and for this reason it is more appropriate to describe the heat balance as a dynamic balance instead of steady state balance, Parsons (2003). If the heat energy stored in the body is greater than that leaving the body, the temperature of the body rises. If the heat leaving the body is greater than that going into it, the body temperature falls.

The heat balance of the human body during the heat exchange with the surrounding environment can be expressed and modelled by the following equation.

$$M - W = E + R + C + K + S \quad \text{(Eq. 2.3)}$$

where,

M = rate of metabolic heat production, Wm^{-2}

W = rate of mechanical work accomplished, Wm^{-2}

E = rate of evaporation heat loss from skin and respiration, Wm^{-2}

R = rate of radiation heat loss from skin, Wm^{-2}

C = rate of convection heat loss from skin and respiration, Wm^{-2}

K = rate of conduction heat loss through clothing, Wm^{-2}

S = rate of heat storage in the skin and core, Wm^{-2}

All the variables of the heat balance equation are measured by Wm^{-2} units. If the body is in thermal equilibrium state, no heat is stored in the body. Insufficient heat loss to the body results in body overheating (hyperthermia) and excessive heat loss from the body leads to body overcooling (hypothermia). This conceptual heat balance equation has been used by Fanger (1972) in establishing the predictive mean vote (PMV) model.

The previous overview is about the basic environmental and personal variables which affect the thermal comfort of the occupants, where further detailed descriptions about the effects of other variables (nonuniform conditions and secondary factors) can be found in the literature (Giovoni, 1976; McIntyre, 1980; Fanger, 1972; Clark and Edholm, 1985; Parsons, 2003; and ASHRAE, 2009).

In this study, the effect of two related secondary factors (age and gender) on the occupants' thermal sensation will be focused and discussed in details in the following chapters.

2.5 Thermal Heated Manikin

In recent years, a great industrial revolution is realized with respect to the manufacturing and design of different human occupational and environmental protective means (clothing, headwear; hand wear and footwear). Thermal manikins are intensively and widely used for clothing testing in the governmental, industrial, and academic research to evaluate and assess the clothing protective capabilities in different environments. However, the testing methodology for assessing and measuring the thermal resistance of clothing, evolves from using heated flat plates in 1930s to the recently human forms thermal manikins controlled by complicated and advanced electric circuits and software to simulate the heat transfer between humans and their thermal environment.

Manikin is typically made from metal or plastic, and manufactured as adult size human shape consists of a number of heated body segments that represents the human body parts (head, chest, abdomen, back, buttocks, arms, hands, fingers, legs and feet). The temperature of each part can be controlled and the heat flux monitored for each segment independently or over the whole body. Detailed descriptions about the standard manikin specifications and calibration, controlled climatic chamber, test procedure and the clothing thermal insulations calculation methods can be found in literature and standards, (Parsons, 2003; ASTM, 2004 and ISO 15831, 2004).

In this study the measurements of the different school clothing worn by the girls and boys in Kuwait schools were done using a male (Newton) and a female (Victoria) thermal manikins of the human thermal environments laboratories (HTEL) at Loughborough University, UK. Newton was manufactured by MTNW (Seattle, Washington, USA) and has a surface area of 1.8 m^2, while Victoria was manufactured by PT-Teknik (Denmark) and has a surface area of 1.6 m^2.

2.6 Thermal Comfort

The thermal comfort of person can be defined as "that condition of mind which expresses satisfaction with the thermal environment" (ASHRAE 55, 2004 and ISO 7730, 2005), while Ronald *et al*. (2010) defined the thermal environment as “the characteristics of the environment that affect the heat loss from the human body”. According to the thermal comfort definition, a subjective response of the occupants is derived from the effect of the physical environment on the physiological responses of the body. Thermal comfort indices are a means to evaluate the effect of the thermal comfort variables and it is interaction on the occupants’ thermal state.

2.7 Thermal Comfort Indices

Thermal comfort index is a single value that represents and describes any thermal environment and its effect on an occupant. Many researchers proposed and suggested different thermal comfort indices. These indices can be divided into three main categories according to their rationale: Direct, Empirical and Rational indices, (Parsons, 2003 and NIOSH, 1986).

2.7.1 Direct Indices

Direct indices are based on direct measurements of the environmental variables. These indices can either be determined using simple instruments to estimate the thermal environmental state in a way that can be understood easily by human, or by employing empirical calculations of environmental variables. Some examples of direct indices will be discussed in the following sections.

WBGT (Wet Bulb Globe Temperature) Index

WBGT is a heat stress index that indicates the effect of the thermal environment conditions on the human body, in which the person can express considerable unacceptable heat strain and can lead to illness and death. This index uses the Dukes-Dobos and Henschel (1971 and 1973) relation to integrate the black globe temperature t_g, dry-bulb temperature t_{db} and naturally ventilated (not aspired) wet-bulb temperature t_{nwb} into a single value, determined by:

$$WBGT = 0.7\, t_{nwb} + 0.2\, t_g + 0.1\, t_a \qquad \text{(Eq. 2.4)}$$

Where;

t_{nwb} = temperature of naturally ventilated wet-bulb thermometer, ^oC

t_g = temperature of a 150 mm diameter black globe thermometer, ^oC

ta = air temperature, ^oC

This index is modified to be used in indoor environments as follows

$$WBGT = 0.7\ t_{nwb} + 0.3\ t_a \qquad \text{(Eq. 2.5)}$$

Air velocity and the mean radiant temperature measurements are included in the WBGT index through the black globe thermometer, where the humidity can be measured through the naturally ventilated wet-bulb thermometer. The acclimatization state, metabolic rate and the heat exposure limits, expressed in time per hour are incorporated in this index. This index is commonly used for estimating the heat stress potential of industrial environments (Davis, 1976).

WGT (Wet Globe Temperature)

This index proposed by Botsford (1971) to be a simpler approach than the WBGT approach. It uses the temperature of a wetted globe thermometer called a Bots-ball, which consists of a 65 mm diameter black copper sphere covered with a damp black cloth. As the WBGT index, the environmental variables are incorporated in WGT index. To show the relationship between WBGT and WGT indices, Onkapam *et al.* (1980) reported that in a temperate to warm environments, the WBGT can be calculated with acceptable accuracy by WGT, with limitations, using the following relation

$$WBGT = 1.044(WGT)-0.187 \qquad \text{(Eq. 2.6)}$$

Where;

WBGT = wet bulb globe temperature, ^oC

WGT = wet globe temperature, ^oC

For simple and practical measurements of the thermal environments, direct indices can be used to provide a good, quick approximation with reasonable accuracies with more attention to the limitations of each index.

2.7.2 Empirical Indices

These types of indices are developed from human subjects' responses (subjective) and objective measurements in a known environment. Examples of empirical indices include the Cumulative Heat Strain Index (CHSI), the Physiological Strain Index (PhSI), and the Perceptual Strain Index (PeSI).

2.7.3 Rational Indices

Rational thermal indices are based upon the calculations involving the heat balance equation. All the environmental and behavioral variables are integrated in these indices. In these indices, some of the heat balance equation parameters are assumed to be constant, because it cannot be practically calculated or recorded. If the heat loss from the human body is equal to its heat production, the human body is considered to be in thermal equilibrium state. Any deviation from this state can cause a discomfort state for people. Several of these indices are described and discussed here.

Operative temperature (t_o)

This index proposed by Winslow *et al.* (1937). ASHRAE (2009) defines the operative temperature (t_o) "as the average of the mean radiant temperature (t_r) and the ambient temperature (t_a) weighted by their respective heat transfer coefficients", and is expressed by the equation:

$$t_o = \frac{h_r \bar{t}_r + h_c t_a}{h_r + h_c} \quad \text{(Eq. 2.7)}$$

Where,

t_o = operative temperature, ^oC

t_r = mean radiant temperature, ^oC

t_a = ambeint temperature, ^oC

h_r = radiation heat transfer coefficient, W/m^2K

h_c = convection heat transfer coefficient, W/m^2K

ASHRAE 55 (2004) shows another expression for calculating the operative temperature according to the effect of relative air speed (v_r) as:

$t_o = A\, t_a + (1\text{-}A)\, t_r$ (Eq. 2.8)

Where, A is a coefficient that depends on the relative air speed value as can be found from Table 2.3, below:

Table 2.3: The A coefficient values according to the relative air velocity (ASHRAE 55, 2004)

Relative air speed, v_r (m/s)	< 0.2	0.2 - 0.6	0.6 - 1.0
Coefficient, A	0.5	0.6	0.7

Gagge *et al*. (1971) stated that the operative temperature can be considered as a direct measure of the environmental heat stress on a human subject due to sensible heat loss alone.

New Effective Temperature (ET*)

This index is the most commonly used worldwide in many thermal comfort applications. Gagge *et al*. (1941 and 1971) redefined the original empirical effective temperature (ET) index developed by Houghton and Yaglou (1923) using a rational approach. ET* can be defined as the temperature of an environment at 50% relative humidity in which a human subject would have the same total heat loss from the skin as they would in the actual environment. Due to its definition, the ET* is defined in terms of t_o, where the effects of the integration of t_r, t_a, and P_a are combined into a single index.

In this index and at any given ET* line, the skin wetness w and the permeability index i_m must be constant and need to be specified for the specific environment being assessed. Mathematical representation is provided by ASHRAE (2009) to calculate ET*,

$ET^* = t_o + w_{im} * LR * (P_a - 0.5\, P_{ET^*,s})$ (Eq. 2.9)

Where,

$P_{ET^*,s}$ = saturated vapour pressure at ET*, kPa, LR = Lewis ratio, °C/kPa, this ratio describes the relationship between convective heat transfer and mass transfer coefficients at a surface (h_e/h_c).

ET* lines are affected by the occupant's clothing and activity, where each ET* line can be plotted for given clothing and activity levels. For this reason it is not possible to create a universal ET* chart.

Standard Effective Temperature (SET*)

Calculating the ET* for a subject in a set of standardized indoor environment activity conditions, mathematically represents the Standard New Effective Temperature (SET*). The definition of the SET* index is "the effective air temperature of an imaginary standard (isothermal) environment at 50% relative humidity in which a subject, while wearing clothing standardized for the activity concerned, would have the same total heat exchange from the skin surface as in the actual environment", ASHRAE (2009).

Predicted Mean Vote (PMV)

The predicted mean vote (PMV) model is a combination of several relationships that balance the human energy between the human body heat production and the heat loss. These relations have been integrated by Fanger (1972) into a single steady state equation called the PMV comfort index. This index incorporates the effects of the six basic variables into a single value indicates the occupant's comfort level on the psycho-physical ASHRAE sensation scale. Three conditions were set by Fanger for thermal comfort situation: the body must be in thermal equilibrium; mean skin temperature is at a level appropriate for thermal comfort and sweating is at a preferred rate for comfort.

Thermal neutrality situation can be achieved by the interaction of the environmental parameters that will result in thermal neutral state for the human body and give a thermal sensation response of zero (neutral) on the ASHRAE sensation scale. Thermal neutrality for a person is defined as the condition in which the subject would prefer neither warmer nor cooler conditions. Thermal neutrality differs from thermal comfort in that people can expresses satisfaction and comfortable with thermal environment conditions that are away from their neutral conditions.

The thermal comfort can be written as:

$$(M-W)=3.05\{5.73-0.007(M-W)-p_a\}$$
$$+0.42\{(M-W)-58.15\}+0.0173M(5.87-p_a)+0.0014M(34-t_a)$$
$$+3.69*10^{-8}f_{cl}\{(t_{cl}+273)^4-(\bar{t}_r+273)^4\}+f_{cl}h_c(t_{cl}-t_a) \quad \text{(Eq. 2.10)}$$

where, $t_{cl}=35.7-0.0275(M-W)-0.155I_{cl}[(M-W)-3.05\{5.73-0.007(M-W)-p_a\}$
$$-0.42\{(M-W)-58.15\}-0.0173M(5.87-p_a)-0.0014M(34-t_a)]$$

$$h_c=\begin{cases}2.38(t_{cl}-t_a)^{0.25} & \text{for, } 2.38(t_{cl}-t_a)^{0.25}>12.1\sqrt{v_{ar}}\\ 12.1\sqrt{v_{ar}} & \text{for, } 2.38(t_{cl}-t_a)^{0.25}<12.1\sqrt{v_{ar}}\end{cases} \quad \text{(Eq. 2.11)}$$

$$f_{cl}=\begin{cases}1.00+0.2I_{cl} & \text{for } I_{cl}<0.5 \text{ clo}\\ 1.05+0.1I_{cl} & \text{for } I_{cl}>0.5 \text{ clo}\end{cases} \quad \text{(Eq. 2.12)}$$

Where, M = metabolic rate, *met*

W = external work, W/m^2

P_a = water vapor pressure, kP_a

t_a = ambient temperature, ^oC

f_{cl} = clothing area factor

t_{cl} = clothing surface temperature, ^oC

$\bar{t}_r$ = mean radiant temperature, ^oC

h_c = convective heat transfer coefficient, W/m^2K

I_{cl} = thermal insulation of the clothing, *clo*.

v_{ar} = relative air velocity, *m/s*

The predicted mean vote (PMV) index predicts the mean response of a large group of people according to the ASHRAE thermal sensation scale. Fanger proposed that the thermal sensation of a person at a known activity level is a function of the thermal load (L). The thermal load can therefore be considered as the physiological strain upon the thermoregulatory mechanisms to maintain comfort.

The relationship between the actual heat flow from the body in a given environment and the heat flow required for optimum comfort at the specified activity is given by:

$$PMV= [0.303\ e^{(-0.036M)} +0.028]\ L \qquad \text{(Eq. 2.13)}$$

where, L = thermal load on the body

The thermal load L is the difference between the internal heat production and heat loss in an actual environment for a person in a comfort value of t_{sk} and E_{rsw} at the actual activity level. The clothing temperature t_{cl} is found by iteration as:

$$t_{cl} = 35.7-0.028(M-W)-R_{cl}\{39.6*10^{-9} f_{cl}[(t_{cl}+273)^4-(t_r+273)^4]+ f_{cl}\ h_c\ (t_{cl}-t_a)\} \qquad \text{(Eq. 2.14)}$$

where, R_{cl} = intrinsic clothing insulation, $m^2.^oC/W$

Fanger stated an assumption, which is valid for normal indoor clothing worn in typical indoor environments with low or moderate activity levels, and that is all sweat generated is evaporated to eliminate the clothing permeation efficiency. The PMV index may has a limited accuracy in high activity levels (M_{act}>3 met) where a significant amount of sweating occurs even at optimum comfort conditions.

Predicted Percentage Dissatisfied (PPD)

Output of the previous thermal sensation index (PMV) represents the predicted mean vote of a large group of persons. An important question is raised here, and that is "how can the PMV output value on the ASHRAE psycho-physical scale, be interpret with regards to the satisfaction of people in that environment?".

It is not always possible, for technical or economic reasons, for a thermal environment to provide optimal thermal comfort situation that satisfies all occupants. Fanger (1972) stated that due to inter personal differences; people are not the same in responding to a given surrounding environment. The responses differences will result as a percentage of subjects that are not dissatisfied with their thermal environment. The ASHRAE psycho-physical scale is represented as follow: (-3) cold; (-2) cool; (-1) slightly cool; (0) neutral; (+1) slightly warm; (+2) warm and (+3) hot.

Estimating the percentage of people dissatisfied is the next step after discussing the PMV method. Fanger (1972) established the predicted per cent dissatisfied (PPD) method to estimate people dissatisfaction as follows:

$$PPD = 100\text{-}95 \exp\left[-(0.03353PMV^4+0.2179PMV^2)\right] \quad \text{(Eq. 2.15)}$$

Fanger considered that subjects who voted within the three central categories (-1 slightly cool; 0 neutral and +1 slightly warm) are satisfied with their environment, while dissatisfied subjects are those voting cool, cold, (-2, -3) and warm, hot, (+2, +3). A PMV range of $\pm$0.5 lead to 10% PPD and a PMV= 0 lead to 5% of the occupants are dissatisfied.

Fanger PMV-PPD model integrated the occupants' physiological and psychophysical responses (thermal sensations) to describe the thermal environment and predict how much the occupants are satisfied toward their environment. It is described as relatively simplistic thermal comfort model which made it the dominant thermal comfort model of the last decades to assess the occupants' thermal sensation through a wide range of built environments, (Loveday *et al*., 1998 and de Dear and Brager, 2001).

Adaptive Model

Kempton and Lutzenhiser (1992) argued that, ASHRAE standard 55 and ISO 7730, which are originally developed in fully climate controlled buildings, ignored the cultural and social differences and their importance in perceiving the need of people and their expectations for air-conditioning environments. The main question appeared for many researchers, is "are the ASHRAE 55 and ISO 7730 standards applicable for all types of buildings, especially non-conditioned buildings?". In other words, engineers have not had a suitable tool to help decide when and where full HVAC system is required in a building, and under what circumstances they can incorporate more-energy conserving strategies without sacrificing comfort, Brager and de Dear (2000).

ASHRAE sponsored a series of high–quality field experiments across hot-dry, hot-humid, Mediterranean and cold climatic zones (Schiller *et al.* 1988; de Dear and Fountain 1994, and Donnini *et al.* 1997). The main purpose of the ASHRAE project RP-884 " Developing an Adaptive Model of thermal Comfort and Preferences" is to study, develop and test the adaptive models and complied an extensive database from past field studies to account for contextual and perceptual factors absent in the laboratory setting. Olesen and Parsons (2002) have reviewed the ISO 7730 standard and suggested that, due to the individual differences, it may be very difficult to satisfy everybody in a space but some forms of individual control of the thermal environment combined with individual adaptation (clothing, activity) will increase the level of acceptance.

DeDear and Brager (2002) finished an accepted revision to ASHRAE standard 55, which includes a new adaptive comfort standard (ACS) index for naturally ventilated buildings. Brager and de Dear (2000) explained that the theory behind this model is the factors, beyond the traditional 4 environmental parameters and the personal parameters, which influence a person's perception of thermal sensation. The theory behind this model is the adaptive hypothesis which is divided into three types of adaptations; Behavioral (Adjustments); Physiological (Acclimatization) and Psychological (Expectation and Habituation) Adaptations.

From the extensive database of the past field studies, the Adaptive Comfort Standard (ACS) was proposed to calculate the optimum comfort temperature (t_c) as,

$$t_c = 17.8 + 0.31 * t_{a,\ out} \quad (°C) \qquad \text{(Eq. 2.16)}$$

Where, $t_{a,\ out}$ = the outdoor monthly mean dry bulb temperature, ^oC

Previous adaptive equations

Before the establishment of the adaptive comfort standard (ACS) by De Dear and Brager (2002), some researchers were interested in investigating the relationship between the outdoor temperature and the occupants' comfort temperature inside the buildings under different types of ventilation modes (free-running and air-conditioned) and how did the building occupants adapt to reduce the discomfort and the physiological strain. Different adaptive models were established to investigate the occupants' neutral temperature regarding to these different ventilation modes, free-running, air-conditioned or both. Numerous past field studies from various countries around the world have been references to create the new adaptive model.

Auliciems (1969) suggested that there might be a statistical relationship between indoor thermal neutralities (comfortable) and outdoor climate as well. Humphreys (1976), concluded that "the range of recent experience is better regarded as one of the factors which will contribute to acceptability of the environment to which the respondent is exposed".

Humphreys (1978) plotted the indoor comfort (neutral) temperature (t_n) determined in previous surveys against the outdoor monthly mean temperature (t_m), and found convincing evidence for adaptation to outdoor climate, and cleared the influences of the outdoor climate on indoor comfort. Humphreys created linear regression model separately for naturally ventilated "free running" buildings and air-conditioned or heated (centrally conditioned) buildings, where the relationship is more complex, and end up with equations as:

Naturally ventilated (free-running) buildings

$$t_n = 11.9 + 0.534t_m \qquad (r = +0.97) \qquad \text{(Eq. 2.17)}$$

Centralized HVAC (Climate- controlled buildings)

$$t_n = 23.9 + 0.295(t_m\text{-}22)\exp(-((t_m\text{-}22)/(24\sqrt{2}))^2) \qquad (r = +0.72) \qquad \text{(Eq. 2.18)}$$

where;

t_m = monthly mean temperature, ^oC

The exponential term in this equation represents the change of occupants' expectations level.

Auliciems (1981) revised the statistical regression database done by Humphreys and deleted incompatible field studies from those based on asymmetric rating scales or depended on children as a subjects, and added more recent studies done in various climatic zone that have been published after Humphreys (1976) paper. Auliciems integrated the naturally ventilated and the air-conditioned building databases together and the indoor-outdoor temperatures and created one linear regression model for both types of buildings to predict the neutral temperature as:

All types of buildings

$$t_n = 0.48\, t_i + 0.14\, t_m + 9.22 \qquad (r = 0.95) \qquad \text{(Eq. 2.19)}$$

where;

t_n = neutral temperature, ^oC

t_i = indoor mean temperature, ^oC

t_m = outdoor mean temperature, ^oC

Another expression of Auliciems' equation related to the monthly mean temperature is:

$$t_n = 17.6 + 0.31\, t_m \qquad \text{(Eq. 2.20)}$$

where;

t_m = monthly mean temperature, ^oC

This equation represented a widely cited statistical expression for the adaptive hypothesis of human thermal perception.

After a revision of the Humphreys (1978) database, Humphreys and Nicol (2000) proposed a new model to represent the average comfort (neutral) temperature for both naturally (free-running) and air-conditioned (centralized Air) building types;

$t_n = 24.2 + 0.43(t_m\text{-}22)\exp(-((t_m\text{-}22)/(24\sqrt{2}))^2)$ (Eq. 2.21)

where;

t_m = monthly mean temperature, ^oC

The exponential term in this equation represents the change of occupants' expectations level.

2.8 Thermal Comfort Indices Used (PMV, ePMV, PMV_{10}, Humphreys' and Auliciems's equations and Adaptive Comfort Model).

In this study some of the previously discussed indices will be investigated and tested for its applicability to predict the Kuwaiti classrooms occupants' neutral temperature. These models are PMV-PPD model; Humphreys' and Auliciems's equations, and the Adaptive Comfort Model.

Some new models like the extension of the predicted mean vote model (ePMV) were proposed by Fanger and Toftum (2002). This new model was established by the authors after criticising the prediction error of the PMV model in warm environment. The authors stated that the PMV model predicts well the sensation of occupants group in cool and air-conditioned environments, but in warm environment prediction differences can be related to the differences in the occupants expectancy. In this model, Fanger and Toftum suggested that the occupants of the non-air-conditioned buildings have a lower expectation toward their thermal environment than those in air-conditioned buildings. An expectancy factor '*e*' was proposed as a multiplication factor to the PMV model to improve its prediction.

Table 2.4, shows the ranges of the expectancy factor proposed by Fanger and Toftum. Due to the common use of air-conditioned building in Kuwait and no air-conditioned building are found with short warm periods in summer, building's occupants in Kuwait are expected to have high level of expectancy. According to the table, the suitable range for '*e*' in Kuwait classrooms should be 1.0. According to this expectancy value, the prediction of the PMV and ePMV are identical which means that the 'e' factor does not really apply in Kuwait.

A further approach was taken by the author of this study which involved reducing the estimated sedentary metabolic rate used in the PMV model (which was originally based on adults) by 10% in order to fit the children's metabolic rate. This modification was based on Havenith (2007) published findings for 9-11 years old children, which is the only study found that practically measured the children metabolic rates during the school day. This new approach will be referred to as PMV_{10} in this thesis

Table 2.4: Ranges of Expectancy Factor for Non Air-Conditioned Buildings in Warm Climate

Expectation Level	Building Classification	Expectancy Ranges, e
High	Non air-conditioned building located in regions where air-conditioned building are common, warm periods occurring briefly during the summer.	0.9-1.0
Moderate	Non air-conditioned buildings located in regions with some air-conditioned building, warm summer seasons.	0.7-0.9
Low	Non air-conditioned buildings located in regions with few air-conditioned buildings, warm weather during all seasons.	0.5-0.7

2.9 Worldwide Thermal Comfort Studies in Classrooms

There are many field studies and experiments conducted in different regions of the world to investigate and understand the effects of the thermal comfort different variables on students in classrooms.

During the winter seasons of the period 1966-1968, in Reading area in England, Auliciems (1972) studied the relationship between the comfort performance (mental performance) and the students' thermal sensations. More than 600 boys and girls aged 11-16 years old, in 23 classes drawn from 19 secondary schools participated in this study. Children in this study have worn a customary winter school clothing (unknown clo values) and seated as usual on their desks (sedentary activity, unknown met values). Auliciems found some significant statistical associations between the performance decrements at some tasks and the environmental warmth.

Humphreys (1977) conducted a study of thermal comfort and clothing in 5 naturally ventilated primary schools in UK during the 1971 and 1972 summers. A total number of 641 male and female children aged 7-9 years old in sedentary activity and occupying 17 classrooms participated in this study, where 262 produced records were suitable for analysis. A 7-points thermal comfort rating scale was used by the children to assess their thermal state, with clothing check-lists provided to estimate the children clothing insulation vales. The average clothing insulation value was found to be equivalent to 1 clo. The author found that the desirable temperature by the children is 24^{o}C. The results of the study showed that the children were less sensitive to temperature change than the normal adult, where Humphrey attributed this to the higher normal level of activity of the young children.

Kwok (1998) carried out a field study to examine the applicability of the comfort criteria of ASHRAE Standard 55 in classrooms in Hawaii, which has a tropical climate, and its influence on the energy conservation. This study involved more than three thousands secondary school students from 15 to 18 years old, in 29 naturally ventilated and air-conditioned classrooms at six schools. It took place during two seasons; a hot season, September-October 1996, and winter season, January 1997.

The average clothing insulation (0.45 clo) and the metabolic rate (sedentary activity) of the students' were estimated from the standard tables. The measured average air speed during the naturally and air-conditioned ventilation modes were equal 0.36 m/s and 0.15 m/s, respectively. Kwok found that the indoor climatic conditions in Hawaii classrooms did not meet the requirements of the ASHRAE standard 55 comfort zone and the occupants' acceptability votes of both the naturally ventilated and air-conditioned classrooms exceeded the 80% acceptability criteria of the standards, regardless of whether physical conditions were in or out of the comfort zone. The subjects of this study experiencing non-neutral thermal sensations might consider acceptable and neutral thermal sensations do not correlate to people's ideal or preferred thermal state. The neutral temperatures of the students in naturally and air-conditioned classrooms were found to be equal 26.8^{o}C and 27.4^{o}C, respectively. The study suggested that in order to achieve the thermal comfort standards in classroom, the energy conservation issue must be taken into consideration.

Xavier and Lamberts (2000) have performed a thermal comfort surveys in four classrooms in a free-running, naturally ventilating, secondary school building, where the students' ages are 15-18 years old, in Florianopolis in Brazil. The climate of

Florianopolis -Santa Catarina is temperate to humid tropical climate. The comfort survey was conducted in 1997 during the school academic year (from April to December) in order to investigate and set a new criterion for thermal comfort for students.

The aim of Xavier and Lamberts was to present indices similar to the existing ISO 7730 and ASHRAE 55 standards (PMV-PPD and Adaptive) developed from field studies, in which the subjects are executing their normal activities, by correlating the thermal sensation only with environmental variables for one specific activity, while people wearing their own choice of clothing (average 0.61 clo). In this study the students' neutral temperature was 23.1^{o}C. A good agreement was found in this study between the subjects' sensations and those obtained from predictions determined by regression analysis.

Another field study carried out by Ben Hussein *et al*. (2001) to estimate the comfort zone for air-conditioned classroom in campus building for adults students during summer season in Malaysia. The clothing insulation value and the metabolic rate of the students were estimated from the standard tables to be 0.5 clo summer clothing with a setting quietly activity of 1.2 met. The authors found that the comfort zone for student in the classroom have a temperature range of 23-24.5 ^{o}C, and a relative humidity 74%-83% which is slightly different than that recommended by ASHRAE standard. The respondent thermal sensations were slightly different than that predicted by the PMV index.

In Singapore, Cheong *et al*. (2003) conducted a thermal comfort study in an air-conditioned lecture theatre inside an institutional building with adult students. The climate in Singapore is tropical, where the weather is hot and humid. The objective of this study was to evaluate the thermal comfort conditions in an air-conditioned lecture theatre with an operative temperature of 23^{o}C by using objective measurement, computational fluid dynamics (CFD) modelling and subjective assessments, and examine the applicability of the PMV-PPD indices to the lecture theatre.

The metabolic rate (sedentary activity) and the clothing insulation (0.6 clo) of the subjects were estimated from the standard tables. In this study, it was found that although temperatures and humidity were located at the extreme of the limits, the measured air temperatures, air velocities and humidity were within the limits of thermal comfort set out by ISO 7730 and SHRAE 55 standards. The authors found that the subjects' neutral temperature is equal to 25.8^{o}C. The subjective assessment of this study showed that the occupants were slightly uncomfortable and dissatisfied.

A field study was conducted by Wong and Khoo (2003) in the classrooms of a secondary school consists of four story blocks classrooms in Singapore, which were mechanically ventilated by fans. The tropical weather in Singapore is considered hot and humid. The field study was conducted for two days in August 2001 with varying weather conditions to enable wide range of indoor thermal conditions to be captured to facilitate the determination of the neutral temperature and preferred temperature.

The aim of this study is to measure the thermal comfort variables to assess the classrooms thermal conditions for students, ages 13-18 years old, during their lesson hours. Also, the objectives of their study was to check the applicability of the PMV-PPD and ePMV models by finding out the thermal conditions in classrooms and compare them with that prescribed by ASHRAE standard 55; to investigate occupants' perception of the level of thermal comfort in classrooms and finally, to determine neutral temperature, preferred temperature and acceptable temperature range in classrooms.

Wong and Khoo estimated the students' clothing insulation (0.45 clo) and the metabolic rate (sedentary activity) from ASHRAE 55 standard tables. In this study the analysis of the objective data showed that none of the classes had thermal conditions falling within the comfort zone of ASHRAE standard 55, and occupant found the temperature range beyond the comfort zone acceptable. The students' neutral temperature was found to be 28.8^{o}C where students preferred temperatures lower than the neutral by 1-2^{o}C. The researchers suggested that the standard is not applicable in free-running buildings in the local climate and the new PMV model, extension of PMV for warm climate, still showed discrepancy in predicting actual thermal sensations, especially at lower temperature.

Ahmad and Ibrahim (2003) conducted a field study in the Faculty of Architecture, Planning and Surveying (FSPU) classrooms at the university Teknologi MARA in Malaysia during two serial days on January 2002 involving 12 interior spaces and 4 outdoor spaces. Malaysia is a tropical country, were the weather is hot and humid. The aim of their study is to assess the thermal comfort conditions in the classrooms, which were either mechanically ventilated by fans or air-conditioned, during the day by finding out the thermal conditions in these different types of classrooms and compare the results with ASHRAE standard 55.

They also investigated the thermal acceptability level of occupants in both air-conditioned and fan ventilated classrooms using the ASHRAE scale and to determine the neutrally temperature and acceptable temperature range in both air-conditioned and fan ventilated classrooms.

In this study the students' clothing insulation (0.6 clo) and the metabolic rate (sedentary activity) were estimated from the standard tables. The students' neutral temperature for the naturally and air-conditioned classrooms were found to be 27.7^{o}C and 26.5^{o}C, respectively. The results indicated that Malaysian are acclimatized for much higher environmental temperatures and suggested higher thermal comfort range compared to the thermal comfort range proposed by ASHRAE standards 55. Also, adopting the international standards for interior comfort conditions for Malaysian hot-humid tropical climate will lead to overcooling and energy waste.

Kwok and Chun (2003) conducted surveys in two classrooms occupied by students from 13 to 15 years old in one public naturally ventilated and another private air-conditioned school in Japan, where the climate is temperate to subtropical. This climate allowed a tradition of naturally ventilated residential buildings to develop, including most public schools. The field survey took place during the late summer, September 2000, where the weather is hot and humid and the maximum summer temperature reaches 32^{o}C with a relative humidity ranges from 60 to 85% during the year.

The principal goal of the study was to examine the application of the thermal comfort standard in the cultural and climatic context of Japan. The case study of thermal comfort in schools have: characterized the physical environment of two typical conditioning regimes, naturally ventilated and air conditioned classrooms for summer conditions; compared the classroom physical conditions to the specifications of the thermal comfort standards and compared responses and behaviors to exiting field studies. The authors estimated average subjects' clothing and metabolic rates to be 0.37 clo and 1.2 met, respectively.

In this field study, it was found that although the indoor climatic conditions in naturally ventilated classrooms in Tokyo and Yokohama did not fall within the ASHRAE 55 summer comfort zone, occupants in naturally ventilated classroom expressed satisfaction with the indoor conditions and voted that the conditions were within the central three categories (surrounding neutral) of the ASHRAE thermal sensation scale. The air-conditioned classrooms fall well within the comfort zone, causing occupants to report 'slightly cool' thermal sensation. The neutral temperatures of the subjects in the naturally and air-conditioned classrooms were found to be 27.5^{o}C and 23.1^{o}C, respectively. This study suggested that the neutral thermal sensation is not always the ideal, or preferred thermal state for people.

In autumn 2004, two field studies were conducted by Wang and Wang (2006) in naturally ventilated university classroom at Harbin in China. The studies are to assess the thermal conditions and the subjective effects on adults' undergraduate students' thermal comfort before and after learning the theory of the thermal comfort. The subjects' clothing insulation and metabolic rate were estimated. They found that the students' thermal acceptability before the learning of the thermal comfort theory is higher than that after. These results confirm the subjective effects on thermal comfort.

Hwang *et al*. (2006) conducted field experiments in 10 naturally ventilated and 26 air-conditioned campus classrooms in Taiwan. The objective of this study is to find the range of thermal acceptability, neutral temperature and preferred temperature in hot-humid classrooms and compare it with that prescribed by ASHRAE standard 55.

Like other researchers, the authors of this study estimated the students' clothing insulation (0.6 clo) and the metabolic rate (sedentary activity) from the standard tables. The students' neutral temperature in the naturally and air-conditioned classrooms was found to equal 26.3^{o}C. The study concluded that students' satisfaction with air temperature, wind velocity and solar isolation in classrooms are significant aspects that influence their thermal sensation, where the humidity has no statistical significance. Also, it showed that female students have narrow neutral temperature range, but the same neutral and preferred temperatures with male students. Although the majority of the air-conditioned and naturally ventilated classrooms fell outside the ASHRAE standard 55 summer comfort zone, 80% of the students found their thermal environments acceptable.

Hussein and Rahman (2009) carried out a field study on environmental conditions and occupants comfort in two schools, primary and secondary, and a public waiting area in a public health clinic, which are mechanically ventilated in Malaysia. The respondent's ages were from 10-50 years old, with average clothing and metabolic rate values estimated from the standard tables to be 0.5 clo and 1.2 met, respectively. The authors found that more than 80% of the occupants accept indoor thermal conditions beyond that specified by ASHRAE comfort zone. The occupants' neutral temperature according to their thermal sensation votes (28.4^{o}C) was higher than that predicted by the PMV model (25.9^{o}C).

Under hybrid and natural ventilation modes, Al-Rashidi *et al.* (2009a and b), investigated the thermal comfort sensations for males and females students 11-17 years old in Kuwait classrooms with regard to the gender differences. The metabolic rate in these studies was estimated to be 1.2 met, where the average clothing insulation values for the males and females students were equals 1.17 and 0.95 clo, respectively, during both ventilation modes. In these studies the clothing insulation values of the different scholarwears were measured using thermal manikins with adult versions of the scholarwears used in classrooms (Details can be found in chapter 5 in this thesis). The authors concluded that there is no difference between the males and females sensations in these studies, where the neutral temperatures for both genders during the hybrid and natural ventilation modes were 21.5°C and 21.6°C, respectively.

In another study by Hussein *et al*. (2009) conducted a comparison study to investigate the differences between the occupants' thermal comfort sensations in air-conditioned and non-air-conditioned buildings. Three different air-conditioned buildings were within the UNITEN campus, while another three non-air-conditioned buildings were primary and secondary schools and a public waiting area in a health clinic. The non-air-conditioned buildings were mechanically ventilated by fans. The occupants' metabolic rate and the clothing insulation values were estimated according to tabulated data of the standard tables.

In the study it was found that the neutral temperatures according to the occupants' votes in air-conditioned and non-air-conditioned buildings were 24.4°C and 28.4°C, respectively. The occupants' acceptable comfort ranges of temperature were 23.1-25.6°C for air-conditioned buildings and 26.0-30.7°C for non-air-conditioned buildings.

Fong *et al*. (2010) conducted an experimental study during 2009 summer break using environmental chamber to evaluate the neutral thermal conditions for 48 college age students, aged 20-23 years old, under different ventilation modes, mixing; displacement and stratum ventilations, under two different air change rates (10 and 15 ACH). The clothing insulation and the metabolic rate values of the occupants were estimated from the standard tables (0.57 clo and 1.0 met). The authors found the neutral temperature under the stratum ventilation, in all air change rates, is higher than the other neutral temperatures using the mixing and displacement ventilation modes. They suggested that using the stratum ventilation could provide satisfactory thermal comfort level in addition to saving 12% due to energy loss by ventilation alone.

Al-Rashidi *et al.* (2010) extended their previous investigations in Kuwait classrooms by investigating the thermal comfort sensations of males and females students 11-17 years old in Kuwait classrooms with regard to the gender differences under air-conditioned ventilation mode. The metabolic rate in this study was estimated to be 1.2 met, where the average clothing insulation values for the males and females students were equals

0.65 and 0.73 clo, respectively during this ventilation modes. As the previous studies the clothing insulation of the scholarwears used in classrooms were measured using thermal manikins with adult versions of the scholarwears (Details can be found in chapter 5 in this thesis). The authors concluded that there is no difference between the males and females sensations in this study, where the neutral temperatures for both genders during the air-conditioned ventilation modes was found to be 23.7^{o}C.

The previous literature review of the thermal comfort studies conducted in classrooms worldwide are summarised in Table 2.3.

2.10 Thermal Comfort Studies in Kuwait

In Kuwait, there is a rarity in the thermal comfort studies and research. While searching the literature, only three thermal comfort field studies were found for Kuwait. Two of them were conducted in governmental offices and the other was for residential buildings. The subjects in all of these studies were adults and no young children were included, except those mentioned earlier by Al-Rashidi *et al.* (2009a and b and 2010) which investigated the thermal comfort of school children 11-17 years old with regards to the gender differences.

An earlier thermal comfort research was conducted, during early winter 1977, by Jarrar (1979) in offices at KISR to determine the optimal thermal environment of 30 female and male subjects exposed to two environmental variables (air temperature and relative humidity), while the other two variables (mean radiant temperature and air velocity) were kept constant. A distinction was made between the participants according to the gender and between Kuwaitis and non-Kuwaitis subjects regarding to climate acclimation effect. The clothing insulation and the metabolic rate of subjects were estimated from the standard tables to be equal to 0.8 clo and 1.2 met (light office work) In this study, it was found that the mean comfort temperature for Kuwaitis males, non-Kuwaitis males and both Kuwaitis and non-Kuwaitis females are 25.2^{o}C, 23.9^{o}C and 25^{o}C, respectively. The author related the difference between the Kuwaitis and non-Kuwaitis males for two reasons. The first reason is the effect of acclimation, where Kuwaiti males' subjects are acclimatized to their hot environment conditions, while non-Kuwaitis males' subjects are not. The second reason is attributed to the Arab dress worn by Kuwaitis males which has a marked effect in increasing physiological comfort, since it allows greater air flow around the body. Due to the similarity of dress between the Kuwaitis and non-Kuwaitis females, no noticeable differences occurred.

Table 2.3: Summary of the worldwide thermal comfort studies in classrooms

Researcher & Published Year	Study Location	Climatic Region	Subject's Ages (years)	Average clothing insulation value (clo)	Clothing insulation calculation method	Metabolic Rate (MET)	Metabolic Rate calculation method	Classrooms Ventilation Type*	Neutral Temperature t_n (°C)
Auliciems (1972)	Reading, UK	Temperate maritime	11-16	N/A	N/A	N/A	N/A	NV	15.2
Humphreys (1977)	UK	Temperate maritime	7-9	1	Estimated	1.2	Estimated	NV	24
Kwok (1998)	Hawaii, USA	Tropical	15-17	0.42	Estimated	1.2	Estimated	NV & A/C	26.8 in NV 27.4 in A/C
Xavier and Lamberts (2000)	Florianopolis –Santa Catarina, Brazil	Tropical	15-17	0.61	Estimated	1.2	Estimated	NV	23.1
Ben Hussein *et al.* (2001)	Malaysia	Tropical	Adults	0.50	Estimated	1.2	Estimated	A/C	23-24.5
Cheong *et al.* (2003)	Singapore	Tropical	Adults	0.60	Estimated	1.2	Estimated	A/C	25.8
Wong and Khoo (2003)	Singapore	Tropical	13-18	0.45	Estimated	1.2	Estimated	NV	28.8
Ahmad and Ibrahim (2003)	Shah Alam, Malaysia	Tropical	Adults	0.60	Estimated	1.2	Estimated	NV & A/C	27.6 in NV 26.5 in A/C
Kwok and Chun (2003)	Tokyo, Japan	Sub-Tropical	13-15	0.37	Estimated	1.2	Estimated	NV & A/C	27.5 in NV 23.1 in A/C
Wang and Wang (2006)	Harbin, China	Tropical	Adults	0.57	Estimated	1.2	Estimated	NV	N/A
Hwang *et al.* (2006)	Center and South Taiwan	Sub-Tropical	Adults	0.60	Estimated	1.2	Estimated	NV&A/C	26.3
Corganti *et al.* (2007)	Turin, Italy	Mediterranean	15-17	N/A	N/A	1.2	Estimated	Hybrid	21.5
Hussein and Rahman (2009)	Malaysia	Tropical	6-17	0.50	Estimated	1.2	Estimated	NV	28.4
Ben Hussein *et al.* (2009)	Malaysia	Tropical	Adults	0.50	Estimated	1.2	Estimated	NV&A/C	23.1-25.6 in A/C 26-30.7 in NV
Al-Rashidi *et al.* (2009a)	Kuwait	Hot, dry	11-17	1.17 boys 0.95 girls	Measured[2]	1.2	Estmated	Hybrid	21.5
Al-Rashidi *et al.* (2009a)	Kuwait	Hot, dry	11-17	1.17 boys 0.95 girls	Measured[2]	1.2	Estimated	NV	21.6
Fong et al. (2010)	Hong Kong	Tropical	Adults	0.57	Estimates	1.0	Estimated	DM	27.0
Al-Rashidi *et al.* (2010)	Kuwait	Hot, dry	11-17	0.65 boys 0.73 girls	Measured[2]	1.2	Estimated	A/C	23.7

NV: Natural Ventilation; A/C: Air-Conditioning;; Hybrid: Air-Conditioning system is turned on and off during different parts of the day; DM: different ventilation modes; mixing; displacement and stratum; N/A: Not available; [1]with Havenith (2007) corrections, [2]Using thermal manikins with adult size clothing, Al-Mutawa *et al*. (2004) conducted field thermal comfort experiments and surveys in 10 air-conditioned governmental offices in Kuwait to assess the applicability of the PMV standard to evaluate the thermal comfort conditions. In these experiments, the researchers estimated the occupants' clothing insulation and the metabolic rate (sedentary activity) values according to the ASHRAE 55 standard tables, while for some traditional Kuwaiti clothing items which are not included in the published tables yet were estimated by the authors. Results of this study were compared with other comfort indices to obtain the most viable comfort index and the appropriate temperature range for local comfort for Kuwait offices. In this study it was found that people in Kuwait are comfortable for PMV values in the range (-0.5 to 0), where the subjects' neutral temperature in this study was about 24^{o}C. It was found that people in Kuwait preferred temperature 1^{o}C lower than their neutral temperature (23^{o}C).

A recent thermal comfort study was conducted by Al-ajmi and Loveday (2010) during summers 2006 and 2007 to investigate the indoor climate and occupants' thermal comfort in 25 residential buildings in Kuwait. A number of 111 subjects participated in this field study and were wearing traditional indoor clothing with a mean clothing insulation value of 0.9 clo. The clo values of the Kuwaitis' indoor and outdoor traditional clothing were measured by the authors using thermal manikins. The metabolic of the subjects were recommended from the standard tables and equal to 1.2 met for sedentary activity. The authors found that the occupants' neutral operative temperature based on their actual mean vote (AMV) and that according to the predicted mean vote (PMV) model were 25.2^{o}C and 23.3^{o}C, respectively.

2.11 Kuwait Weather and Classrooms Ventilation Modes

Kuwait is a hot and dry country with a short cold winter and long hot summer and scarce rains fall during the cold season from November to May. Spring and autumn in Kuwait are two observed transitional seasons. Winter conditions prevail often from mid-December and fade away after mid-February, where the manifestations of the summer, appears in late March and lasts and dominants until the end of October.

In winter the prevailing winds are north-westerly and are characterized by continental cold winds with an average maximum temperature in January of 18^{o}C and may drop during the extreme conditions to freezing temperatures during the day and especially during the night.

The weather in spring is warm during the day, cold at night, especially in March, where the temperature rises steadily from the winter levels to hot levels ranging from 30^{o}C during April. During this season, heat waves effect the country from the blowing currents Genoese East and South, which raise the maximum temperature to 40^{o}C or higher. During March and April months, the weather is characterized by a sudden change in the daily temperatures where the difference between a day and another can be about 15^{o}C or more and sands storms may occur during the months of April and May
Summer in Kuwait is a hot season, especially during the day and the average temperature in the afternoon can be 48^{o}C, where the maximum temperature sometimes can exceed 55^{o}C, especially in late July and during August and often after the end of each moist period, where the wind blows from the dry and warm west or south-west and north-west. The wind is active during some periods and causes dust storms, which sometimes takes about 10 hours a day. In the second half of this season another type of weather of high humidity and temperature occurs.

In autumn, temperatures start to decrease from early October to 22^{o}C at the end of November. The moderate north-westerly winds may prevail and warm weather is characterized by a sudden change in temperature during the day and especially after the end of October occurs. Figure 2.1 shows the average maximum, minimum monthly and indoor design temperatures for Kuwait classrooms during the academic year, (MD, 2004 and MEW/R-6, 2010).

According to this weather in Kuwait, most buildings, including schools, extensively use air-conditioning systems during summer, while in winter the weather is cold and dry and the air conditioning systems are not in use. Since the beginning of 1990's, the school buildings in Kuwait were extensively constructed or renovated. Air-conditioning systems were installed in those buildings to provide comfortable thermal conditions. The control of those systems is not under the direct control of the students, and this may have a negative effect on the student comfort in the classroom.

The academic year in Kuwait schools runs from October to June. According to the outside weather three different modes of ventilation (hybrid; natural and air-conditioned) are operated in classrooms during the academic year. The hybrid ventilation mode is seen during November, where this period represents the end of the hot season and the beginning of the cold season.

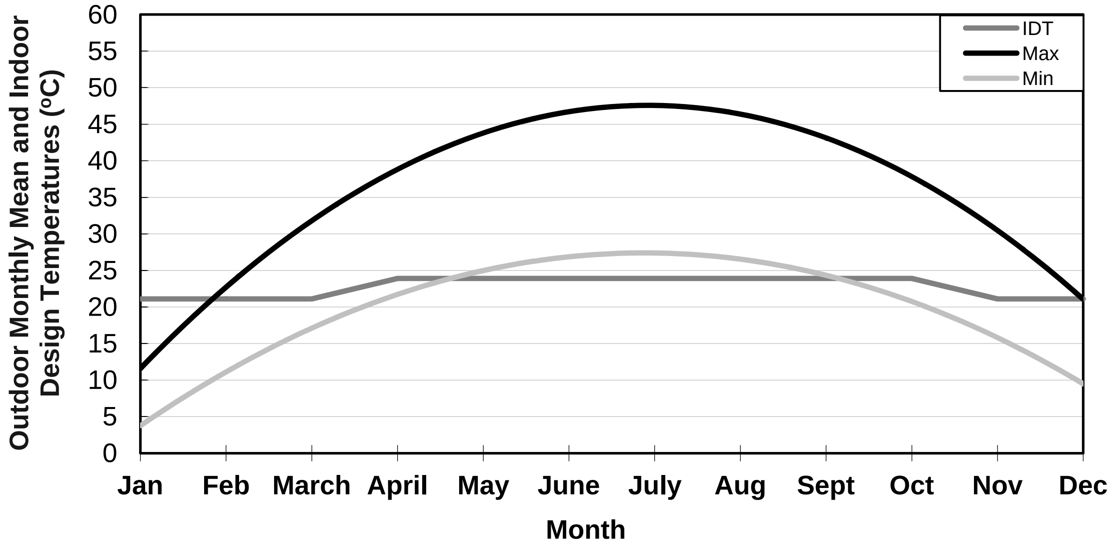

Figure 2.1: The outdoor average maximum, minimum monthly and the indoor design temperatures for Kuwait classrooms, [MD, 2004 and MEW/R-6, 2010]

The weather in November is considered as thermally fluctuating and some of the classrooms are still using air-conditioning systems. In these classrooms the operation of the air-conditioning systems is considered to be in the 'hybrid mode' where the air-conditioning systems are turned on and off during different parts of the day. The natural ventilation mode is seen in February, where this period in Kuwait is considered to be cold, classroom windows are open and all the classrooms are neither using air-conditioning nor heating systems. The air-conditioned ventilation mode is seen in May, where the weather is hot, classroom windows are kept close and all the classrooms are cooled using air-conditioning systems

2.12 Discussion

Although the interest in thermal comfort issues began at the beginning of the last century, and an extensive developments have occurred for better understanding of the human thermal comfort issues ended with the establishment of standards such as ASHRAE standard 55 and ISO 7730 standard, there were no serious and real considerations taken to investigate the relationship between the occupants and their environments and toward the thermal comfort issues and its applicability in Kuwait classrooms.

From the previous literature review of thermal comfort issues in classrooms, it is clear that there are some lack points that may affect the results accuracy of these studies which may create some uncertainty about some findings in general and if applied on Kuwait environment in particular. These lack points are summarized as:

1. All the previous studies investigated the thermal comfort conditions in classrooms in tropical or hot humid climatic environments where no studies done in classrooms in hot dry (desert) climatic environment like Kuwait classrooms.
2. The previous field studies investigated the thermal sensation of either adults or children in intermediate or secondary school levels, at ages between 10-18 years old, where their reading and writing abilities are developed. They did not investigated the thermal sensations of younger children, especially between 6-10 years old, in the earlier academic level such as the elementary level, especially the children in the first academic years who's learning abilities are still not developed and may have difficulties in reading and writing.
3. The thermal sensations of females and males children were combined in the previous studies, where the separation of classrooms in Kuwait can help to investigate if there is any difference in the thermal sensations of each gender separately.
4. The thermal clothing insulation values of the subjects were estimated in the previous studies from the tabulated data of the standards, which originally based on adult persons measurements, and are not scientifically measured or adopted to fit children sizes to ensure any differences between the adults and children measurements.

5. The previous studies do not study the effect of the different thermal environments on the students' performance and productivity.

Chapter 3

Indoor Air Quality (IAQ) literature Review

3.1 Chapter Summary

This chapter introduces a literature review about the indoor air quality (IAQ) issues in classrooms. The sources of the common indoor pollutants and the sick building syndrome (SBS), and its effects on the student's and staff's comfort, health, learning performance and productivity were discussed. The different international IAQ standards including Kuwait for the recommended levels of the common indoor pollutants and the exposure time were tabulated in this chapter. The ventilation rate as an indication for the quality of the classrooms indoor air was discussed, by reviewing the previous work done in classrooms with respect to the different ventilation rates and its effect on the health and performance of the students. From this literature, it is clear that more research and investigations are needed to provide more information about the indoor air quality inside Kuwait classrooms and its effect on the student's comfort, health and productivity.

3.2 Introduction

Air pollution is an expression used to describe the air state when the concentrations of chemicals, particulate matter, or biological agents in the air exceeds the recommended levels and became a source of health hazard or cause discomfort to humans and other organisms, or cause damages to the living natural environment. Pollution can be a result from man-made daily industrial processes and activities or by the nature. There are many forms of pollutants: solid particles, liquid droplets, or gases. Indoor air pollution can arise from indoor and outdoor pollutant sources.

People, especially students, spend about 90% of their live in sealed controlled environments, EPA (2001). These sealed environments may have pollutant sources that could have short or long effects on occupants' health, comfort, well-being, morale and productivity. The strength of the effects depends on the level of the quality of the inside air (pollution levels). In recent years, the issue of indoor air and its quality (IAQ) has become an internationally recognized issue that caught the attention of researchers and the occupants toward improving the quality of air inside buildings environments. Fanger (2006) defines the indoor air quality (IAQ) as "the desire of human to perceive the air as fresh and pleasant, with no negative impacts on their heath and productivity". Many researchers such as Wark and Warner (1981) and Singh (1996) investigated the sources of the outdoor and the indoor pollution that affected the indoor air. They found that the indoor air quality can be influenced by the outdoor air pollution sources such as traffic; industrial; construction, and combustion activities and the indoor sources such as ventilation equipment, furnishings, and human activities.

3.3 Common Indoor Air Pollutant

In this section, the common indoor air quality parameters and their outdoor and indoor sources, in addition to their health hazard on human shall be discussed. The common IAQ parameters consist of three physical parameters (room temperature, relative humidity, and air movement) related to occupants' thermal comfort which is defined in the previous chapter, and eight gaseous contaminant parameters (sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), formaldehyde (HCHO) , radon (Rn), ozone (O_3) and hydrocarbons), in addition to three airborne contaminants parameters, particulates matters (PM); bio aerosols (bacteria, viruses, fungi and pollen, …etc) and dusts. Odours are also a parameter.

3.3.1 Sulphur Dioxide (SO_2)

This type of pollutant gas has been extensively studied by many researchers around the world in outdoors environments due to its high tendency to react with wide range of chemicals. SO_2 is a colourless gas with a characteristic pungent odour and results from the fossil fuels combustion. Acid rain is one of the outdoor pollution problem caused by this gas. Indoor SO_2 concentrations are usually lower than outdoor, probably around 0.1 ppm, (Andersen 1972; Yocom, 1982 and Meyer, 1983).

Due to its tendency to react with many chemicals, indoor SO_2 can reacts with building materials and be absorbed by the building surfaces (Andersen 1972). This gas can dissolve in water and mixes with air in all temperatures. The main indoor sources of SO_2 are coal burning inside fireplaces and using fuel oil stoves and heaters. Sulphur dioxide causes headache, general discomfort, anxiety, and inflammation of the respiratory tract, wheezing, lung damage, and irritation of the eyes, nose and throat, choking and coughing, ASHRAE (2009).

3.3.2 Nitrogen Dioxide (NO_2)

Nitrogen dioxide is a corrosive gas with pungent odour and formed in outdoor atmosphere from high temperature combustion processes by the reaction of the nitric oxide (NO) with Oxygen (O_2) and Ozone (O_3). Motor vehicles contribute to about 55% of the manmade NOx emissions, EPA (2008a). The major sources of this gas in indoors environments are gas cooking stoves and heaters and tobacco smoke, Samet *et al*., (1987). In a study done by Yocom (1982) among British school children, it was found that students whom they suffer from reduced respiratory function are living in houses with gas stoves.

Exposure to low levels of Nitrogen dioxide (NO_2) causes shortness of breath, tiredness, nausea and irritation to the eyes, nose, throat, and lungs; exposure to high levels cause rapid burning, spasms, swelling of tissues in the throat and upper respiratory tract, reduced oxygenation of body tissues, a build-up of fluid in the lungs, and may lead to death, (Burgess and Crutchfield, 1995; Bascom *et al*. 1996 and ASHRAE, 2009).

3.3.3 Carbon Monoxide (CO)

CO is a very poisonous asphyxiate and non-irritating gas that has no colour, odour or taste. This gas is produced by the incomplete combustion of carbon-based fuels (Yocom, 1982 and Meyer, 1983). Vehicular exhaust is a major source of carbon monoxide, (Moolenaar *et al*., 1995; Girman *et al*., 1998 and EPA, 2008a). The indoor carbon monoxide concentrations are often higher than the outdoor concentrations due to the emission from gas stoves and tobacco smoke, (Yocom, 1982 and Girman *et al*., 1998). The main effect of this gas on human health is its affinity for hemoglobin in blood.

The inhaled CO mixes with the hemoglobin in the blood and forms carboxyhaemoglobin that reduces the oxygen carrying capacity of the blood vessels. CO is 240 times more efficient at hemoglobin binding than Oxygen, ASHRAE (2009). Exposure to carbon monoxide causes headaches, shortness of breath, muscle aches, chest pain, especially in people with previous heart problems history, blurry vision, dizziness, nausea/vomiting, weakness, confusion, fatigue, rapid heart rate at high levels, fast deep breathing at high levels, fainting and death at high levels, CPSC (2006).

3.3.4 Carbon Dioxide (CO_2)

Carbon dioxide is a colourless, odourless; asphyxiate greenhouse gas emitted from the complete combustion of the carbon with Oxygen. The average typical concentrations of CO_2 in the outdoor and indoor (nonindustrial) environment are 350-400 ppm, and 400-1200 ppm, respectively, ASHRAE (2009). The principal sources of the indoor CO_2 are human body through the metabolism process (food consumption), and occupants' activity.

The health problems associated with carbon dioxide exposure are headaches, dizziness, restlessness, feeling of an inability to breathe, malaise (vague feeling of discomfort), increased heart rate, increased blood pressure, visual distortion, impaired hearing, nausea/vomiting, loss of consciousness, coma, convulsions, death from asphyxiation (body cells do not get the oxygen they need to live), EPA (2008a).

3.3.5 Formaldehyde (HCHO)

Formaldehyde is a colourless gas with a strong pungent odour and considered as the most important substance in the aldehydes group due to it is mostly used in the production process of many building materials such as foam insulation, plywood, carpets, combustion appliances and particle board adhesives which releases again the formaldehyde to the indoor environment. The typical indoor formaldehyde concentrations range from 0.05 to 1 ppm, while in the new buildings the indoor levels of the formaldehyde are higher, (Meyer, 1983; Samet and Spengler, 1991) and most of the complains were from buildings with formaldehyde foam insulation and mobile homes that uses plywood panelling, Wadden and Scheff (1983). The rate of diffusion of this substance is a function of the indoor temperature and humidity. Exposing to formaldehyde can cause health effects including eye, nose, and throat irritation; wheezing and coughing; fatigue; skin rash; severe allergic reactions, EPA (2008a). High concentrations of formaldehyde may cause cancer and other effects listed under organic gases.

3.3.6 Radon (Rn)

Radon is an inert radioactive, colourless, odourless, tasteless noble chemical gas element. Naturally, this element can be found as soil gas contained radon formed from the decay product of uranium and can remains as a gas under normal environmental conditions. This contaminant element can be found indoors due to some sources such as building materials, especially that rich with radium, such as alum shale-based material and phosphogypsum wallboard, deep wells water and natural gas having high radon concentrations. Another principal source is the flow of the soil gas into the homes through building cracks, sumps and any other openings or around the concrete slab, Bale (1980). Due to tightness of the building's design, the indoor concentrations are usually higher than that in outdoor environment. Recently, this element is considered as carcinogen element due to it is radioactivity, which has a vital health hazard on building occupants, where it is considered to be the second most reason of lung cancer after cigarette smoking, EPA (2008b).

3.3.7 Ozone (O_3)

Ozone is a very reactive pollutant that can oxidizes most of the chemicals in nature such as aldehydes. In natural outdoor environment, Ozone produces from the effect of the sunlight on the nitrogen oxides and hydrocarbons. Usually the Ozone concentrations in the outdoor environment are higher than that found in indoors. The main sources of the high indoor Ozone concentration are the photocopy machines, laser printers, electrostatic air cleaners and x-ray generators, (Yocom, 1982 and Wadden and Scheff, 1983).

These sources develop electrostatic fields that can generate highly toxic concentrations of ozone in air. Exposing to low concentration levels of Ozone can cause eye irritation, visual disturbances, headaches, dizziness, mouth and throat irritation, chest pain, insomnia, breath shortness and coughing (Sittig, 1991 and Apte *et al*. 2008), where exposure to high levels of ozone can reduce lung function, and cause respiratory problems, such as asthma or bronchitis, (Bates, 1989; EPA, 2008a and ASHRAE, 2009).

3.3.8 Hydrocarbons

Most of the indoor hydrocarbon sources are results from the different housekeeping materials such as widows, oven, drain, and clothing cleaners, paint solvent; and human use materials such as deodorants, shaving creams, hair sprays and air refreshers sprays. The indoor hydrocarbons levels reach high levels when housekeeping is in progress, Meyer (1983). The indoor cooking gas (mostly Propane gas) is considered also a major source of the indoor hydrocarbons which may results in serious fire accidents or death due to insufficient maintenance or checking for the gas burner and cooking equipment, Meyer (1983).

3.3.9 Particular Matters (PM)

Particulate matters (PM) can be found as solid and/or liquid droplets particles suspended in air. Particulate matters can be generated from man-made (fossil fuels combustion and mechanical processes) or natural (volcanoes, dust storms, and forest and grassland fires) processes, ASHRAE (2009). There are many sources of the indoor particles such as pets, gas stoves, and tobacco smoke. Particles are classified according to their size, as fine particles are those whose size is smaller than 2.5 μm, while coarse particles are those which are larger than 2.5 μm. Heinrich and Slama (2007) argued that the fine particles are the major threat source that affects the children health, where exposing to fine particles can results in cardiac and respiratory problems, (Dockery *et al.*, 1993; Dockery and Pope, 1994; Pope *et al.*, 2002; Wu *et al.*, 2005 and Gilliland *et al.*, 2005). The PM metals components are a major source that involves in the development of pulmonary, cardiovascular and allergic diseases, Schwarze *et al.* (2006). Exposure to high levels of fine particles causes health hazards such as heart diseases; respiratory diseases; altered lung functions, especially in children, and lung cancer and death, EPA (2008).

3.3.10 Bio aerosols Parameters

Fungi, viruses, bacteria, fungal and bacteria spores, pollen and allergens are types of the microbiological indoor particulate contaminants. The major sources of these contaminants are human, animals and plants, where it can be found anywhere these sources are available, Meyer (1983). Due to the insufficient maintenance of the HVAC system parts (condensers, cooling coils, ducts and drainage pans), it can be another source of contamination by encouraging the proliferation of the microbes, (Wark and Warner, 1981 and Samet *et al.*, 1991). The concentrations of the indoor microbes are higher than that in the outdoor environment due to the building tightness and the source availability.

3.3.11 Dust

Dust is one type of the solid particulate contaminants. ASHRAE (2009) defines dust as "solid particles projected into air by natural forces such as wind, volcanic eruption, earthquakes, or by mechanical processes including crushing, grinding, demolition, blasting, screening, drilling, shovelling and sweeping". Dust immigrates from outside to inside environment by infiltration air through the building's crack, unsealed windows and doors and through the ventilation system. Dust has health effects on people with ultra-sensitive lungs such as people with asthma, young children and elderly people.

Dust causes discomfort for people and damages home furniture and household equipment.

3.3.12 Odours

Indoor odours are arising from occupant's bodies and their indoor activities such as smoking, cooking, garbage, sewage and industrial processes. The human body normally dissipates around 200 types of chemicals which are responsible for the human odours, (Meyer, 1983). Odours do not have any major effects on the occupant's health, but it causes discomfort sensation to the occupants which make it as a sign of the poor indoor air quality.

During this study, the CO_2 contaminant will be studied to investigate the quality of indoor air inside Kuwaiti's classrooms. The indoor concentration of carbon dioxide (CO_2) has often been used as a surrogate for the ventilation rate per occupant, (Lee and Chang, 1999 and Daisey *et al*., 2003), where providing good ventilation rates with sufficient amounts of fresh air can dilutes and reduces the concentrations levels of indoor air pollution generated by the different indoor pollutants sources.

3.4 International and Kuwait Indoor Air Quality Standards and Regulations

Since the last decade, researchers were interested in investigating the indoor air pollution for different indoor environments and the contaminant sources to indicate the acceptable indoor concentration levels for these pollutants. As a result of these researches, many IAQ standards and regulations have been developed and established by different organizations to indicate the recommended acceptable concentrations levels for these indoor pollutants. A summary of the common indoor air pollutants standards in ppm (unless otherwise specified) are given in Table 3.1.

Table 3.1: International and Kuwait Standards and Guidelines for Common Indoor Air Pollutants, (in ppm).

	NIOSH (1992)	**Canadian (1995)**	**OSHA**	**MAK (2000)**	**NAAOS/EPA (2000)**	**WHO/Europe (2000)**	**ACGIH (2001)**	**Hong Kong (2003)**	**KW-EPA (2001)**
Sulphur Dioxide (SO_2)	2 [8 hr] 5 [15 min]	0.019 [8 hr] 0.38 [5 min]	5 [8hr]	0.5 [8 hr] 1.0 [5 min]	0.14 [24 hr] 0.03 [1 yr]	0.047 [24 hr] 0.012 [1 yr]	2 [8 hr] 5 [15 min]	0.03 / 0.04 [8 hr]	2 [8 hr] 5 [15 min]
Nitrogen Dioxide (NO_2)	1.0 [15 min]	0.05 [1 yr] 0.25 [1 hr]	5 [Ceiling]	5 [8 hr] 10 [5 min]	0.05 [1 yr]	0.1 [1 hr] 0.02 [1 yr]	3 [8 hr] 5 [15 min]	0.021/ 0.08 [8 hr]	0.026 / 0.08 [8 hr]
Carbon Dioxide (CO_2)	5000 [8 hr] 30000 [15 min]	3500 [8 hr]	5000 [8 hr]	5000 [8 hr] 10000 [15 min]			5000 [8 hr] 30000 [15 min]	800 / 1000 [8 hr]	600 / 1000 [8 hr]
Carbon Monoxide (CO)	35 200 [Ceiling]	11 [8 hr] 25 [1 hr]	50	30 60 [30 min]	9 [8 hr] 35 [1 hr]	86 [15 min] 51 [30 min] 25 [1 hr] 8.6 [8 hr]	25	1.7 / 8.7 [8 hr]	86 [15 min] 51 [30 min] 25 [1 hr] 8.6 [8 hr]
Particular Matter (< 2.5 µm)		0.1 mg/m^3 [1 hr] 0.04 mg/m^3 [8 hr]	5 mg/m^3	1.5 mg/m^3 For < 4 µm	35$\mu g/m^3$ [24hr] 15$\mu g/m^3$ [1 yr]	25$\mu g/m^3$ [24hr] 10$\mu g/m^3$ [1 yr]	3 mg/m^3		0.23 mg/m^3 [24 hr] 0.07 mg/m^3 [1 yr]
Formaldehyde (HCHO)	0.016 [8 hr] 0.1 [15 min]	0.1 [5 min] 0.04 [1 yr]	0.75 [8 hr] 2 [15 min]	0.3 [8 hr] 1.0 [5 min]	0.4 [8 hr]	0.081 [30 min]	0.3 [ceiling]	0.024 / 0.081 [8 hr]	0.08 [30 min]
Radon (Rn)	4 pCi/L [1 yr]	5 pCi/L [1 yr]	4 pCi/L [1 yr]		4 pCi/L [1 yr]	2.7 pCi/L [1 yr]		4 / 5 pCi/L [8 hr]	4 pCi/L [1 yr]
Ozone (O_3)	0.1 [8 hr]	0.02 [8 hr]	0.1 [8 hr]	0.06 [8 hr]	0.12 [1 hr] 0.07 [8 hr]	0.06 [8 hr]	0.05 – heavy work 0.2 – any work [2 hr]	0.025 / 0.061 [8 hr]	0.03 / 0.1 [8 hr]

Where; Numbers in brackets [ ] refers to average time (min=minutes; hr=hours and yr=years).

- NIOSH (1992). *NIOSH Recommendations for Occupational Safety and Health – Compendium of Policy Documents and Statements.* National Institute for Occupational Safety and Health, January. [Online at: http://www.cdc.gov/niosh/chem-inx.html];
- Canadian - Health Canada (1995). *Exposure Guidelines for Residential Indoor Air Quality: A Report of the Federal-Provincial Advisory Committee on Environmental and Occupational Health.* Ottawa: Health Canada;
- OSHA - U.S. Department of Labor, Occupational Safety and Health Administration. *Code of Federal Regulations,* Title 29, Part 1910.1000-1910.1450. [Online at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992];
- MAK (2000). *Maximum Concentrations at the Workplace and Biological Tolerance Values for Working Materials 2000.* Commission for the Investigation of Health Hazard of Chemical Compounds in the Work Area, Federal Republic of Germany;
- NAAOS/EPA (2000). U.S. Environmental Protection Agency. *Code of Federal Regulations*, Title 40, Part 50. National Ambient Air Quality Standards. [Online at: http://www.epa.gov/ttn/naaqs/];
- WHO/Europe (2000). World Health Organization. *Air Quality Guidelines for Europe* (2nd Edn.). World Health Organization Regional Publications, European Series No. 91. World Health Organization, Regional Office for Europe, Copenhagen. [online at: http://www.euro.who.int/document/e71922.pdf];
- ACGIH (2001). *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* American Conference of Governmental Industrial Hygienists, 1330 Kemper Meadow Drive, 6500 Glenway, Building D-7, Cincinnati, OH, 45240-1630;
- Hong Kong (2003). The Government of the Hong Kong Special Administrative Region, *A Guide on Indoor Air Quality Certification Scheme, 2003* [online at: http://www.iaq.gov.hk/cert/doc/CertGuideeng.pdf] and
- KW-EPA (2001). Kuwait Environmental Public Authority, Requirements and Environmental Standards in Kuwait, 2001.

These standards are established according to the purpose and activity of the indoor zone and characteristics of its users or occupants. For this reason, some differences in values for the same pollutant can be seen in the table.

3.5 Sick Building Syndrome (SBS)

Since people spend most of their times in indoor environments in buildings, these buildings are expected to be well designed in order not to threaten the occupants' well-being and health. Occupants, in general, have good knowledge of the different types of the indoor pollutants and its health hazards on human, but are still unaware of the quality of the air inside the building envelope and whether it is adequate or inadequate which may have a threat to occupants' health.

Due to the energy crisis of the 1970s and its effects on some countries, tighter buildings designs with low air exchange (fresh air) with outside environment have been constructed in order to save energy costs. Indoor air recirculation ventilation strategy has been used for building ventilation purposes. Although significant energy savings was accomplished, researchers reported occupants' complains due to a complex and even disabling syndromes. These syndromes are defined as sick building syndrome (SBS) and were linked to the pollution of the inside air and the level of the ventilation.

Unacceptable indoor air quality (IAQ) conditions may occur in 30% of the new buildings (WHO/Europe, 2000), and may cause diverse symptoms and illnesses that affect the occupants' well-being, which may results in increasing the occupants' productivity lost and work absenteeism. This symptom syndrome which referred to as SBS, may lead to significant work time lost and medical costs that affects the national economy. The sick building syndrome (SBS) can be identified by the following typical symptoms such as headache; chest tightness; lethargy; dry chest; stuffy nose; loss of concentration; dry skin; blocked, runny an itchy nose and watering or itchy eyes.

Sick building syndrome (SBS) and the building related illnesses (BRI) are not necessarily the same, where the BRI symptoms such as diseases, rhinitis and asthma are more acute than SBS symptoms in the buildings, Singh (1996).

3.6 Indoor Air Quality in Schools

Schools are the most important indoor environments, where children spend most of their times besides homes. It is well documented that IAQ problems in schools and other buildings types, commercial and residential, occurred as an unexpected results from applying energy conservation measures in buildings. Ventilation in these buildings has decreased to save energy by depending on the indoor recycled air inside the occupied zone. Children breathe higher volumes of air relative to their body weights which make them more susceptibility to some environmental pollutants than adults, (Faustman *et al*., 2000 and Landrigan, 1998). Poor IAQ in the classroom could have negative impacts on children's learning and performance, which may have both immediate and lifelong consequences, for the students and for society (Mendell and Heath, 2005).

Many researchers investigated IAQ problems in schools around the world, where these investigations were conducted often for a specific single indoor air pollutant or a combination of pollutants (GAO, 1995). In schools, pollutant emissions can occur in many places within the school envelope such as cafeterias, swimming pools, science labs (often without fume hoods) and computer rooms. IAQ problems can results also from the building design, construction materials, type of the HVAC units and the lack of maintenance of these units, and crowded classrooms. The following literature is some examples of the studies conducted in classrooms around the world to investigate the effects of the different indoor pollutants on the student's health and performance.

The NO_2, TVOC, formaldehyde, PM_{10} and asbestos dust concentrations were measured by Cavallo *et al*. (1993) in 10 naturally ventilated schools and seven air-conditioned office buildings in Italy. The findings of this study suggested that the average NO_2, PM_{10} and asbestos dust concentrations were the same indoors and outdoors in all schools.

The effects of generated pollutants from gas heaters on children in 41 classrooms in Australia were studied by Pilotto *et al*. (1997). A significant relation was found between the indoor NO_2 concentration and the absences of the students from school. The authors reported that strong evidence was found between the association of NO_2 concentration levels and the student's sore throat, clods and absences from school even at low concentrations levels.

Lee and Chang (1999) measured and compared the indoor and outdoor relative humidity (rh), and the concentration levels of CO_2, SO_2, NO, NO_2, PM_{10}, and HCHO, in addition to the total bacteria counts in five air-conditioned or naturally ventilated classrooms in Hong Kong. The aim of the study was to check whether the measured indoor concentration levels are complied with the Hong Kong standard.

In a study by Daisey *et al*. (2003) reviewed and analysed the literature of the exiting IAQ, ventilation rates and indicated building health problems information related to the school buildings. The measured ventilation and CO_2 concentrations showed that many of the classrooms were having inadequate ventilation. They suggested that although levels of the measured indoor pollutants concentrations (HCHO, VOCs and bioaerosols) were lower than that recommended by standards and guidelines, exposures to pollutants in schools are associated with allergy, asthma, and SBS symptoms

In Denmark, Meyer *et al*. (2004) conducted a cross-sectional epidemiological study, which included 1053 school children aged 13–17 years, in 15 school buildings. The study utilized a questionnaire about the building related symptoms and health aspects affecting the students' exposure to some indoor pollutants. In this study the room temperature, CO2, relative humidity levels were measured; the dust from the floors, air, ventilation ducts during school day were collected and building characteristics including mold infestation were assessed. The authors reported that there is no positive association between building-related symptoms and the moisture of the air and growth of moulds in the school buildings. The authors concluded that mould exposure is a secondary source and not a main source to asthma, hay fever, recent airway infection, or psychosocial factors.

A field study, included 358 students in traditional and portable mechanical ventilated classrooms in 22 primary and secondary schools, conducted by Shendell *et al*. (2004) to investigate the effect of the difference between the outdoor and indoor CO_2 concentrations (dCO_2), and the student absence in Washington and Idaho, USA. The short-term CO_2 concentrations were higher in more than half of the classrooms. The authors found that a 1000 ppm increase in the dCO_2 will decrease the annual average daily attendance of the students by 0.5-0.9%, corresponding to relative10-20% increase in the student's absence.

In a critical scientific review about the evidence for the direct association of the indoor pollutants and thermal conditions on the students' performance and attendance in schools, Mendell and Heath (2005) concluded that exposing to indoor microbial and chemical pollutants sources in schools can be linked to increased school absenteeism, asthma, and allergy in children and adults.

In eight schools buildings in France, which were either naturally or mechanically ventilated, Blondeau *et al*. (2005) carried out a field study to measure the outdoor and indoor pollution in these building. In this field study the authors continuously monitored the outdoor and indoor gaseous pollutants (Ozone, NO and NO_2), and airborne particle pollutants in addition to the indoor humidity, temperature, CO_2 concentration for a two-week period.

The findings of this study showed an acceptable NO and NO_2 outdoor/indoor concentrations ratio, while the outdoor/indoor Ozone concentrations ratio was high and was affected by the outdoor environment. The authors argued that "the more airtight the building envelope, the lower the Ozone ratio occurred". They also found that the occupancy is strongly influencing the indoor concentration level of the measured airborne particles when the buildings were occupied.

In parallel classes of 10-year-old children, Wargocki *et al*. (2005) studied and measured the impact of the IAQ, by increased ventilation rates, on the children's learning performance. In appropriate lessons each week, the children's usual teachers administered parallel performance from reading to mathematics tasks during a school week period. The authors found that if the ventilation rate increased from 5 to 10 L/s, a significant improvement by more than 15% in the performance of school work is achieved.

In a field study conducted in 64 elementary and middle school classrooms in Michigan, USA, Godwin and Batterman (2007), monitored and examined the Indoor air quality (IAQ) parameters to assess the levels of different indoor pollutants (CO_2, VOCs and bio aerosols), the emission sources, relative humidity, temperature and the ventilation rates over one school week period. During this study the authors completed a comprehensive and the measurements were used to investigate the differences in air quality levels within and between schools. It was found that in many of the tested classrooms the CO_2 concentrations are higher than the standard level (1000 ppm) which indicated inadequate ventilation rates, where the levels of the measured indoor pollutants were low to moderate concentrations.

In Kuwait there is no studies conducted to investigate the quality of the indoor air and it is effects on the students and staff's comfort, health and performance in classrooms. This lack of information will be roughly covered in this thesis by measuring the ventilation rates in classrooms to investigate the level of indoor air quality inside the classrooms and link them to the thermal comfort conditions of these classrooms.

3.7 Ventilation Rates and Student's Performance and Productivity

Through the literature there are few studies conducted to investigate the effect of the different ventilation rates on the student's and staff's school work performance and productivity in classrooms. Myhrvold and Olesen (1997) conducted a field study in 35 Norwegian classrooms to measure the students' concentration by measuring their reaction times with different ventilation rates. They found that by increasing the ventilation rate per person from 4 L/s to 12 L/s, the students' reaction times were 5.4% less (i.e. faster).

In three performance tests used by Ito *et al*. (2006) and Murakami *et al*. (2006) in Japanese classrooms, researchers found that with an increase in ventilation rate from 0.6-5 L/s the performance was improved 5.5% respectively. Wargocki and Wyon (2006; 2007a and b) investigated the impact of increasing the ventilation rate on the performance of 10 years old school children with parallel performance tasks. The authors found that by increasing the ventilation rate from 5 to 10 L/s , the school work performance has improved by 15% and cause a noticeable children's school performance and learning. In two UK classrooms, it was found that the pupils' work rate increased by 7% in the mathematical tests of addition and subtraction by increasing the supplied fresh air from 0.3-5 to 13-16 L/s, (Bako-Biro *et al*., 2007).

3.8 Ventilation Rates and Energy Consumption in Kuwait Schools

Ventilation process is providing amounts of outdoor air (fresh air) from the outside environment to the inside spaces or zones via flow through naturally means (open doors and window) or mechanically means (fans and HVAC systems) or by infiltration through the building cracks. The main idea of the ventilation process is to provide the comfort and healthy conditions for the occupants by balancing the thermal comfort conditions and diluting the concentrations of the indoor pollutants within the occupied zone envelope.

The consumption of energy in the ventilation process in buildings is due to the use of mechanical ventilation systems to thermally conditioning the ventilation air by cooling, heating, dehumidification or humidification processes or using ventilation fans. The capacity of the energy consumption by these systems is proportional directly to the increase of the amount of the ventilation air needed. The ventilation process is guided by the international standards and regulations, such as ASHRAE 62 standard, by specifying the minimum ventilation rates that can meet the occupant's comfort and health conditions to maintain their performance and productivity, while saving energy.

Due to Kuwait's hot and dry desert climate, the operation of the HVAC systems is essential, in all buildings, most of the year. The annual energy production in Kuwait is (21 G.kWh) in the year 2009, with a projected annual increase of 5 %. Air-conditioning in Kuwait consumes about 45% of the annual energy production with an annual operation cost of about KD 0.7 billion, (MEW/R6, 2010 and MEW, 2010).

In Kuwait, there are 540 school buildings occupied by about 360 thousands students with an average ratio of about 25 students per classroom, MOE (2009). The number of schools is subjected to be increased by 10% yearly, MOE (2009). Since the beginning of 1990's, the school buildings in Kuwait were extensively constructed or renovated. Air-conditioning systems were installed in those buildings to provide comfortable thermal and health conditions. The control of those systems is not under the direct control of the students, and this may have a negative effect on the student comfort and health in the classroom.

These schools consume about 10% of the country’s annual energy production, which comes to (2.1 G.kWh), and cost about KD 60 million, with a daily energy consumption rate of 21.6 kWh per student, MEW (2010).

The ASHRAE standard 62 (2004) for ventilation requirements is adapted by Kuwait’s energy code, MEW/R6 (2010), for the different types of buildings and spaces. According to this standard, a minimum ventilation rate of 7.5 L/s (15 ft^3/min) is recommended per occupant in classrooms, with a typical occupant density of 33 persons per 90 m^2 (1000 ft^2) and ceiling height of 3 m (10 ft). The current ASHRAE standard would require an air exchange rate of about 3 air change per hour (ACH) for classroom. Kuwait’s ministry of electricity and water recommended an air change of 0.5 ACH for classrooms for energy saving requirements, MEW/R6 (2010).

The indoor air quality conditions in classrooms have to be seriously considered because students are still physically developing, where poor indoor air quality conditions could affect the students’ and staff’s comfort, health and may indirectly affect their learning and performance and productivity – this may have detrimental consequences on them and the society’s future.

3.9 Discussion

The literature review in this chapter, have shown the importance of investigating the indoor air quality in the different occupied zones, especially classrooms in schools, where indicating the pollution sources and the level of the different pollutants that may occur in classrooms, would help in finding solutions to overcome any obstacles in the student learning and performance.

The necessity to regularly investigate the indoor air quality inside the classrooms is due to the changing density of students in classrooms and the long period of exposure to the different pollutants sources. This exposure may seriously affect the occupants' comfort and health and resulted in serious health problems that can increase the absence from school and degrade the performance and productivity levels. These health problems will affect the national economy through increasing the national health care expenses and lost expenses due to the insufficient students and staff's performance and productivity in schools.

Investigating the indoor air quality conditions inside classrooms is an expensive and potentially problematic issue due to its function of different factors such as the building materials, equipment, furniture and HVAC systems, where all of them are varying as functions of time exposure and ventilation rates. The rate of ventilation inside any occupied zone can be a measure for the quality of the indoor air. The adequately ventilation rate can be an indicator for inside environment, where the literature showed many researchers reporting that inadequate (low) ventilation rates indicates poor indoor air quality.

During this study, the ventilation rates measurements inside the classrooms can be inferred by the indoor pollutant carbon dioxide measurements, where the indoor concentration of carbon dioxide (CO_2) has often been used as a surrogate for the ventilation rate per occupant in schools, Lee and Chang (1999) and Daisey *et al*. (2003). Higher CO_2 concentrations levels indicate inadequate ventilation rates and results in poor indoor air quality conditions inside the classrooms.

The effect of ventilation rates on the students and staff's performance and productivities, will be related, later in the thesis, to the worldwide findings of similar recent field studies conducted by the different researchers.

Chapter 4

A new Questionnaire for Gathering Reported Thermal Comfort Sensations from Very Young People (ages 6-10 years)

4.1 Chapter Summary

A new thermal comfort questionnaire has been developed to assess the subjective thermal comfort sensation of very young people (ages 6-10 years), whose reading, writing and comprehension skills are still developing. The proposed new thermal comfort questionnaire has been created by rewording questions used in standard thermal comfort questionnaires and by the introduction of images and colours. The questionnaire was tested on pupils in classroom environments in the Gulf Region.

The results suggest that the new questionnaire can help the children to assess better their thermal comfort sensation as compared with the standard questionnaire without affecting responses or introducing bias. The development of this new proposed thermal comfort questionnaire can help to uncover how the environment affects children's thermal comfort sensations and health, and how they react towards these environments.

4.2 Introduction

The issue of thermal comfort has been studied in many different climatic zones in different parts of the world over the last few decades. The main objective of those studies was to investigate the combinations of factors that led to the sensation of thermal comfort by occupants. The thermal comfort status as defined by ASHRAE standard 55 is "that state of mind which expresses satisfaction with the thermal environment" (ASHRAE 55, 2004). The evaluation of the thermal comfort sensation requires knowledge of several parameters that environmental factors (ambient air temperature, mean radiant temperature, air velocity and the humidity) and personal factors (activity level and the clothing insulation value).

Many people in their lives today spend most of their time in artificial climate controlled environments. Creating suitable indoor thermal environment conditions that are healthy and comfortable is an essential requirement to satisfy human needs. The modern life style makes HVAC systems an essential component in the lives of humans living in places with harsh climatic conditions such as the climate of the State of Kuwait, where people seek comfortable thermal environment conditions in a climate that is hot and dry. In spite of the fact that the HVAC systems in Kuwait are used for heat and moisture removal in buildings in order to create comfortable environments, they can also be one of the sources of occupants' dissatisfaction, raising the possibility of thermal dissatisfaction and consequent potential impact upon health, performance and productivity.

There are two main directions in which to conduct thermal comfort studies; field studies and laboratory-based studies. Field studies are carried out to investigate and measure the thermal comfort status of people in their everyday life by measuring variables in their surrounding environment. At the same time, people are asked to vote on their thermal sensation using suitable psycho-physical scales via questionnaires. On the other hand, laboratory based studies consist of a group of experiments conducted in a controlled climatic chamber in order to study the influence of one or more variables on a relatively small number of subjects, where in some cases physiological parameters are measured.

The relation between those variables and the human comfort sensation basically considers the human body as a core within a shell, where the human body is exchanging energy through conduction, convection and radiation with its environment, losing heat by evaporation, and adjusting to conditions through the body's regulatory system. Prediction of thermal comfort has been a substantial issue for many researchers and for ASHRAE, which sponsored many thermal comfort studies that have led to the development of an original comfort index. Different thermal comfort models have been set up over the last decades. These models varied from fundamental models to more advanced models.

The PMV-PPD model is one of the fundamental models, which is based on the results of extensive experiments carried out by Fanger (1970). This model predicts the thermal comfort sensation for any combination of the four environmental variables and the two personal variables at steady state conditions. Since Fanger's model was based on experiments conducted on American college-age subjects, it may be questioned as to whether it could be generally applied to other national geographical locations and other age groups. Extensive researches have been carried out to investigate thermal comfort issues in different countries all over the world for sedentary subjects and in different climatic zones. Most of these studies have been conducted among adult age groups of both males and females and showed no significant differences in thermal comfort requirements between them and that predicted by Fanger's model.

A few field studies such as Kwok (1998); Xavier and Lamberts (2000); Cheong et al. (2003); Wong and Khoo (2003); Ahmed and Ibrahim (2003); Kwok and Chun (2003); Hwang et al. (2006) and Corganati et al. (2007) have been conducted in classrooms to investigate the thermal comfort conditions for school children or adult college students. The ages of those students ranged from 13-22 years old and the findings of these studies agreed with the findings of the adults in the same environments. A logical question to be raised is whether the PMV-PPD model is applicable to younger children, 6-10 years old, and whether the subjective data extracted through standard questionnaires is reliable since their skills in reading, writing and comprehension are still developing.

An impediment to researchers investigating the thermal comfort status of this age group can be attributed to difficulties that may face children in understanding the concept of thermal comfort and the influences of the thermal comfort variables on their thermal sensation. As a result there may exist, some uncertainty in the children's rating of their thermal comfort status. We address this research problem by focusing on the classroom environment.

4.3 History of thermal comfort questionnaires in classrooms

Kwok (1998) investigated the thermal conditions for high school students from 15-17 years old in the tropics. She used a six-page standardized questionnaire consisting of four sections and requiring approximately 15 minutes to complete. Questions on thermal sensation and thermal acceptability were included in the first section by asking the students to assess their thermal comfort on a variety of subjective scales. Respondents answered the thermal sensation questions by marking "X" along the graphic, seven-point, continuous scale. Respondents were asked to determine their current thermal acceptability by answering the acceptability question as ‘acceptable’ or ‘unacceptable’. The McIntyre thermal preference scale was used to ask the students if they would like to be ‘cooler’; ‘no change’ or ‘warmer’ at the moment of testing.

Questions about other variables, such as humidity, air movement, air quality, and acoustics, were subsequently asked in the formats of both the preference and acceptability scales. Subsequent sections asked the respondents about other environmental conditions (e.g., acoustics, air quality, and thermal conditions) and their influence on school work. Clothing items worn during the class visit and demographic information about age, gender, weight, height, and number of years spent in the tropics were also recorded. The standard questionnaire used in this study whilst probably being adequate for older children, takes a long time to be completed and may not be suitable for use with younger children.

Xavier and Lamberts (2000) used a specific standard questionnaire when investigating the thermal comfort conditions for high school children from 15-17 years old. The questionnaire was in accordance with ISO Standard 7730 (ISO 1995); ISO Standard 10551 (ISO 2001); ISO Standard 8996 (ISO 2004); ISO Standard 9920 (ISO 2003), and ASHRAE Fundamentals (ASHRAE 1997) to assess the personal variables such as clothing, thermal sensations and thermal preferences.

The questionnaire contained information about the student age and gender and a table of the most expected items that students will wear during their school day. Students were asked to assess their thermal sensations and thermal preferences on a seven point scale. The activity was constant (school activity) and was not considered to be an independent variable influencing the sensation of thermal comfort.

Cheong et al. (2003) conducted a field study in Singapore to evaluate the current thermal comfort conditions of college students in an air-conditioned lecture theatre within an institutional building using objective measurements, computational fluid dynamics (CFD) modelling and subjective assessments. Indoor comfort parameters such as temperature, airflow and relative humidity, was simulated by the CFD tool. The questionnaire used in this study was modelled on, and modified after, the one used in the "European Audit project to optimize Indoor Air Quality and Energy Consumption in Office Buildings" (Roulet, 1994 and Bluyssen et al. 1995) to make it more applicable to lecture theatre environments. The questionnaire dealt with health, indoor environment satisfaction and personal control.

The thermal comfort assessment used by Wong and Khoo (2003) to investigate the thermal comfort conditions in classrooms for school children ranged from 13-17 years old, was based on responses to a questionnaire survey which was administered simultaneously together with physical measurements in each class. Subjective responses were sought on thermal sensation (seven-point scale), thermal preference (McIntyre scale), and thermal acceptability (the latter using a seven-point scale comprised of: -3 much too cool; -2 too cool; -1 comfortably cool; 0 comfortable; +1 comfortably warm; +2 too warm; +3 much too warm). Questions about other variables, such as humidity and air flow, subsequently used the format of the thermal sensation and thermal acceptability scale (seven point scale).

Ahmad and Ibrahim (2003) used only the ASHRAE 7-point scale in their field study to assess the comfort level of college students who are adults and can understand the questionnaire idea and answer the standard question. A comfort survey used by Kwok and Chun (2003) to investigate the thermal conditions for school children in the age range from 13-15 years old covered three sections: current status of thermal comfort, clothing and demographic information. Various comfort scales were used to ask the respondents to make a subjective rating of their thermal sensations during their current and immediate classroom environment the (ASHRAE seven-point scale; McIntyre preference scale). Other scales used in the survey included general comfort questions asking subjects to rate the overall comfort of their classrooms, ranging from 'very uncomfortable' to 'very comfortable'; and a direct acceptability question asking respondents to reply 'acceptable' or 'unacceptable' about their current thermal conditions.

Hwang et al. (2006) conducted a field study using a questionnaire to determine the thermal comfort requirement for college students in seven University classrooms (26 air-conditioned and 10 naturally ventilated classrooms) located in the center and south of Taiwan. The questionnaire consisted of four sections. The first section is the demographic information about age; gender; weight; height; and the usage of home air-conditioning. The second section addressed subjective thermal sensation; thermal preference and acceptability level (ASHRAE seven-point scale; McIntyre preference scale).

The acceptability question was posed by asking the subjects if the current temperature was acceptable to them or not. In this section the subjects were also asked to indicate their level of satisfaction regarding other classrooms characteristics such as air flow, humidity solar radiation. The answers to these questions were to be placed on a to six-point systematically scale ranging from “very satisfied’ to “very dissatisfied”. The third and fourth sections addressed other aspects of the classroom environment (acoustics, air quality, lighting, etc), schoolwork satisfaction and health status.

Corganti et al. (2007) conducted a field study during the heating period to investigate the environmental comfort in 13 classrooms at four different high schools and four typical medium-size University classrooms in Politecnico di Torino in Italy. In this study, a questionnaire consisting of six sections was used to investigate the college and high school students' sensation of the thermal environment of the classroom. These sections were concerned with the general information, thermal comfort (thermal sensation, acceptability level and thermal preferences), indoor air quality (IAQ), visual comfort, acoustic comfort and finally, synthesis of information.

In all the above studies, the ages of the subjects ranged from adult down to a minimum of 13 years, and it can therefore be expected that reading and writing skills, as well as comprehension of the concept of thermal comfort, will be fully developed. This cannot be assumed for subjects of a younger age, nor can the time required to complete detailed questionnaires be considered appropriate for such groups. In all previous questionnaires, standard questions with little variation have been posed, with modifications made to reflect the researches' specific investigation. When surveying younger age groups, such questions will require modification.

In Kuwait, the girls' schools are separate from the boys' schools at all academic levels, which are structured as follows: elementary level which consists of five classroom grades from the 1st class to the 5th class and the students ages are from 6-10 years; intermediate level which consists of 4 classroom grades from the 6th class to the 9th class and the students ages are from 11-14 years; and secondary level which consists of 3 classroom grades from the 10th class to the 12th class and the students ages are from 15-17 years. This segregation gives a wide range for researchers to investigate the influence of the thermal environment and its variables on the thermal comfort state of the students at each academic level separately for both genders (boys and girls).

Since the elementary level in presented 42% of the classrooms in Kuwait, designing a new proposed thermal comfort questionnaire that applicable to these younger ages may help to investigate their thermal comfort conditions by help them to assess their thermal sensation and satisfaction. This can help to provide better thermal and health conditions which can improve their learning, performance and productivity. As a result from this study, additional benefits can be occurred by improve the energy consumption in schools.

Aims and Objectives

This part of the study addresses the issue of applicability of previous structural questionnaires for extracting subjective data from students and children of younger age groups. For example, detailed questions and questionnaires may be too challenging for satisfactory completion by children. Previous questionnaires clearly do not take into account the differences in the comprehension or the writing and reading skills that may occur among the children (students), especially for children of 6-10 years old. These factors may have an effect on their understanding of the survey questions leading to uncertainty in the thermal sensation evaluation. The aim of the work reported here is to devise, construct and test a new style of questionnaire aimed specifically at younger students/children. It is part of a wider study investigating thermal comfort in schools in Kuwait.

4.4 Methodology and Underlying Principles

The thermal comfort questionnaire is a standard method that is used to assess the thermal comfort sensation experienced by persons subjected to a range of indoor climatic conditions. Such questionnaires provide subjective data that supplement objective assessments. Any questionnaire must be carefully designed so as to be easy to understand, and no longer than necessary in order to save the occupants time and effort and encourage them to participate within a spirit of co-operation.

This paper describes the design construction and testing of a new thermal comfort questionnaire aimed at helping younger students, 6-8 years old, to understand the questionnaire purpose and to better assess their thermal sensation in a school classroom environment It is essential that modifications incorporated into the new questionnaire do not introduce bias, and this is tested by its application to older children who are able to use their reading and writing skills to assess their thermal sensation in the normal way. The questionnaire is tested by application to younger school students of 6-10 years old during their school day. The investigation took place in the State of Kuwait.

The proposed new questionnaire will be designed and built in accordance with ISO 10551 standard "Ergonomics of the thermal environment- Assessment of the influence of the thermal environment using subjective judgment scales", where some modifications or word substitutions will be added to help the elementary school students to understand what is being asked and to be sure that the uncertainty in the answers will be minimized. To extend the use of a standard questionnaire to younger children, this proposed survey was based on three approaches:

1. Re-wording or modification of some or all of the questions in existing thermal comfort surveys in order to achieve a better match with the children's ages and comprehension level.
2. Introduction of simple facial icons and coloured illustrations as aids to understanding the questionnaire and for clarifying scale ranges and the meaning of the question.
3. Direct interviews with the students to help them understand the survey questions.

We next describe the detail of each of these approaches together with the underlying principles.

4.4.1 The effect of Questionnaire wording in children's learning:

The use of surveys in studies with children may pose critical methodological problems which may affect the data quality. These problems can be avoided only when we understand children's cognitive development, which improves over time, and design and construct questions appropriate for each age group. Special attention should be given to questionnaire construction when surveying children and questionnaires should be pre-tested for good data quality.

In any survey or question-answer process, Tourangeau & Rasinski (1988) and Schwarz & Sudman (1996) stated that some important steps must be considered: (1)

understanding the question; (2) retrieving relevant information from memory, and (3) formatting the answer by choosing the appropriate response category 'scale'.

Many studies have shown that adults may experience problems with certain questions, especially very complex questions, and that question characteristics may affect the data quality in surveys (Krosnick & Fabriger, 1997 and Eisenhower et al., 1991). If the subjects (respondents) are children whose cognitive, communicative and social skills are still developing, the same problems will occur because of ambiguity and this will affect different stages of the survey and the question-answer process. (Borgers et al, 2000).

The global classification of developmental stages of children and Piaget's (1929) theory of cognitive growth provides helpful and useful tools in surveying children. According to Piaget (1929), children's intellectual development evolves in a fixed sequence of stages. These are: (1) *Sensory-motor intelligence*, from birth until about 2 years, (2) *Preconceptual thought*, from 2 till 4 years, (3) *Intuitive thought*, from 4 till 7-8 years, (4) *Concrete operations*, from 8 till 11, and (5) *Formal thought*, which develops between 11 until 15-16 years of age. From the age of 16, the cognitive capacities are, in general, fully developed.

The language development of the age group, from 4 until 7 to 8 years old, (Intuitive thought), is still limited, which implies limitations in comprehension and in verbal memory. Children can be interviewed with extreme care. Borgers et al. (2000) stated that, "Verbal comprehension and verbal memory are extremely important in the first two steps of the question-answer process: understanding the question and retrieval of relevant information from memory" and "questions should be short, simple and clear". The authors suggested that "Question wording is extremely important, researchers should first try to learn which words the child itself uses and these words should be then used for the questions".

Finally, when the children of this age group are not very concerned or interested in the topic or when they are unsure of the meaning of the question, they are more likely to use satisficing "the simple heuristic to give an answer, instead of going through the complete question-answer" approach (Vaillancourt, 1973). With long questionnaires, especially lack of motivation and difficulties in keeping up concentration will result in poorer data quality, (Holaday and Turner-Henson, 1989 and Borgers et al., 2000).

During the development of 'concrete operations' which is "the developmental stage from 8 to 11 years old", the language and reading skills of this age group are developed but they still experience the same problem as younger children with `depersonalized' or indirect questions. Questionnaires have to be specially developed for this group, one cannot use the standard questionnaires used for adults.

The authors suggested that "researchers should design the questionnaire very carefully, and be fully aware of the fact that language is still developing, and that the children are only just acquiring reading skills. Language skills, especially understanding language, are very important for data quality. De Leeuw and Otter (1995), found that older children (14 years) cope better with ambiguous questions than younger children (9 years), although it should be emphasized that ambiguous questions are difficult for all respondents, even for adults. This age group can answer well-designed questions with some consistency. The older the children are, and the better the children are in understanding language (reading with understanding), then the better the data quality, (Borgers et al., 2000).

In general, for all previous age groups from 4 to 7-8 years and from 8-11 years old, much more care should be taken to write appropriate questions, which must be simple, clear and unambiguous, and such a questionnaire should be pre-tested. If possible, one should use visual stimuli and response cards, to make the task more concrete and interesting, (Borgers et al. (2000)).

For the development of formal thought which occurs at the developmental age stage from 11 to 15-16 years old, standardized questionnaires similar to those for adults, and large scale surveys can be used successfully for this age group (Borgers et al., 2000).

4.4.2 The effect of Images and colours in children's learning:

Images

"Without image, thinking is impossible"- Aristotle stated, and old Chinese wisdom states: "a picture's meaning can express ten thousand words".

Since the beginning of the 1970's, research which investigated and examined the utilization of images and colours in teaching and learning has increased and has provided early evidence that using images and colours in teaching and learning supports and enhances the learning process by enhancing the students' comprehension, retention and motivation to learn. Cole et al. (1971) and Paivio and Csapo (1973) showed early evidence for the superior effect of pictures. Duchastel and Waller (1979) reported that by adding illustrations, simple line diagrams, graphs and charts, flow diagrams or realistic images, most texts can be enhanced. Many studies have been conducted: Nickerson (1968) and Standing et al. (1970) investigated the superiority of pictures over words in communication and comprehension. Stokes (2001) concluded that the literature suggests that using visual elements in teaching and learning yields positive results. The previous studies also confirm the superiority of pictures in recognition memory "The ability to recognize elements in the surrounding environment such as faces or places".

In today's teaching and learning process, the increased use of visual elements is obvious in school textbooks, instructional materials and classroom presentations. (Benson, 1997 and Kleinman and Dwyer, 1999). Levie and Lentz (1982) state that the presence of pictures relevant to the text will assist learning and can help learners to understand what they read and also to remember it.

Chanlin (1997) suggested that the effect of visual materials is more evident in students inexperienced with the subject domain. The influences of lessons without any type of graphics (still or animated) on students with different prior knowledge levels have been reported by Chanlin (1998). In this study the author suggested that, when prior knowledge is low, graphics, either still or animated, are better for learning descriptive facts than lessons with text only. The author reports no difference in learning procedural facts ("facts resulted or executed after performing or executing some activities or skilled techniques") with the use of text or graphics. However, students with a high level of prior knowledge of the subject responded better with the animated form of graphics in learning descriptive facts, but responded better with still (non-animated) graphics when learning procedural knowledge.

Levie and Lentz (1982) state that pictures may assist learners with poor verbal skills more than those with good verbal skills and pictures can sometimes be used as substitutes for words or as producers ("conveyors") of non-verbal information. The authors concluded that, in general, users prefer material which is illustrated.

Colours

Extensive studies were conducted to investigate the effects of colours on teaching and learning performance. Berry (1984, 1990) found that there are significant differences in favour of colour over black and white formats. A study by Kleinman and Dwyer (1999) aimed at examining the effects of specific visual skills in facilitating learning; found that the use of colour graphics in instructional modules promotes achievement more than black and white graphics, particularly in concept learning. Berry (1991) also found that colour is superior to black and white and that black and white is superior to line drawing in recall tasks.

Holliday (1976), Weidenmann (1989) and Bernard (1990) reported the evidence that text should sometimes be used to support pictures. Bernard (1990) stresses the importance of placing the image near the text that it supports or making obvious the links between image and text. Levin (1989) states "pictures interact with text to produce levels of comprehension and memory that can exceed what is produced by text alone". Chanlin (1997) proposed that the integration of visual and verbal methods facilitate mental connections in learning. Chanlin (1999) suggests that providing visual control of animated graphics enhances learning. The use of visuals in education, although consistently shown to aid in learning, must be carefully planned.

After reviewing the effect of images in education, another question was raised about the effect of colours on children and its association to their learning and psychology.

Amber (1964) investigated the effect of visible lift colours in human therapy, relating colours to 'temperatures', where red is felt as 'hot' and violet is experienced as 'cold'. Colours have different associations and impressions, Birren (1961). According to Birren (1961), the colour association and impressions are as in Table 4.1.

Table 4.1: Birren's table for colour association and impressions (Birren; 1961)

Colour	Mental Association	Direct Association	Objective Impressions	Subjective Impressions
Red	hot, fire, blood	danger, Christmas	passionate, exciting	Rage, fierceness
Orange	warm, autumnal	Halloween, Thanksgiving	lively, energetic	exuberance
Yellow	sunny	caution	cheerful, inspiring	high spirit, cowardice
Green	cool, nature	St. Patrick's day	refreshing	disease, guilt
Blue	cold, sky, water, ice	service, flag	subduing, melancholy	unhappiness
Purple	mist, shadow	mourning, Easter	dignified, mystic	loneliness
White	cool, snow	cleanliness, flag	pure, clean	brightness of spirit
Black	night, emptiness	mourning	death, depressing	negation of spirit

Birren's table is considered as a standard table, and some or all of these associations have been accepted in the field of education. These colour associations and impressions can be different from culture to culture, so that attention must be paid when relating the colours to be used in teaching and education in different cultures. According to the opinions of some experts and researchers in children's learning and education in Kuwait, the mental associations and objective impressions of each colour in Birren's table are fully applicable for children in Kuwait.

Stone and English (1998) tested the effects of colors in workplaces and its correlation to the workers performance, and found that a red office is more stimulating and may cause vigour, anger or tension; however it was found to increase performance. They also found that blue in an office may cause greater depression, as well as sadness, fatigue or relaxation. The authors found workers in white offices complained of more head aches and instances of nausea.

4.5 The construction of the new proposed questionnaire

In Kuwait schools, students are used to answering questionnaires. This point encourages presenting the key questions of the standard questionnaire, where the main challenge involves how to make younger subjects (6-10 years old), who's reading and writing skills are not fully developed, familiar with the thermal comfort issue and understand it in order to assess their own thermal sensations. Generally, the term 'thermal comfort' is new in Kuwait, especially for children, and none of the young subjects in this study have heard of it before, which adds more difficulty to the design of the new proposed questionnaire. A further difficulty might be attributed to the nature of the psychological behaviour for the children (movement, boredom ...etc), the effects of these reflecting on their understanding of the importance of the survey and leading to uncertainty in assessing their answers.

The proposed new survey form consisted of six questions that ask the young subjects to assess their thermal sensation toward the current temperature inside the classroom, their 'comfortable' level toward the current temperature inside the classroom, their thermal preferences, their acceptability of the thermal environment and, finally, their feelings toward two of the thermal comfort variables, which are the air velocity and the humidity. The new proposed survey questions were built following the ISO 10551 standard. Details for the choice of wording are given next.

4.5.1 The wording of the thermal sensation question

In the previous classroom-type studies, the ASHRAE 7-point scale has been widely used by many researchers to indicate the thermal comfort sensation of respondents with age groups ranged from 13 to 18+ years. In these studies, each researcher used and developed different wording for this question to account for variation in understanding of this term from culture to culture or community to community.

Some researchers such as Kwok (1998), Kwok and Chun (2003), Hwang et al. (2006) and Corganti et al. (2007) did not adjust the question wording for their subjects, instead opting to retain the standard wording about thermal sensation and the 7-point scale. In other studies, Xavier and Lamberts (2000) used the question "How are you feeling at this moment?", Cheong et al. (2003) used the wording "How would you describe the indoor conditions in the lecture theatre?" and Ahmad and Ibrahim (2003) asked "How do you rate the thermal conditions in the room in this moment?". We suggest that the question wording used in these latter studies cannot be used with younger subjects due to subjects' understanding, potential ambiguity of the question and the level of the direct relation to classroom thermal conditions. This may lead to uncertainty in the students' answers and hence to incorrect conclusions. Wong and Khoo (2003) asked a direct question about the temperature, "How do you feel about the temperature in the classroom at this moment?". This wording can be considered, with some modifications and word substitution, as sufficiently easy, simple and direct to be asked of younger subjects, especially from 6 to 10 years old. This wording implies a direct relation of 'temperature' to 'thermal sensation' to understanding by younger age groups. The appropriateness of this is tested by comparison with an older age group, and is discussed later in this paper.

The suggested thermal sensation question used in this study, was therefore reworded to be, "How are you feeling the temperature in the classroom to be at this moment?", where the wording of the response to this question was "I feel that the classroom temperature is……". The wording of the question response and scale were designed in accordance with the ISO 10551 standard and the ASHRAE 7-point thermal comfort scale.

4.5.2 The wording of the comfort level question

A question about the students' thermal comfortable level toward the existing temperature inside the classroom was included in some of the previous thermal comfort studies in classrooms. In some studies such as that of Kwok and Chun (2003), the wording of this question was not clarified, and the standard wording was retained for this question, where the response ranged from "very uncomfortable" to "very comfortable". The question "How would you describe your typical level of thermal comfort in the lecture theatre" with a response on 4-point scale "comfortable, slightly comfortable, uncomfortable and very uncomfortable" was used by Cheong et al. (2003), whereas Wong and Khoo (2003) used the question "Do you feel comfortable now?" with a long 7-points Bedford response scale ranging from "much to cool" to "much too warm".

The wording of the Cheong e al. (2003) question we propose should not be used with younger subjects due to the subjects' understanding and further that it does not directly relate the personal thermal comfort level with the classroom thermal conditions. The question wording used by Wong and Khoo (2003), with some modifications and rewording, can be considered sufficiently simple and as a direct question that links the temperature with the subjects' thermal comfort and can be asked to the younger subjects. However, the response scale for this question must be modified to minimize the reading and writing differences between the young subjects, and to save time.

The suggested thermal comfort level question used in this study was therefore reworded to be "Do you feel thermally comfortable now?", where the wording of the response scale was "I feel that I'm thermally …..comfortable, uncomfortable or very uncomfortable".

4.5.3 The wording of the thermal preferences question

The McIntyre thermal preferences scale was widely used, with slightly differences in question wording, in the previous studies such as Kwok (1998); Kwok and Chun (2003); Wong and Khoo (2003); Hwang et al. (2006) and Corganti et al. (2007) to assess the subjects' preferences responses. The wording of the thermal preferences question was different among these studies. Kwok (1998); Kwok and Chun (2003) and Hwang et al. (2006) asked the students, "Right now, I would prefer to be…", where the question used by Wong and Khoo (2003) was "Would you like to be…". Corganti et al. (2007) used different wording for this question which is "at this moment, would you prefer to feel warmer, cooler or no change". In another study, Xavier and Lamberts (2000) used the question "How would you like to feel at this moment".

Among all the previous classroom studies, the wording of this question that was used by Wong and Khoo (2003) and its response scale can be considered with some word substitution to be quick as that is sufficiently simple and direct to be asked of younger subjects. The suggested thermal preferences question used in this study was "Now, would you like to be ……". The same McIntyre thermal preference scale was used to indicate the subjects' responses.

4.5.4 The wording of the acceptability level question

The acceptability level of subjects inside classrooms attracted much attention amongst researchers in determining the acceptance of classroom thermal conditions. Some researchers such as Kwok (1998); Kwok and Chun (2003) and Hwang et al. (2006) did not clarify the wording of the question or the response scale used with their subjects. Wong and Khoo (2003) asked "How would you rate the overall acceptability to the temperature at this moment", while Cheong et al. (2003) asked "How would you rate the typical overall acceptability to the indoor air quality in this lecture theatre" and Corganti et al. (2007) asked "at this moment, do you consider the thermal environment to be acceptable or not". The wording of this question differed amongst these studies due to the researchers' respective interests, and the response scales ranged from simple to detailed.

The question of the acceptability level used in the Wong and Khoo (2003) study was used in our study but with some modification and word substitution. The wording of this question is "in general, how do you rate the classroom environment?". This question was designed and built according to the ISO 10551 standard, and the response to this question is 'acceptable' or 'not acceptable'.

4.5.5 The wording of the airflow question

Airflow is another of the thermal comfort variables that can influence the students' thermal sensations. This variable has been taken into account by many researchers in previous thermal comfort field studies in classrooms. Some researchers such as Kwok (1998), Cheong et al. (2003) and Hwang et al. (2006) did not clarify the wording of their questions related to air flow so as to take account of their subjects' understanding and knowledge. Wong and Khoo (2003) asked subjects "How do you feel about the airflow at this moment", where a response scale of 7-points ranged from 'much too still' to 'much too breezy'.

The Wong and Khoo (2003) question with little modification or word substitution can be considered as a sufficiently simple and direct question to be asked of younger subjects so as to minimize the influence of the reading and writing skills of the younger subjects. The wording of this question in our study, is "How do you feel about the air movement in the classroom?", where the response was according to a simple 3-point scale ‘breezy’, ‘just right’ and ‘still’. This question and its response scale were designed and built according to the ISO 10551 standard.

4.5.6 The wording of the humidity question

Humidity is another important thermal comfort variable that has an effect on the subjects’ thermal sensation in the occupied zone. The humidity question was included in the Kwok (1998), Cheong et al. (2003) and Hwang et al. (2006) studies, but the wording of the question was not clarified with their subjects. In addition, some of these studies used relatively long response scales that may not be used for younger subjects. Wong and Khoo (2003) asked the subjects “How do you feel the humidity at this moment” and used the 7-points response scale, ranging from ‘much too dry’ to ‘much too humid’.

The humidity question of Wong and Khoo (2003) was used in this study, with some modifications and word substitutions, to ask the younger subjects about the humidity in the classroom. The wording of this question is "How do you feel about the humidity in the classroom?", and the response was dry, just right or humid. This question and the response scale was designed and built according to the ISO 10551 standard.

A summary of the selected questions from the previous literature review and the modified questions used in the new proposed thermal comfort questionnaire are shown in Table 4.2.

4.5.7 The addition of images and colours to the new proposed questionnaire

Images and colours have been utilized in the new proposed questionnaire for better representation and clarification and with the support of verbal clarification and thus to help younger subjects to understand the meaning of each question.

Table 4.2: The selected questions from the previous thermal comfort questionnaires used in classrooms and the re-wording of those questions in the new proposed thermal comfort questionnaire.

Question No.	Question type	Researchers and publication year	Question and Answer changed
Question (1)	Thermal Sensation	Wong and Khoo (2003)	From: Q: How do you feel about the temperature in the classroom at this moment? A: cold, cool, slightly cool, neutral, slightly warm, warm and hot To: Q: How are you feeling the temperature in the classroom to be at this moment? A: I feel that the classroom temperature is …… cold, cool, slightly cool, neutral, slightly warm, warm and hot
Question (2)	Comfort Level	Wong and Khoo (2003)	From: Q: Do you feel comfortable now? A: much to cool, too cool, comfortable, comfortably warm, too warm and much too warm To: Q: Do you feel thermally comfortable now? A: I feel that I'm thermally ….. comfortable, uncomfortable and very uncomfortable
Question (3)	Thermal Preferences	Wong and Khoo (2003)	From: Q: Would you like to be….. A: cooler, no change and warmer To: Q: Now, Would you like to be…. A: cooler, no change and warmer
Question (4)	Acceptability Level	Wong and Khoo (2003)	From: Q: How would you rate the overall acceptability to the temperature at this moment? A: acceptable or not acceptable To: Q: In general, how do you rate the classroom environment? A: I'm rate the classroom environment as acceptable or not acceptable
Question (5)	Airflow question	Wong and Khoo (2003)	From: Q: How do you feel about the airflow at this moment? A: much too still, too still, slightly still, just right, slightly breezy, too breezy and much too breezy To: Q: How do you feel about the air movement in the classroom? A: I feel that it is ……. still, just right and breezy
Question (6)	Humidity question	Wong and Khoo (2003)	From: Q: How do you feel the humidity at this moment A: much too dry, too dry, slightly dry, just right, slightly humid, too humid and much too humid To: Q: How do you feel about the humidity in the classroom? A: I feel that it is …… dry, just right and humid.

A drawing consisting of a student sitting at a desk while writing in a relaxed situation with a thermometer on a board behind him, Figure 4.1, was added to question (1) in order to support and clarify the meaning of this question and to help the students concentrate on the classroom indoor temperature not themselves. The value of each response on the scale is represented by a specific colour that indicates to the subjects' thermal sensation as follows:

Dark blue represents the cold sensation (-3); blue represents the cool sensation (-2); light blue represents the slightly cool sensation (-1); white represents the neutral sensation (0); yellow represents the slightly warm sensation (+1); orange represents the warm sensation (+2), while red represents the hot sensation (+3).

The comfort level question, question (2), was supported by the drawing of faces with different expressions (happy, sad and very sad), Figure 4.2, to help the younger subjects, especially those 6-10 years old to express their actual comfort level toward the temperature and the thermal conditions inside the classroom. The coding of the responses to this question was graded as follows: yellow happy face represents the comfortable situation; unhappy or sad yellow face represents the uncomfortable situation and angry or red face represents the very uncomfortable situation.

The response scale of thermal preferences, question (3), is: cooler, no change and warmer, and were supported with colour codes as shown in Figure 4.3 to clarify the meaning of each answer and link it to the subjects' thermal sensation. The colour coding of the response to this question is: blue colour represents the 'cooler' situation; white colour represents the 'no change' situation; and orange colour represents the 'warmer' situation.

The response scale of the acceptability level question, question (4), was supported by drawings as shown in Figure 4.4, where faces with differing expressions (happy and sad) were added to help the younger subjects to state their acceptability toward the internal classroom environment as follows: yellow happy face represents 'acceptable' situation, while the yellow sad face represents the 'not acceptable' situation of the classroom environment.

The previous three questions (questions 2, 3 and 4), were supported with happy boy character to encourage the students to choose the appropriate response that indicate their sensations toward the classroom thermal conditions.

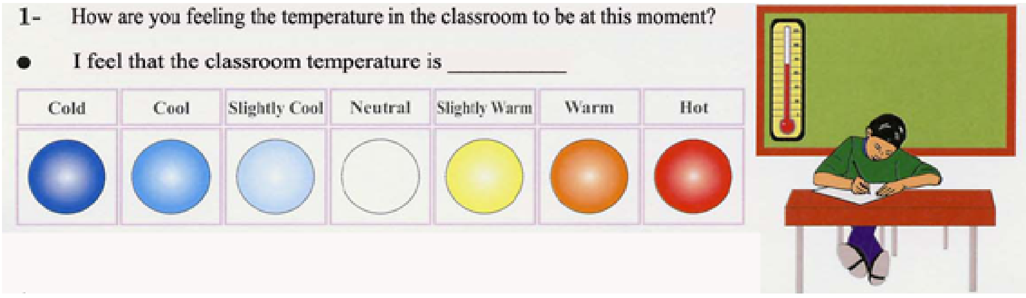

Figure 4.1: Question (1) in the thermal comfort questionnaire

Conveying the ‘airflow’ concept

The airflow concept is difficult to be directly represented graphically, especially low indoor airflow rate in classrooms. The difficulty can be related to the fact that the airflow cannot be seen yet is a sensual variable the effects of which can be noticed on our bodies and the surrounding environment. The difficulty can also be related to the fact that the airflow measuring equipment (anemometers) are neither simple nor popularly used within the indoor environment.

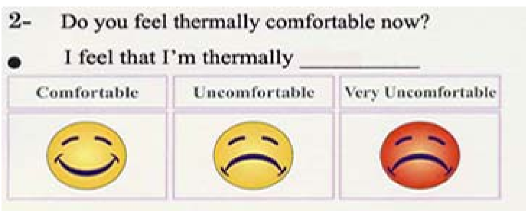

Figure 4.2: Question (2) in the thermal comfort questionnaire

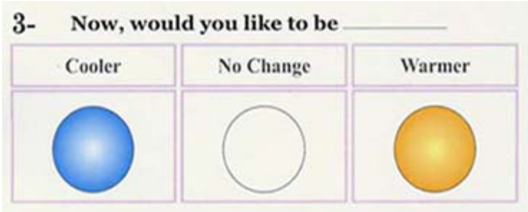

Figure 4.3: Question (3) in the thermal comfort questionnaire

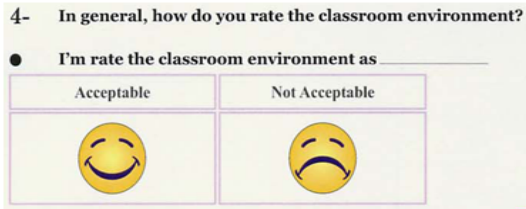

Figure 4.4: Question (4) in the thermal comfort questionnaire

These issues related to the airflow were addressed by an image that represents a student writing while sitting at a desk where there is an air flow stream within his occupied zone. The air movement was represented by orange waves which slightly disturbed some paper in front of the student. This graphics representation and the meanings of the answers were also supported by verbal clarification to help students to understand. The response to this question is 'breezy', 'just right' and 'still'. In Figure 4.5, each response is supported with an image of a facial expression as a happy face indicates the breezy case, while the smiley face indicates the just right case and finally the sad face indicates the still case.

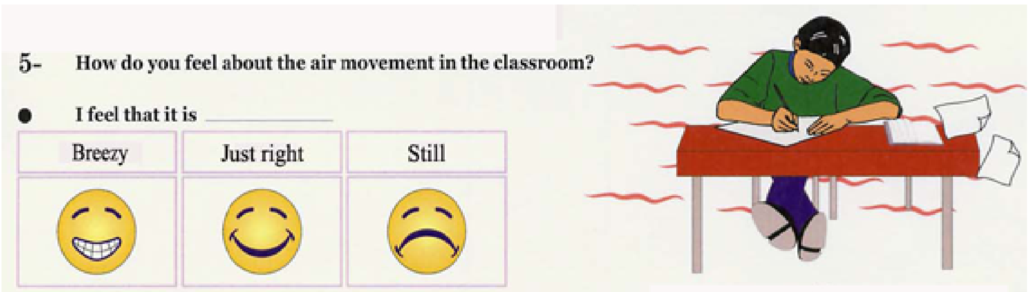

Figure 4.5: Question (5) in the thermal comfort questionnaire

Conveying the 'humidity' concept

Although the concept of the humidity is understood in Kuwait, humidity is difficult to be represented without any verbal clarification, especially to young subjects, to support its meaning. Humidity refers to the quantity of water vapour in the air, where high humidity levels leads to decrease in the evaporation of sweat from the skin, and hence to sweat remaining on the skin. In addition friction between the skin and the clothing increases with wet skin, producing a discomfort sensation for people.

The concept of humidity is addressed in this study by an image representing a student sitting and writing in a relaxed situation at a desk and executing a writing job with sweat drops appearing to indicate the humidity. Here, the sweat drops was explained with verbal support and it was clarified to the subjects that the sweat drops indicate the level of humidity, to prevent the misconception of thinking that it results from hard working. The responses to question (6) are ‘humid’, ‘just right’ and ‘dry’, where each response is supported by a facial expression. Figure 4.6 clarifies the meaning of the answer, where the yellow ‘happy’ face indicates the ‘dry’ environment, while the yellow ‘smiley’ face indicates the ‘just right’ humidity level and finally the yellow ‘sad’ face indicates a ‘humid’ environment.

For time saving, a male with normal indoor uniform image was used in this questionnaire, however male or female images with school uniforms could be used in future questionnaires. All the six questions are built with strong and clear scales to save the subjects' time and prevent them from becoming bored. The proposed new questionnaire is translated to the Arabic language version with specific words being selected that are compatible and conformable to the English version in order to simplify its concepts to the students.

In the next section, the new questionnaire is tested with older age-groups to determine whether any bias is introduced by the new wording and imaging.

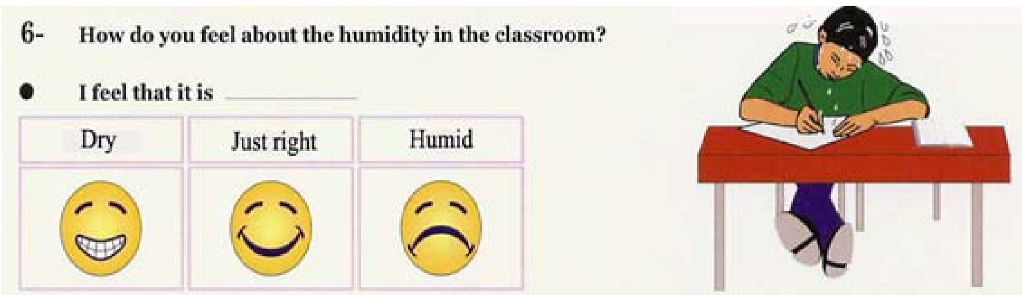

Figure 4.6: Question (6) in the thermal comfort questionnaire

4.6 Data collection

4.6.1 Physical measurements

Air speed and relative humidity inside the classrooms were measured with standards-approved equipment, namely an Indoor Climatic Analyser Type 1213 manufactured by Brűel and Kjær. Measurements with this equipment meet the requirements of ASHRAE 55 and ISO 7730 standards in addition to the ISO Standard 7726 (ISO 2001).

During the testing process, the measuring equipment was placed in five different locations within each classroom at two different heights above the floor (1.1 m and 0.6 m) as recommended by ASHRAE and ISO standards. At each position the equipment was left to run for about 3 minutes before the mean values of the environmental parameters were recorded.

According to the separation of the boys' schools and girls school, this field study was conducted in 4 classrooms using 4 groups (females and males), to investigate the effect of using both types of questionnaire (new proposed with colour and images and the traditional standard thermal comfort questionnaires) on the thermal sensation of these age groups. The 4 groups were divided in to 2 elementary boys and girls groups from 6 to 10 years old and 2 intermediate boys and girls groups with ages from 11 to 14 years old, respectively. Each gender of these groups was tested separately. The work was carried with the permission of the Kuwait Ministry of Education, the schools administrations and with the presence of the classes' teachers at all times.

The duration of the measurements is about 2 hours in each classroom, where the test readings were recorded every 6 minutes on an average basis. The readings are taken after 3 minutes' operation of the equipment, which is the time needed for the device to reach equilibrium. The equipment started 15 minutes before the students entered the classroom and the survey questionnaire was issued to the students 75 and 90 minutes after their entry into the classroom, in order to ensure that the students' had reached thermal steady state. The metabolic rate of the students in the seated position was estimated in accordance with ASHRAE 55 and ISO 7730 standards. The metabolic rate used for this study was estimated to represent the sedentary activity which is equal to

1.2 met. The recorded data were analysed in order to evaluate the PMV-PPD indices according to ASHRAE 55 and ISO 7730 standards and compare later with students' AMV to investigate the difference between the younger and older groups.

4.6.2 Testing the validity of using the wording of Wong and Khoo (2003) thermal sensation question

In producing a newly-warded such as the question, the thermal sensation question of Wong and Khoo (2003) it is important to ascertain whether the new wording has the potential to introduce "bias" into the responses of the subjects.

Wong and Khoo (2003) modified the wording of the standard thermal sensation question by referring directly to the 'temperature' in the classroom as a measure of the subject's thermal sensation. Here a question may arises which is "does the feeling toward the surrounding temperature represent the thermal sensation of the subjects?". To verify this issue, a number of steps have been followed: comparing the findings of the Wong and Khoo (2003) study with similar studies in the classroom; comparing the wording of this question to the recommendations of the ISO 10551 standards, testing both types of wording with real subjects to investigate whether their understanding of the "temperature" is to assess their thermal sensation.

It was found that the findings of the Wong and Khoo (2003) study in naturally ventilation classrooms, using the modified question, are similar to those found in other studies such as Kwok (1998), Ahmed and Ibrahim (2003), Kwok and Chun (2003) and Hwang et al. (2006) which were conducted in naturally ventilated classrooms in tropical and subtropical climatic regions. In addition to it is compliance with the ISO 10551 recommendations in regard to the cultural attitude and language differences. The standard gave the researcher the ability "to incorporate the scales into a list of more comprehensive or more specific questions".

The proposed and standard wording of the thermal sensation question were statistically tested using secondary school level group aged 15-17 years. The group consisted of 60 subjects seated (1.2 MET) in a controlled air conditioned classroom environment, while listening to a regular school lecture and writing a little homework, for an experiment time period of about 1 hours. The clothing insulation values of the subjects' school wear was equal to 0.65 clo. The thermal environmental classroom conditions were: 22.5°C operative temperature; 0.1 m/s air speed and 40% relative humidity, respectively, and the calculated Predicted Mean Vote value was equal to PMV= -0.6.

The group had been divided into two parts, each part consisting of 30 students. One part answered the standard wording, while the other part answered the Wong and Khoo (2003) proposed new wording. The proposed and the standard questions have been mixed and distributed randomly so that no two adjacent students take the same questionnaire at the same time. The distribution process of the thermal sensation question during the test and the placement of the equipment during the field experiment is shown in Figure 4.7.

4.6.3 Testing the new proposed thermal comfort questionnaire

In producing a new questionnaire, by changing wording and adding images as described before, it is important to ascertain whether the images or the new wording have the potential to introduce "bias" into the responses of the subjects. This can be investigated by testing the new questionnaire (the one with colours and drawings), against a standard questionnaire (the one without the colours and drawings) in the same thermal conditions using a set of subjects who are capable of completing both styles of questionnaire.

The proposed and the standard thermal comfort questionnaire were therefore tested with four separate elementary and intermediate school level groups, boys and girls groups of ages 6-10 and 11-14 years using the same testing procedure as in the previous section 4.6.2. Each group consisted of 60 students.

The four experiments have been conducted at four different places and dates. Each group was seated in a controlled air conditioned classroom environment, while listening to a regular school lecture and writing a little homework, for an experiment time period of about 2 hours.

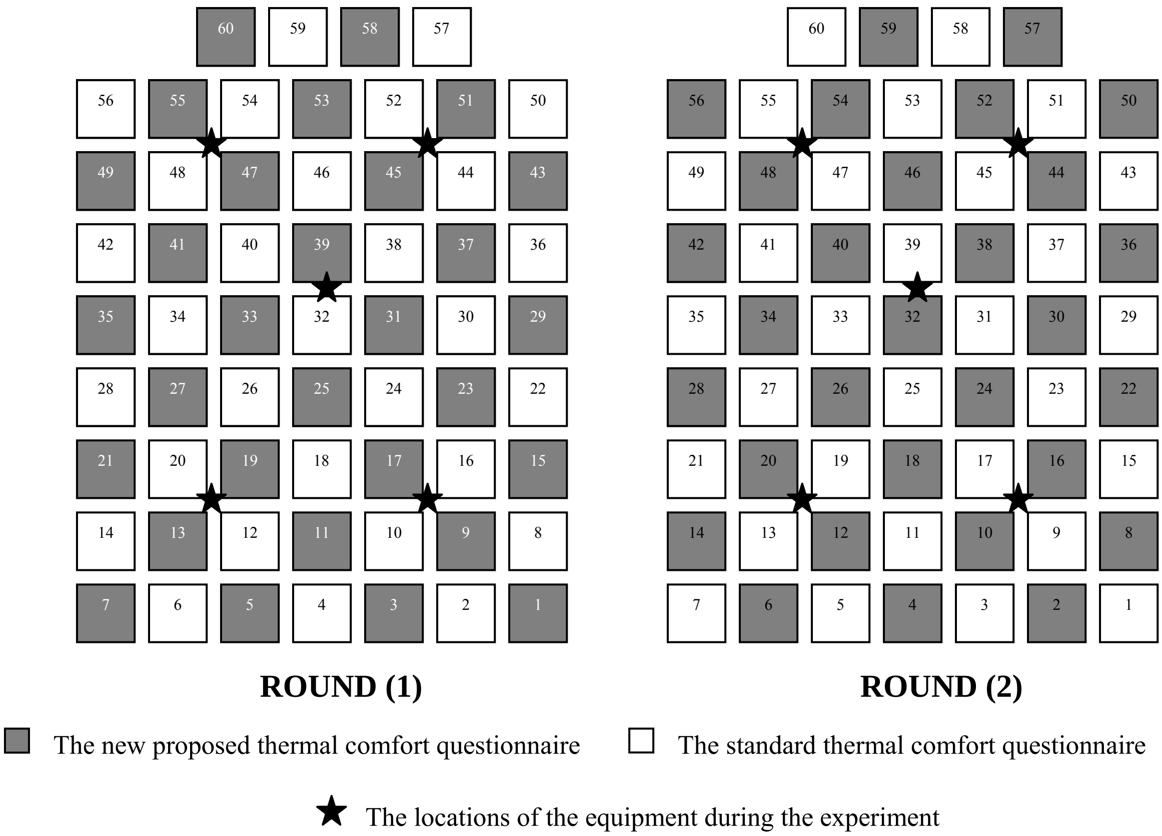

Figure 4.7: The distribution procedure of the two types of thermal comfort questionnaires in each round and the locations of the indoor climatic analyser equipment inside the classroom

The experiments were conducted on four different days in four different schools and all started at 10.00 a.m. The boys' groups were seated in a central air conditioned lecture theatre, while the girls' groups were seated in a large classroom which was conditioned with 2 split air conditioning units. The average clothing insulation values were estimated to be 0.65 clo for all boys, 0.68 clo for elementary girls and 0.72 clo for intermediate girls (ISO 2003).

Each gender group had been divided into two parts, each part consisting of 30 students. One part answered the standard questionnaire, while the other part answered the proposed new questionnaire (with colours and drawings). The proposed and the standard questionnaire have been mixed and distributed randomly so that no two adjacent students take the same questionnaire at the same time. Also, the student who has taken the standard questionnaire will take the proposed new one in the next run.

Figure 4.7 illustrates the distribution process of the thermal comfort questionnaire during each round and the placement of the equipment during the field experiment.

4.7 Results and Discussion

The statistical Students' z-test (if the sample > 29 subjects) and t-test (if the sample ≤ 29 subjects) are hypothesis-testing methods. These methods have been adopted to investigate the differences between the subjects' mean responses using the standard thermal sensation or thermal comfort questionnaire and their mean responses for each question when using the new proposed thermal sensation or thermal comfort questionnaire. The probability of rejecting the statistical hypothesis tested when in fact, that hypothesis is true, is denoted by (α) which is defined as the significance level in hypothesis-testing problems.

Before conducting any statistical test, it is important to establish a value for alpha (α), where most statisticians (and for many other scientists) it is customary to set the value of alpha at 0.05. The interval that has probability of capturing the test z-score is called the confidence interval. The confidence interval here is equal to (1-α)*100 or 95%, Kaniji (2006). Since the same subjects sample is used twice (one with the new questionnaire and one with the standard questionnaire), two or repeated measurements are taken in the same sampling unit, and within the same experimental conditions (same environmental conditions), Lehmann and Romano (2005), where the method of statistical testing is called paired sample z-test "test used in inference which determines if the difference between a sample mean and the population mean is large enough to be statistically significant when the samples are dependent; that is, when there is only one sample that has been tested twice (repeated measures) or when there are two samples that have been matched or "paired"".

For these reasons some statistical hypotheses were considered to compare the means of both thermal comfort questionnaires (standard and proposed). These hypotheses are the null hypothesis (H_o) which assumes there is no difference between the means responses of both types of thermal comfort sensation questions (ISO standard, (AMV_ISO) and the Wong Khoo question, (AMV_WK)). The alternative hypothesis assumes that there is a difference in means between the responses of the two questions types.

The validity of using the wording of the Wong and Khoo (2003) thermal sensation question was statistically tested using the z-test statistical analysis to compare the mean responses of both parts of the group. These hypotheses are the null hypothesis (H_o) which assumes there is no difference between the means of both types of thermal comfort questionnaires (AMV_ISO and AMV_WK). The alternative hypothesis assumes that there is a difference in means between the two questionnaire types:

⇒ The null hypothesis (H_o):

$\mu_{AMV\_ISO} = \mu_{AMV\_WK}$

or

$\mu_{AMV\_ISO} - \mu_{AMV\_WK} = \mu_d = 0$

and

⇒ The alternative hypothesis (H_A):

$\mu_{AMV\_ISO} \neq \mu_{AMV\_WK}$

or

$\mu_{AMV\_ISO} - \mu_{AMV\_WK} = \mu_d \neq 0$

where; μ is the population mean of the paired samples values, which in this case is the mean value of the answer for each question in the thermal comfort questionnaire for both the standard , $\mu_{\mathbf{AMV\_ISO}}$, and the proposed, $\mu_{\mathbf{AMV\_WK}}$, questionnaire.

The criterion of rejection is: $|z_0|>z_{\alpha/2,\, n-1}$

where;

z_0 is the test z-score,

$z_{\alpha/2,\, n-1}$ is the critical value of z,

α is the alpha value and equal to 0.05, and

n is the sample size (numbers of the subjects) equal to 60 students.

In this study the critical z value is:

$z_{\alpha/2,\, n-1} = z_{0.025,\, 59} = 1.96$ (from standard statistical tables).

After the validation of using the Wong and Khoo (2003) thermal sensation question, the work was continued to validate the new thermal comfort questionnaire. The aim of this part of this thesis is to design and build a new thermal comfort questionnaire that can be used by school children, especially younger children, 6-10 years old, but at the same time with a restricted condition that this new questionnaire must not bias or change the reported thermal comfort sensation. The issue of whether any bias is introduced can be investigated by allowing a group of older students (whose reading, writing and comprehension skills are already developed) to use the new questionnaire, as well as the standard questionnaire. For these reasons some statistical hypotheses were considered to compare the means of both thermal comfort questionnaires (standard and proposed). These hypotheses are the null hypothesis (H_o) which assumes there is no difference between the mean responses of both types of thermal comfort questionnaires (standard and proposed). The alternative hypothesis assumes that there is a difference in means between the responses of the two questionnaires types:

⇒ The null hypothesis (H_o):

$\mu_{\text{Standard}} = \mu_{\text{Proposed}}$

or

$\mu_{\text{Standard}} - \mu_{\text{Proposed}} = \mu_d = 0$

and

⇒ The alternative hypothesis (H_A):

$\mu_{\text{Standard}} \neq \mu_{\text{Proposed}}$

or

$\mu_{\text{Standard}} - \mu_{\text{Proposed}} = \mu_d \neq 0$

where; μ is the population mean of the paired samples values, which in this case is the mean value of the answer for each question in the thermal comfort questionnaire for both the standard , $\mu_{\textbf{Standard}}$, and the proposed, $\mu_{\textbf{Proposed}}$, questionnaire.

The criterion of rejection is: $|z_0| > z_{\alpha/2,\, n-1}$

where;

z_0 is the test z-score,

$z_{\alpha/2,\, n-1}$ is the critical value of z,

α is the alpha value and equal to 0.05, and
n is the sample size (numbers of the subjects) equal to 60 students.

In this study the critical z value is:
$z_{\alpha/2,\, n-1} = z_{0.025,\, 59} = 1.96$ (from standard statistical tables).

In order to understand the analysis procedure in this study, a term representation was used for each question in this study as follows:

- AMV-S: is the student's actual mean vote according to the ASHRAE 7-points scale using the standard questionnaire.
- AMV-P: is the student's actual mean vote according to the ASHRAE 7-points scale using the proposed questionnaire.
- COMFORT-S: is the student's comfort level vote using the standard questionnaire.
- COMFORT-P: is the student's comfort level vote using the proposed questionnaire.
- TP-S: is the student's thermal preferences vote according to McIntyre scale using the standard questionnaire.
- TP-P: is the student's thermal preferences vote according to McIntyre scale using the proposed questionnaire.
- ACCEPT-S: is the student's acceptability level vote using the standard questionnaire.
- ACCEPT-P: is the student's acceptability level vote using the proposed questionnaire.
- AIRFLOW-S: is the student's vote toward the airflow using the standard questionnaire.
- AIRFLOW-P: is the student's vote toward the airflow using the proposed questionnaire.
- HUMID-S: is the student's vote toward the humidity using the standard questionnaire.
- HUMID-P: is the student's vote toward the humidity using the proposed questionnaire.

4.7.1 Testing the wordings of the standard ISO and Wong and Khoo (2003) thermal sensation question with older age groups (15-17 years)

The statistical results in Table 4.3 show that there is no evidence of significant differences between the two parts. The most important columns in Table 4.3 are the confidence interval, the z-score and the sig. (2 tailed) “p-value” columns. Sig. (2 tailed) or the p-value (a measure of how much evidence we have against the null hypothesis), which is the probability of obtaining a test statistics equal to or more extreme than the result obtained from the sample data. Since all the absolute values of the z-scores for all pairs are less than the critical z-value of 1.96, the null hypothesis H_o ($\mu_{AMV\_ISO} = \mu_{AMV\_WK}$) is true and cannot be rejected.

Table 4.3: z-test for the comparison of the Actual Mean Votes (AMV) using ISO 10551 standard wording and Wong and Khoo (2003) modified wording of the thermal sensation question.

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Differences				
				Lower	Upper			
Pair AMV-ISO & AMV-WK	1.2172	0.2222	-0.4212	-0.4212	0.4878	0.150	59	0.882

Where, AMV-ISO: the subject’s actual mean vote using the standard wording of the thermal sensation question; AMV-WK: the subject’s actual mean vote using the proposed wording of the thermal sensation question by Wong and Khoo (2003); Mean: the mean for both questionnaires; Std. Deviation: the standard deviation for both questionnaires; Std. Error Mean: mean of the standard error for both questionnaires; t: t-value; df: degree of freedom; Sig. (2-tailed): significance of difference of both sides.

Also, since the interval of the pairs differences is located in between the negative (lower) and positive (upper) sides the 95% confidence interval of difference, so there is no evidence of a difference in the mean values between the answers of the students for both questionnaire types. This indicates that the null hypothesis H_o is true and cannot be rejected. Moreover, the p-value, sig. (2 tailed), is greater than α, which also indicates that the null hypotheses H_o ($\mu_{AMV\_ISO} = \mu_{AMV\_WK}$) is true and cannot be rejected.

It can be concluded that there are no differences between the mean values of all boys’ responses to the standard wording and the proposed wording by Wong and Khoo (2003) of the thermal sensation question. Therefore, the proposed wording of the thermal sensation question by Wong and Khoo (2003) does not affect the boys’ understanding to assess their thermal sensations, where asking about their feeling toward the surrounding temperature in the classroom can have the same result as asking about the thermal sensation of the subjects.

For more evidence, the actual mean votes of the two parts of the group, AMV_ISO and AMV_WK, were compared with the predicted mean vote (PMV) and the operative temperatures in the classroom as shown in Table 4.4. From Table 4.4, it is clear that the difference between the subjects' actual mean votes, using the different wordings of the thermal sensation question, through the two parts of the group, and the PMV values is about -0.5 units which can give more evidence that the use of both wording types of the thermal sensation question (standard and proposed by Wong and Khoo (2003)) to assess the subjects' thermal sensations leads to the same results.

From the previous discussion, it can be concluded that using the standard or the proposed wording by Wong and Khoo (2003) for the thermal sensation question leads to similar values of reported sensation responses and the wording style of Wong and Khoo (2003) can be used to investigate the thermal comfort sensations reported in Kuwait classrooms for students aged from 6 to 17 years old.

Table 4.4: the subjects' actual mean votes according to the different wordings of the thermal sensation questions used and the measured PMV and to values inside the classrooms.

Gender	Age, years	I_{cl} (clo)	AMV-ISO	AMV-WK	PMV	t_o, °C
Boys	15-17	0.65	-0.1	-0.13	-0.62	22.5

Where, I_{cl}: the clothing insulation value (clo); AMV-ISO: the subject's actual mean vote using the standard wording of the thermal sensation question; AMV-WK: the subject's actual mean vote using the proposed wording of the thermal sensation question by Wong and Khoo (2003); PMV: the predictive mean vote; t_o: the operative temperature, (°C)

4.7.2 Testing the standard and proposed thermal comfort questionnaire with intermediate age groups (11-14 years)

The standard and proposed thermal comfort questionnaires have been tested with intermediate level age groups from 11-14 years old, boys and girls, separately. The statistical data of the intermediate boys and girls groups are shown in Tables 4.5 and 4.6.

The most important columns in Table 4.5 (boys, 11-14 years) are the confidence interval, the z-score and the sig. (2 tailed) "p-value" columns. Sig. (2 tailed) or the p-value (a measure of how much evidence we have against the null hypothesis), which is the probability of obtaining a test statistic equal to or more extreme than the result obtained from the sample data. Since all the absolute values of the z-scores for all pairs are less than the critical z-value of 1.96, the null hypothesis H_o ($\mu_{Standard} = \mu_{Proposed}$) is true and cannot be rejected.

Also, since the interval of the pairs differences located in between the negative (lower) and positive (upper) sides of the 95% confidence interval of difference, so there is no evidence of a difference in the mean values between the answers of the students for both questionnaire types. This indicates that the null hypothesis H_o is true and cannot be rejected. Moreover, the p-value, sig. (2 tailed), is greater than α, which also indicates that the null hypotheses H_o is true and cannot be rejected.

It can be concluded that there are no differences between the mean values of all boys' responses in the standard questionnaire and their responses in the proposed new questionnaire. Therefore, the new proposed thermal comfort questionnaire does not affect the boys' answers to the different questionnaire questions, where the addition of colours and images in the new proposed questionnaire did not introduce bias into the boys' sensations.

The same z-test was applied to the girls' (11-14 years) group and their analysed data are listed in Tables 4.6. It is found that the null hypothesis H_o ($\mu_{Standard} = \mu_{Proposed}$) is true and failed to be rejected, and it can be concluded that there are no differences between the mean values of all girls' responses in the standard questionnaire and their responses in the proposed questionnaire. Therefore, the new proposed thermal comfort questionnaire has no effect on the girls' answers to the different questionnaire questions and the addition of colours and images in the new proposed thermal questionnaire did not introduce bias into the girls' sensations.

From the above discussion, it can be concluded that using either type of questionnaire (standard and new proposed) leads to similar values of reported sensation responses.

Table 4.5: Boys (11-14 years) Paired Samples Z-Test

		Paired Differences							
					95% Confidence Interval of the Differences				
		Mean	Std. Dev.	Std. Error Mean	Lower	Upper	Z	df	Sig. (2-tailed)
Pair 1	AMV-S & AMV-P	-0.067	1.07	0.140	-0.340	0.210	-0.482	59	0.632
Pair 2	COMFORT-S&COMFORT-P	-0.050	0.53	0.069	-0.190	0.088	-0.725	59	0.471
Pair 3	TP-S & TP-P	-0.017	0.79	0.100	-0.220	0.190	-0.163	59	0.871
Pair 4	ACCEPT-S & ACCEPT-P	0.033	0.49	0.063	-0.092	0.160	0.531	59	0.596
Pair 5	AIRFLOW-S &AIRFLOW-P	0.000	0.74	0.095	-0.190	0.190	0.000	59	1.000
Pair 6	HUMID-S & HUMID-P	0.120	0.74	0.095	-0.074	0.310	1.224	59	0.226

Where, Mean: the mean for both questionnaires; Std. Dev.: the standard deviation for both questionnaires; Std. Error Mean: mean of the standard error for both questionnaires; Z: Z-value; df: degree of freedom; Sig. (2-tailed): significance of difference of both sides.

Table 4.6: Girls (11-14 years) Paired Samples Z-Test

		Paired Differences							
					95% Confidence Interval of the Differences				
		Mean	Std. Dev.	Std. Error Mean	Lower	Upper	Z	df	Sig. (2-tailed)
Pair 1	AMV-S & AMV-P	-0.083	0.98	0.140	-0.170	0.340	0.659	59	0.512
Pair 2	COMFORT-S&COMFORT-P	0.017	0.34	0.044	-0.072	0.110	0.375	59	0.704
Pair 3	TP-S & TP-P	0.017	0.62	0.081	-0.140	0.180	0.207	59	0.831
Pair 4	ACCEPT-S & ACCEPT-P	0.017	0.47	0.061	-0.100	0.140	0.275	59	0.784
Pair 5	AIRFLOW-S&AIRFLOW-P	0.000	0.49	0.063	-0.130	0.130	0.000	59	1.000
Pair 6	HUMID-S & HUMID-P	0.100	0.48	0.062	-0.023	0.220	1.625	59	0.109

Where, Mean: the mean for both questionnaires; Std. Dev.: the standard deviation for both questionnaires; Std. Error Mean: mean of the standard error for both questionnaires; Z: Z-value; df: degree of freedom; Sig. (2-tailed): significance of difference of both sides.

4.7.3 Testing the standard and proposed thermal comfort questionnaire with elementary age groups (6 -10 years)

The standard and proposed thermal comfort questionnaires have been tested with elementary level age groups from 6-10 years old, boys and girls, separately. The statistical data of the intermediate boys' and girls' groups are shown in Tables 4.7 and 4.8. From Table 4.7 for boys (6-10 years), it is clear that all the absolute values of the z-scores for all pairs are greater than the critical z-value which is 1.96, the null hypotheses H_o ($\mu_{\text{Standard}} = \mu_{\text{Proposed}}$) is not true and must rejected and the alternative hypotheses H_A ($\mu_{\text{Standard}} \neq \mu_{\text{Proposed}}$) is true and must be accepted. Also, since the interval of the pairs differences located in one side of the negative (lower) and positive (upper) sides of the 95% confidence interval of difference, thus there is an evidence of a difference in the mean values between the students' responses of the students for both questionnaire types; which indicates the null hypotheses H_o is not true and must be rejected and the alternative hypotheses H_A is true and must be accepted. Moreover, the p-value, sig. (2 tailed), is lower than $\alpha = 0.05$, which also indicates that the null hypotheses H_o is not true and must be rejected and the alternative hypotheses H_A is true and must be accepted.

From the results of Table 4.7, it can be concluded that there are differences between the mean values of all boys' responses in the standard questionnaire and their responses in the proposed new questionnaire. Therefore the new proposed thermal comfort questionnaire affects the boys' answers to the different questionnaire questions, where the addition of colours and images in the new proposed thermal questionnaire can help the children to assess their sensation in better way than that when the standard questionnaire was used. This means that the boys in this young age group (6-10 years) have difficulties in their reading, writing and understanding skills to use the standard questionnaire to assess their sensations toward the different environmental variables.

The same z-test was applied to the girls' (6-10 years) group and their analysed data were listed in Table 4.8. It is found that the null hypotheses H_o ($\mu_{\text{Standard}} = \mu_{\text{Proposed}}$) is not true and must be rejected and the alternative hypotheses H_A ($\mu_{\text{Standard}} \neq \mu_{\text{Proposed}}$) is true and must be accepted. From results in Table 4.8, it can be concluded that there are differences between the mean values of all girls' responses in the standard questionnaire and their responses in the proposed questionnaire. Therefore the new proposed thermal comfort questionnaire effect the girls' answers to the different questionnaire questions, where the addition of colours and images in the new proposed thermal questionnaire can help the children to assess their sensation in better way than that when the standard questionnaire was used. Thus means that the girls in this age group have difficulties in understanding the standard questionnaire to assess their sensations toward the different environmental variables.

4.7.4 Comparing the answers of the younger children (6-10 years) with the older children (11-14 years)

Following the previous statistical evidence of the effects of both the standard and the

Table 4.7: Boys (6-10 years) Paired Samples Z-Test

		Paired Differences							
					95% Confidence Interval of the Differences				
		Mean	Std. Dev.	Std. Error Mean	Lower	Upper	Z	df	Sig. (2-tailed)
Pair 1	AMV-S&AMV-P	-1.10	1.82	0.230	-1.570	-0.630	-4.682	59	0.000
Pair 2	COMFORT-S&COMFORT-P	0.43	0.83	0.110	0.220	0.650	4.040	59	0.000
Pair 3	TP-S&TP-P	0.57	0.91	0.120	0.330	0.800	4.830	59	0.000
Pair 4	ACCEPT-S&ACCEPT-P	0.15	0.52	0.070	0.0170	0.280	2.256	59	0.028
Pair 5	AIRFLOW-S&AIRFLOW-P	0.43	0.93	0.120	0.190	0.670	3.620	59	0.001
Pair 6	HUMID-S&HUMID-P	0.27	0.99	0.130	0.010	0.520	2.088	59	0.041

Where, Mean: the mean for both questionnaires; Std. Dev.: the standard deviation for both questionnaires; Std. Error Mean: mean of the standard error for both questionnaires; Z: Z-value; df: degree of freedom; Sig. (2-tailed): significance of difference of both sides.

Table 4.8: Girls (6-10 years) Paired Samples Z-Test

		Paired Differences							
					95% Confidence Interval of the Differences				
		Mean	Std. Dev.	Std. Error Mean	Lower	Upper	Z	df	Sig. (2-tailed)
Pair 1	AMV-S&AMV-P	-1.58	1.73	0.220	-2.03	-1.14	-7.089	59	0.000
Pair 2	COMFORT-S&COMFORT-P	0.25	0.89	0.120	0.019	0.48	2.164	59	0.035
Pair 3	TP-S&TP-P	0.62	0.96	0.120	0.37	0.86	4.984	59	0.000
Pair 4	ACCEPT-S & ACCEPT-P	-0.17	0.83	0.11	-0.38	0.05	-1.561	59	0.128
Pair 5	AIRFLOW-S & AIRFLOW-P	0.30	0.98	0.13	0.047	0.55	2.373	59	0.021
Pair 6	HUMID-S & HUMID-P	0.47	0.93	0.12	0.23	0.71	3.891	59	0.000

Where, Mean: the mean for both questionnaires; Std. Dev.: the standard deviation for both questionnaires; Std. Error Mean: mean of the standard error for both questionnaires; Z: Z-value; df: degree of freedom; Sig. (2-tailed): significance of difference of both sides.

new proposed thermal comfort questionnaire on the children's understanding in each age group, and according to the literature no previous studies have explored the thermal comfort sensations of very young children such as school children from 6-10 years old, the actual mean votes of the younger children were compared with the actual mean votes of older children to gather more evidence about the effects of both questionnaire types on their understanding to assess their thermal sensation on the ASHRAE thermal sensation scale. Separate thermal comfort test was conducted to each group in different classrooms thermal conditions.

The actual mean votes (AMV) of each gender in each age group (gathered according to the standard and proposed thermal comfort questionnaire), and the predicted mean vote (PMV) and the operative temperatures in each classroom are tabulated in Table 4.9.

Table 4.9: the children actual mean votes according to the different thermal comfort questionnaires and the measured PMV and to values inside the classrooms.

Gender	Age, years	I_{cl} (clo)	AMV-S	AMV-P	PMV	t_o, °C
Boys	11-14	0.65	-0.35	-0.28	-0.83	22.5
Girls	11-14	0.65	-0.42	-0.50	-0.96	22.3
Boys	6-10	0.65	0.57	-0.53	-1.00	22.5
Girls	6-10	0.65	1.02	-0.57	-1.10	21.8

Where: I_{cl} , clothing insulation value (clo); AMV-S, children actual mean votes according to the standard questionnaire; AMV-P, children actual mean votes according to the proposed questionnaire; PMV, the measured Predicted Mean Vote value; to, the classroom average operative temperature

From Table 4.9, it is clear that the difference between the children's actual mean votes (according to the proposed thermal comfort questionnaire), through all age groups and the PMV values is about -0.5 units which means that the younger children's votes (6-10 years) and the older children (11-14 years) are almost close, whereas when the standard questionnaire is used big differences occurred between the two age groups.

This gives more evidence that the use of the new proposed thermal comfort questionnaire with the addition of images and colours may help the younger children to assess their thermal sensations better than if the standard questionnaire used.
From the previous discussion, it can be concluded that using the new proposed thermal comfort questionnaire with the addition of the images and colours with children 6-10 years can help the children of this age group to assess their thermal sensation better, while the use of either type of questionnaire (standard or new proposed) with children 11-14 years old or older leads to similar values of reported sensation responses.

4.8 Conclusions

A new thermal comfort questionnaire has been devised for gathering data on the reported thermal comfort sensations of very young people, typically aged 6-10 years. The questionnaire contains modifications consisting of colours and images, together with re-wordings of questions to make them more easily understood by the younger people. The questionnaire was tested for bias using a group of older subjects.

- The new proposed thermal comfort questionnaire has the potential to extend thermal comfort research by helping researchers to investigate and study the thermal comfort sensations of very young people, such as school children. This new development can help to uncover how the environment affects children's thermal comfort sensations and health, and how they react towards these environments. In the near future, the new proposed questionnaire will be used to investigate the thermal comfort sensations reported in Kuwait classrooms for students' aged from 6 to 17 years old.

- From the results it can be concluded that the proposed new thermal comfort questionnaire did not introduce bias to the students' understanding and voting, for the age range 11-14 years, as regards their thermal sensations. The students' feelings towards the different environmental factors have not been affected by the images and colours of the new questionnaire.
- The findings of the younger children's (6-10 years) votes show that there is a difference in the reported sensation votes using the new and standard thermal comfort questionnaire, hence in the new proposed thermal comfort questionnaire is more appropriate for extracting thermal sensation data from very young people, whereas when young children used the standard questionnaire some missing answers occurred because young children did not understand them.
- The comparison the younger and older children's age groups using the new thermal comfort questionnaire, suggests no differences in the thermal sensation amongst these age groups, which can support the use of the new thermal questionnaire in predicting the thermal sensation of younger children using the PMV model.

Chapter 5
Assessing the Thermal Insulation Values of Children's Schoolwear in Kuwait

5.1 Chapter Summary

In this chapter, three methods were used to determine the thermal insulation values of different school clothing worn by 6 to 17 year old girls and boys in Kuwait classrooms for both summer and winter seasons. The different clothing ensembles' insulations were determined by 1: measurement using adult-sized versions of the clothing on thermal manikins, 2: estimations from adult clothing data obtained from the standards tables in ISO 9920 and ASHRAE 55, and 3: calculations using a regression equation from McCullough *et al.* (1985) that was adapted to accommodate children's sizes for ages 6-17 years. Values for the clothing area factor, f_{cl}, were also determined by measurement and by using a prediction equation from ISO 9920.

The results suggested that the clothing insulation values found from the measured and adapted data were similar to the adult's data in standards tables for the same summer and winter seasons. Further, the effect of the insulation values on the different scholars' age groups were investigated using the clothing temperature rating technique and compared to the scholars' comfort temperature found in recent field studies. Results showed that the temperature ratings of the clothing using the three methods described above are close and in agreement with the scholars' comfort temperature. Though estimated and measured f_{cl} data differed, the impact on the temperature ratings was limited.

An observed secular change in the children's heights and weights in the last few decades implies that, for adolescents, the children's body surface areas are similar to those of adults, making the use of adult clothing tables even more acceptable. In conclusion, the study gives some evidence to support the applicability of using adults' data in ASHRAE 55 and ISO 9920 standards to assess the thermal insulation values of different children's clothing ensembles, provided that careful selection of the garments, ensembles material and design takes place.

5.2 Introduction

5.2.1 Previous Research

In 1972 Fanger established the PMV-PPD index (ISO 7730) to predict the suitable thermal comfort conditions for occupants in indoor environments. This index predicts the occupants' thermal comfort sensations according to the effects of environmental factors (ambient air temperature; humidity; mean radiant temperature and air speed) and personal factors (activity level and clothing insulation) together with people's satisfaction with the thermal environment of the space. In this index, Fanger considered the insulation of the clothing as an important part in the comfort prediction method. For this reason, assessing the clothing type worn by occupants and its thermal insulation value is essential for predicting the thermal sensation of occupants in that space.

The major function of clothing is to maintain a static air layer next to the skin (Hardy *et al.*, 1953), where the insulation value of the clothing ensemble may increase or decrease according to the amount of air trapped between the body and garments, between fabric layers in a single garment, and between layers of different garments (Havenith, 2002). The clothing distribution over the body and its insulation value affects the convective, conductive and radiant heat loss from the skin to the environment. The clothing ensemble increases the surface area of the body, and because the heat loss takes place from a larger surface than when nude, the efficiency of the thermal insulation of a clothing ensemble decreases.

In 1972, ASHRAE supported a clothing research project that investigated the effects of clothing on occupants' thermal comfort. A clo value index was developed by assessing thermal insulation values for many individual items of clothing as well as several ensembles. These values (in units of ‘clo’, where one clo ≡ 0.155 m^2KW^{-1}) were tabulated in standard tables (ISO 7730, ASHRAE 55). Therefore it is necessary for the users of these standards to know what types of clothing provide different amounts of insulation. To meet this need, the standards contain a list of clo values for selected garment types and a formula for estimating the insulation provided by a total clothing ensemble. McCullough and Jones (1984) and Olesen and Nielsen (1983) established standard tables containing the insulation values for the most commonly-worn western indoor clothing ensembles. All these standard tables are based on adult measurements data. If applied to children’s clothing, the use of these data to assess the children’s thermal comfort sensation may result in the introduction of errors.

A number of field studies such as those of Kwok (1998); Xavier and Lamberts (2000); Cheong *et al*. (2003); Wong and Khoo (2003); Ahmed and Ibrahim (2003); Kwok and Chun (2003); Hwang *et al*. (2006); Corgnati *et al*. (2007); and Havenith (2007) have been conducted in classrooms to investigate the thermal comfort conditions for school children or adult college students. The only field studies conducted in Kuwait classrooms was those of Al-Rashidi *et al*. (2009a, b and 2010) for different modes of classroom ventilation. A summary of these studies is shown in Table 5.1.

From Table 5.1, it is clear from all studies, except those of Havenith (2007) and Al-Rashidi *et al*. (2009a, b and 2010), the children’s clothing insulation was estimated from the data presented in the standard tables which are originally based on adult measurements. Havenith (2007) took a regression equation introduced by McCullough *et al*. (1985), which itself was based on adult clothing, and adapted it to children’s sizes by scaling the measurements of the equation’s input parameters. Al-Rashidi *et al.* (2009a, b and 2010) measured children’s clothing insulation values using adult-sized thermal manikins and children’s clothing manufactured in adult’s sizes.

Table 5.1: Classrooms thermal comfort research for different regions

Researcher & Published Year	Study Location	Climatic Region	Subject's Ages	Average clothing insulation value (clo)	Clothing insulation calculation method
Kwok (1998)	Hawaii, USA	Tropical	15-17	0.42	Estimated
Xavier and Lamberts (2000)	Florianopolis–Santa Catarina, Brazil	Tropical	15-17	0.61	Estimated
Cheong *et al.* (2003)	Singapore	Tropical	Adults	0.60	Estimated
Wong and Khoo (2003)	Singapore	Tropical	13-17	0.45	Estimated
Ahmad and Ibrahim (2003)	Shah Alam, Malaysia	Tropical	Adults	0.60	Estimated
Kwok and Chun (2003)	Tokyo, Japan	Sub-Tropical	13-15	0.37	Estimated
Hwang *et al*. (2006)	Center and South Taiwan	Sub-Tropical	Adults	0.60	Estimated
Corganti *et al.* (2007)	Turin, Italy	Mediterranean	15-17	N/A	Estimated
Havenith (2007)	Netherlands	Mild, Maritime	9-18	1.1	McCullough *el al*. (1985) equation[1]
Al-Rashidi *et al.* (2009a and b)	Kuwait	Hot, dry	11-14	1.17 boys 0.95 girls	Measured[2]
Al-Rashidi *et al.* (2010)	Kuwait	Hot, dry	11-14	0.65 boys 0.73 girls	Measured[2]

[1]with Havenith (2007) corrections, [2]Using thermal manikins with adult size clothing

5.2.2 Kuwaiti Schoolwear and Research Objectives

Education in Kuwait consists of 3 academic levels: elementary; intermediate and secondary levels. The elementary level consists of five classroom grades from the 1st class to the 5th class and the scholars' ages are from 6-10 years; the intermediate level consists of 4 classroom grades from the 6th class to the 9th class and the scholars' ages are 11-14 years; the secondary level consists of 3 classroom grades from the 10th class to the 12th class and the scholars' ages are 15-17 years. The girls' and boys' schools are completely segregated in all academic levels.

The main objectives of this study are to investigate the applicability of using clothing insulation values presented in the standard tables (ISO 7730, ASHRAE 55), which are based on adult measurements, to estimate the clothing insulation values for schoolwear by comparing a number of different methods for determining clothing insulation values applied to children's clothing. These methods are:

- Estimating clothing insulation using adult values as in standards ISO 9920 and ANSI/ASHRAE 55.

- Practically measuring the clothing insulation values (I_{cl}) for the different scholar codes, summer and winter, of the students' clothing in Kuwait, based on adults' sized versions of the clothing, using adult sized thermal manikins.
- Following the approach of scaling proposed by Havenith (2007), based on the McCullough *el al*. (1985) regression equation to calculate the insulation values for the different scholar codes.

After collection of these data, the insulation values obtained with the different methods will be compared and the impact of these on observed differences on the children's comfort sensation will be assessed. In addition, the effect of different methods for assessing the clothing surface area factor (detailed later) will be investigated as it was shown earlier (Al-Ajmi *et al*., 2008) that this can be a problem for non-western clothing. Finally, this study will also add to the database of insulation values for non-western clothing ensembles, for which currently only limited information is available.

5.3 Methodology

5.3.1 Clothing

The school children and adolescents' clothing ensemble codes selected in this study are representatives of the scholarly clothing worn in Kuwait classrooms for both girls and boys for summer and winter seasons. A description of each code for both genders for summer and winter, and an image of each ensemble are provided in Table 5.2 and Figure 5.1, respectively. It should be noticed from Table 5.2 that in summer, there are two different clothing ensembles for girls in the secondary level, while there are other two different clothing ensembles for them in the winter. The same analysis but slightly different clothing ensembles are also seen for the girls in the intermediate level. At about student ages (11-12 years), and according to some religion and social traditions, females are required to start wearing the traditional dress (i.e. Hejab). However, regarding to the freedom of believe in Kuwait all girls have the freedom to choose to wear the Hejab or not; so the Ministry of Education in Kuwait is offering two different clothing ensembles in each level (intermediate and secondary) to give the girls the choice to wear the Hejab or not.

Table 5.2: Description of different scholar clothing codes worn by students in Kuwait classrooms for both summer and winter seasons.

Ensemble Type/Code		Summer		Winter	
Gender	School Level	Ensemble No.	Clothing Ensemble	Ensemble No.	Clothing Ensemble
Girls	Secondary	1	Hejab (hair cover), long sleeve shirt, sleeveless long gown, Half-long legged pants, bra, ankle socks	7	Hejab (hair cover), long sleeve shirt, sleeveless long gown, half-long legged pants, bra, ankle socks and long sleeve sweater (cardigan)
		2	Long sleeve shirt, sleeveless short dress, half-long legged pants, bra, ankle socks	8	Long sleeve shirt, sleeveless short dress, half-long legged pants, bra, ankle socks and long sleeve sweater (cardigan)
	Intermediate	3	Hejab (hair cover), long sleeve long gown, half-long legged pants, bra, ankle socks	9	Hejab (hair cover), long sleeve long dress, half-long legged pants, bra, ankle socks and long sleeve sweater (cardigan)
		4	Long sleeve short dress, half-long legged pants, bra, ankle socks.	10	Long sleeve short dress, half-long legged Pants, bra, ankle socks and long sleeve sweater (cardigan)
	Elementary	5	Long sleeve short dress, half-long legged pants, Sleeveless scoop neck shirt, ankle socks	11	Long sleeve short dress, long sleeve shirt, pantyhose, ankle socks and long sleeve sweater (cardigan)
Boys	All Levels	6	Short sleeve shirt, straight fitted trouser, short legged pants, T-shirt, calf length Socks	12	Long sleeve shirt, straight fitted trouser, long sleeve underwear shirt, long legged pants, calf length socks, long sleeve sweater (cardigan)

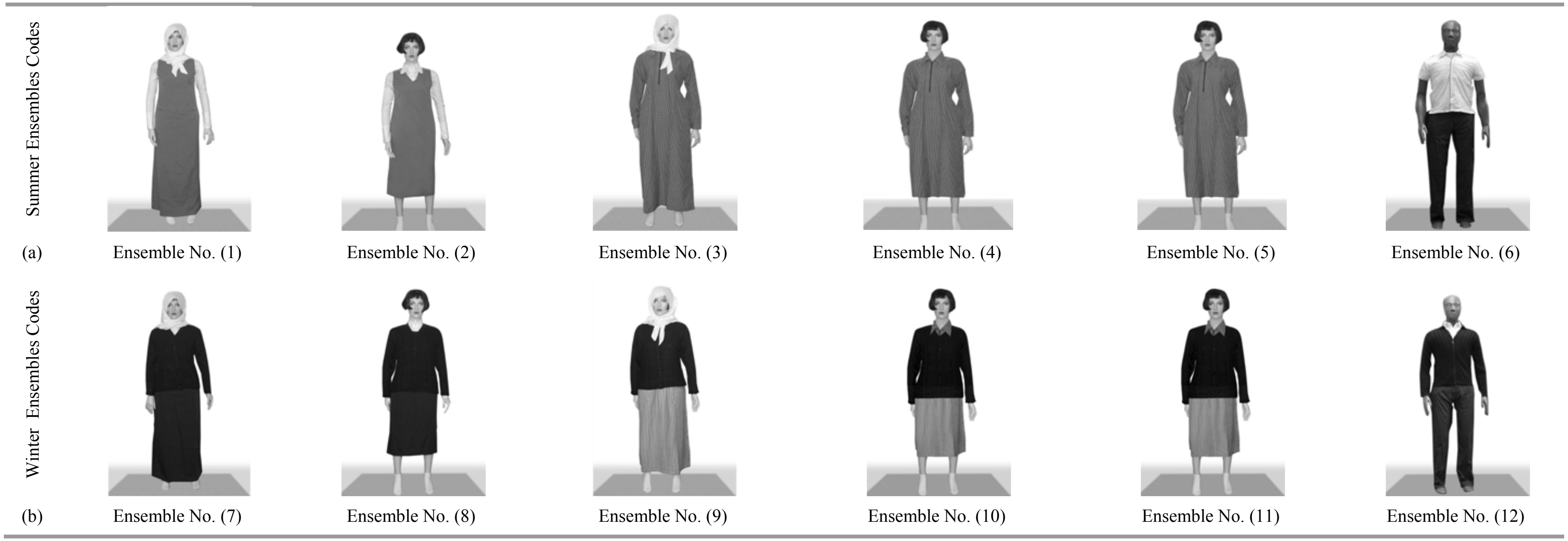

Figure 5.1: Photographs of the girls' and boys' ensembles for (a) summer and (b) winter seasons

5.3.2 Insulation Values of Kuwaiti Schoolwear Using Adult Thermal Manikins.

Measurement of clothing thermal insulation values was carried out by using an electrically heated manikin housed in a controlled environment. Thermal manikins are essentially an engineering tool that provide information about the physical properties of garments and garment systems. They are principally used to measure the amount of insulation provided by a garment, or the heat loss from the body that occurs when a garment is being worn (Havenith, 2005).

Though some baby manikins exist, no children manikins covering different sizes/ages were available for this testing. Adult male and female thermal manikins (‘Newton’, MTNW, Seattle, USA and ‘Victoria’, PT-Teknik, Denmark) were placed in a controlled climatic chamber at the Human Thermal Environments Laboratories (HTEL), Loughborough University and dressed with the different scholar ensembles, manufactured in adult sizes, for both genders as worn in Kuwait classrooms. Manikins were calibrated in the climatic chamber according to the standard procedures (ASTM, 2004) unclothed and clothed.

Insulation value measurements (I_T) were made for the following conditions: air speed less than 0.15 m/s, ambient and mean radiant temperatures equal at 23°C, relative humidity of 50%, and manikin mean skin temperature of 35°C. The measurements of the heat loss were recorded every second and averaged over ten-minute periods. The intrinsic or basic clothing insulation (I_{cl}), which is defined as the insulation from the skin surface to the clothing surface, can be deduced from the measured (I_T) value by the following equation:

$$I_{cl} = I_T - \frac{I_a}{f_{cl}} \quad \text{(clo)} \qquad (5.1)$$

Where:

I_T = Insulation of the whole body clothing, (clo)

I_a = Insulation of the surface boundary air layer, (clo)

f_{cl} = clothing area factor, the ratio of the body surface area while clothed to the body surface area while nude

The insulation of the surface air layer on the nude manikins (I_a) were separately measured at 0.57 clo and 0.66 clo for the male and female manikins, respectively. The clothing surface area factor (f_{cl}) can be determined using the McCullough and Jones (1984) equation based on the intrinsic insulation:

$$f_{cl} = 1.0 + 0.30\, I_{cl} \qquad (5.2)$$

Note that f_{cl} is solved iteratively using equations (5.1) and (5.2), or by using photographic techniques (Seppanen *et. al.*, 1972 and Sprague and Munson, 1974) or computer-aided anthropometric scanning (Havenith 2005, 2010).

In this study, the clothing surface area factor (f_{cl}) of the different scholar ensembles used in Kuwait were determined using photographs taken by a high-resolution digital camera from the front view of semi-nude and clothed persons (Al-Ajmi *et al*., 2008).

5.3.3 Comparing the Measured Insulation Values and Clothing Surface Area Factor (f_{cl}) with Standard Tables

The insulation values (I_{cl}), measured using thermal manikins, of the different scholar codes for both genders in summer and winter seasons (sized up to fit the manikins) were compared with the estimated insulation values of the same ensembles selected from the ASHRAE 55 and ISO 9920 standard tables. Also the measured area clothing factor (f_{cl}) values using the photographic techniques were compared to the values calculated by McCullough and Jones (1984) for the different scholar codes for both genders in summer and winter seasons. The measured area clothing factor (f_{cl}) values using the photographic techniques were used to calculate the measured intrinsic insulation values (I_{cl}), using thermal manikins. The comparisons will be discussed in detail in section 5.4.1 of this chapter.

5.3.4 Calculating and adapting the (I_{cl}) Values for Children's Sizes.

Use of the existing ISO 9920 tables that are based on adult sizes may not be sufficiently accurate for assessing the clothing insulation for children. Therefore, the McCullough *et al.* (1985) regression equation calculates clothing insulation by assuming an insulation based on the weight for multi layer clothing and then subtracting insulation for nude and single layer areas. As McCullough's equation can be linked to the heat transfer through multi- and single layer clothing and the nude areas, Havenith (2007) suggested the equation could be scaled for children. The surface areas are automatically scaled (%) so the smaller size of the children is not an issue. The clothing weight in the equation is an absolute value however, and for the smaller children sizes this would be an issue. Havenith proposed to upscale the clothing weight based on body surface area of the children (Dubois and Dubois 1916), taking a 1.8 m^2 person as reference. This procedure was applied to all schoolwear worn in Kuwait classrooms for male and female ensembles for age range 6-17 years old. The McCullough *et al.* (1985) regression equation for calculating the intrinsic clothing insulation is:

$$I_{cl} = 0.919 + 0.255\ weight^{*} - 0.00874\ BSA_0 - 0.0051\ BSAC_1 \quad \text{(clo)} \qquad (5.3)$$

where;

I_{cl} = intrinsic clothing insulation (clo)

weight *= actual clothing weight (kg) excluding shoes * 1.8/child's body surface area

BSA_0 = body surface area nude (%)

$BSAC_1$ = body surface area covered by one layer of clothing (%)

In this equation, the clothing insulation is calculated by subtracting the insulation for the nude case and the single clothing layer case from the insulation based on the weight of the multi-layer clothing. Given that the surface areas are already expressed as percentages of the whole body surface, only the clothing weights have to be scaled. Havenith (2007) suggested doing this based on body surface area (A_D, Dubois and Dubois 1916) by taking a 1.8 m^2 person as reference. Statistical data on the average weights, heights and body surface areas for Kuwaiti children aged from 6-17 years old over the last two decades have been obtained from the Ministry of Public Health (MOPH) in Kuwait. Also the different schoolwear ensembles for summer and winter seasons for both genders have been studied and weighted for these age groups.

The intrinsic clothing insulation equation, Equation (5.3), have been used to calculate (I_{cl}) values for the different schoolwear for boys and girls, in Kuwait classrooms. These were compared with the actual measured (I_{cl}) values based on testing adult sizes with thermal manikins, and with the estimated (I_{cl}) values from adult-sized clothing in standard tables. This procedure was carried out to investigate the differences between the two sets of results and the impact of these differences on the children's thermal sensation and energy consumption of HVAC systems used in classrooms.

5.4 Results and Discussion:

5.4.1 Comparing Measured ($I_{cl,measured}$) and Estimated ($I_{cl,e}$) Clothing Insulation Values

In most of the previous thermal comfort studies related to children (i.e. schools), the clothing thermal insulation values of the schoolwear were estimated from the ANSI/ASHRAE 55 and ISO 9920 standard tables, which are originally based on adults size measurements. This estimation may lead to inaccuracies that may affect the assessment of children's thermal comfort sensations. The present study provides a practical comparison of different methods and may give some guidance as to the applicability of using standard tables for children's ensembles.

Measuring the different schoolwear ensembles of Kuwait students, especially those that cover about 95% of the body surface area (girls' ensembles with hejab; No. 1, 3, 7 and 9 in Figure 5.1), give a wide range and a good chance to extensively investigate some non-western ensembles that are not included in standard tables (i.e. long dress with hejab).

Al-Ajmi *et al.* (2008) identified problems for non-western clothing with the f_{cl} determination based on regression equations given in ISO 9920. Therefore, in this study two methods were used to find the clothing area factor: i) the photographic technique (Al-Ajmi *et al.*, 2008) and, ii) McCullough and Jones (1984) regression equation. The results for the two methods, as applied to Kuwaiti schoolwear, are given in Tables 5.3 and 5.4 and in Figure 5.2. The differences between the results obtained by the photographed clothing area factor ($f_{cl,\ photographed}$) and the estimated clothing area factor ($f_{cl,\ estimated}$) for female ensembles in summer and winter range from 4-19%, while for males the range is 0.5-3%. Figure 5.2 clearly shows that the McCullough and Jones (1984) regression equation (i.e. Equation (5.2)) makes large errors in the determination of f_{cl}, the average deviation being around 9%. This is consistent with earlier findings by Al-Ajmi *et al*. (2008) and shows that the equations to calculate f_{cl} given in the standards should be applied with care to non-western clothing.

The largest differences in the clothing area factors between the photographed and estimated methods occurred for girls' ensembles 1 and 3 in Table 5.3; 7 and 9 in Table 5.4. These differences may be attributed to the sophisticated shape and design of these ensembles which are fit loosely and long, and most of the head is covered. Though these differences in f_{cl} are substantial, the effect on the I_{cl} calculation is limited as shown by Al-Ajmi *et al.* (2008). The difference in the I_{cl}, on average, is 5% with a range of 0-11%. Comparison between the measured I_{cl} values using thermal manikins (using the measured f_{cl}) and estimated values from the regression equations for both genders (using f_{cl} values from the regression equation) are shown in Figure 5.3, and are also shown in Tables 5.3 and 5.4 for summer and winter seasons, respectively. The measurements were conducted with the same school ensemble types but for adult sizes. From these tables, it is clear that the measured thermal insulation values ($I_{cl,\ measured}$) of some girls' and boys' ensembles, which correspond to Western clothing in the standards, are close to the estimated values ($I_{cl,\ estimated}$) from the regression equations.
Some of the tested ensembles here (i.e. girls' ensembles no. 1; 3; 7 and 9) are new data which will help extend the usability of the existing standard tables. These new data are in agreement with those of Al-Ajmi *et al.* (2008), especially for the female traditional and religious ensembles. In general, the measured data are in agreement with those estimated from the standard tables and the selection of different ensembles from the standards tables is typical and acceptable, with accuracy in the order of $\pm$ 20% where good matches between ensembles are found (ASHRAE 2009).

Table 5.3: Comparison between the measured and estimated insulation values (I_{cl}) and the (f_{cl}) values using the photographic techniques and the regression equation by McCullough and Jones (1984) of Kuwait student's scholar summer clothing ensembles.

Gender	School Level	Ensemble No.	I_a		I_T		$I_{cl, measured}$		$I_{cl, estimated}$		I_{cl} Difference (%)	$f_{cl, photographs}$	$f_{cl, estimated}$	f_{cl} Difference (%)
			clo	$m^2.^oC.W^{-1}$	clo	$m^2.^oC.W^{-1}$	clo	$m^2.^oC.W^{-1}$	clo	$m^2.^oC.W^{-1}$				
Girls	Secondary	1	0.66	0.102	1.23	0.191	0.75	0.116	0.68	0.105	9	1.38	1.204	13
		2	0.66	0.102	1.20	0.186	0.70	0.109	0.65	0.109	8	1.31	1.194	9
	Intermediate	3	0.66	0.102	1.21	0188	0.74	0.115	0.66	0.102	11	1.42	1.198	16
		4	0.66	0.102	1.20	0.186	0.68	0.110	0.65	0.101	4	1.27	1.194	6
	Elementary	5	0.66	0.102	1.20	0.186	0.68	0.105	0.65	0.101	4	1.27	1.194	6
Boys	All Levels	6	0.57	0.088	1.13	0.175	0.65	0.101	0.65	0.109	0	1.19	1.196	0.5

Table 5.4: Comparison between the measured and estimated insulation values (I_{cl}) and the (f_{cl}) values using the photographic techniques and the regression equation by McCullough and Jones (1984) of Kuwait student's scholar winter clothing ensembles.

Gender	School Level	Ensemble No.	I_a		I_T		$I_{cl, measured}$		$I_{cl, estimated}$		I_{cl} Difference (%)	$f_{cl, photographs}$	$f_{cl, estimated}$	f_{cl} Difference (%)
			clo	$m^2.^oC.W^{-1}$	clo	$m^2.^oC.W^{-1}$	clo	$m^2.^oC.W^{-1}$	clo	$m^2.^oC.W^{-1}$				
Girls	Secondary	7	0.66	0.102	1.48	0.229	1.03	0.160	0.97	0.150	6	1.48	1.291	14
		8	0.66	0.102	1.39	0.215	0.91	0.141	0.87	0.135	4	1.38	1.261	9
	Intermediate	9	0.66	0.102	1.47	0228	1.05	0.163	0.96	0.149	9	1.59	1.290	19
		10	0.66	0.102	1.40	0.217	0.90	0.140	0.88	0.136	2	1.32	1.263	4
	Elementary	11	0.66	0.102	1.40	0.217	0.90	0.140	0.88	0.136	2	1.32	1.263	4
Boys	All Levels	12	0.57	0.088	1.58	0.245	1.17	0.181	1.16	0.180	1	1.39	1.350	3

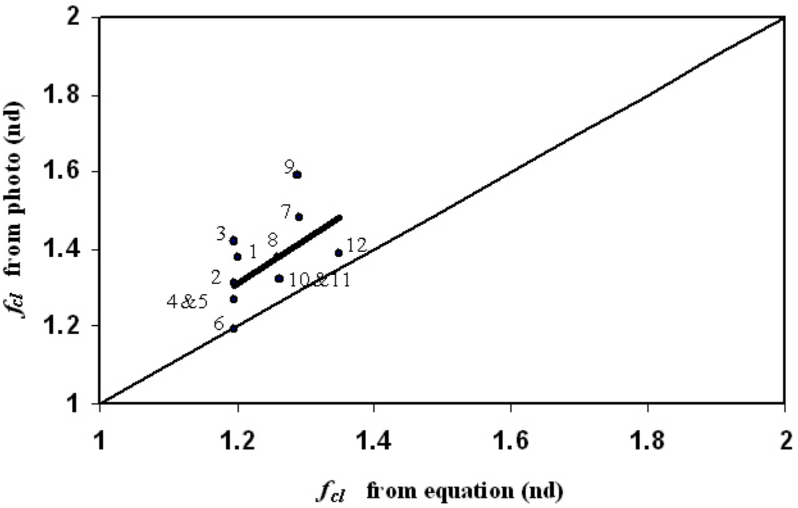

Figure 5.2: Relation between f_{cl} values determined by photographic technique and those from the regression equation. Numbers refer to ensemble number shown in Figure 5.1.

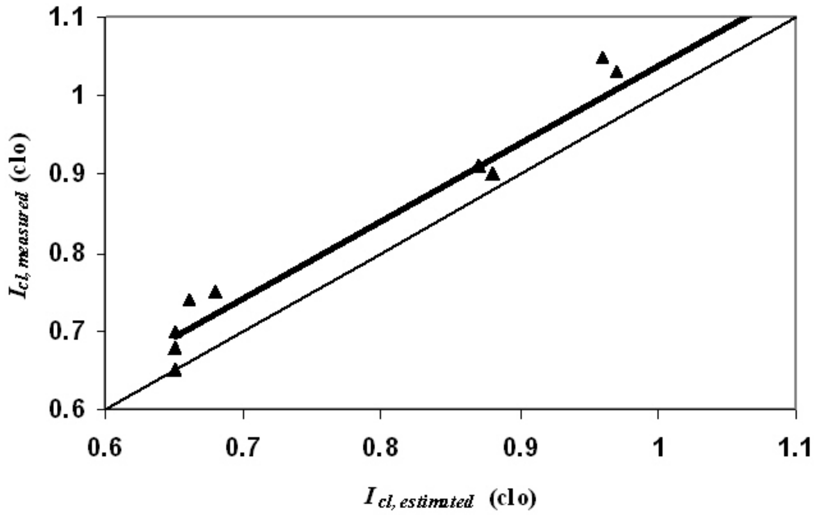

Figure 5.3: Relation between I_{cl} values measured by thermal manikins and those estimated from the regression equation.

5.4.2 Comparison of Schoolwear Clothing Insulation Values: Calculated ($I_{cl,c}$), Measured ($I_{cl, measured}$) and Estimated ($I_{cl,e}$).

The clothing insulation values for Kuwaiti schoolwear in summer and winter, calculated using McCullough *et al.*'s (1985) regression equation with Havenith (2007) corrections, are shown in Table 5.5 for girls and in Table 5.6 for boys. It should be clear in Tables 5.5 and 5.6, that the clothing insulation values are calculated for each classroom grade in consideration to the different student weights of each grade, to satisfy the weight parameter in equation (5.3). It should also be noticed in Table 5.5 for girls, that the clothing insulation values are calculated twice for each classroom grade in the intermediate and secondary academic levels for both summer and winter. This procedure is due to the fact that, in the girls' intermediate and secondary levels, there are two different clothing ensembles, where clothing is a major parameter in equation (5.3).

In these tables, the insulation values ($I_{cl,c}$) for each classroom grade have been compared to the corresponding insulation values as measured on the thermal manikin ($I_{cl,m}$), and as estimated ($I_{cl,e}$), for summer and winter seasons for both genders. The calculated, measured and estimated clothing insulation values, for summer and winter, are also plotted in Figure 5.4 for girls and in Figure 5.5 for boys.

For the girls' data, Table 5.5 shows an acceptable percentage difference between the calculated, measured and estimated thermal insulation values for the different girls' classroom grades. The average overall percentage differences between $I_{cl,c}$ and $I_{cl,m}$, and between $I_{cl,c}$ and $I_{cl,e}$ values for the girls' classroom grades are 4% and 2% for summer clothing, and 4% and 4% for winter clothing, respectively.

Table 5.6 shows that the average overall percentage differences between $I_{cl,c}$ and $I_{cl,m}$, and between $I_{cl,c}$ and $I_{cl,e}$ values for the different boys' classroom grades is about 2% for both summer and winter clothing. Results in Tables 5.5 and 5.6 show similar average insulation values with slight variations in the clothing thermal insulation values within each age group for each academic level for both boys' and girls' groups. This can be explained by the same ensemble types worn by each gender in each academic level which results in similar covered body areas (BSA_0 and $BSAC_1$) - these will provide similar insulation values corrected by clothing weight. The average $I_{cl,c}$; $I_{cl,m}$ and $I_{cl,e}$ values for winter and summer scholar clothing for both boys and girls are in agreement with Al-Rashidi *et al.* (2009a, b and 2010) findings.

Table 5.5: Comparison between the girl's clothing insulation value ($\boldsymbol{I}_{cl}$) by adapted data using McCullough *et al*. (1985) regression equation, the measured using thermal manikin, adult size and the estimated values for summer and winter codes for all classroom grades.

							Summer clothing codes										Winter clothing codes									
A.L.	G	Age (yr)	Weight (kg)	Height (m)	A_{Du} (m^2)	$1.8/A_{Du}$	E.T	W (g)	W_{corr} (g)	BSA_o (%)	$BSAC_1$ (%)	$I_{cl,c}$ (clo)	$I_{cl,m}$ (clo)	$I_{cl,e}$ (clo)	Dif_1. (%)	Dif_2. (%)	E.T	W (g)	W_{corr} (g)	BSA_o (%)	$BSAC_1$ (%)	$I_{cl,c}$ (clo)	$I_{cl,m}$ (clo)	$I_{cl,e}$ (clo)	Dif_1. (%)	Dif_2. (%)
E	1	6	22.4	1.171	0.85	2.11	5	261	551	23.4	38.9	0.66	0.68	0.65	2.9	1.5	11	483	1019	12.6	21.0	0.96	0.90	0.88	6.7	9.1
E	2	7	25.7	1.226	0.93	1.94	5	307	596	23.4	38.9	0.67	0.68	0.65	1.5	3.1	11	532	1032	12.6	21.0	0.96	0.90	0.88	6.7	9.1
E	3	8	29.8	1.286	1.03	1.75	5	342	599	23.4	38.9	0.67	0.68	0.65	1.5	3.1	11	570	998	12.6	21.0	0.96	0.90	0.88	6.7	9.1
E	4	9	33.4	1.323	1.11	1.62	5	375	608	23.4	38.9	0.67	0.68	0.65	1.5	3.1	11	623	1009	12.6	21.0	0.96	0.90	0.88	6.7	9.1
E	5	10	39.1	1.397	1.25	1.46	5	411	600	23.4	38.9	0.67	0.68	0.65	1.5	3.1	11	651	951	12.6	21.0	0.94	0.90	0.88	4.4	6.8
I	6	11	45.3	1.467	1.35	1.33	4	450	598	23.4	38.9	0.67	0.68	0.65	1.5	3.1	10	761	1012	23.4	19.2	0.88	0.90	0.88	2.2	0.0
I	6	11	45.3	1.467	1.35	1.33	3	499	664	10.5	41.4	0.79	0.74	0.82	6.8	3.7	9	851	1132	10.5	24.0	0.99	1.05	0.96	6.1	3.1
I	7	12	50.2	1.518	1.44	1.25	4	486	608	23.4	38.9	0.67	0.68	0.65	1.5	3.1	10	822	1028	23.4	19.2	0.88	0.90	0.88	2.2	0.0
I	7	12	50.2	1.518	1.44	1.25	3	532	665	10.5	41.4	0.79	0.74	0.82	6.8	3.7	9	910	1138	10.5	24.0	1.00	1.05	0.96	5.0	4.2
I	8	13	56.0	1.538	1.53	1.19	4	513	610	23.4	38.9	0.67	0.68	0.65	1.5	3.1	10	868	1033	23.4	19.2	0.88	0.90	0.88	2.2	0.0
I	8	13	56.0	1.538	1.53	1.19	3	560	667	10.5	41.4	0.79	0.74	0.82	6.8	3.7	9	964	1147	10.5	24.0	1.00	1.05	0.96	5.0	4.2
I	9	14	56.6	1.556	1.55	1.16	4	520	603	23.4	38.9	0.67	0.68	0.65	1.5	3.1	10	879	1020	23.4	19.2	0.88	0.90	0.88	2.2	0.0
I	9	14	56.6	1.556	1.55	1.16	3	563	653	10.5	41.4	0.79	0.74	0.82	6.8	3.7	9	973	1129	10.5	24.0	0.99	1.05	0.96	6.1	3.1
S	10	15	63.5	1.564	1.63	1.10	2	552	607	23.4	25.4	0.74	0.70	0.74	5.7	0.0	8	939	1033	23.4	19.2	0.88	0.91	0.87	3.3	1.1
S	10	15	63.5	1.564	1.63	1.10	1	586	644	10.5	41.4	0.79	0.75	0.80	5.3	1.3	7	1024	1127	10.5	24.0	0.99	1.03	0.97	4.0	2.1
S	11	16	61.5	1.574	1.62	1.11	2	541	601	23.4	25.4	0.74	0.70	0.74	5.7	0.0	8	927	1029	23.4	19.2	0.88	0.91	0.87	3.3	1.1
S	11	16	61.5	1.574	1.62	1.11	1	589	654	10.5	41.4	0.79	0.75	0.80	5.3	1.3	7	1018	1130	10.5	24.0	0.99	1.03	0.97	4.0	2.1
S	12	17	61.9	1.576	1.62	1.11	2	543	603	23.4	25.4	0.74	0.70	0.74	5.7	0.0	8	927	1029	23.4	19.2	0.88	0.91	0.87	3.3	1.1
S	12	17	61.9	1.576	1.62	1.11	1	589	654	10.5	41.4	0.79	0.75	0.80	5.3	1.3	7	1018	1130	10.5	24.0	0.99	1.03	0.97	4.0	2.1

A.L.: Academic Level (E=Elementary; I=Intermediate; S=Secondary); G: Classroom grade; A_{Du} : Body surface area (m^2); $1.8/A_{Du}$: Scaled factor for body surface area proposed by Havenith (2007); E.T: Ensemble Type as shown in Table 5.2 and Figure 5.1; W: Actual clothing weight (g); W_{corr}: Corrected clothing weight proposed by Havenith (2007) (g); BSA_0: Body surface area nude (%); $BSAC_1$: Body surface area covered by one layer of clothing (%); $\boldsymbol{I}_{cl,c}$: The thermal insulation value calculated from McCullough *et al*. (1985) regressed equation (clo); $\boldsymbol{I}_{cl,m}$: The actual measured thermal insulation value using thermal manikins; $\boldsymbol{I}_{cl,e}$: The estimated thermal insulation value from the standard tables (clo); Dif_1.: The percentage of difference between calculated and the measured insulation values (%); and Dif_2.: The percentage of difference between calculated and the estimated insulation values (%).

Table 5.6: Comparison between the boy's clothing insulation value (**I_{cl}**) by adapted data using McCullough *et al*. (1985) regression equation, the measured using thermal manikin, adult size and the estimated values for summer and winter codes for all classroom grades.

							Summer clothing codes										Winter clothing codes									
A.L.	G	Age (yr)	Weight (kg)	Height (m)	A_{Du} (m^2)	1.8/A_{Du}	E.T	*W* (g)	W_{corr} (g)	BSA_o (%)	$BSAC_1$ (%)	$I_{cl,c}$ (clo)	$I_{cl,m}$ (clo)	$I_{cl,e}$ (clo)	Dif_1. (%)	Dif_2. (%)	E.T	*W* (g)	W_{corr} (g)	BSA_o (%)	$BSAC_1$ (%)	$I_{cl,c}$ (clo)	$I_{cl,m}$ (clo)	$I_{cl,e}$ (clo)	Dif_1. (%)	Dif_2. (%)
E	1	6	22.4	1.176	0.85	2.11	6	361	762	25.8	44.0	0.66	0.65	0.68	1.5	2.9	12	640	1350	12.6	0.00	1.15	1.17	1.13	1.7	1.8
E	2	7	25.8	1.235	0.94	1.91	6	405	774	25.8	44.0	0.67	0.65	0.68	3.1	1.5	12	723	1381	12.6	0.00	1.16	1.17	1.13	0.9	2.7
E	3	8	29.0	1.286	1.01	1.78	6	452	805	25.8	44.0	0.67	0.65	0.68	3.1	1.5	12	763	1374	12.6	0.00	1.16	1.17	1.13	0.9	2.7
E	4	9	32.8	1.329	1.09	1.65	6	490	809	25.8	44.0	0.68	0.65	0.68	4.6	0.0	12	820	1460	12.6	0.00	1.18	1.17	1.13	0.9	4.4
E	5	10	37.8	1.381	1.20	1.50	6	532	798	25.8	44.0	0.67	0.65	0.68	3.1	1.5	12	881	1322	12.6	0.00	1.15	1.17	1.13	1.7	1.8
I	6	11	43.3	1.441	1.31	1.37	6	575	788	25.8	44.0	0.67	0.65	0.68	3.1	1.5	12	948	1299	12.6	0.00	1.14	1.17	1.13	2.6	1.0
I	7	12	48.2	1.445	1.40	1.29	6	621	801	25.8	44.0	0.67	0.65	0.68	3.1	1.5	12	992	1280	12.6	0.00	1.15	1.17	1.13	1.7	1.8
I	8	13	61.0	1.576	1.61	1.12	6	653	731	25.8	44.0	0.66	0.65	0.68	1.5	2.9	12	1090	1221	12.6	0.00	1.12	1.17	1.13	4.3	1.0
I	9	14	62.2	1.633	1.67	1.08	6	673	727	25.8	44.0	0.65	0.65	0.68	0.0	4.4	12	1252	1352	12.6	0.00	1.15	1.17	1.13	1.1	1.8
S	10	15	67.2	1.673	1.75	1.03	6	711	732	25.8	44.0	0.66	0.65	0.68	1.5	2.9	12	1355	1396	12.6	0.00	1.16	1.17	1.13	0.9	2.7
S	11	16	72.3	1.698	1.83	0.98	6	733	718	25.8	44.0	0.65	0.65	0.68	0.0	4.4	12	1401	1373	12.6	0.00	1.16	1.17	1.13	-0.9	2.7
S	12	17	74.8	1.713	1.87	0.96	6	740	710	25.8	44.0	0.65	0.65	0.68	0.0	4.4	12	1422	1365	12.6	0.00	1.16	1.17	1.13	-0.9	2.7

A.L.: Academic Level (E=Elementary; I=Intermediate; S=Secondary); G: Classroom grade; A_{Du} : Body surface area (m^2); 1.8/A_{Du} : Scaled factor for body surface area proposed by Havenith (2007); E.T: Ensemble Type as shown in Table 5.2 and Figure 5.1; *W*: Actual clothing weight (g); W_{corr}: Corrected clothing weight proposed by Havenith (2007) (g); BSA_0: Body surface area nude (%); $BSAC_1$: Body surface area covered by one layer of clothing (%); **$I_{cl,c}$**: The thermal insulation value calculated from McCullough *et al*. (1985) regressed equation (clo); **$I_{cl,m}$**: The actual measured thermal insulation value using thermal manikins; **$I_{cl,e}$**: The estimated thermal insulation value from the standard tables (clo); Dif_1.: The percentage of difference between calculated and the measured insulation values (%); and Dif_2.: The percentage of difference between calculated and the estimated insulation values (%).

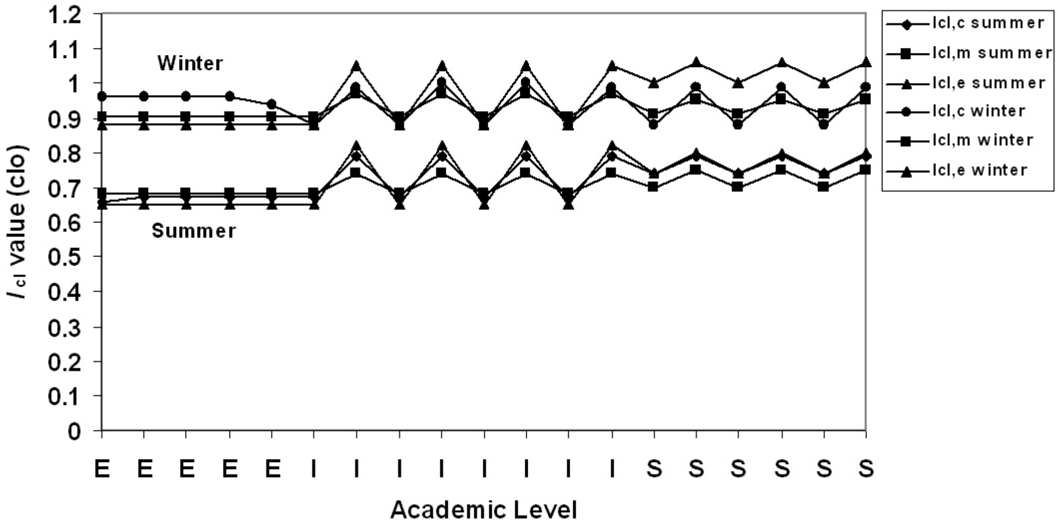

Figure 5.4: Comparison between the $I_{cl,c}$; $I_{cl,m}$ and $I_{cl,e}$ values using the three methods for the different girls' classrooms grades for summer and winter seasons (Academic levels are in accordance with Table 5.5)

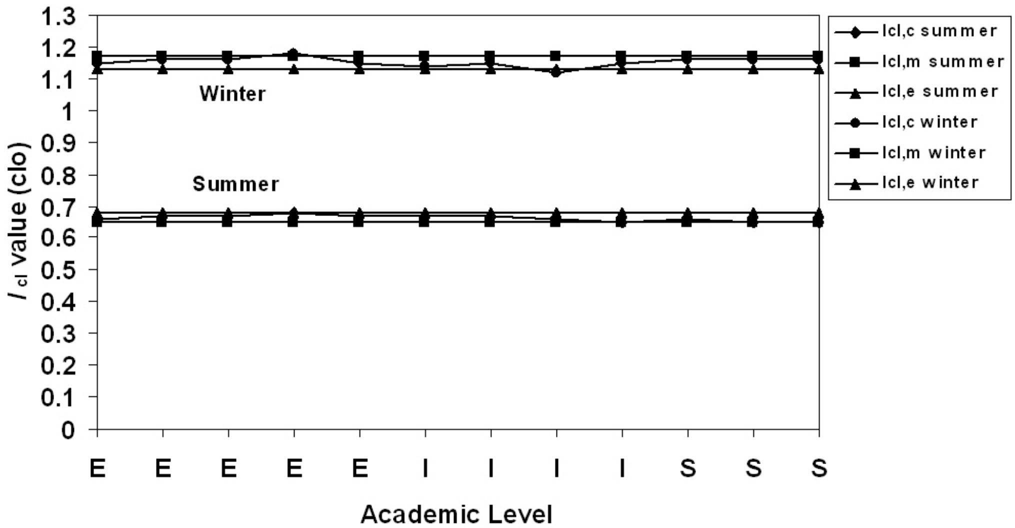

Figure 5.5: Comparison between the $I_{cl,c}$; $I_{cl,m}$ and $I_{cl,e}$ values using the three methods for the different boys' classrooms grades for summer and winter seasons (Academic levels are in accordance with Table 5.6)

The McCullough *et al.* (1985) regression equation with Havenith (2007) corrections gives better estimations than that of the normal McCullough *et al*. (1985) regression equation for estimating children's clothing insulation values.

Considering the relationship between the clothing insulation value and the predicted subjective thermal sensation, ASHRAE (2009) states that an increase of 0.1 clo will produce a reduction of 0.6K in the neutral temperature and vice versa, whereas a temperature change of 3K will change the subjective sensation vote by one unit or temperature category. In this study, the values of the $I_{cl,c}$, $I_{cl,m}$ and $I_{cl,e}$ are close to each other and the differences between them is small which, in turn, will not affect the predicted thermal sensation of the subject.

A new procedure has been followed to indicate the temperature rating of an ensemble, which is the lowest environmental temperature for comfort at which the average adult person will have an acceptable level of thermal comfort when using the outdoor product (i.e. ensemble) (McCullough *et al.* 2009). This was applied for the different schoolwear ensembles used in Kuwait classrooms. These data are shown in Table 5.7 for the different schoolwear ensembles used in the different academic levels in Kuwait. The average $I_{cl,c}$ values for all classroom grades are 0.72 clo and 0.94 clo for girls, and 0.66 clo and 1.15 clo for boys, for summer and winter seasons, respectively. The winter (0.94 clo and 1.15 clo) and summer (0.72 clo and 0.66 clo) data in Tables 5.5 and 5.6 for girls and boys are in agreement with Al-Rashidi *et al.* (2009a, b and 2010) findings for different classroom ventilation modes for children age ranges from 11-17 years. The neutral temperature (according to the children's votes) is found to be 21.6^{o}C for girls and 23.7^{o}C for boys. These are also in agreement with the winter schoolwear data shown in Table 5.7. In addition, the winter data for this study are in agreement with the Havenith (2007) findings for free choice clothing which is the only data available for measuring and adapting the clothing insulation of school children.

The results of this study gave reasonable evidence that the existing data on adults' sizes in the standard tables could be used for children if the ensembles are accurately and carefully selected.

Finally, from Tables 5.5 and 5.6, it is clear that the children's sizes and body surface areas, from 13-17 years old for both genders are close to those for adults, and this is in agreement with the recommendation of McCullough *et al.* (2009). This gives more confidence to use the existing standard data. These changes may be related to the secular changes taking place in the heights and weights of children over the last few decades. This latter point merits further investigation.

Table 5.7: Temperature ratings for the different children's scholar clothing used in Kuwait classrooms – sedentary activity

Scholar Clothing Type	E.N.	I_T (clo)	Temperature Rating (°C)		
			Academic Level		
			Elementary (6-10 y)	Intermediate (11-14 y)	Secondary (15-17 y)
Summer	1	1.23	NU	NU	20.3
	2	1.20	NU	NU	20.5
	3	1.21	NU	21.2	NU
	4	1.20	NU	21.3	NU
	5	1.20	21.3	NU	NU
	6	1.13	21.7	21.7	20.9
Winter	7	1.48	NU	NU	19.3
	8	1.39	NU	NU	19.8
	9	1.47	NU	20.1	NU
	10	1.40	NU	20.5	NU
	11	1.40	20.5	NU	NU
	12	1.58	19.4	19.4	18.6

E.N.: Ensemble No. as shown in Figure 5.1.; I_T: Total insulation value; y: years and NU: Not Used

5.5 Conclusions

In this study, three methods were used to indicate and compare the thermal insulation values of different schoolwear ensembles as worn by girls and boys in Kuwait classrooms during summer and winter seasons. The different clothing ensembles were measured using adult sized thermal manikins and compared to the adults' data obtained from the standards tables, and to an adapted procedure using a regression equation to fit the children sizes from 6-17 years old. The effect of the insulation values for the different scholars age groups were investigated using the clothing temperature rating technique and compared to the scholars' comfort temperature found in recent field studies. Results from this study suggest that:

- The clothing insulation values found from the measured and adapted data were similar to the adult's data in standards tables for the same summer and winter seasons.
- The temperature ratings of the clothing are close to, and in agreement with, the scholars' comfort temperature.

- An observed secular change in the children's heights and weights over the last few decades suggests that, for adolescents, the body surface areas are similar to those of adults.
- This study gives evidence to support the applicability of using adult data in ASHRAE 55 and ISO 9920 standards to assess the thermal insulation values of different children clothing ensembles, provided that the garments and ensembles material and design are carefully selected.

Chapter 6
Investigating the Applicability of Different Thermal Comfort Models in Kuwait Classrooms under Different Ventilation Modes

6.1 Chapter Summary

Using the questionnaire developed in chapter 4, and the clothing insulation data determined in chapter 5, the applicability of different models to predict thermal comfort in Kuwait classrooms during the academic year and under different ventilation modes was investigated via a field study, to assess the thermal conditions during the school day. The distribution of the classrooms throughout the different academic levels of the girls' and the boys' schools in Kuwait at all academic levels, offered a wide range of conditions to investigate the differences in thermal comfort sensations between different age groups (6-10 and 11-17 years old) during the different ventilation modes (hybrid, natural and air-conditioned).

The newly designed thermal comfort questionnaire was used to collect responses from students of 6 to 17 years old, whilst measuring the thermal comfort variables at the same time. Results have shown all the investigated thermal comfort indices to predict higher neutral temperatures than that determined from the students' actual mean votes (AMV) for both age groups. No significant difference was found in the yearly average neutral temperature between both age groups during the different ventilation modes.

The study showed the students' yearly average neutral temperature under different ventilation modes to be in agreement with the indoor design temperature set by the Kuwait government. The yearly average comfort zone for Kuwaiti students, according to their actual mean votes (AMV), has been shown to have an operative temperature range from 20.8°C - 23.8°C, while this range of thermal comfort is also in agreement with Kuwait's Energy Code.

The yearly average preferred temperature for Kuwaiti students is 1.6°C lower than their neutral temperature. This difference suggests that the neutral thermal sensations do not always represent the ideal thermal state of occupants. Providing temperatures that are preferred by the students, to meet their preferred thermal comfort conditions, could increase the energy consumption inside Kuwait classrooms. This point must further be studied in the future to investigate the effects of increasing the cooling loads and energy consumption on the student's learning performance, health and productivity. In addition, achieving preferred conditions via lower-carbon means should accompany any such decision to meet increased cooling loads.

6.2 Introduction

6.2.1 Research Background

Kuwait is a hot and dry country, where during summer the temperature can reach 48°C (July and August) in the afternoon and sometimes exceeds 55°C, Figure 6.1. Furthermore, Kuwait has a desert climate which is characterized by the high percentage of sunshine, wide diurnal temperature extremes and little rainfall with an average summer relative humidity of about 18%, (MD, 2004).

Therefore, most buildings extensively use air-conditioning systems during summer, while in winter the weather is cold and dry and the air conditioning systems are not in use. Since the beginning of 1990's, the school buildings in Kuwait were extensively constructed or renovated. Air-conditioning systems were installed in those buildings to provide comfortable thermal conditions. The control of those systems is not under the direct control of the students, and this may have a negative effect on the student comfort in the classroom.

The question of thermal conditions in classrooms has to be seriously considered because students are still physically developing. For example, poor thermal conditions could affect the students' health and may indirectly affect their learning and performance – this may have detrimental consequences on them and society in the future.

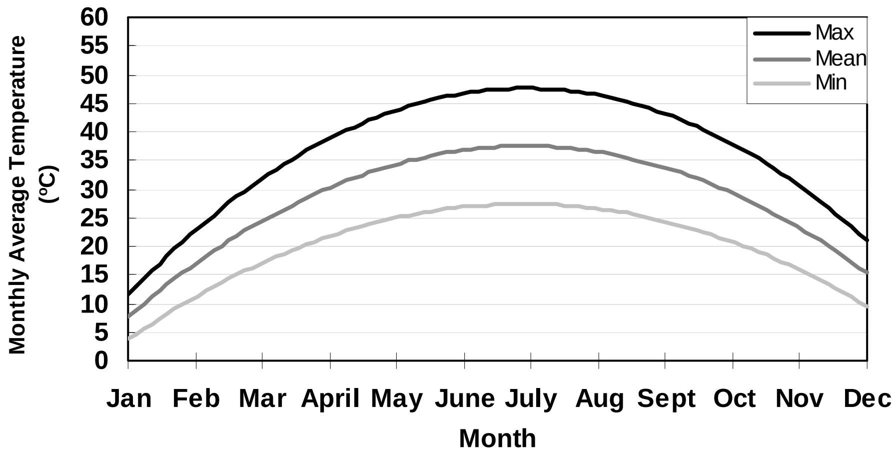

Figure 6.2: The average maximum, mean and minimum monthly temperature for Kuwait, [MD, 2004]

In Kuwait, the girls' schools are separate from the boys' schools at all academic levels, which are structured as follows: elementary level which consists of five classroom grades from the 1st class to the 5th class and the students' ages ranges from 6-10 years; intermediate level which consists of 4 classroom grades from the 6th class to the 9th class and the students ages ranges from 11-14 years; and secondary level which consists of 3 classroom grades from the 10th class to the 12th class and the students' ages ranges from 15-17 years. Students with ages 6-10 years old (elementary level) occupied about 42% of the total number of classrooms in Kuwait (MOE, 2009). Students in Kuwait classrooms have a strict code of scholarly clothing which is imposed by the Ministry of Education in Kuwait (refer to chapter 5).

The main objectives of the study reported here, which apply to students between the ages of 6 to 17 years old are:

- To examine the applicability of different thermal comfort indices (PMV, ePMV, PMV_{10} and adaptive model, and various comfort equations) in a set of Kuwait classrooms under three different ventilation modes; hybrid, natural and air-conditioned ventilation modes, and to determine whether one model is more appropriate than the others for thermal comfort prediction in such situations.
- To determine the neutral temperature (t_n) for both student age groups, 6-10 years and 11-17 years, in the classrooms during different ventilation modes; hybrid, natural and air-conditioned ventilation modes and throughout the whole academic year.
- To compare findings with similar studies conducted elsewhere and reported in the literature.
- To determine the comfort zone for Kuwaiti students on the ASHRAE psychrometric chart.
- To determine the preferred temperature for both student age groups, 6-10 years and 11-17 years, in the classrooms during the different ventilation modes and throughout the whole academic year.
- To investigate the potential impacts of the students' neutral and preferred temperature on energy consumption.

6.2.2 Field Studies on Thermal Comfort in Classrooms

Many field studies and experiments have been conducted in different regions of the world to investigate and understand the effects of the thermal comfort variables on students occupying classrooms in different building types. A summary description of these studies and the corresponding neutral temperature of subjects found in these studies are shown in Table 6.1. It is clear from the table, that all previous studies, which investigated the thermal comfort conditions in classrooms, have their studies conducted in sub-tropical or tropical environments, except for Al-Rashidi *et al*. (2009a, b and 2010).

Table 6.1: Classrooms Thermal Comfort Research Conducted for Different Regions

Researcher & Published Year	Subjects' Ages (years)	Study Location	Climatic Region	Study Period	Classrooms Ventilation Type*	Neutral Temperature t_n (°C)
Kwok, 1998	15-18	Hawaii, USA	Tropical	Sept-Oct.,1996 Jan., 1997	NV & A/C	26.8 in NV 27.4 in A/C
Xavier and Lamberts, 2000	15-18	Florianopolis–Santa Catarina, Brazil	Tropical	April-Dec., 1997	NV	23.1
Cheong *et al.*, 2003	18+	Singapore	Tropical	12th Oct., 1999	A/C	25.8
Wong and Khoo, 2003	13-18	Singapore	Tropical	21st and 24th August, 2001	NV	28.8
Ahmad and Ibrahim, 2003	18+	Shah Alam, Malaysia	Tropical	16th and 17th January, 2002	FV & A/C	27.6 in NV 26.5 in A/C
Kwok and Chun, 2003	13-15	Tokyo, Japan	Sub-Tropical	Sept., 2000	NV & A/C	27.5 in NV 23.1 in A/C
Hwang *et al.*, 2006	18+	Center and South Taiwan	Sub-Tropical		NV&A/C	26.3
Al-Rashidi *et al.*, 2009a	11-17	Kuwait	Hot and Dry	Nov.,2005	Hybrid	21.5
Al-Rashidi *et al.*, 2009b	11-17	Kuwait	Hot and Dry	February, 2006	NV	21.6
Al-Rashidi *et al.*, 2010	11-17	Kuwait	Hot and Dry	May, 2006	A/C	23.7

* NV: Natural Ventilation; A/C: Air-Conditioning; FV: Fan Ventilation; Hybrid: Air-Conditioning system is turned on and off during different parts of the day.

Al-Rashidi *et al*. (2009a, b and 2010) are among the few studies, if any, that have been carried out to investigate the effect of the gender differences on the subjects' thermal perception in classrooms located in hot and dry climatic regions like that of Kuwait. The subjects' ages in these studies are from 11-17 years old, but in this part of this thesis the consideration was given to investigate the effect of the age differences on the subjects' thermal sensation using two subject age groups, younger subjects 6-10 years old and older subjects 11-17 years old. The thermal sensations of female and male students were combined in all of the previous studies, except that of Al-Rashidi *et al*. (2009a, b and 2010), whereas the separation of the genders into separate classrooms, that is the practice in Kuwait, gave a new advantage of investigating the thermal sensations of each gender separately.

6.3 Methodology

6.3.1 Timing and Structure of the Study

The academic year in Kuwait schools runs from October to June. This field study has been conducted in November, 2005 and February and May, 2006 to represent the different climatic periods in a set of classrooms within the academic year, where three different modes of ventilation (hybrid; natural and air-conditioned) are found inside the classrooms. The hybrid ventilation mode is seen during November, where this period represents the end of the hot season and the beginning of the cold season. The weather in November is considered as thermally fluctuating and some of the classrooms are still using air-conditioning systems. In these classrooms the operation of the air-conditioning systems is considered to be in the 'hybrid mode' where the air-conditioning systems are turned on and off during different parts of the day. The natural ventilation mode is seen in February, where this period in Kuwait is considered to be cold, classroom windows are open and all the classrooms are neither using air-conditioning nor heating systems. The air-conditioned ventilation mode is seen in May, where the weather is hot, classroom windows are kept close and all the classrooms are cooled using air-conditioning systems.

In each ventilation mode the thermal sensations of the younger and older subjects were analysed separately to investigate the differences in thermal sensations between both age groups. A total of seventy two classrooms (36 classrooms for each gender) located in 10 different schools were tested during this study, 24 classrooms in each ventilation mode (12 for each gender) representing the different academic levels (elementary, intermediate and secondary levels) in Kuwait. The students in Kuwait have limited and restricted scholar clothing codes in summer and winter seasons. From November to March, the students wear the winter school dress code, while from April to June, the students wear the summer school dress code and these are different for girls and boys. The description of the different scholar clothing codes worn by each gender and age group for each academic level in Kuwait classrooms and their thermal insulation values for summer and winter seasons were discussed and presented in chapter 5.

6.3.2 Objective Measurements

In this field study, the type 1213 Bruel & Kjaer indoor climate analyser was used to measure the environmental variables (air temperature, air velocity, relative humidity and the mean radiant temperature) during the different ventilation modes. The mean radiant temperature was calculated using Eq. 2.1 in chapter 2 by measuring the plane radiant temperature. The outside weather measurements were collected from closest weather stations to each school via Kuwait Meteorological Department in the General Department of the Civil Aviation.

The measuring equipment was placed in five different locations within each classroom at two different heights above the floor (1.1 m head level and 0.6 m waist level) that represents the occupant's seated level, as recommended by ASHRAE 55 (2004) and ISO 7730 (2005) standards, and with suitable distance from the students. At each position the equipment was turned on 15 minutes before the students entering the classroom and left to run for about 3 minutes before the mean values of the environmental parameters were recorded and averaged every 6 minutes basis time. At the end of the experiment, the measurements of each variable at these five positions were averaged to values that represent the thermal conditions in each classroom. The metabolic rate of the students in the seated position (sedentary activity) was estimated in accordance with ASHRAE 55 and ISO 7730 standards to be equal to 1.2 met.

The average clothing insulation values (clo) for the elementary, intermediate and secondary girls' school dress code are 0.71 clo and 0.96 clo for summer and winter, respectively; while that for the boys are 0.65 clo and 1.17 clo for summer and winter, respectively. The measurements of these different clothing insulation values were described in detail in chapter 5.

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6.3.3 Subjective Assessment

The newly designed thermal comfort questionnaire survey presented in chapter 4 was used in the classrooms to evaluate the students' thermal sensation in the different classroom environments. A sample of 1811 student subjects, with a 1811 responses, 884 girls and 927 boys, in 72 classrooms from the elementary, intermediate and secondary academic levels in 12 different schools were surveyed to assess their thermal comfort sensations in different ventilation modes; hybrid, natural and air-conditioned modes. The younger subjects' (6-10 years old) classrooms represent 42% of the total number of the classrooms occupied by 799 subjects from both genders and represent 44% of the subjects sample size, while the older subjects' (11-17 years old) classrooms represent 58% of the total number of the classrooms occupied by 1012 subjects from both genders and represents 56% of the subjects sample size.

The total votes gathered are equal to 1811 votes. The questionnaire survey was administered simultaneously with the physical measurements in each classroom. The questionnaire was handed to the students 30 minutes after they had entered the classroom to ensure that the students' metabolic rate has settled and reached the recommended sedentary metabolic rate level (1.2 met) and that thermal equilibrium (steady state) was approaching.

6.3.4 Thermal Comfort Indices and Equations Used

The applicability of various thermal comfort indices and equations was tested in this study to assess the applicability of a range of thermal comfort prediction models and which a particular model might be more appropriate to predict the students' thermal sensations in Kuwaiti classrooms during the different ventilation modes (hybrid, natural and air-conditioned). These indices and equations are: the standard predictive mean vote (PMV) established by Fanger (1972); the extended predictive mean vote (ePMV) proposed by Fanger and Toftum (2002); the PMV_{10} proposed by the author of the thesis (described later); the adaptive model established by De Dear and Brager (2002), and Humphreys' (1978) and Auliciems' (1981) equations.

The ePMV model was proposed by Fanger and Toftum (2002) to give better prediction of the actual thermal sensation of occupants in non-air conditioned buildings in warm climates. This new model takes into account the psychological adaption effects and the reduction in the metabolic rate in warmer climates. In this model, Fanger and Toftum suggested that the occupants of non-air-conditioned buildings have a lower expectation toward their thermal environment than those in air-conditioned buildings. An expectancy factor '*e*' was proposed as a multiplication factor to the PMV model to improve its prediction. Table 6.2 shows the ranges and condition of applications of the expectancy factor proposed by Fanger and Toftum (2002).

Table 6.2: Ranges of Expectancy Factor for Non Air-Conditioned Buildings in Warm Climate, (Fanger and Toftum, 2002)

Expectation Level	Building Classification	Expectancy Ranges, e
High	Non air-conditioned building located in regions where air-conditioned building are common, warm periods occurring briefly during the summer.	0.9-1.0
Moderate	Non air-conditioned buildings located in regions with some air-conditioned building, warm summer seasons.	0.7-0.9
Low	Non air-conditioned buildings located in regions with few air-conditioned buildings, warm weather during all seasons.	0.5-0.7

From this table it is clear that the suitable range for '*e*' in Kuwait classrooms, when operated in natural ventilation mode should be 0.9-1.0. A further approach was taken by the author of this study which involved reducing the estimated sedentary metabolic rate used in the PMV model (which was originally based on adults) by 10% in order to fit the children's metabolic rate. This modification was based on findings by Havenith (2007) and Parsons (2003). The modified model presented in this thesis is called PMV_{10}.

6.4 Hybrid Ventilation Mode

The results of the field study conducted in Kuwait classrooms under the hybrid ventilation mode will be discussed in this section of the chapter. A sample total of 601 students (294 females and 307 males) in 4 different schools took part in this part of the study occupied in 24 classrooms (12 girls' and 12 boys' classrooms). The number of younger subjects' age group (6-10 years) from both genders represents 44% (265 subjects) of the sample, where the older age group (11-17 years) represents 56% (336 subjects). The average insulation values of the school wear imposed by the ministry during this ventilation period for each age group is equal 1.01 and 1.06 clo for younger and older subjects, respectively. The detailed description of the children sample is shown in Table 6.3.

This study was conducted during November, 2005, which represents the end of the hot season and the beginning of the cold season. The weather in this period is considered as thermally fluctuating and some of the classrooms are still using air-conditioning systems. In these classrooms, the operation of the air-conditioning systems is considered to be in the 'hybrid mode' where the air-conditioning systems are turned on and off during different parts of the day. Focus was placed on the investigation of age group effects, as opposed to gender effects.

6.4.1 Results and Discussion

Analysis of subjects' votes using the new thermal comfort questionnaire during the hybrid mode

The measured classrooms' thermal conditions, under the hybrid ventilation mode, for both genders in different academic levels (elementary; intermediate and secondary) are shown in Table 6.3. In this table, the actual mean votes , according to the ASHRAE thermal sensation scale, of each age group within the same academic level were combined together to investigate the differences in thermal sensation between the different age groups, 6-10 and 11-17 years old, within the different academic levels. The average of the operative temperature; the air flow speed; the relative humidity were measured and calculated for each academic level for both gender and age groups, where the operative temperature was calculated according to Eq. 2.8 in chapter 2.

Subjects' votes on ASHRAE scale

The occupants' votes for both age groups on thermal perception in all classrooms during this period are shown in Table 6.3 and illustrated in Figures 6.2a and 6.2b with regards to the classrooms indoor temperatures. From figure 6.2a it is clear that most of the classrooms have higher indoor temperatures during this period. The effect of these higher temperatures and the higher clothing insulation values of the strict schoolwears in each classooms, leads most of the subjects to vote toward the warm side of the ASHRAE comfort scale.

Table 6.3: The measured thermal conditions for both age groups in different academic levels under hybrid ventilated environment

Gender	Academic Level	Class Grade	No. of Students	Age (year)	School Dress Code	Vent. Mode	t_o °C	v_a m/s	RH (%)	Mean Votes	(-1,0,+1) Votes (%)	Votes distribution according to ASHRAE scale						
												-3	-2	-1	0	+1	+2	+3
Girls	Elementary	1st - 5th	125	6 – 10	winter	Hybrid	23.01	0.05	41.6	0.43	74.0	0	0	43	20	29	31	2
	Intermediate	6th- 9th	110	11 – 14	winter	Hybrid	24.25	0.13	45.0	1.34	55.5	0	0	4	7	50	46	3
	Secondary	10th-12th	59	15 - 17	winter	Hybrid	22.09	0.09	63.3	0.29	72.9	0	7	6	20	17	7	2
Boys	Elementary	1st - 5th	140	6 – 10	winter	Hybrid	25.00	0.15	33.0	1.17	73.6	0	0	0	15	88	35	2
	Intermediate	6th- 9th	108	11 – 14	winter	Hybrid	23.03	0.16	43.0	0.79	68.5	0	0	17	30	27	27	7
	Secondary	10th-12th	59	15 - 17	winter	Hybrid	21.26	0.10	41.6	0.06	88.1	0	3	18	22	12	4	0
Both	Elementary	1st- 5th	265	6 – 10	winter	Hybrid	24.00	0.10	37.3	0.82	73.6	0	0	43	35	117	66	4
Both	Intermediate and Secondary	6th-12th	336	11 - 17	winter	Hybrid	22.95	0.12	48.2	0.73	68.5	0	10	45	79	106	84	12
All		1st - 12th	601	6 - 17	winter	Hybrid	23.47	0.11	42.8	0.77	70.6	0	10	88	114	223	150	16

Vent. Mode: Ventilation mode; t_o: Classroom operative temperature, °C; v_a: Classroom air flow speed, m/s; RH: Relative humidity, % and (-1, 0 and +1) Votes (%): Votes around the three central points on ASHRAE scale.

Figure 6.2b, shows the percentages of votes around the central points of the ASHRAE scale considering the % distribution of votes in the range -1 to +1, (-1 ‘slightly cool’, 0 ‘neutral’ and +1 ‘slightly warm’), these percentages, as indicated in Table 6.3, are 73.6 % for younger age group (6-10 years) with average classrooms temperatures of 24.0°C, and 68.5 % for older age group (11-17 years) with average classrooms temperatures of 22.95°C. The percentages of votes around the neutral central categories (-1, 0 and +1) for both age groups are close which suggests that the use of the thermal sensation question in the new proposed thermal comfort question in chapter 4, helped the younger children to assess their sensation better as the older subjects. The overall percentage of votes for both age groups around the three central points of the scale during this period is 70.6 % with average classrooms temperature of 23.47°C.

Although there is a high percentage of subjects of both age groups who voted around the three central categories (-1, 0 and +1), it can be noticed that most of the subjects’ votes for both age groups tend to be higher on the warm side (+1, +2 and +3) of the ASHRAE scale, 70.6% and 60.1% for younger and older subjects respectively, than the cool side (-1, -2 and -3). This may be explained by the fact that, due to the fluctuated outside thermal conditions during this period, most of the classrooms had high average operative temperatures in addition to the high to the insulation values of the school wear imposed by the ministry and worn by the subjects during this ventilation period (1.01

and 1.06 clo for younger and older subjects, respectively). This situation has a big effect on the subjects and drives the subjects to feel warmer and discomfort and thus vote toward the warmer side of the scale. Another observation to be made from this figure is that although the voting around neutral categories (-1, 0 and +1) represents the thermally neutral situation, most of the subjects' votes may be centred on the slightly cool (-1) or slightly warm (+1) categories which is slightly away from the neutral situation and the subjects still may feel and express discomfort.

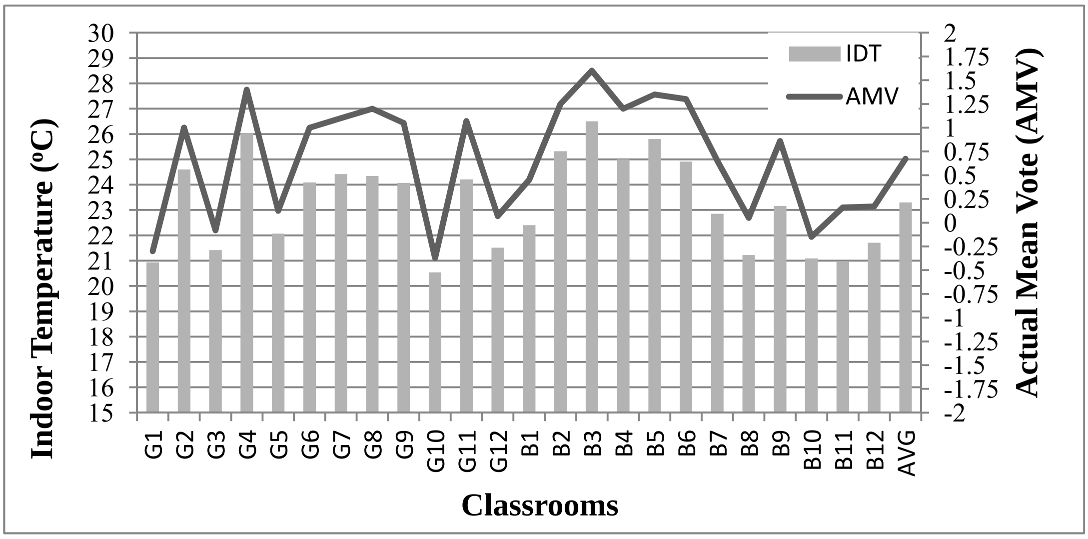

Figure 6.2a: The votes of each classroom occupants and the classroom indoor temperature during the hybrid ventilation mode

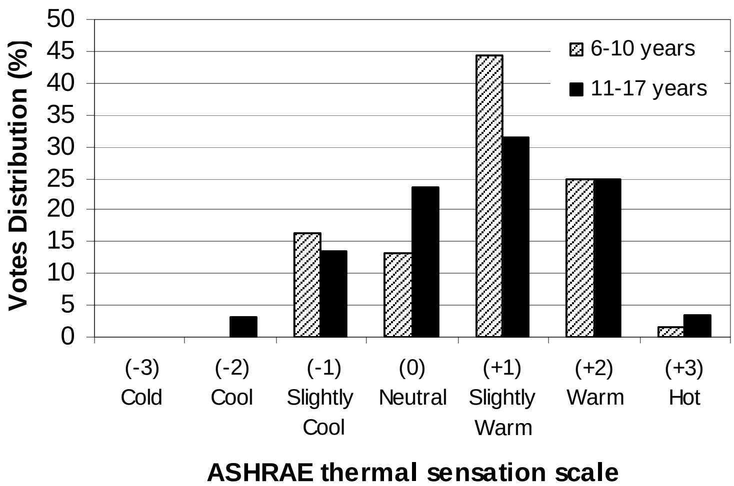

Figure 6.2b: The distribution of the younger and older children actual votes along the ASHRAE Scale during the hybrid ventilation mode

Subjects' comfort level

The subjects' thermal comfort votes toward the existing classroom thermal conditions using the comfort question "do you feel thermally comfortable now", is shown in Figure 6.3 for both age groups in all classrooms. The 265 young subjects and 336 old subjects answered this question. From Figure 6.3, its clear the distribution of responses of both age groups is almost the same, where 33 % of younger and 35 % of older age groups are feeling comfortable and most of the comfort votes of both age groups were centred around the uncomfortable category (56% and 51% for younger and older subjects respectively) in addition to a significant number of very uncomfortable people. These percentages suggest that there are no differences between both age groups in indicating their thermal comfort level using the previous question. By comparing the subjects' votes on the ASHRAE thermal sensation scale with their responses of the thermal comfort question, Figures 6.2b and 6.3 show that most of the age groups subjects who vote on the warm side of the ASHRAE scale corresponds to the high percentage of votes around the uncomfortable and very uncomfortable categories, despite a high percentage of both age groups voted around the three central categories (-1, 0 and +1). The situation suggested that voting around the central neutral categories (-1, 0 and +1) on the ASHRAE scale doesn't always represents the comfort situation to the subjects.

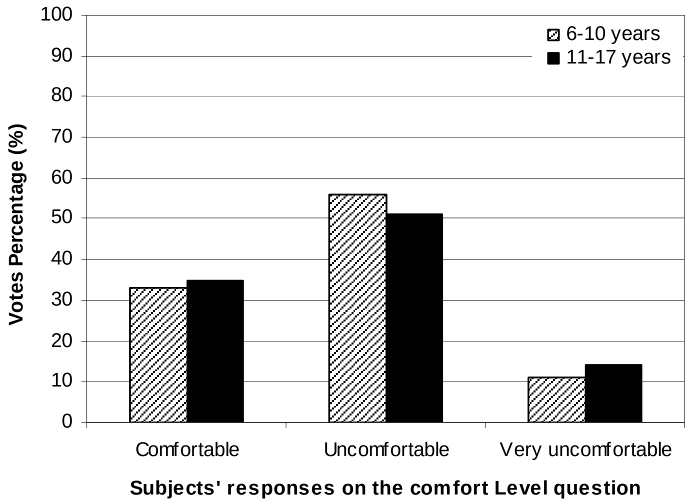

Figure 6.3: The distribution of the younger and older children votes using the thermal comfort level question during the hybrid ventilation mode

Subjects' thermal preferences

The thermal preference voting using the McIntyre preference scale of the different age groups is illustrated in Figure 6.4, where 71 % and 67% of the younger the older subjects want to be cooler than the existing thermal conditions inside the classrooms. By referring to the young and old subject's votes distribution in table 6.3 and Figure 6.2b, it is clear that most of the young and old subject's vote are in the warm side of the ASHRAE scale (+1, +2 and +3). The votes distribution of both younger and older subjects are almost the same on the thermal preferences scale which suggests that both of age groups responds symmetrically to the thermal preference question. The percentages of votes of both age groups are close on the "more cooler" category and almost equal to their percentage of votes on the three central categories (-1, 0 and +1). This can be related to the higher clothing insulation values of the scholarwears for both age groups and the high classrooms indoor temperatures during this period. This situation suggest that people are not always satisfied and comfort with the neutral thermal state, and the neutral state is not always the ideal, optimum or preferred thermal state for the subjects. This finding is in agreement with the findings of the different studies conducted by Kwok, 1998; Wong and Khoo, 2003; Kwok and Chun, 2003; Hwang *et al*., 2006 and Al-Mutawa *et al*. 2004).

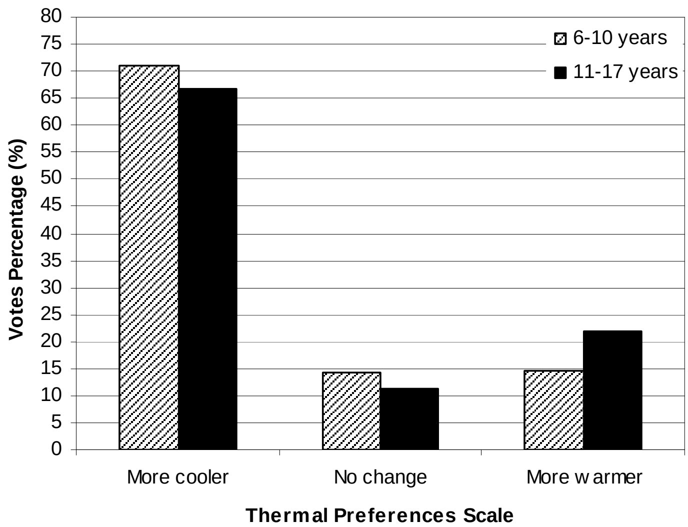

Figure 6.4: The distribution of the younger and older children votes using the McIntyre thermal preferences scale during the hybrid ventilation mode

Subjects' acceptability level

The subjects' responses of the different age groups on the acceptability level question "In general, how do you rate the classroom environment?" toward the classrooms thermal conditions is shown in Figure 6.5. The classrooms conditions were unacceptable for most of both age groups' subjects (72 % and 63% of the younger and the older subjects, respectively). Again, these percentages are almost equal to the percentages of both age groups who voted around the neutral state (i.e. the three central categories, -1, 0 and +1), which may suggests that votes around the three central categories may not necessarily express thermal comfort and subjects who expressing neutral sensations might still consider the thermal neutral state is un acceptable and discomfort for them. The distribution of the responses for both age groups are almost symmetrically, which suggests that there are no differences in the understanding the question between both age groups.

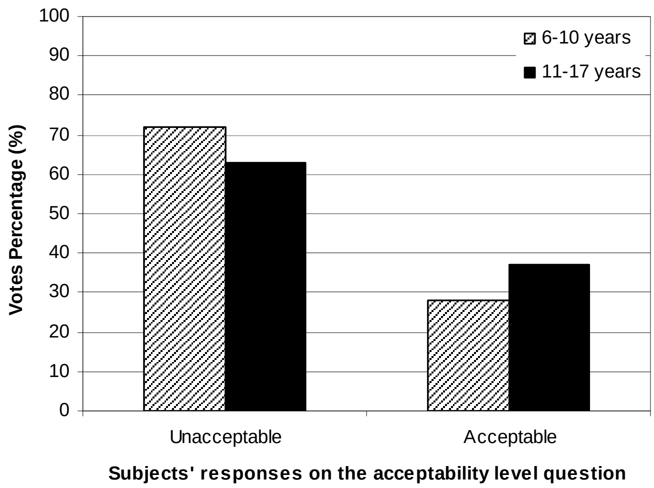

Figure 6.5: The distribution of the younger and older children votes using the acceptability level question during the hybrid ventilation mode

Subjects' votes toward the air flow level

The average air flow speeds of the younger and older classrooms are shown in Table 6.3. Most of the younger and older children's responses toward the air flow level inside the classrooms using the question wording " how do you feel about the air movement in the classrooms?" were agreed together and centred on the "just right" category with an air flow speed of 0.1 and 0.12 m/s for younger and older subjects, respectively. The distribution of the votes confirms that both of the age groups have the same understanding to the question. From Figure 6.6 it can be shown that, 57 % and 68% of the younger and older subjects, respectively, felt that the air flows inside the classrooms is “just right”, while 27% of both of the younger and older subjects felt that the air flow speed inside the classrooms is “Breezy”.

Subjects’ votes toward the relative humidity level

Figure 6.7, shows the distribution of votes for both age groups toward the relative humidity level inside the classrooms during the hybrid ventilation mode period using the humidity level question “How do you feel about the humidity in the classroom”. A slightly difference between the distribution of the different age groups votes among the humidity response scale, where most of the younger and older subjects’ votes were agreed together and centred on the “just right” and “Dry” categories, 84% and 63%, respectively, with average classrooms relative humidity of 37.3%; while the older subjects’ voted around “just right” and “humid” categories with average classrooms relative humidity of 48.2%. The differences may relate to the difference in the average relative humidity levels inside the younger and older subjects’ classrooms, but in general, the vote’s distribution of both age groups shows the same understanding level from both age groups toward the humidity level question used in this study.

In general, and according to the vote’s distribution of both age groups among the different scale of the different thermal question used in this thermal comfort questionnaire, shows that the same level of understanding among both age groups subjects’ to rate the different environmental variables inside the classrooms.

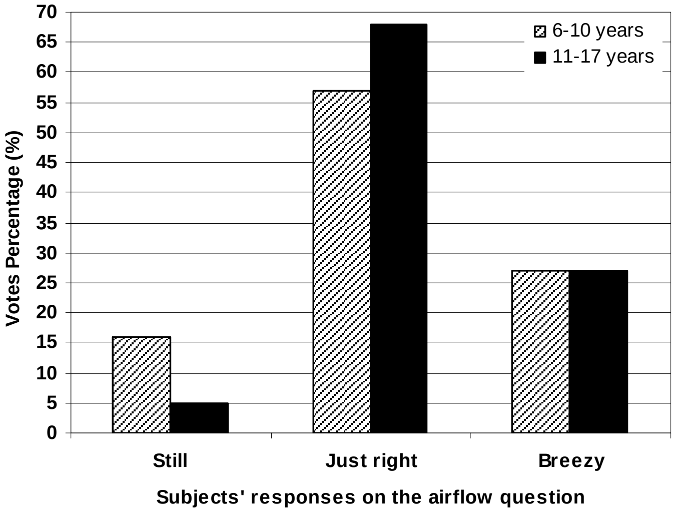

Figure 6.6: The distribution of the younger and older children votes using the airflow question during the hybrid ventilation mode

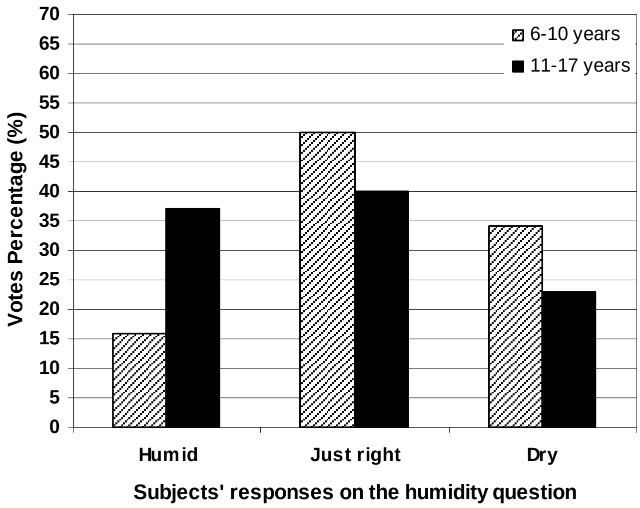

Figure 6.7: The distribution of the younger and older children votes using the humidity question during the hybrid ventilation mode

Applicability of the different thermal comfort indices in Kuwait classrooms during the hybrid mode

During this study, 24 girls' and boys' classrooms (10 classrooms occupied by 6-10 years old subjects and 14 classrooms occupied by 11-17 years old subjects) located in 4 different schools were visited to investigate the applicability of the different thermal comfort indices for prediction of sensation inside Kuwait classrooms. The distribution of the young and older children's on the ASHRAE scale with respect to the classrooms indoor temperatures are shown in Figure 6.8a. The mean subjects' AMV votes and the calculated PMV were averaged for each classroom.

The distribution of the subjects' average actual mean vote (AMV) and the calculated predicted mean vote (PMV) values for each classroom along the ASHRAE thermal sensation scale are shown in Figure 6.8b, where the younger classrooms are from C1 to C10, while the older subjects' classrooms are from C11 to C24. In this Figure it can be seen that, throughout all the classrooms, the PMV model is under predicts the subject's actual mean vote of both age groups on the warm side of the scale (+1, +2 and +3) and over predicts it on the cool side of the scale (-3, -2 and -1). The average AMV and PMV values for all classrooms are equal to 0.74 and 0.39, respectively, with a difference between them equals 0.35 units, which is within the uncertainty bands in PMV prediction ($\pm$0.5) which could be related to the uncertainties in the metabolic rate and clothing insulation values. From the figure it is clear that using the newly proposed thermal comfort questionnaire, chapter 4, helps the younger subjects to assess their thermal sensations better as older age groups.

The PMV and ePMV values for all classrooms (younger and older subjects' classrooms treated separately) were regressed and plotted against the AMV. For younger subjects' classrooms in addition to PMV and ePMV values, other thermal comfort index PMV_{10} was used and plotted against the AMV values to investigate the effect of the reduction in the metabolic rate (10%) on the prediction of the younger age group sensations. This reduction in the metabolic rate was not done to the older subjects according to findings in chapter 5, where in these ages, 11-17 years old, an observed secular change in the children's heights and weights over the last few decades suggests that, for adolescents, the body surface areas are similar to those of adults in present days. The regression lines are shown in Figure 6.9 for the younger age group and Figure 6.10 for the older age group

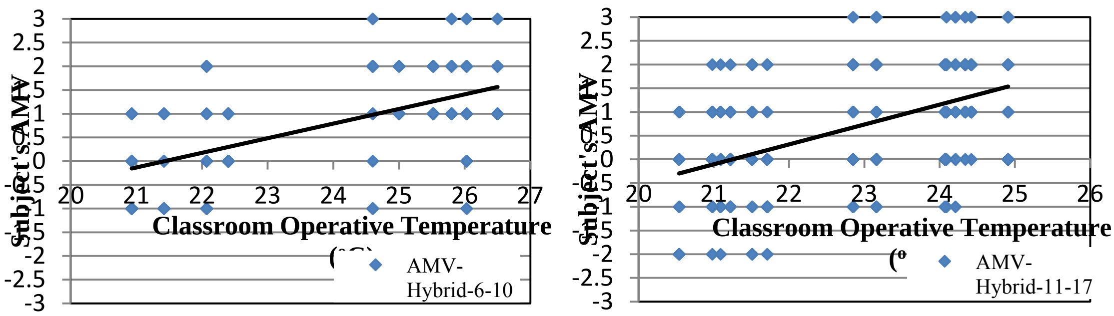

Figure 6.8a: The distribution of the younger and older children's on ASHRAE scale with respect to the classrooms indoor temperatures during the hybrid ventilation mode.

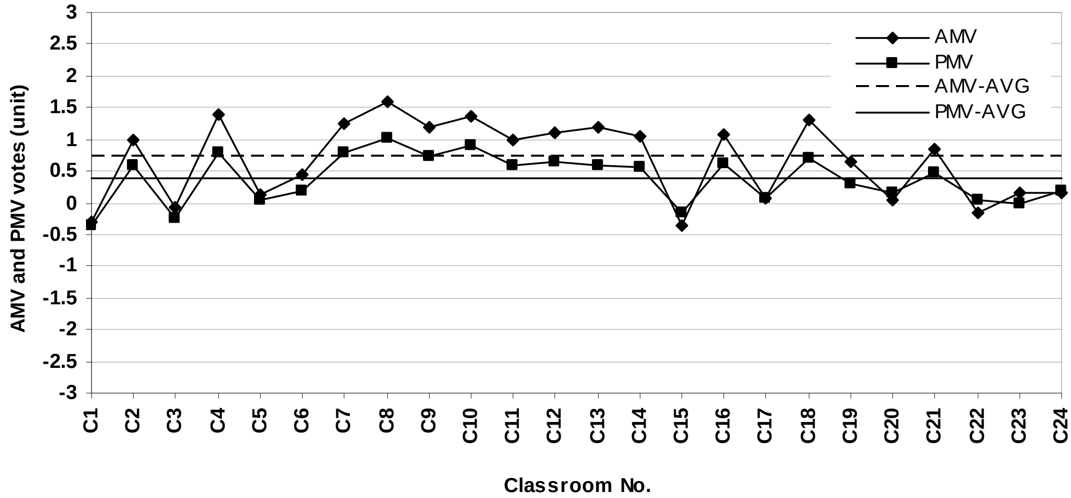

Figure 6.8b: The average values of the younger (C1-C10) and older (C11-C24) children's AMV and the PMV values for each classroom during the hybrid ventilation mode

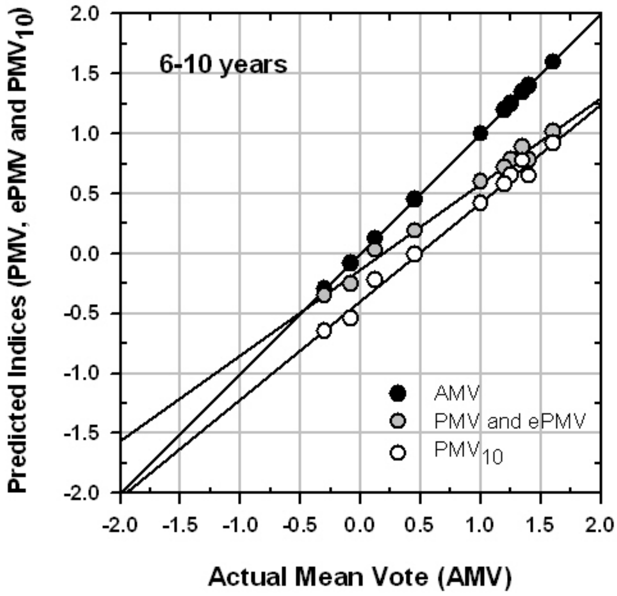

Figure 6.9: The relationship between the younger children (6-10 years) actual mean vote (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during the hybrid ventilation mode

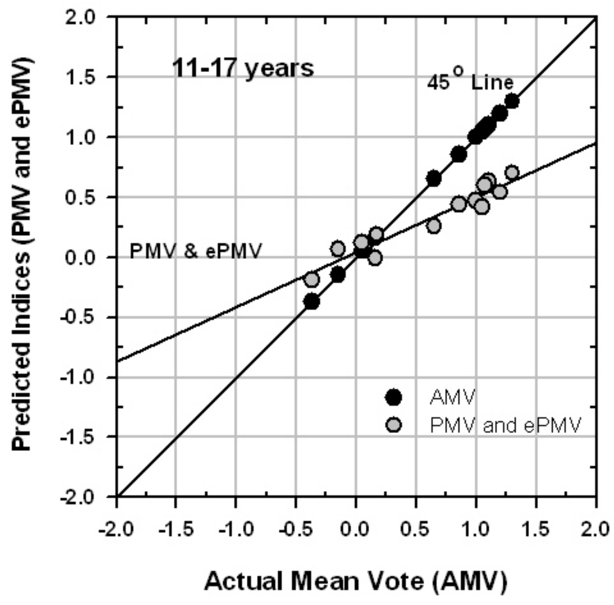

Figure 6.10: The relationship between the older children (11-17 years) actual mean vote (AMV) in all academic levels and the predicted indices (PMV and ePMV) during the hybrid ventilation mode

From these figures it is clear that the PMV and ePMV are identical, due to the high expectancy, refer to Table 6.2, of the subjects in Kuwait classrooms (e = 1), and under-predict the subjects' AMV for the warm side of neutral, and over-predict the AMV for the cold side of neutral. For younger subjects, The PMV_{10} is always under-predicting the students' AMV along the ASHRAE thermal sensation scale. A shift in prediction difference between the younger subjects' PMV_{10} and PMV and ePMV values occur and equal to the effect of the reduction in the metabolic rate, where the shift vanishes on the warm-hot side of the scale.

The prediction differences between the PMV, ePMV models and the AMV according to the regressed lines at the neutral situation for younger and older subjects is equal to -0.25 and + 0.1 units, respectively, where the prediction differences between the PMV_{10} model and the AMV at the neutral situation for younger and subjects is equal to -0.4 units. An important finding can be observed here in this ventilation mode, that at higher temperature the effect of the reduction in the metabolic rate reduction will not affect the subjects' votes prediction and the PMV model works better than the PMV_{10} in predicting the thermal sensations in the among of the ASHRAE scale.

Predicting the neutral temperature

The values of the AMV, PMV, ePMV and PMV_{10} for the younger age group and the values of the AMV, PMV and ePMV for the older age group were regressed and plotted against the operative temperature inside the classrooms as shown in Figure 6.11 and Figure 6.12. In both figures, the intersection of any model line with the zero scale of the y-axis, reads a temperature value on the x-axis, which represents the predicted neutral temperature (t_o) by that model.

From these figures it can be seen that the predicted operative temperatures by the PMV and ePMV prediction models for both age groups are higher (under-predicting) than those based on prediction by the occupants' actual mean votes on the warm side of neutral, and lower (over-predicting) on the cool side of neutral on the ASHRAE scale. For the younger subjects, the PMV_{10} model is always predicts higher (under-predicting) operative temperatures than those based on prediction by the young occupants' actual mean vote and the PMV model. From the figure of younger age group, it is clear PMV ePMV models predicts better neutral temperatures than that predicted by the PMV_{10} in most of the ASHRAE scale. The neutral temperatures resulting from the different thermal comfort indices (PMV, ePMV and PMV10), adaptive model using the De Dear & Brager (2002) equation and various equations are tabulated in Table 6.4.

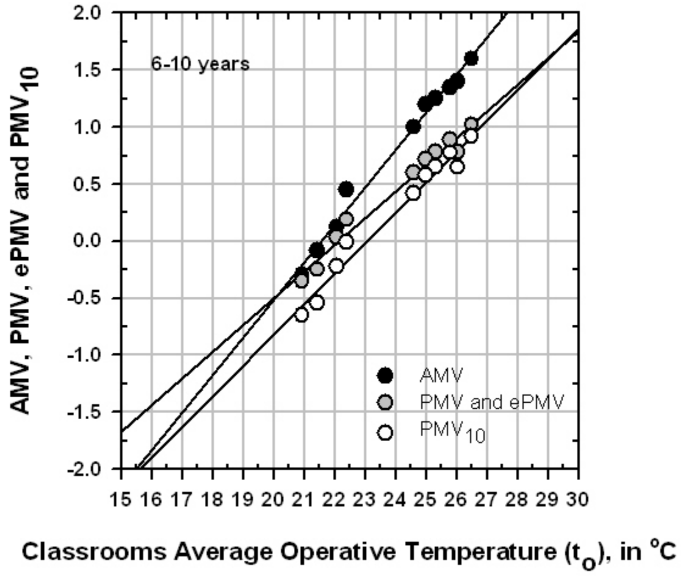

Figure 6.11: The regressed neutral temperature according to the younger children (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during the hybrid ventilation mode

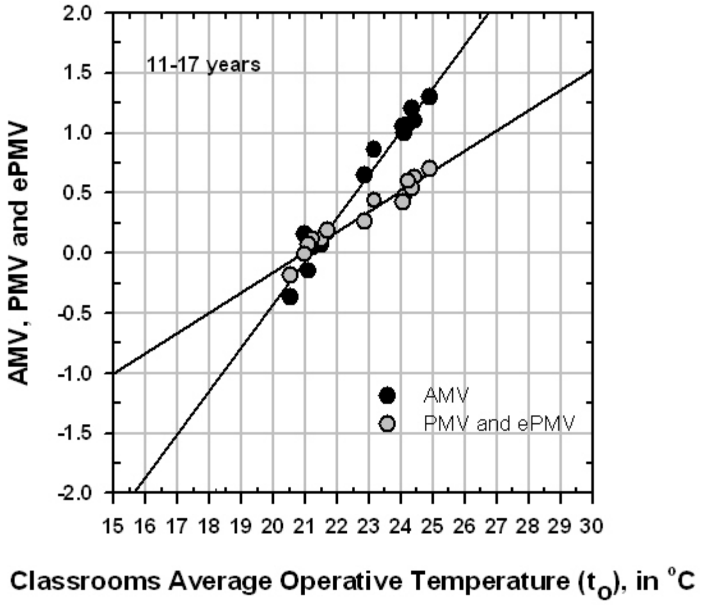

Figure 6.12: The regressed neutral temperature according to the older children (AMV) in all academic levels and the predicted indices (PMV and ePMV) during the hybrid ventilation mode

Table 6.4: Predicted neutral temperatures using the children's mean votes and various thermal comfort indices and equations during the hybrid ventilation mode.

	AMV	PMV	ePMV	PMV_{10}	De Dear & Brager, (2002)	Humphreys, (1978)	Auliciems, (1981)

					NV	NV	
							All
Equation					$17.8+0.31T_{a\ out}$	$11.9+0.543T_m$	$17.6+0.31T_m$
6-10 years	21.5	22.1	22.1	23.5	24.0	22.8	23.8
11-17 years	21.2	21.0	21.0	---	24.0	22.8	23.8
All	21.4	21.6	21.6	---	24.0	22.8	23.8

Where; $T_{a\ out}$ and T_m are the monthly mean outdoor temperature.

From Table 6.4, it is clear that the neutral temperature of both age groups according to their actual votes is almost the same and a small difference of 0.3^{o}C in the neutral temperature was found between the two age groups. This difference may be related to the slightly difference in the clothing insulation values worn by each age group subjects compared to that of the younger in addition to the classrooms different thermal conditions. By combining the votes of younger and older subjects, the average neutral temperature of both age groups is equal to 21.4^{o}C and this value is lower than the average neutral temperature predicted by the PMV and ePMV models by 0.2^{o}C.

Reduction of the younger metabolic rate in this ventilation mode represented by PMV_{10} values, predicted values of 2.0^{o}C higher neutral temperatures than those from the AMV and the normal PMV and the ePMV, respectively. These findings suggested that the metabolic rate of the younger subjects is similar to the older subjects (11+).This may be related to the same findings in chapter 5, where according to the secular change in the children's heights and weights, over the last few decades, results suggest that the metabolic rate of the children are similar to those for adults. This means the modification of reducing the metabolic rate of the adults to suit the younger ages, may not always be a right choice and may results in more inaccurate results.

This point may need more future researches to measure practically the metabolic rate of younger children 6-17 years old. The Humphreys' and Auliciems' equations have under-predicted the neutral temperature for younger and older subjects by 1.4^{o}C and 2.4^{o}C, respectively. The adaptive approach (De Dear and Brager, 2002) gave higher neutral temperatures than that obtained from the AMVs of both subjects (by 2.6^{o}C). At first sight, this might suggest that the PMV and ePMV models are the more appropriate thermal comfort indices to predict the thermal comfort sensations of the children in ages 6-17 years old in Kuwait classroom during this period. This may be attributed to the domination of the air-conditioning system operation periods inside the classrooms, during the period of this study. This might suggest that the classroom environment during this hybrid mode might still be considered as an air-conditioned mode instead of being a naturally-ventilated one, whereas the adaptive approach is more applicable to the naturally ventilated environments.

Finally, the neutral temperature found in this study during this period is lower than that found in previous studies conducted in classrooms in tropical and sub-tropical climates by about 3-5^{o}C, and this can be related to the higher insulation values of school wear used in Kuwait, but in agreement with Al-Rashidi *et al*. (2009a and b) studies where gender differences were investigated.

The subjects' thermal preferences temperature versus the thermal neutrality temperature during the hybrid mode

Throughout the literature review, many researchers followed a procedure by extending the usability of the McIntyre preference scale to find the preferred temperature of a group of subjects beyond the neutral state by plotting the votes of the subject in terms of who wants to be warmer and who wants to be cooler on the McIntyre preference scale against the occupied zone temperature. The neutral temperature is the temperature corresponding with the subject's mean vote of neutral on the ASHRAE thermal sensation scale, whereas the preferred temperature can be defined as the temperature that the subjects want to be feeling other than the neutral temperature.

According to the students' thermal preferences on the McIntyre thermal preference scale discussed in chapter 4, students preferred temperatures cooler than the existing temperatures inside the classroom. To investigate the target or preferred temperature wanted by the younger and older subjects', the percentage of the student's votes who wanted to be cooler and those who wanted to be warmer in each classroom, in accordance with the McIntyre thermal preference used in this period, were regressed and plotted against the classrooms' operative temperatures.

The plots are shown in Figure 6.13 for younger subjects and Figure 6.14 for older subjects, where the intersection between the percentage of student votes who wanted to be warmer and those who wanted to be cooler represents the preferred temperatures by each age group under the hybrid ventilation mode.

From these figures it is clear that the preferred temperatures of the younger and older subjects are close and equal 20.6°C and 20.1°C, respectively. These preferred temperatures are lower than the neutral of both age groups by 1-2°C. This situation suggested that neutral thermal sensations are not always representing the ideal, optimal or preferred thermal state of the occupants (Kwok. 1998; Wong and Khoo, 2003; Kwok and Chun, 2003; Hwang *et al*., 2006 and Al-Mutawa *et al*. 2004).

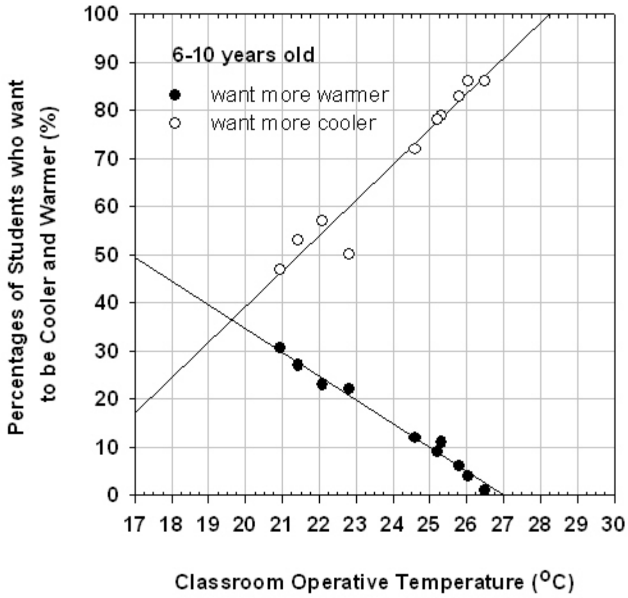

Figure 6.13: The preferred temperature due to the percentage of younger children who want to be cooler and warmer in all academic levels during the hybrid ventilation mode

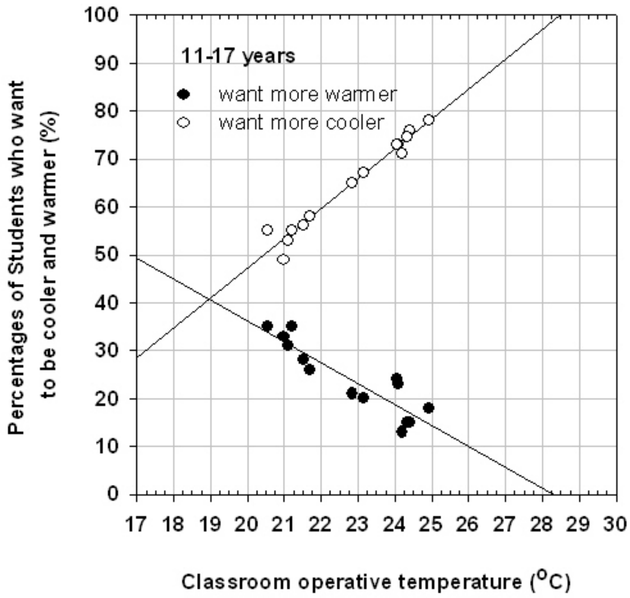

Figure 6.14: The preferred temperature due to the percentage of older children who want to be cooler and warmer in all academic levels during the hybrid ventilation mode

6.4.2 Key points of Hybrid Ventilation Mode

- All the thermal comfort indices investigated in this study under-predicted the younger and older children's actual thermal sensation on the warm side of the ASHRAE scale and over-predicted it on the cool side of the scale.
- The PMV and ePMV indices gave similar results in Kuwait classroom environments where the expectation level of the occupants is high.
- In case of younger children, the PMV ePMV models predicts better neutral temperatures than that predicted by the PMV_{10} in most of the ASHRAE scale.
- The metabolic rate of the younger children (6-10 year) are similar to those for older children (11-17 years old) and adults, due to secular change in the children's heights and weights over the last few decades.
- This finding implies that the modification of reducing the metabolic rate of the adults to suit the younger ages, may not always be a right choice and may results in more inaccurate results, while in the hybrid ventilation mode using the normal PMV model with the adult metabolic rate produce better predicted values.
- The hybrid ventilation mode could be considered as more that of an air-conditioned mode instead of being a naturally-ventilated mode, where the PMV and ePMV

indices, which predicts better the occupants' thermal sensation in air-conditioned spaces, are more appropriate to predict the children thermal sensations in Kuwait classrooms in this period than other thermal comfort indices.

- The neutral temperatures of the younger (6-10 years) and older (11-17 years) subjects are almost the same and equal to 21.5^{o}C and 21.2^{o}C, respectively, with a difference of 0.3^{o}C considered to be the result of the slight difference in clothing ensembles insulation between younger and older pupils.
- The average neutral temperature (21.4^{o}C) for both age groups of pupils during this period is lower than that found in previous studies conducted in classrooms in subtropical or tropical environments. This may be related to the higher insulation values of the school dress codes as worn by the students in Kuwait classrooms during this period than compared with those worn in the studies in the other countries reported, in addition to the differences in climates.
- In this part of the study and during this hybrid ventilation mode, it was noticed that the high insulation of school wear (high clo values) worn by both age groups of subjects in Kuwait classrooms, had an effect on the subject's thermal sensation which may suggests that the Ministry of Education (MOE) in Kuwait to review the school wear code for both genders during this thermal fluctuated period by reducing the amount of clothing wear by the students to provide better comfort conditions for the students in the classrooms.
- The neutral thermal sensations are not always representing the ideal, optimal or preferred thermal state of the children, where they preferred temperatures lower than the neutral temperature by 1-2^{o}C during this ventilation mode.

6.5 Natural Ventilation Mode

Continuing the work of the thermal comfort study inside Kuwait classrooms, investigations were extended for another period that represents the natural ventilation mode in Kuwait classrooms. A total sample of 604 female and male students (295 females and 309 males) took part in this part of the study they occupied 24 classrooms (12 girls and 12 boys classrooms). The number of younger subjects' age group (6-10 years) from both genders represents 45% (271 subjects) of the sample, while the older age group (11-17 years) represents 55% (333 subjects). The average insulation values of the school wear imposed by the ministry during this ventilation period for each age group was equal 1.01 and 1.06 clo for younger and older subjects, respectively. The detailed description of the children sample is shown in Table 6.5. The results of the field study conducted in Kuwait classrooms under the natural ventilation mode will be discussed in this section of the chapter. This study was conducted over the period from 4^{th} to 28^{th} of February, 2006. This period in Kuwait is considered to be a cold season, where all the classrooms are using neither air conditioning nor heating systems.

6.5.1 Results and Discussion

Analysis of subjects' votes using the new thermal comfort questionnaire during the natural mode

The measured thermal conditions, under the natural ventilated environment, for both age groups in different academic levels (elementary; intermediate and secondary) are shown in Table 6.5. Again in this table, the same approach was followed by combining the actual mean votes, according to the ASHRAE thermal sensation scale, of each age group within the same academic level together to focus investigation on the differences in thermal sensation between the different age groups, 6-10 and 11-17 years old, within the different academic levels as opposed to the effects of gender. The average data for the operative temperature; the air flow speed; the relative humidity were measured and calculated for each academic level for both gender and age groups, where the operative temperature was calculated according to Eq. 2.8 in chapter 2.

Subject's votes on ASHRAE scale

The occupants' votes for both age groups on thermal perception in all classrooms during this period are shown in Table 6.5 and illustrated in Figure 6.15a and 6.15b with regards to the classrooms indoor temperatures. From figure 6.15a shows that the classrooms have indoor temperatures during the NV period. The effect of these temperatures and the clothing insulation values of the strict schoolwears in each classooms, leads most of the subjects to vote around the three central points (-1,0 and +1) of the ASHRAE comfort scale.

Figure 6.15b shows the percentages of votes around the three central points of the ASHRAE scale (-1 'slightly cool', 0 'neutral' and +1 'slightly warm'). From Table 6.5, it is clear that the mean votes of the younger subjects is equal to 0.43 where 89.7 % of them voted around the three central categories (-1, 0 and +1) of the ASHRAE scale with average classrooms temperatures of 23.39°C. For the older age group the mean vote was -0.29 and 84.2 % of the older age group (11-17 years) votes around three central categories (-1, 0 and +1) with average classrooms operative temperatures of 19.23°C.

The overall percentage of votes for both age groups around the three central points of the scale during this period is 86.5 % with average classrooms temperature of 21.3°C, where the higher percentage of the younger subject's votes are among the neutral-slightly warm side of the scale categories where most of the older subjects votes are among the slightly cool-neutral categories. This may be explained by the fact that the measurements of the younger subjects, specifically younger girls' data, were collected during warmer operative temperatures that that for the older subjects which were collected in cooler operative temperatures. This situation has a big effect on the subjects and drives the younger subjects' to feel warmer and discomfort and thus vote toward the warmer side of the scale, on the other hand drives the older subjects' to feel cooler and discomfort and thus vote toward the cooler side of the scale. The distribution of the younger and older subjects' votes on the ASHRAE scale suggests are close which suggests that the use of the thermal perception question in the new proposed thermal comfort question in chapter 4, helped the younger children to assess their sensation better as the older subjects, where both age groups understands the meaning of thermal perception question and response to it in the same manner.

Table 6.5: The measured thermal conditions for both age groups in different academic levels under natural ventilated environment

Gender	Academic Level	Class Grade	No. of Students	Age (year)	School Dress Code	Vent. Mode	t_o °C	v_a m/s	RH (%)	Mean Comfort Votes	(-1,0,+1) Votes (%)	Votes distribution according to ASHRAE scale						
												-3	-2	-1	0	+1	+2	+3
Girls	Elementary	1st - 5th	128	6 – 10	winter	NV	25.15	0.07	58.8	0.77	85.9	0	0	13	30	67	12	6
	Intermediate	6th- 9th	110	11 – 14	winter	NV	22.81	0.23	42.3	0.31	87.3	0	0	26	37	33	14	0
	Secondary	10th- 12th	57	15 - 17	winter	NV	19.10	0.21	26.7	-0.56	80.7	1	10	16	24	6	0	0
Boys	Elementary	1st - 5th	143	6 – 10	winter	NV	21.72	0.22	34.8	0.13	93.0	3	7	6	80	47	0	0
	Intermediate	6th- 9th	107	11 – 14	winter	NV	18.69	0.25	26.3	-0.39	87.9	7	6	36	31	27	0	0
	Secondary	10th- 12th	59	15 - 17	winter	NV	16.33	0.31	30.0	-0.91	74.6	6	9	25	12	7	0	0
Both	Elementary	1st- 5th	271	6 – 10	winter	NV	23.39	0.15	46.8	0.43	89.7	3	7	19	110	114	12	6
	Intermediate and Secondary	6th- 12th	333	11 - 17	winter	NV	19.23	0.25	31.3	-0.29	83.4	14	25	103	104	73	14	0
All		1st - 12th	604	6 - 17	winter	NV	21.3	0.20	39.1	0.03	86.6	17	32	122	214	187	26	6

Vent. Mode: Ventilation mode; t_o: Classroom operative temperature, °C; v_a: Classroom air flow speed, m/s; RH: Relative humidity, % and (-1, 0 and +1) Votes (%): Votes around the three central points on ASHRAE scale.

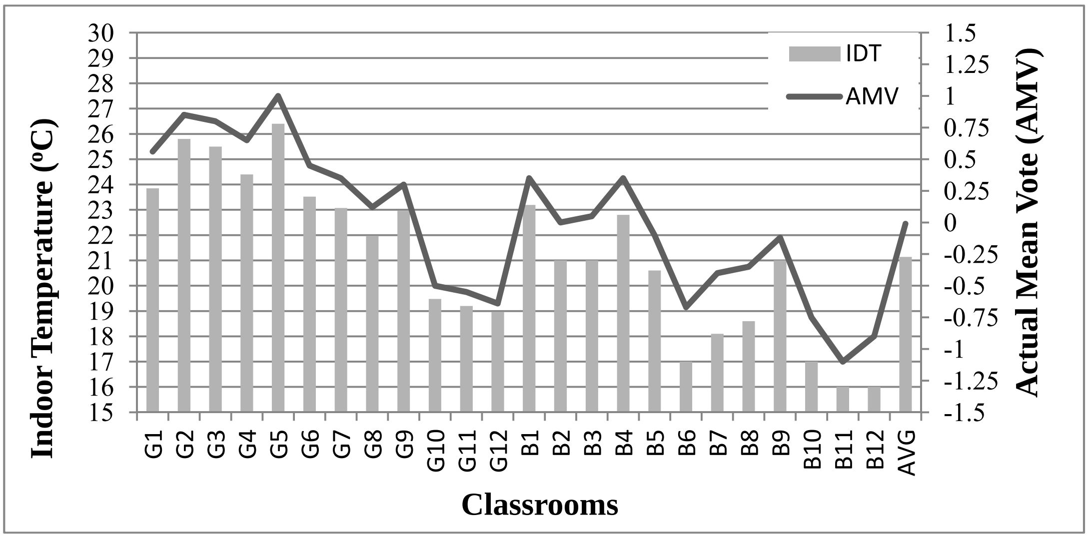

Figure 6.15a: The votes of each classroom occupants and the classroom indoor temperature during the natural ventilation mode.

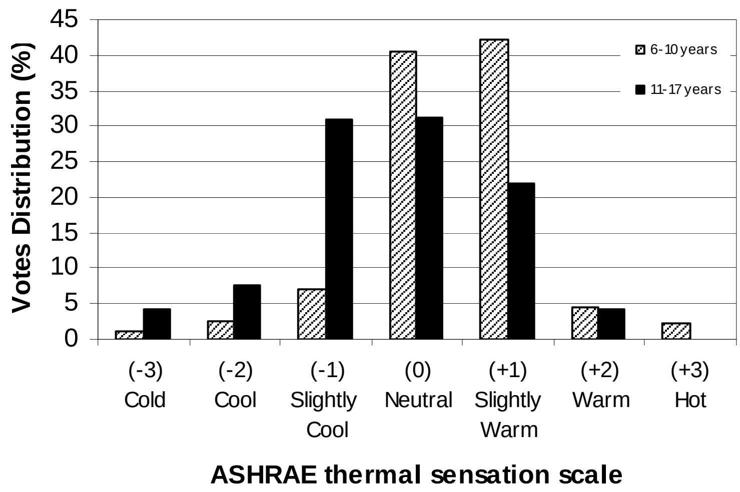

Figure 6.15b: Total percentage of the younger and older children votes versus the ASHRAE comfort scale during the natural ventilation mode

Subjects' comfort level

The subjects' thermal comfort votes toward the existing classroom thermal conditions during this ventilation mode used the same comfort question "do you feel thermally comfortable now" of the new designed thermal comfort questionnaire in chapter 4. The distribution of the subjects' votes in Figure 6.16 show that most of the subjects' votes were around the uncomfortable category of the scale, where 88 % of younger and 85 % of older subjects are feeling uncomfortable toward the exited classrooms' thermal conditions. By comparing the subject's votes on the ASHRAE thermal sensation scale and the comfort scale, Figures 6.15 and 6.16, it is show that most of the age groups subjects who vote on the three central categories (-1, 0 and +1) of the ASHRAE scale corresponds to the high percentage of votes around the uncomfortable categories of the comfort level scale. The situation suggest that there are no differences between both age groups in indicating their thermal comfort level using the previous question that voting around the central neutral categories (-1, 0 and +1) on the ASHRAE scale doesn't always represents the comfort situation to the subjects.

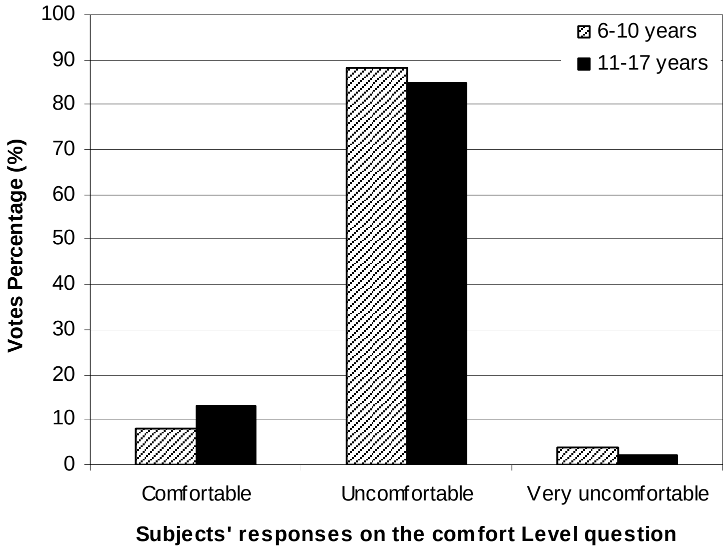

Figure 6.16: The distribution of the younger and older children votes using the thermal comfort level question during the natural ventilation mode

Subjects' thermal preferences

The trend of voting for both age groups on the ASHRAE scale dominant on the student's thermal preferences voting using the McIntyre preference scale, where most of the younger subjects who voted among the neutral-slightly warm side of the ASHRAE scale, voted around the "more cooler" category (64%), this can be related to the higher clothing insulation values of the strict scholarwears for younger age groups and the high classrooms indoor temperatures during this period. Most of the older subjects who voted among the slightly cool-neutral side of the ASHRAE scale, voted around the "more warmer" category (52%), as can be seen in Figure 6.17This can be related to the low indoor temperatures and high speed of the air flow inside their classrooms. The trend of votes distribution of both younger and older subjects on the thermal preferences scale, suggests that both of age groups responds logically to the thermal preference question and there is no difference in the younger and older responses. Again, this situation suggest that people are not always satisfied and comfort with the neutral sensations and the neutral state is not always the ideal, optimum or preferred thermal state for the subjects, which in agreement with the findings of the different studies conducted by Kwok, 1998; Wong and Khoo, 2003; Kwok and Chun, 2003; Hwang *et al*., 2006 and Al-Mutawa *et al*. 2004.

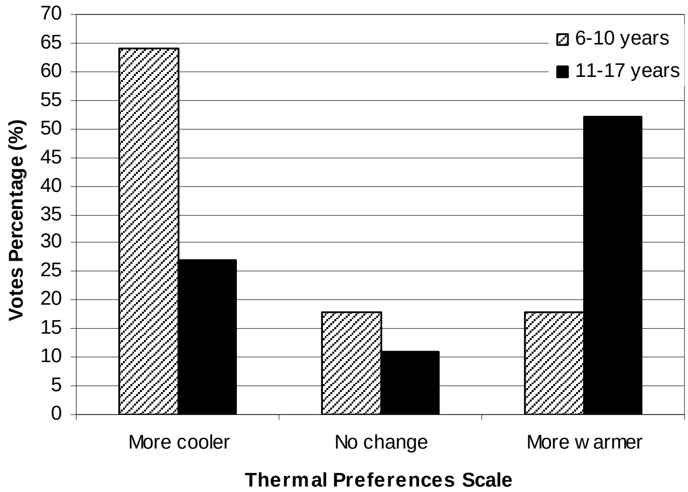

Figure 6.17: The distribution of the younger and older children votes using the McIntyre thermal preference scale during the natural ventilation mode

Subjects' acceptability level

The acceptability level toward the classrooms thermal conditions, using the acceptability level question designed in chapter 4, for the different age groups is shown in Figure 6.18. From the figure it is clear that higher percentage of unacceptable votes from both age groups for the thermal conditions inside the classrooms. 83 % and 79% of the younger and the older subjects, respectively, don't accept their classrooms environmental conditions. Comparing the acceptability voting of both age groups subjects with their thermal sensation and thermal preferences voting it would be accepted that subjects who expressing neutral sensations and preferred states beyond neutrality, can express high percentage of unacceptability level toward their classroom environment. Both the younger and older subjects' votes followed this trend, which implies that there is no difference between the age groups responses to this question, and this difference of voting may related to the different classrooms thermal conditions during the part of the study.

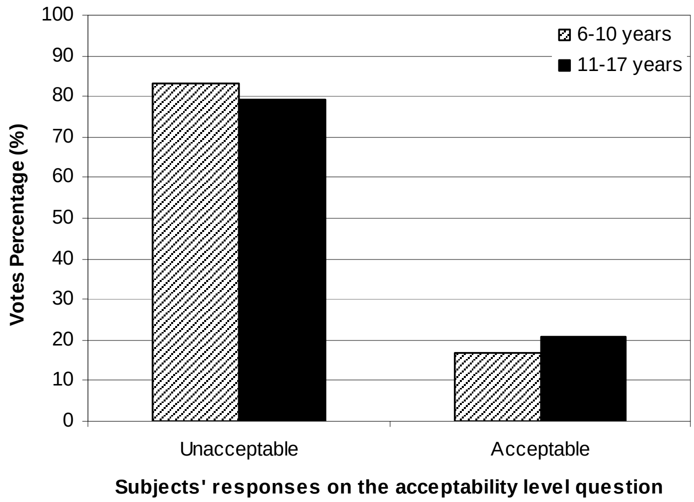

Figure 6.18: The distribution of the younger and older children votes using the acceptability level question scale during the natural ventilation mode

Subjects' votes toward the air flow level

The younger and older children's responses toward the air flow level inside the classrooms, Table 6.6, using the question wording "how do you feel about the air movement in the classrooms?", can be seen in Figure 6.19. While most of the younger subjects' felt that the average 0.15 m/s air flow inside their classrooms is "just right", most of the older subjects voted the average 0.25 m/s air flow inside their classrooms to be "Breezy". The difference of voting between both the younger and older subjects' may related to different thermal conditions existed inside the younger and older subjects' classrooms during this part of study, which implies there is no difference between the age groups responses to this question.

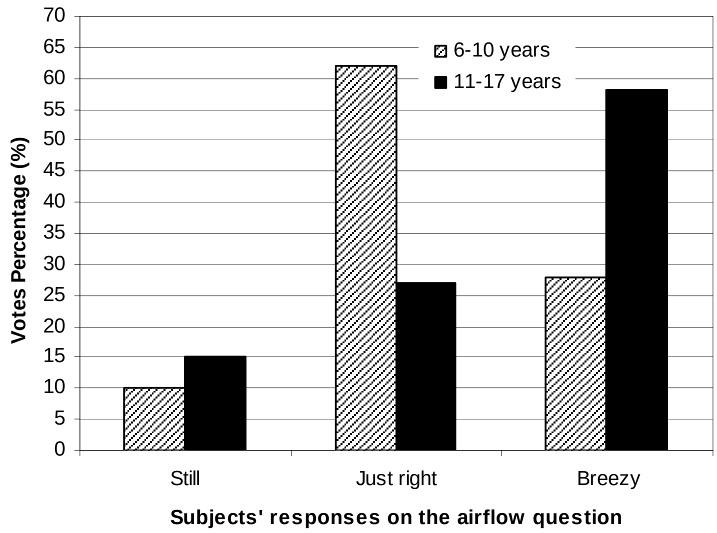

Figure 6.19: The distribution of the younger and older children votes using the air flow question scale during the natural ventilation mode

Subjects' votes toward the relative humidity level

From Table 6.5 and as shown in Figure 6.20, during the natural ventilation mode, most the votes distribution of both younger and older age groups toward the relative humidity level inside the classrooms were agreed together and centred on the " just right" and " Dry" categories. Subjects used the same relative humidity question "How do you feel about the humidity in the classroom". A slightly difference occurs between the distribution of the different age groups votes among the humidity response scale, where the older voting percentages are 37 % for "just right" and 51 % for "Dry" with an average classrooms relative humidity of 21.3%, while the younger subjects votes are 57% for "just right" and 34% for "Dry" for an average classrooms relative humidity of 46.8%.The differences may relate to the difference in the average relative humidity levels existed inside the younger and older subjects' classrooms during the time of this part of study, which implies that both age groups shows the same understanding level from both age groups toward the humidity level question used in this study.

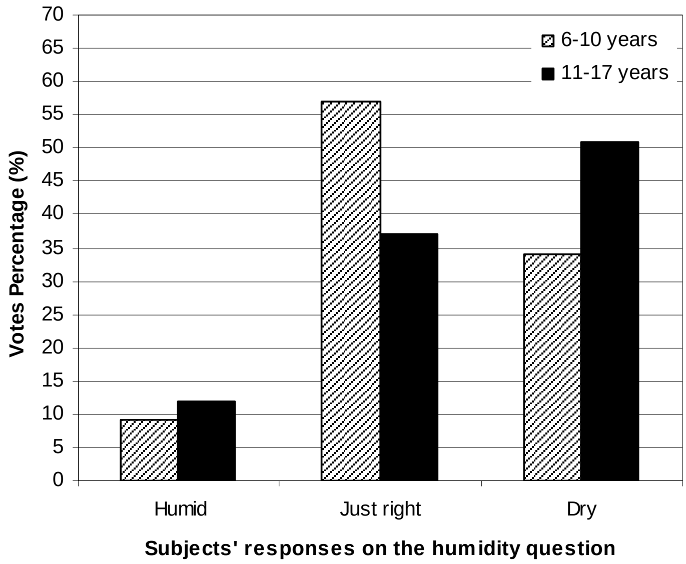

Figure 6.20: The distribution of the younger and older children votes using the relative humidity question scale during the natural ventilation mode

Applicability of the different thermal comfort indices in Kuwait classrooms during the natural mode

During this study, the tests were conducted in 24 girls and boys classrooms (10 classrooms occupied by 6-10 years old subjects and 14 classrooms occupied by 11-17 years old subjects) located in 4 different schools were visited during the naturally ventilated period of the classrooms, to investigate the applicability of the different thermal comfort indices inside these classrooms during this period. The distribution of the younger and older children's votes on ASHRAE scale with respect to the classrooms indoor temperatures are shown in figure 6.21a. The mean subjects' AMV votes and the calculated PMV were averaged for each classroom and the average values of the subjects' average actual mean vote (AMV) and the calculated predicted mean vote (PMV) values for each classroom along the ASHRAE thermal sensation scale are shown in Figure 6.21b, where the younger classrooms are from C1 to C10, while the older subjects' classrooms are from C11 to C24.

In this Figure it can be seen that, throughout all the classrooms, the PMV model is over predicts the subject's actual mean vote of both age groups on the warm side of the scale (+1, +2 and +3) and under predicts it on the cool side of the scale (-3, -2 and -1). The average AMV and PMV values for all classrooms are equal to -0.27 and -0.01 units, respectively, with a difference between them equals -0.26 units, which is within the uncertainty level in PMV prediction (±0.5) which could be related to the uncertainties in the metabolic rate and clothing insulation values. This situation suggest that using the newly proposed thermal comfort questionnaire, chapter 4, helps the younger subjects to assess their thermal sensations better as older age groups.

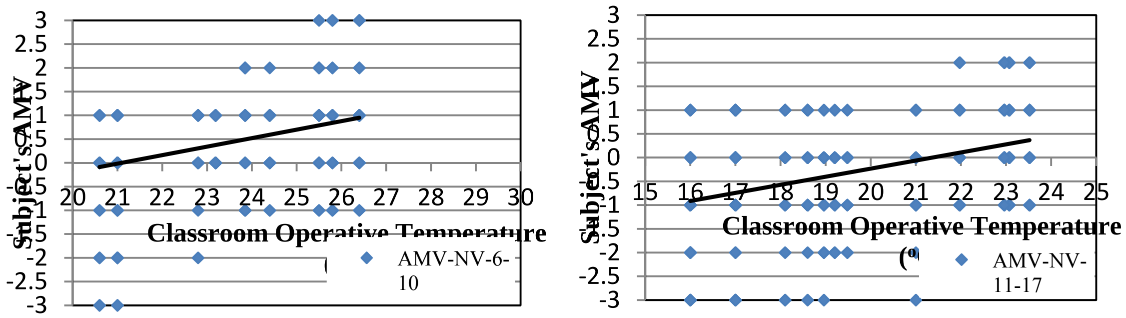

Figure 6.21a: The distribution of the younger and older children's on ASHRAE scale with respect to the classrooms indoor temperatures during the natural ventilation mode.

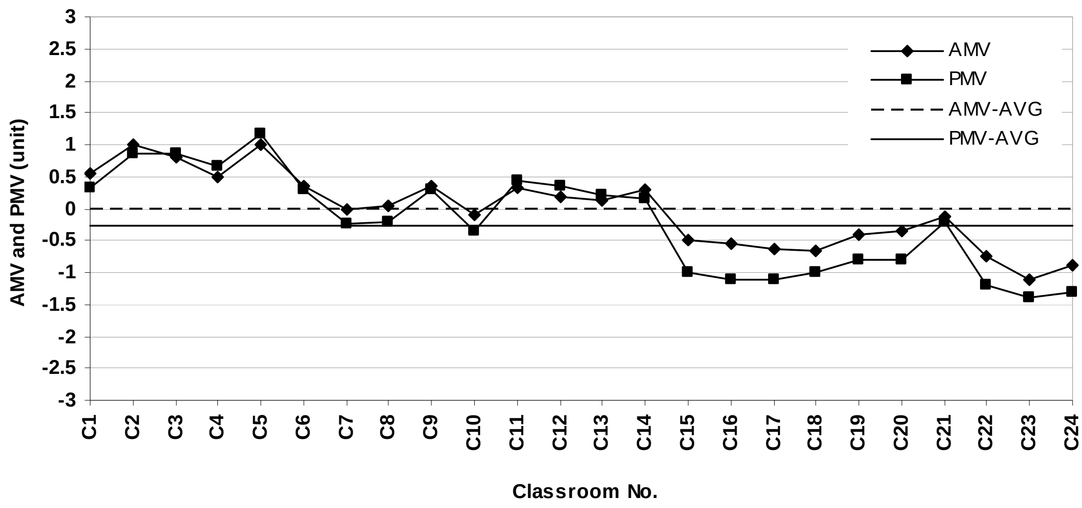

Figure 6.21b: The average values of the younger (C1-C10) and older (C11-C24) children's AMV and the PMV values for each classroom during the natural ventilation mode

The PMV, ePMV and PMV_{10} values for all classrooms (younger and older subjects' classrooms treated separately) were regressed and plotted against the AMV. This reduction in the metabolic rate was not done to the older subjects according to findings in chapter 5, where in these ages, 11-17 years old, an observed secular change in the children's heights and weights over the last few decades suggests that, for adolescents, the body surface areas are similar to those of adults in present days. The regression lines are shown in Figure 6.22 for the younger age group and Figure 6.23 for the older age group.

The PMV, ePMV and PMV_{10} values were regressed and plotted against the AMV for all classrooms (younger and older subjects' classrooms treated separately). For younger subjects' classrooms in addition to PMV and ePMV values, other thermal comfort index PMV_{10} was used and plotted against the AMV values to investigate the effect of the reduction in the metabolic rate (10%) on the prediction of the younger age group sensations. This reduction in the metabolic rate was not done to the older subjects according to findings in chapter 5, where in these ages, 11-17 years old, due to the observed secular change in the children's heights and weights within these ages. In Figure 6.22 for younger and Figure 6.23 for older, t is clear, the PMV and ePMV are identical for both age groups due to the high expectancy, refer to Table 6.2, of the subjects in Kuwait classrooms (***e*** = 1), and over-predict the younger and older subjects' AMV on the slightly warm-hot side, while under-predict the AMV on the cold-slightly warm side of the scale. The prediction difference between the younger and older age groups AMV and both the PMV and ePMV models at the neutral situation is about -0.3 units, while the prediction difference between the younger subjects' AMV and the PMV_{10} model for is about -0.6 units at the neutral situation.

The PMV_{10} model follows the same trend of the PMV and ePMV in predicting the younger subjects' AMV. A shift in prediction difference between the younger subjects' PMV_{10} and PMV and ePMV values occur and equal to the effect of the reduction in the metabolic rate, where the shift vanishes on the warm-hot side of the scale. This situation implies important finding can be seen here that, in this ventilation mode and in agreement with the previous hybrid mode, at higher temperature the effect of the reduction in the metabolic rate reduction will not affect the subjects' votes' prediction. In this mode of ventilation, the PMV model works better than the PMV_{10} in predicting the younger subjects' thermal sensations in the along the ASHRAE scale.

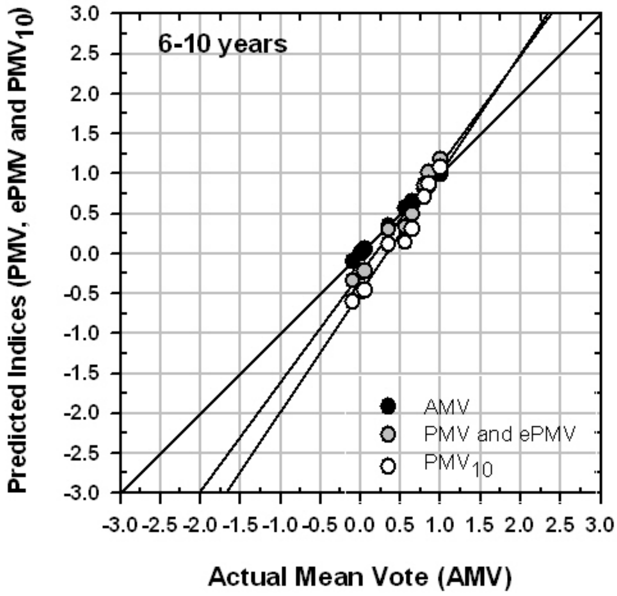

Figure 6.22: The relationship between the younger children actual mean vote (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during the natural ventilation mode

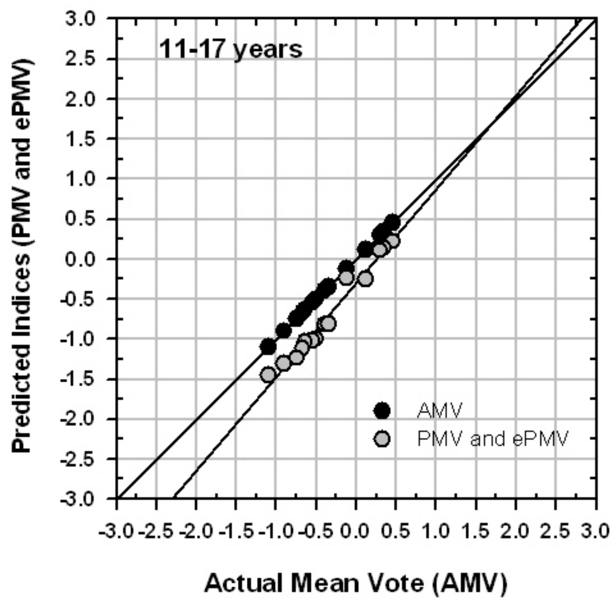

Figure 6.23: The relationship between the older children actual mean vote (AMV) in all academic levels and the predicted indices (PMV and ePMV) during the natural ventilation mode

Predicting the neutral temperature

The values of the AMV and the different predicted thermal comfort models PMV, ePMV and PMV_{10} for each age group were regressed and plotted against the operative temperature inside the classrooms as shown in Figure 6.24 and Figure 6.25. In both figures, the intersection of any model line with the zero scale of the y-axis, reads a temperature value on the x-axis, which represents the predicted neutral temperature (t_o) by that model. From both figures, the predicted neutral temperatures by the PMV and ePMV models are higher (under-predicting) than those based on prediction by the actual mean votes on the cold-slightly warm side of neutral, but lower (over-predicting) on the slightly warm-hot side of neutral on the ASHRAE scale. The PMV_{10} for younger subjects followed the same trend as the normal PMV. This finding is in agreement with other thermal comfort studies findings conducted by Kwok, 1998; Wong and Khoo, 2003; Kwok and Chun, 2003 and Hwang *et al*., 2006 in tropical or subtropical naturally ventilated classrooms.

The neutral temperatures resulting from the different thermal comfort indices (PMV, ePMV and PMV_{10}), adaptive model using the De Dear & Brager (2002) and various equations are tabulated in Table 6.6.

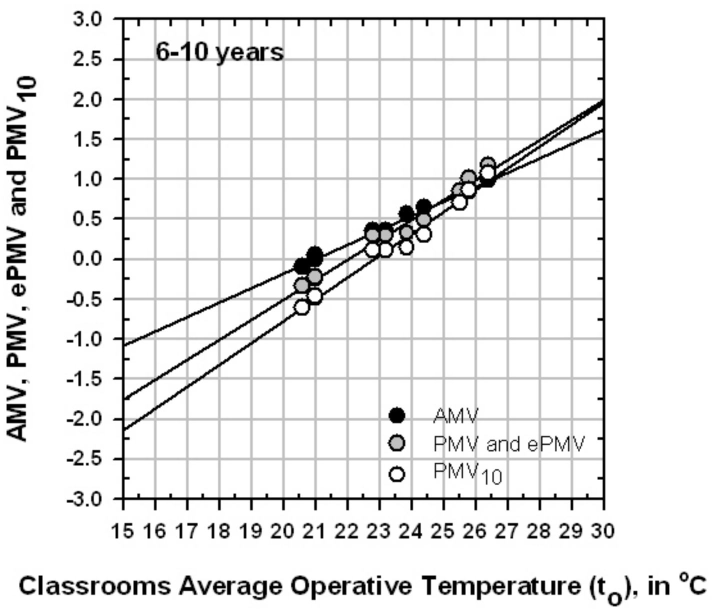

Figure 6.24: The regressed neutral temperature according to the girls' (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during the natural ventilation mode

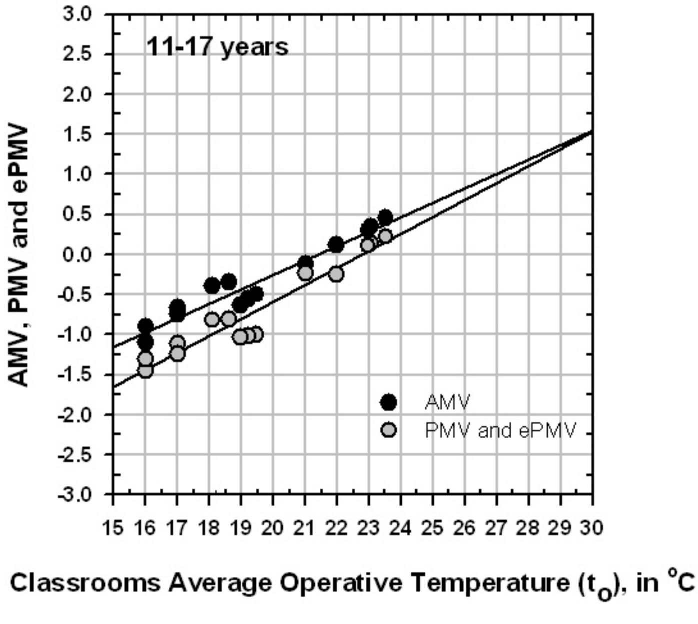

Figure 6.25: The regressed neutral temperature according to the older children (AMV) in all academic levels and the predicted indices (PMV and ePMV) during the natural ventilation mode

Table 6.6: Predicted neutral temperatures using the children's mean vote and various thermal comfort indices and equations during the natural ventilated mode.

	AMV	PMV	ePMV	PMV_{10}	De Dear & Brager, (2002) NV	Humphreys, (1978) NV	Auliciems, (1981) All
Equation					$17.8+0.31T_{a\ out}$	$11.9+0.543T_m$	$17.6+0.31T_m$
6-10 years	21.1	21.9	21.9	22.7	22.7	20.5	22.5
11-17 years	21.3	22.8	22.8	---	22.7	20.5	22.5
All	21.2	22.4	22.4	---	22.7	20.5	22.5

Where; $T_{a\ out}$ and T_m are the monthly mean outdoor temperature.

Table 6.6 shows that the neutral temperatures between both age groups according to their actual votes is almost the same, where a small difference of 0.2°C occurs. By combining the younger and older votes, the average neutral temperature of both genders is equal to 21.2°C, where this value is 1.2°C lower than that predicted by the PMV and ePMV models; 1.5°C lower than that predicted by de Dear and Brager equation; 1.3°C lower than that predicted by Auliciems' equation and 0.7°C higher than that predicted by Humphreys' equation.

Reduction of the younger subjects' metabolic rate in this ventilation mode represented by PMV_{10} values, predicted a 1.6°C and 0.8°C higher neutral temperatures than those from the AMV and the normal PMV and the ePMV, respectively. As found in the hybrid ventilation mode, this finding suggested that the modification of reducing the metabolic rate of the adults to suit the younger ages, may not always be a right choice and may results in more inaccurate result and the metabolic rate of the younger subjects is similar to the older subjects (11+). This finding may also supports the applicability of using the standard data of the metabolic rate of the adults in assessing the younger age's thermal sensations. During this period, it can be consider all the different indices and equations, except PMV_{10}, are appropriate to predict the thermal comfort sensations of the children in Kuwait classrooms during the natural ventilation mode.

Finally, the neutral temperature during this part of study is found to be lower by about 3-5^{o}C than that recorded in the previous studies conducted for classrooms in tropical and sub-tropical climates, but in agreement with Al-Rashidi *et al*. (2009a and b) studies conducted in hot and dry climate were gender differences were investigated.

The subjects' thermal preferences temperature versus the thermal neutrality temperature during the natural mode

In this section and according to the students' thermal preferences on the McIntyre thermal preference scale discussed earlier, the work was extended as previous ventilation mode to investigate the target or preferred temperature wanted by the younger and older subjects, by regressing and plotting the percentage of the student's votes who wanted to be cooler and those who wanted to be warmer in each classroom in this ventilation period against the classrooms operative temperatures. The plots are shown in Figure 6.26 for younger subjects and Figure 6.27 for older subjects, where the intersection between the percentage of student's vote who wanted to be warmer and those who wanted to be cooler represents the preferred temperatures by each age group under the this natural ventilation mode.

From these figures it is clear that the preferred temperatures of the younger and older age groups are 19.8^{o}C and 20.3^{o}C, respectively. These preferred temperatures are lower than the neutral temperatures in Table 6.6 for both age groups by 1-1.5^{o}C. This situation suggests that neutral thermal sensations are not always representing the ideal, optimal or preferred thermal state of the occupants (Kwok. 1998; Wong and Khoo, 2003; Kwok and Chun, 2003; Hwang *et al*., 2006 and Al-Mutawa *et al*. 2004).

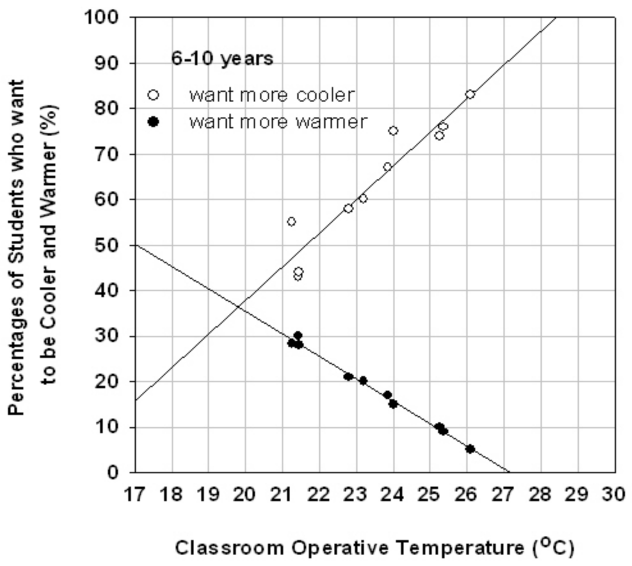

Figure 6.26: The preferred temperature due to the percentage of younger children who want to be cooler and warmer in all academic levels during the natural ventilation mode

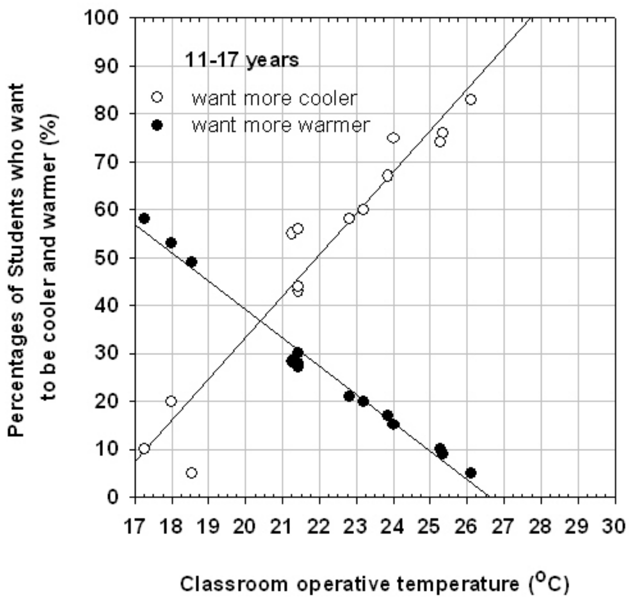

Figure 6.27: The preferred temperature due to the percentage of older children who want to be cooler and warmer in all academic levels during the natural ventilation mode

6.5.2 Key points of Natural Ventilation mode

- All the thermal comfort indices have under-predicted the children's actual thermal sensation on the cold-slightly warm side of the ASHRAE scale and over-predicted it on the slightly warm-hot side of the scale.
- The PMV and ePMV indices have similar effects in Kuwait climate where the expectation level of the occupants is high.
- In this mode of ventilation, the PMV model works better than the PMV_{10} in predicting the younger subjects' thermal sensations in the along the ASHRAE scale.
- The metabolic rate of the children was found to be similar to those for older subjects (11+) to secular change in the children's heights and weights over the last few decades, which may suggests using the standard data of the metabolic rate of the adults are applicable in assessing the younger age's thermal sensations.
- All the thermal comfort indices and equations, except PMV_{10}, are appropriate to predict the children thermal sensations in Kuwait classrooms under natural ventilated environment.
- The neutral temperature of the younger and older subjects are equals to 21.1^{o}C and 21.3^{o}C, respectively, where a difference of 0.2^{o}C was found between both age groups and this difference may related to the higher schoolwears insulation value worn by the younger subjects (1.06 clo) than that worn by the older subjects (1.01 clo).
- The students' average neutral temperature (21.2^{o}C) for both genders, in this naturally ventilated environment in Kuwait, is lower than that indicated for tropical and sub-tropical climatic zones and is in agreement with those in hot and dry climates.
- During this ventilation mode, students preferred temperatures that are lower than the neutral temperature by 1-2^{o}C. This situation suggested that the neutral thermal sensations are not always representing the ideal, optimal or preferred thermal state of the children.

6.6 Air-Conditioned Ventilation Mode

The results of the field study conducted in Kuwait classrooms under the air-conditioned ventilation mode will be discussed in this section of the chapter. A sample of 606 female and male students (295 females and 311 males) in 4 different schools took part in this part of study occupied in 24 classrooms (12 girl's and 12 boy's classrooms). The number of younger subject's age group (6-10 year) from both genders represents 43% (263 subjects) of the sample, where the older age group (11-17 years) represents 57% (343 subjects). The average insulation values of the school wears imposed by the ministry during this ventilation period for each age group equal 0.67 and 0.70 clo for younger and older subjects, respectively. The detailed description of the children sample is shown in Table 6.7. This part of the study was conducted over the period 3rd-24th of May, 2006. This period in Kuwait is considered to be a hot period, where all the classrooms are cooled using air-conditioning systems.

6.6.1 Results and Discussion

Analysis of subjects' votes using the new thermal comfort questionnaire during the air-conditioned mode

During this air-conditioned ventilated environment, the measured thermal conditions, for both age groups in different academic levels (elementary; intermediate and secondary) are shown in Table 6.7. The actual mean votes data of the younger (6-10 years) and older age groups (11-17 years) of both genders within the different academic level, according to the ASHRAE thermal sensation scale, were combined together to investigate the differences in thermal sensation between the different age groups. The average data for the operative temperature; the air flow speed; the relative humidity were measured and calculated for each academic level for both gender and age groups, where the operative temperature was calculated according to Eq. 2.8 in chapter 2.

The measured classrooms thermal conditions, under air-conditioned ventilated environment, for both genders and age groups in the different academic levels (elementary; intermediate and secondary) are shown in Table 6.7, which includes the operative temperature; air flow speed; the relative humidity and the mean comfort votes.

Table 6.7: The measured thermal conditions for both genders in different academic levels under air-conditioned ventilated environment

Gender	Academic Level	Class Grade	No. of Students	Age (year)	School Dress Code	Vent. Mode	t_o °C	v_a m/s	RH (%)	Mean Comfort Votes	(-1,0,+1) Votes (%)	Votes distribution according to ASHRAE scale						
												-3	-2	-1	0	+1	+2	+3
Girls	Elementary	1st - 5th	120	6 – 10	summer	A/C	22.92	0.27	41.0	-0.1	71.7	0	22	28	28	30	7	5
	Intermediate	6th- 9th	115	11 – 14	summer	A/C	23.10	0.27	39.0	-0.03	87.3	0	5	33	47	21	8	1
	Secondary	10th-12th	59	15 - 17	summer	A/C	22.17	0.25	42.3	-0.24	67.8	2	9	15	16	9	8	0
Boys	Elementary	1st - 5th	143	6 – 10	summer	A/C	22.78	0.26	39.0	-0.21	81.8	0	16	47	40	30	10	0
	Intermediate	6th- 9th	108	11 – 14	summer	A/C	20.93	0.21	42.0	-0.65	82.4	4	14	36	49	4	1	0
	Secondary	10th-12th	61	15 - 17	summer	A/C	22.73	0.26	46.7	-0.2	85.2	1	5	13	31	8	3	0
Both	Elementary	1st-5th	263	6 - 10	summer	A/C	22.85	0.27	40.0	-0.16	77.1	0	38	75	68	60	17	5
	Intermediate and Secondary	6th - 12th	343	11 - 17	summer	A/C	22.23	0.25	42.5	-0.29	82.2	7	33	97	143	42	20	1
All		1st - 12th	606	6 - 17	summer	A/C	22.54	0.26	41.3	-0.23	80.0	7	71	172	211	102	37	6

Vent. Mode: Ventilation mode; t_o: Classroom operative temperature, °C; v_a: Classroom air flow speed, m/s; RH: Relative humidity, % and (-1, 0 and +1) Votes (%): Votes around the three central points on ASHRAE scale.

Subjects' votes on ASHRAE scale

The subjects' votes for both age groups on thermal sensation in all classrooms during this period are shown in Table 6.7 and illustrated in Figure 6.28a and 6.28b with regards to the classrooms indoor temperatures. From figure 6.2a it is show that, the effect of existed classrooms indoor temperatures and the summer clothing insulation values of the strict schoolwears in each classooms, leads most of the subjects to vote around the three central points of the ASHRAE comfort scale.

Figure 6.28b, shows the percentages of subject's voted around the different ASHRAE scale categories. From Table 6.7 and Figure 6.28b, it is clear that most of both age groups subjects are voted around the three central categories (-1, 0 and +1), where the average mean voted of the younger subjects is equal to -0.16 and 77.1 % of them voted around the three central categories (-1, 0 and +1) of the ASHRAE scale with average classrooms temperatures of 22.85°C. For the older age group the average mean vote was -0.29 and 82.2 % of the older age group (11-17 years) voted around three central categories (-1, 0 and +1) with average classrooms operative temperatures of 22.23°C. The percentages of votes around the neutral central categories (-1, 0 and +1) for both age groups are close which suggests that the use of the thermal sensation question in the new proposed thermal comfort question in chapter 4, helped the younger children to assess their sensation better as the older subjects. The subjects' overall mean vote equal to -0.23 with overall percentage of votes for both age groups around the three central points of the scale during this period is 80.0 % with average classrooms temperature of 22.5°C.

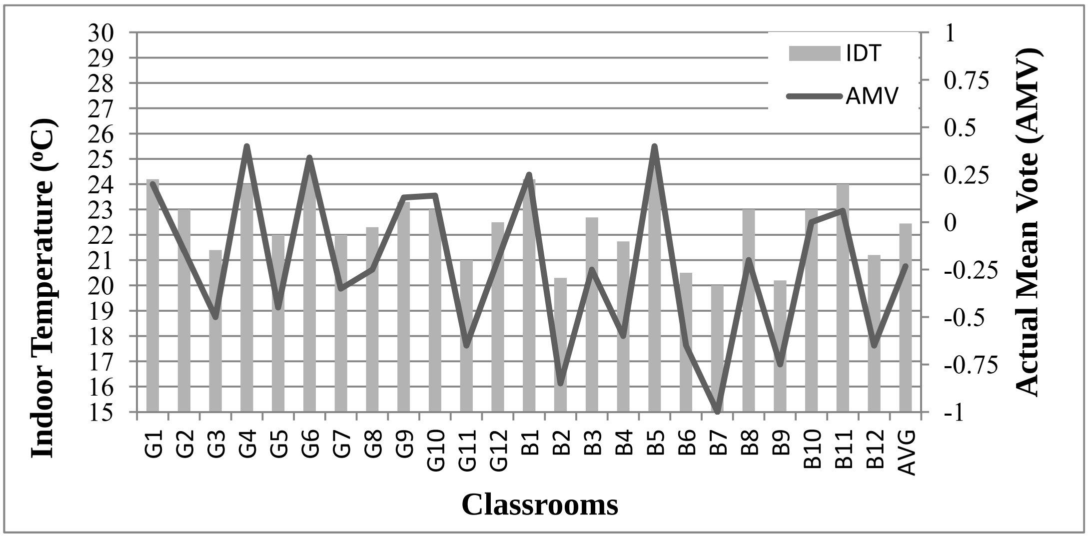

Figure 6.28a: The votes of each classroom occupants and the classroom indoor temperature during the air-conditioned ventilation mode.

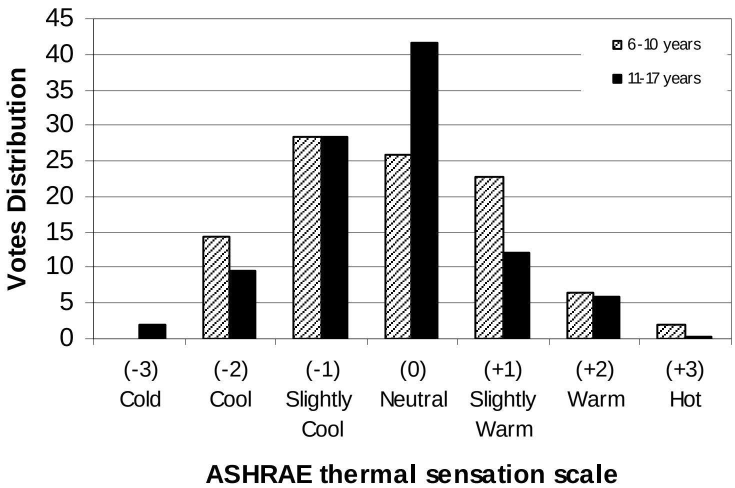

Figure 6.28b: Total percentage of the younger and older children votes along the ASHRAE comfort scale during the air-conditioned ventilation mode

Subjects' comfort level

The subjects' thermal comfort votes toward the existing classroom thermal conditions using the comfort question "do you feel thermally comfortable now", is shown in

Figure 6.31 for both age groups in all classrooms. All the younger and older subjects answered this question. From Figure 6.29, were around the comfortable category of the scale, where 83 % of younger and 77 % of older subjects are feeling comfortable with their classrooms existed thermal conditions. By comparing the subject's votes on the ASHRAE thermal sensation scale and the comfort scale, Figures 6.30 and 6.31, these comfort percentages are the same as the percentages of the subjects voted around the three neutral central categories (-1, 0 and +1) from both age groups, which suggests that during this period of ventilation mode more than 80% of the subjects are feeling thermally comfortable related to the existed thermal comfort conditions inside the classrooms. The rest of the subjects who votes on the other categories (-3 and -2) and (+2 and +3) of the ASHRAE thermal sensation scale voted around the uncomfortable and very uncomfortable categories on the comfort level scale.

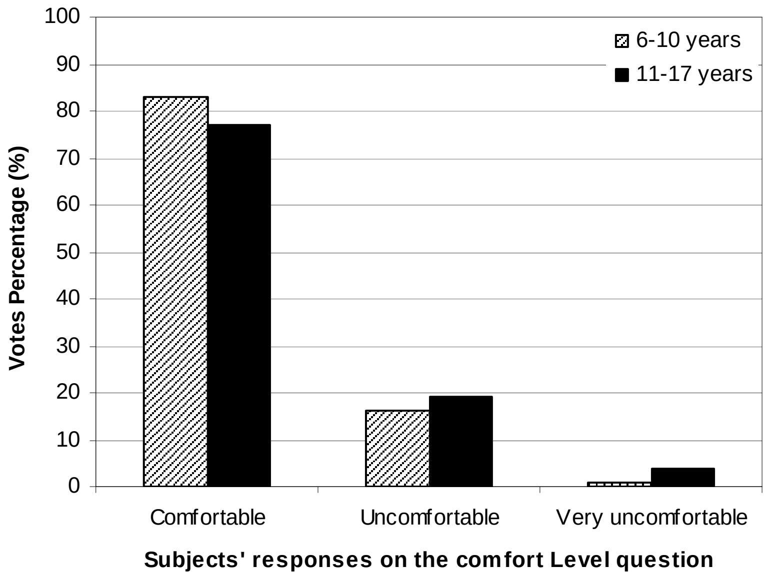

Figure 6.29: The distribution of the younger and older children votes using the comfortable level scale during the air-conditioned ventilation mode

Subjects' thermal preferences

The thermal preference voting using the McIntyre preference scale of the different age groups is illustrated in Figure 6.30. By comparing Figures 6.28, 6.29 and 6.30, it can be seen that most of the younger and older subjects' who votes and around the (-1, 0 and +1) felt comfortable with an existed classrooms operative temperatures, voted around "no change" category on the thermal preference scale. This situation suggest that by using the new proposed thermal comfort question in chapter 4, the younger children's understanding was improved and helped them to assess their sensation better as the older subjects.

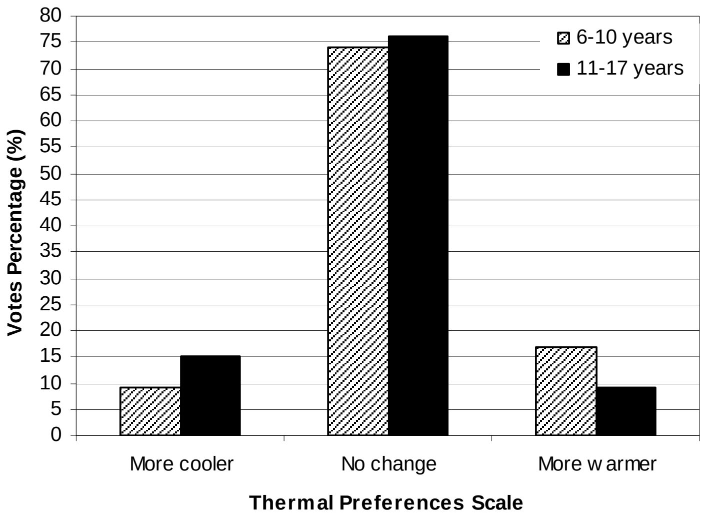

Figure 6.30: The distribution of the younger and older children votes using the McIntyre preference scale during the air-conditioned ventilation mode

Subjects' acceptability level

The subjects' responses of the different age groups on the acceptability level question "In general, how do you rate the classroom environment?" toward the classrooms thermal conditions is shown in Figure 6.31. The relationship between the subject's acceptability level, the thermal perception and comfort level scales toward the classrooms thermal conditions was strong during this ventilation period. By comparing these scales together, it was found that most of the thermal sensation, comfort level and thermal preferences votes of both age groups during this ventilation period reflected on their acceptability level voting where most of the subjects accept their thermal environment. This situation is in agreement with the finding in chapter 4, which implies that there are no differences between the younger and older subjects' responses to the acceptability level question.

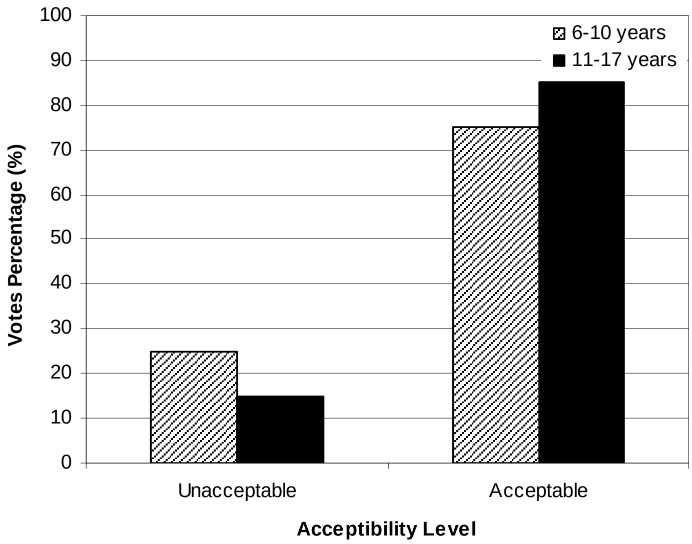

Figure 6.31: The percentage of the younger and older votes using the acceptability level question during the air-conditioned ventilation mode

Subjects' votes toward the air flow level

The distribution of the younger and older subjects' responses to the air flow question "how do you feel about the air movement in the classrooms?", shows most of the younger and older subject's votes toward the air flow level inside the classrooms were are centred on the "breezy" category with an air flow speeds of 0.27 and 0.25 m/s for younger and older subjects, respectively. From table 6.7 and Figure 6.32, it can be show that 78 % and 63 % of the younger and older subjects, respectively, voted on the "breezy" category, where still there is significant percentage of the subjects from both age groups who have felt the air flow speed inside the classrooms is "just right", 17 % of the younger and 27 % of older subjects, respectively. The distribution of the votes confirms that both of the age groups have the same understanding to this question.

Subjects' votes toward the relative humidity level

The humidity level question "How do you feel about the humidity in the classroom" again in this part of this study. From Figure 6.33, it shows that the younger and older age groups percentages votes toward the relative humidity level inside the classrooms during the air-conditioned ventilation mode period. The majority of both age groups votes were around the "just right" category; where 87% of the younger and 81% of the older subjects voted the average relative humidity (44.2%), Table 6.7, inside the classrooms to be “just right”. The distribution of the votes confirms that both of the age groups have the same understanding to this question.

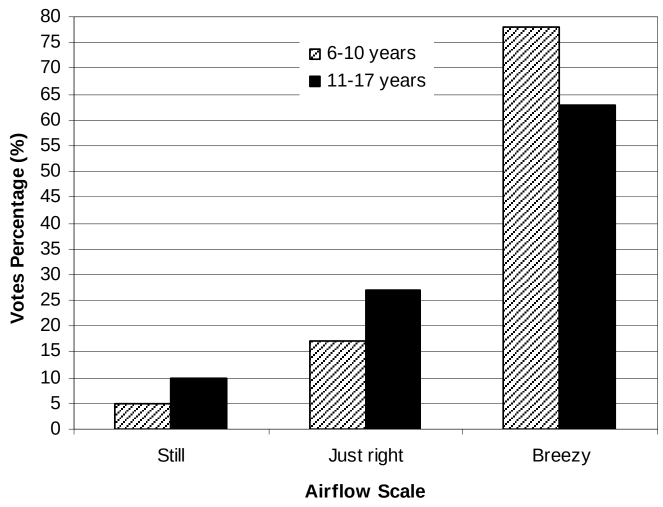

Figure 6.32: The percentage of the younger and older votes using the air flow question during the air-conditioned ventilation mode

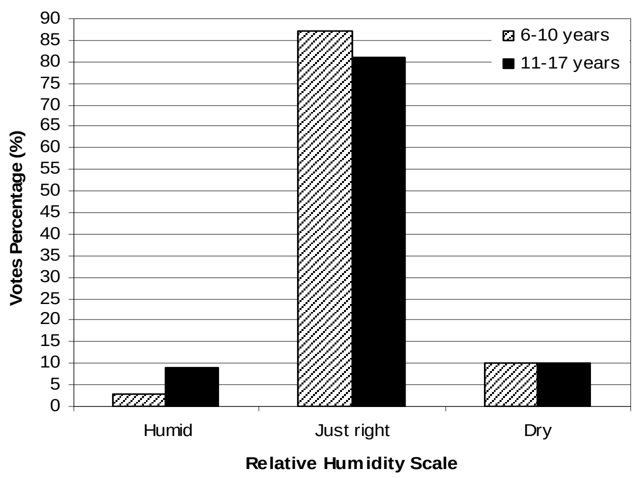

Figure 6.33: The percentage of the younger and older votes using the relative humidity question during the air-conditioned ventilation mode

Applicability of the different thermal comfort indices in Kuwait classrooms during the air-conditioned mode

During this ventilation period, the same number of classrooms and age groups as in the previous hybrid and ventilation mode, 24 girls and boys classrooms (10 classrooms occupied by 6-10 yeas old subjects and 14 classrooms occupied by 11-17 years old subjects) located in 4 different schools were visited to investigate the applicability of the different thermal comfort indices inside Kuwait classrooms during this ventilation mode. The distribution of the younger and older children's votes on ASHRAE scale with respect to the classrooms indoor temperatures are shown in figure 6.34a.

The mean subjects' AMV votes and the calculated PMV were averaged for each classroom and the distribution of the subjects' average actual mean vote (AMV) and the calculated predicted mean vote (PMV) values for each classroom along the ASHRAE thermal sensation scale are plotted and shown in Figure 6.34b, where the younger classrooms are from C1 to C10, while the older subjects' classrooms are from C11 to C24. In this Figure it can be seen that, throughout all the classrooms, the PMV model is under predicts the subject's actual mean vote of both age groups along the ASHRAE scale. The average AMV and PMV values for all classrooms are equal to -0.23 and -0.76, respectively, with a difference between them equals 0.53 units, which is within the uncertainty level in PMV prediction (±0.5) which could be related to the uncertainties in the metabolic rate and clothing insulation values. From the figure it is clear that using the newly proposed thermal comfort questionnaire, chapter 4, helps the younger subjects to assess their thermal sensations better as older age groups.

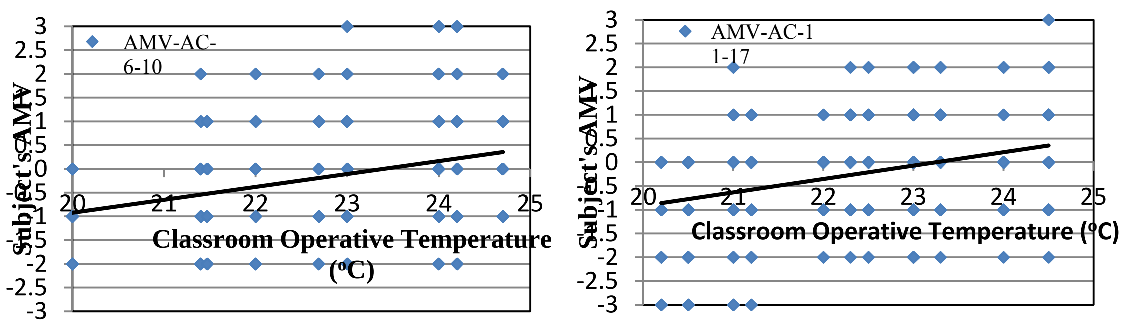

Figure 6.34a: The distribution of the younger and older children on ASHRAE scale with respect to the classrooms indoor temperatures during the air-conditioned ventilation mode.

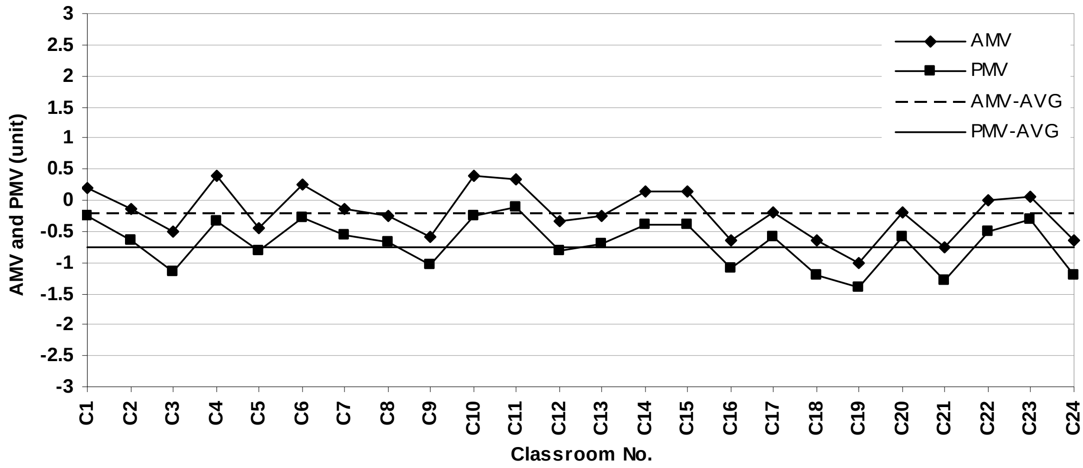

Figure 6.34b: The children's's' AMV and PMV votes on ASHRAE thermal sensation scale in Kuwait classrooms during Air-Conditioned ventilation mode

The PMV and ePMV values for all classrooms (younger and older subjects' classrooms treated separately) were regressed and plotted against the AMV. For younger subjects' classrooms in addition to PMV and ePMV values, in addition to the thermal comfort index PMV_{10} was used and plotted against the younger subjects' AMV values, Figure 6.35 and Figure 6.36 for younger and older subjects, respectively.

From these both figures, PMV and ePMV are identical due to their high expectancy of the Kuwaiti subjects (***e*** =1). From Figure 6.35, for younger subjects, all the different indices (PMV, ePMV and PMV_{10}) are always under-predicting the students' AMV on both sides (warm and cool) of the ASHRAE scale. It is also shown in the figure that there is shift in prediction difference between the younger subjects' PMV_{10} and PMV and ePMV values occur and equal to the effect of the reduction in the metabolic rate, where the shift vanishes on the warm-hot side of the scale. This finding implies that the reduction in the younger diminish and disappear at warm the thermal conditions. The prediction differences between the PMV, ePMV models and the AMV at the neutral situation for both younger and older subjects is equal about -0.5 units, where the prediction differences between the PMV_{10} model and the younger subjects' AMV at the neutral situation is equal to -0.8 units. An important observation can be noticed here that in this ventilation mode, the PMV model works better than the PMV_{10} in predicting the thermal sensations along the ASHRAE scale, which suggests, in this air-conditioned ventilation mode that the reduction of the metabolic rate, which is originally based on the adults data, to suite the children sizes may not be always a correct choice and may produce big differences between the subject's AMV and the calculated PMV values.

Predicting the neutral temperature

The values of the AMV and that predicted by the different models for each age group were regressed and plotted against the operative temperature inside the classrooms as shown in Figure 6.37 and Figure 6.38, to indicate the neutral temperature for each age group. From both figures, the predicted neutral temperatures by the PMV, ePMV and PMV_{10} models for both age groups are always higher (under-predicting) than those based on prediction by the subjects' actual mean votes throughout the ASHRAE scale. It is also seen from the younger subjects' figure that the PMV and ePMV values are lower than the values predicted by PMV_{10} , where the differences begin to decline at high temperatures, where they vanishes at an operative temperature of about 30°C for the boys.

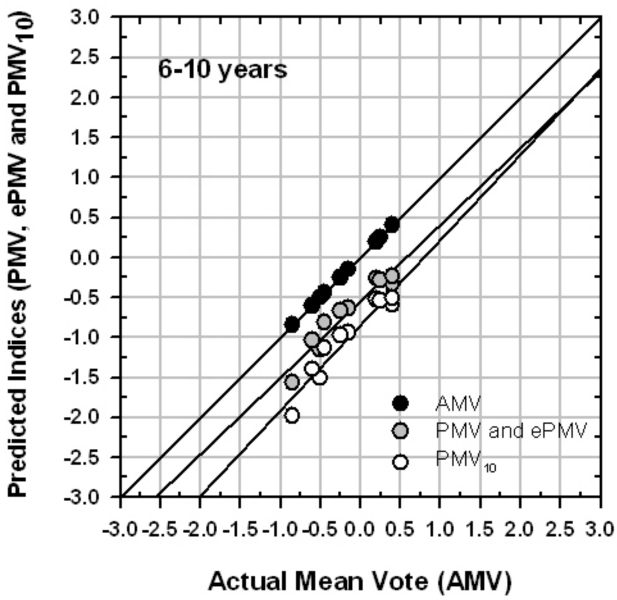

Figure 6.35: The relationship between the younger children actual mean vote (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during the air-conditioned ventilation mode

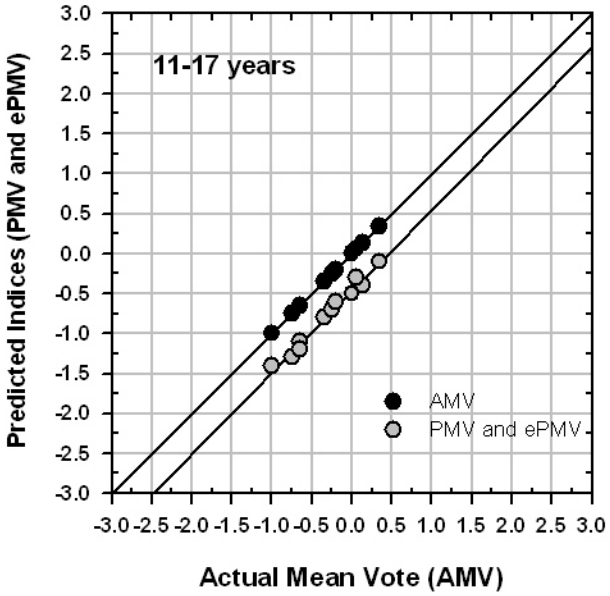

Figure 6.36: The relationship between the older children actual mean vote (AMV) in all academic levels and the predicted indices (PMV, and ePMV) during the air-conditioned ventilation mode

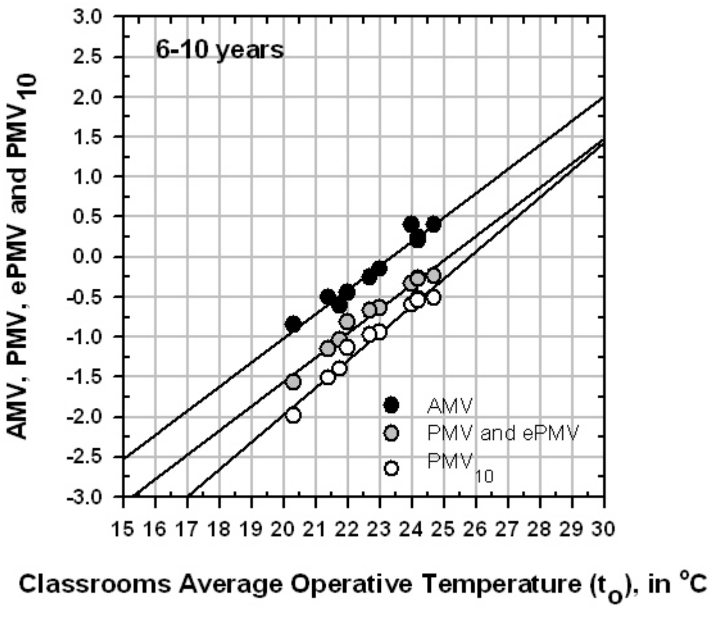

Figure 6.37: The regressed neutral temperature according to the younger children (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during the air-conditioned ventilation mode

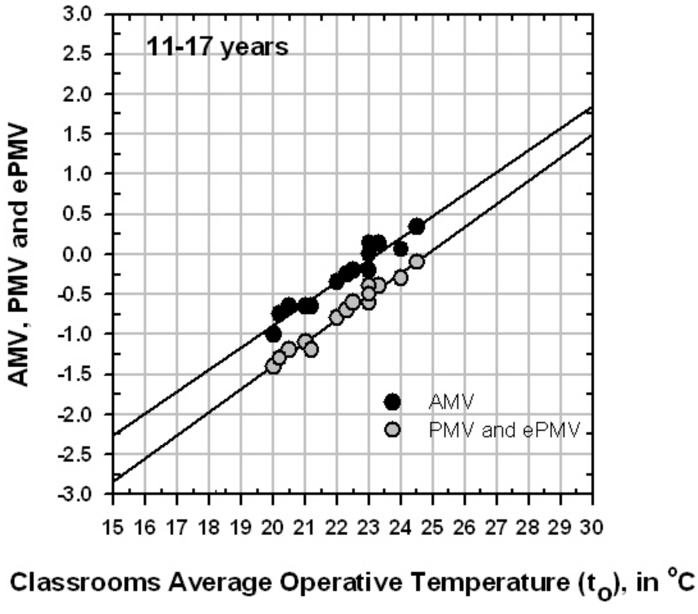

Figure 6.38: The regressed neutral temperature according to the older children (AMV) in all academic levels and the predicted indices (PMV and ePMV) during the air-conditioned ventilation mode

The neutral temperatures resulting from the different thermal comfort indices (PMV, ePMV and PMV_{10}), adaptive model using the De Dear & Brager (2002) equation and various equations are tabulated in Table 6.8.

Table 6.8 shows that the neutral temperature of both age groups according to their votes is almost the same and a small difference of 0.2°C in the neutral temperature was found between the two age groups. This difference may be related to the slightly higher clothing insulation values worn by older subjects (0.70 clo) compared to that of the younger (0.67 clo). By combining the younger and older votes, the average neutral temperature of both age groups is equal to 23.3°C, where this value is 1.7°C; 3.9°C and 5.2°C lower than the average neutral temperature predicted by PMV, ePMV, Humphreys' equation and Auliciems' equation, respectively. In this ventilation mode the PMV_{10} model predicts neutral temperature that higher by 2.5°C than that resulted from the younger subjects' AMV.

Since all of the younger and older subject's data were collected in May, the De Dear and Brager's equation could not be utilized to predict the neutral temperature for the period of this study, because the average monthly mean temperature in May (35^{o}C) in Kuwait is greater than the upper limit (33.5^{o}C) of the De Dear & Brager's equation. All thermal comfort indices and equations are under-predicting the neutral temperature for both age groups. This can be interpreted to consider the PMV and ePMV models the most appropriate thermal comfort indices to predict the thermal comfort sensations of the children in Kuwait classrooms during this period of the study.

Table 6.8: Predicted recommended neutral temperatures using the children's mean votes various thermal comfort indices and equations during the air-conditioned ventilation mode.

	AMV	PMV	ePMV	PMV_{10}	De Dear & Brager, (2002) NV	Humphreys, (1978) AC	Auliciems, (1981) All
Equation					$17.8+0.31T_{a\ out}$		$17.6+0.31T_m$
6-10 years	23.4	25.0	25.0	25.9	----	27.2	28.5
11-17 years	23.2	24.9	24.9	---	----	27.2	28.5
All	23.3	25.0	25.0	---	----	27.2	28.5

Where; $T_{a\ out}$ and T_m are the monthly mean outdoor temperature.

Finally, the neutral temperature determined in this air-conditioned mode is in agreement with the findings of Al-Mutawa *et al*. (2004) for air-conditioned offices in Kuwait; with the studies of Kwok and Chun (2003) for air-conditioned classrooms in Japan and with Al-Rashidi *et al*. (2010) study conducted in air-conditioned classrooms in hot and dry climate were gender differences were investigated. This result of this study is also in agreement with inside design temperature of 23.9^{o}C required by Kuwait's Energy Code (MEW/R-7, 2010). On the other hand, the neutral temperature in this study is lower by about 5^{o}C than that determined by the previous studies conducted for classrooms in tropical and sub-tropical climates.

The subjects' thermal preferences temperature versus the thermal neutrality temperature during the air-conditioned mode

The students' thermal preference on the McIntyre thermal preference scale, discussed earlier, was used to extend the work of this section to investigate the preferred temperature wanted by the younger and older subjects. The data of the student's votes who want to be cooler and those who want to be warmer in each classroom in this ventilation period were regressed and plotted against the classrooms operative temperatures. The plots are shown in Figure 6.39 for younger subjects and Figure 6.40 for older subjects, where the intersection between the percentage of subject's vote who wanted to be warmer and those who wanted to be cooler represents the preferred temperatures by each age group under the this natural ventilation mode.

From these figures it is clear that the preferred temperatures of the younger and older age groups are similar and equal 22.0°C, respectively. These preferred temperatures are lower than the neutral temperatures in Table 6.8 for both age groups by 1.3°C. This situation suggests that neutral thermal sensations are not always representing the ideal, optimal or preferred thermal state of the occupants (Kwok. 1998; Wong and Khoo, 2003; Kwok and Chun, 2003; Hwang *et al.*, 2006 and Al-Mutawa *et al*. 2004).

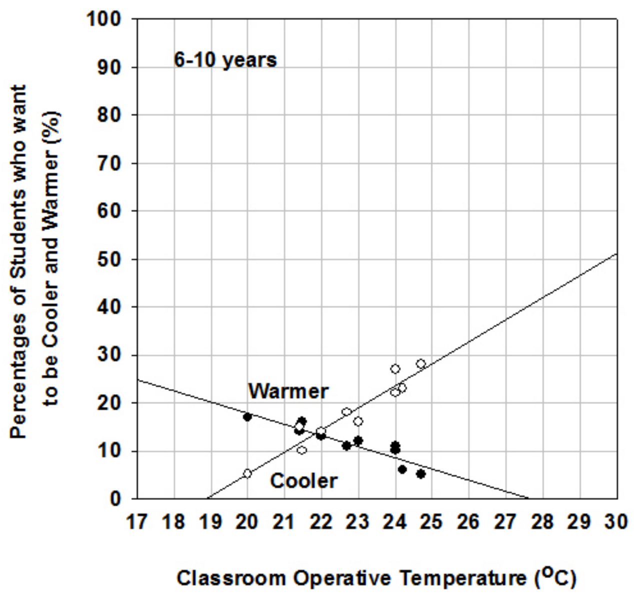

Figure 6.39: The preferred temperature due to the percentage of younger children who want to be cooler and warmer in all academic levels during the air-conditioned ventilation mode

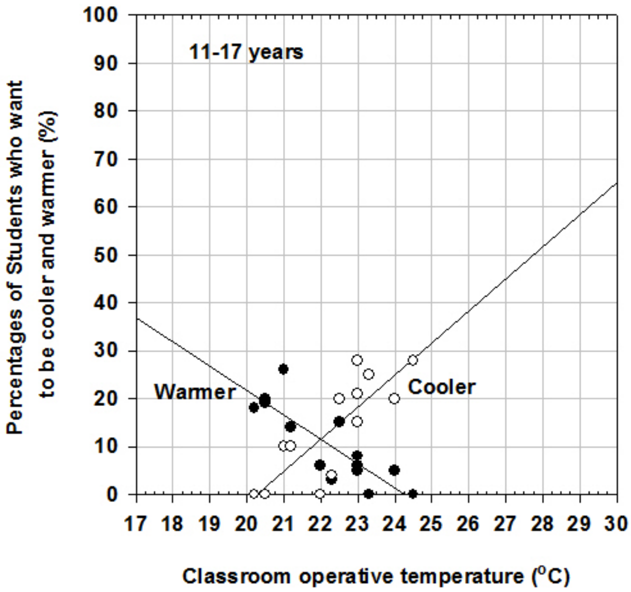

Figure 6.40: The preferred temperature due to the percentage of older children who want to be cooler and warmer in all academic levels during the air-conditioned ventilation mode.

6.6.2 Key points of Air-Conditioned Mode

- All the thermal comfort indices in this part of the study have under-predicted the children's actual thermal sensations along the ASHRAE scale.
- The PMV and ePMV indices have similar effects in Kuwait climate where the expectation level of the occupants is high.
- The PMV and ePMV indices are more appropriate to predict the children thermal sensations in Kuwait classrooms under air-conditioned environment.
- Using the PMV_{10} model for the younger children, will under predicts their thermal sensation more than normal PMV and ePMV models along the ASHRAE scale and at higher temperatures, the difference between the PMV_{10} and normal PMV and ePMV predictions will diminish.
- During this ventilation mode, the metabolic rate of the younger children (6-10 year) are similar to those for older children (11-17 years old) and adults, due to secular change in the children's heights and weights over the last few decades. This finding implies that the modification of reducing the metabolic rate of the adults to suit the younger ages, may not always be a right choice and may results in more inaccurate

results, while in the hybrid ventilation mode using the normal PMV model with the adult metabolic rate produce better predicted values.

- The neutral temperatures of the younger and older subjects are similar and the average neutral for both age groups is equal 23.3°C.
- In this air-conditioned ventilation mode, the average preferred temperatures for both age groups (22.0°C) is lower than the neutral of both genders (23.3°C) by about 1.3°C.
- The students' neutral temperature in air-conditioned environment is in agreement with other studies conducted for offices, classrooms in Kuwait, classrooms in Japan, and with the inside design temperature conditions required by the Energy Code of Kuwait.

6.7 The Combination of the Different Ventilation Modes

In this section of the chapter, the results of the field study conducted in Kuwait classrooms under the different ventilation modes were combined and discussed to investigate the applicability of the different thermal comfort indices and equations throughout the academic year. A general analysis of the overall data is also presented to extract some overall conclusions.

The data of 1811 of the younger and older subjects, with a total 1811 responses, (884 females and 927 males) who took part in the different ventilation modes and occupied in 72 classrooms (36 girls' and 36 boys' classrooms) in 12 different schools, were combined and analysis in this section of the chapter. The number of younger subjects' age group (6-10 year) from both genders represents 42% (799 subjects) of the sample, where the older age group (11-17 years) represents 58% (1012 subjects).

The average insulation values of the schoolwear imposed by the ministry during the different ventilation periods throughout the whole academic year for each age group equal 0.86 clo for younger and older subjects for both summer and winter clothing detailed in chapter 5 of this thesis. The detailed description of both age groups data through the different ventilation mode is shown in Table 6.9. The measured classrooms thermal conditions, under the different ventilated environments discussed previously, for both genders and age groups in the different academic levels (elementary;

intermediate and secondary) are shown in Table 6.9, which includes the operative temperature; air flow speed; the relative humidity and the mean comfort votes.

6.7.1 Results and Discussion

Analysis of subjects' votes using the new thermal comfort questionnaire during the different modes

The overall measured classroom's thermal conditions, for both age groups in different academic levels (elementary; intermediate and secondary) under the different ventilation modes and throughout the whole academic year are shown in Table 6.9. The actual mean votes data of the younger (6-10 years) and older age groups (11-17 years) of both genders within the different academic level, according to the ASHRAE thermal sensation scale, were combined together to investigate the differences in thermal sensation between the different age groups during the whole academic year. The average data for the operative temperature; the air flow speed; the relative humidity were measured and calculated for each academic level for both gender and age groups, where the operative temperature was calculated according to Eq. 2.8 in chapter 2.

Table 6.9: Overall classrooms thermal conditions and the students' actual mean votes for all three different ventilation modes.

Ventilation Mode	Academic Level	No. of Students	Age	School Dress Code	t_o °C	v_a m/s	RH (%)	Mean Comfort Votes	(-1,0,+1) Votes (%)	Votes distribution according to ASHRAE scale						
										-3	-2	-1	0	+1	+2	+3
Hybrid	E	265	6-10	Winter	24.00	0.10	37.3	0.82	73.6	0	0	43	35	117	66	4
	I and S	336	11-17	Winter	22.95	0.12	48.2	0.73	68.5	0	10	45	79	106	84	12
Natural	E	271	6-10	Winter	23.39	0.15	46.8	0.43	89.7	3	7	19	110	114	12	6
	I and S	333	11-17	Winter	19.23	0.25	31.3	-0.29	83.4	14	25	103	104	73	14	0
A/C	E	263	6-10	Summer	22.85	0.27	40.0	-0.16	77.1	0	38	75	68	60	17	5
	I and S	343	11-17	Summer	22.23	0.25	42.5	-0.29	82.2	7	33	97	143	42	20	1
All modes	All E	799	6-10	Winter/ Summer	23.41	0.17	41.4	0.36	80.2	3	45	137	213	291	95	15
	All I and S	1012	11-17	Winter/ Summer	21.47	0.23	40.7	0.05	78.2	21	68	245	326	221	118	13
	All	1811	6-17	Winter/ Summer	22.44	0.20	41.1	0.19	79.1	24	113	382	539	512	213	28

E: Elementary; I: Intermediate; S: Secondary; t_o: Classroom operative temperature, °C; v_a: Classroom air flow speed, m/s; RH: Relative humidity, % and (-1, 0, +1) Votes (%): Votes around the three central points of ASHRAE scale.

Subjects' votes on ASHRAE scale

The overall subjects' votes for both age groups on thermal sensation during the different periods and its combination are shown in Table 6.9 and illustrated in Figure 6.41. The figure shows the percentages of votes around the central points of the ASHRAE scale considering the % distribution of votes in the range -1 to +1, (-1 'slightly cool', 0 'neutral' and +1 'slightly warm'), these percentages, as indicated in Table 6.9. From figure 6.41, it is clear that most of both age groups subjects are voted around the three central categories (-1, 0 and +1), where the average mean voted of the younger subjects is equal to 0.39 and 80.2 % of them voted around the three central categories (-1, 0 and +1) of the ASHRAE scale with average classrooms temperatures of 23.41^{o}C. For the older age group the average mean vote was 0.05 and 78.2 % of the older age group (11-17 years) voted around three central categories (-1, 0 and +1) with average classrooms operative temperatures of 21.47^{o}C.

The percentages of votes around the neutral central categories (-1, 0 and +1) for both age groups are close which suggests that the use of the thermal sensation question in the new proposed thermal comfort question in chapter 4, helped the younger children to assess their sensation better as the older subjects, where the difference may related to the different classrooms' thermal conditions and the slightly differences between the younger and older subjects' schoolwear insulation values, especially at the hybrid and natural ventilated modes. The overall percentage of votes for both age groups around the three central points of the scale during this period is 79.1 % with average classrooms temperature of 22.44^{o}C.

The overall percentage of votes for both age groups around the three central points of the scale during this period is 79.1 % with average classrooms temperature of 22.44^{o}C.

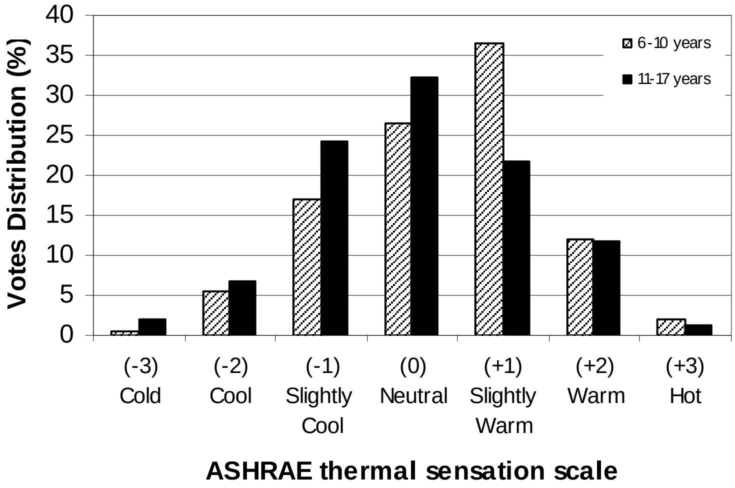

Figure 6.41: Total percentage of the younger and older children votes versus the ASHRAE comfort scale during all three ventilation modes

Applicability of different thermal comfort indices for Kuwait classrooms during the different modes

Seventy two younger and older classrooms' (30 classrooms occupied by 6-10 years old subjects and 42 classrooms occupied by 11-17 years old subjects) were visited during the different ventilation modes to investigate the applicability of the different thermal comfort indices inside Kuwait classrooms. The distribution of the younger and older children's votes on the ASHRAE scale with respect to the classrooms indoor temperatures are shown in figure 6.42a.

The distribution of the subject's average actual mean vote (AMV) and the calculated predicted mean vote (PMV) values for each classroom along the ASHRAE thermal sensation scale for the different ventilation mode are connected and shown in Figure 6.42b, where the younger classrooms are from C1 to C30, while the older subjects' classrooms are from C31 to C72. This figure connecting and shows the shape of the subjects' voting and the prediction of the PMV model throughout all the classrooms, where the PMV model is under predicts the subject's actual mean vote and over predict it on different part of the ASHRAE scale during the different ventilation modes, refer to the previous sections.

The average AMV and PMV values for all classrooms are equal to 0.15 and -0.22, respectively, with a difference between them equals 0.37 units, which is within the uncertainty level in PMV prediction (±0.5) which could be related to the uncertainties in the metabolic rate and clothing insulation values.

The regression lines for the younger and older subject' actual mean vote (AMV) and the different PMV, ePMV and the PMV_{10} models with are shown in Figures 6.43 and 6.44 for younger and older subjects, to investigate the applicability of each model to predict the subjects' thermal sensation along the academic year.

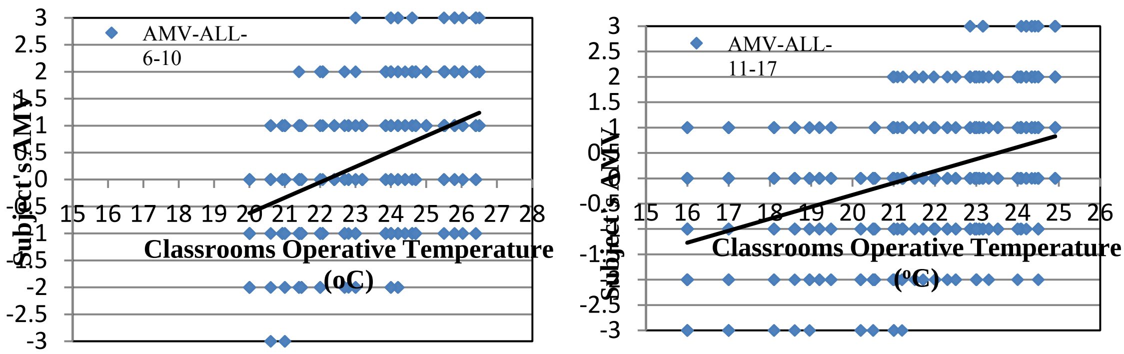

Figure 6.42a: The distribution of the younger and older children on ASHRAE scale with respect to the classrooms indoor temperatures during the three different ventilation modes throughout the academic year.

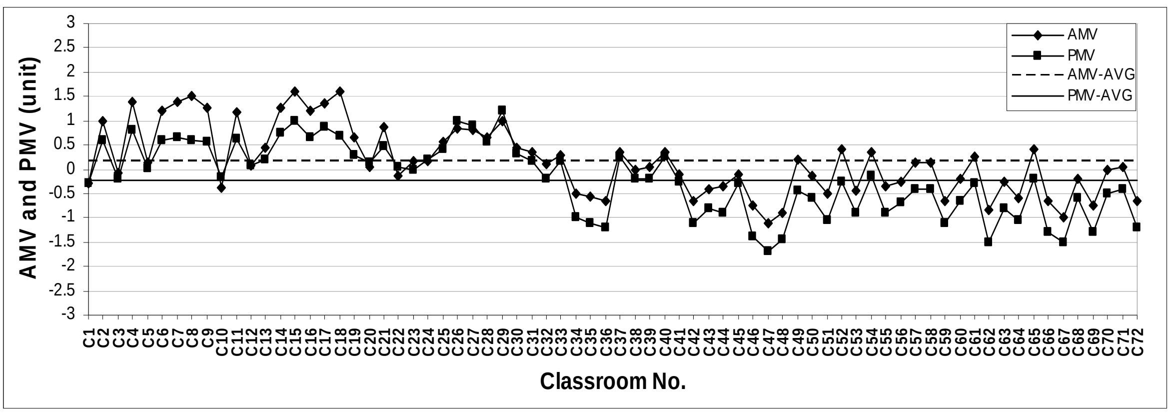

Figure 6.42b: The children's AMV and PMV votes on ASHRAE thermal sensation scale in Kuwait classrooms during different ventilation modes throughout the Academic year

From these figures it is clear that the PMV and ePMV are identical, due to the high expectancy, refer to Table 6.2, of the subjects in Kuwait classrooms (***e*** = 1). The PMV, ePMV models are always under-predicting both of the younger and older subjects' AMV votes on both sides (warm and cool) of the ASHRAE scale. The PMV10 is also under-predict the younger subjects' AMV votes on both sides (warm and cool) of the ASHRAE scale.

It is also shown in the figure that there is shift in prediction difference between the younger subjects' PMV_{10} and PMV and ePMV values occur and equal to the effect of the reduction in the metabolic rate, where the shift vanishes on the warm-hot side of the scale. This finding implies that the reduction in the younger diminish and disappear at warm the thermal conditions. The prediction differences between the PMV, ePMV models and the AMV at the neutral situation for both younger and older subjects is equal about -0.35 units, where the prediction differences between the PMV_{10} model and the younger subjects' AMV at the neutral situation is equal to -0.6 units.

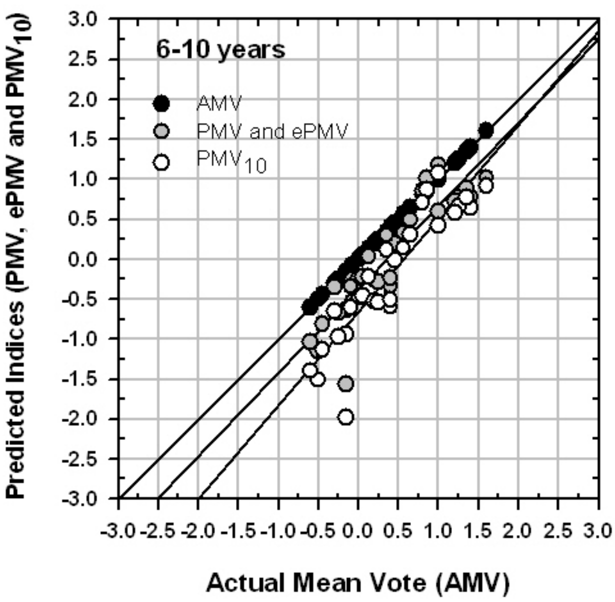

Figure 6.43: The relationship between the younger children's actual mean vote (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during all ventilation modes

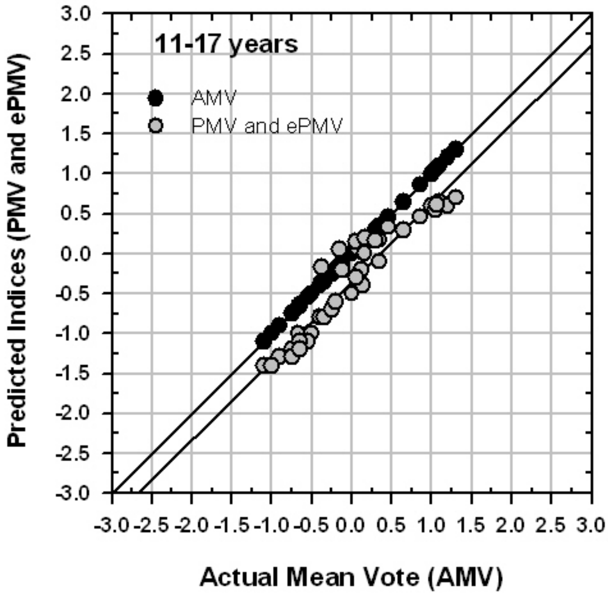

Figure 6.44: The relationship between the older children's actual mean vote (AMV) in all academic levels and the predicted indices (PMV, and ePMV) during all ventilation modes

This shift between both the PMV and ePMV and the PMV_{10} is related to the effect of the reduction in the metabolic rate, and both tend to converge with each other towards the warm side of the neutral situation. This situation, suggest that the PMV_{10} model is not appropriate to predict the children's thermal comfort sensations in Kuwait classrooms.

Predicting the neutral temperature

The values of the AMV and the predicted PMV, ePMV and PMV_{10} were regressed and plotted against the operative temperature (t_o) inside the classrooms as shown in Figures 6.45 and 6.46 for younger and older subjects, respectively. Both figures showed the predicted neutral temperatures by the different prediction models are always higher (under-predicting) than that based on prediction by the AMV model for both age groups. The PMV_{10} predicts temperatures higher (under predict) than the subject's AMVs and PMV and ePMV, which suggests that the PMV_{10} is not appropriate to predict the children's thermal comfort sensations in Kuwait classrooms throughout, the whole academic year. The neutral temperatures that resulted from the different thermal comfort indices and the recommended neutral temperatures in Kuwait using the adaptive model and various equations for the three different ventilation modes are tabulated in Table 6.10.

Results in Table 6.10 shows that the neutral temperature of both age groups according to their votes is almost the same and a small difference of 0.2°C in the neutral temperature was found between the two age groups according to their votes over all the combination of three ventilation modes throughout the academic year.

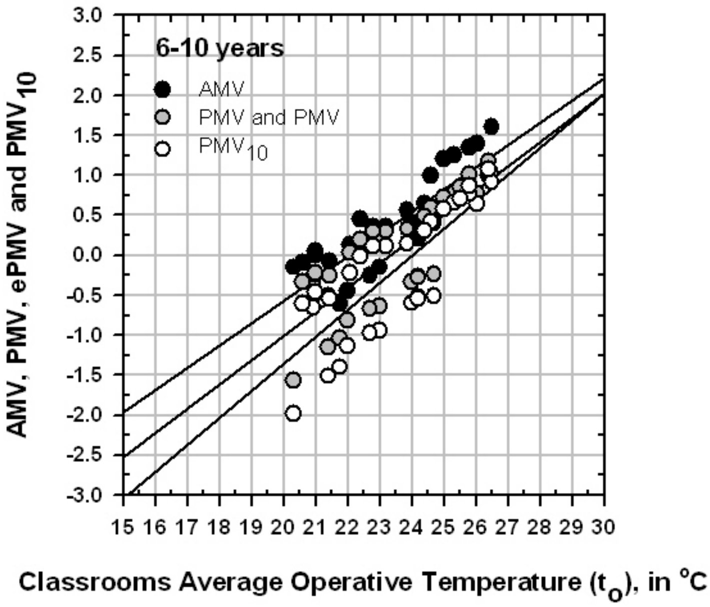

Figure 6.45: The regressed neutral temperature according to the younger's (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during all three ventilation modes

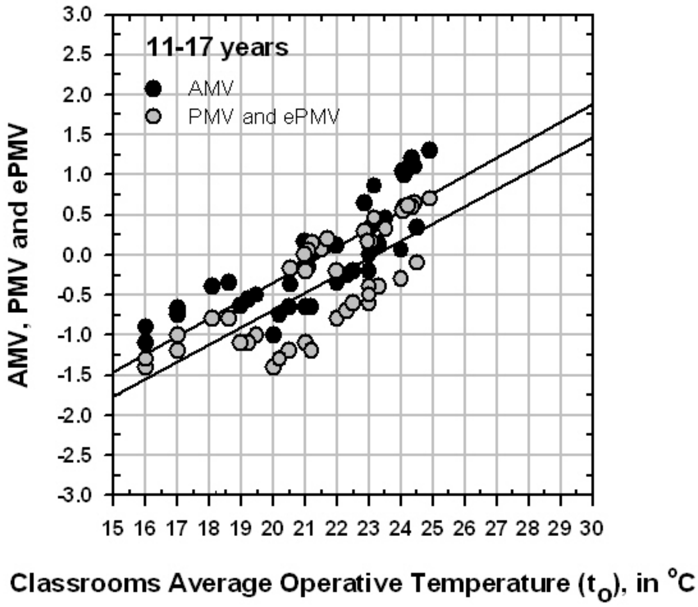

Figure 6.46: The regressed neutral temperature according to the older's (AMV) in all academic levels and the predicted indices (PMV, ePMV and PMV_{10}) during all three ventilation mode

Table 6.10: Predicted neutral temperatures using the children's mean votes various thermal comfort indices and equations during all three ventilation modes

Ventilation Mode		AMV	PMV	ePMV	PMV_{10}	De Dear & Brager, (2002) NV	Humphreys, (1978) NV&AC	Auliciems, (1981) All
	Equation					$17.8+0.31T_{a\ out}$		$17.6+0.31T_m$
Hybrid	6-10 years	21.5	22.1	22.1	23.5	24.0	22.8	23.8
	11-17 years	21.2	21.0	21.0	---	24.0	22.8	23.8
NV	6-10 years	21.1	21.9	21.9	22.7	22.7	20.5	22.0
	11-17 years	21.3	22.8	22.8	---	22.7	20.5	22.0
A/C	6-10 years	23.4	25.0	25.0	25.9	---	27.2	28.5
	11-17 years	23.2	24.9	24.9	---	---	27.2	28.5
All Modes	6-10 years	22.0	23.3	23.3	24.5	---	23.5	24.7
	11-17 years	21.8	23.3	23.3	---	---	23.5	24.7
Both	Yearly Average	21.9	23.3	23.3	---	---	23.5	24.7

Where; $T_{a\ out}$ and T_m are the monthly mean outdoor temperature.

By combining the younger's and older's votes during the different three ventilation modes in Table 6.10, the yearly average neutral temperature for the whole academic year of both genders is equal to 21.9^{o}C, where this value is lower by 1.4^{o}C than the average neutral temperature predicted by the PMV, ePMV; by 2.6^{o}C than the PMV_{10}; by 1.6^{o}C than the Humphreys' equation and by 2.8^{o}C than the Auliciems' equation. The De Dear and Brager's equation could not be utilized to predict the neutral temperature of the occupants in Kuwait for the period from May to September (5 months), because the average monthly mean temperature during this period in Kuwait (36^{o}C) is greater than the upper limit of the De Dear and Brager's equation (33.5^{o}C); refer to Figure 6.1.

All indices and equations, except De Dear and Brager's equation, are under predicting the neutral temperature for younger and older subjects' votes by a range of (1.5-3^{o}C) throughout the whole academic year, but the PMV and ePMV having the closest values to AMV than other models. This might suggest that the PMV and ePMV models are the more appropriate thermal comfort indices to predict the thermal comfort sensations of the children in Kuwait classroom during the whole academic year.

This may be attributed to the domination of the air-conditioning system operation periods inside the classrooms, during the whole academic period, where it might suggest that the classroom environment during most of the whole academic period, might still be considered as an air-conditioned mode instead of being a naturally ventilated one, whereas the adaptive approach is more applicable to the naturally ventilated environments.

Finally, the average neutral temperature for both age groups in the air-conditioned ventilation mode determined in this part of study is in agreement with the inside design temperatures required by Kuwait's Energy Code (21.1^{o}C and 23.9^{o}C for winter and summer seasons, respectively) (MEW/R-6, 2010 and MEW/R-7, 2010). On the other hand, the yearly average neutral temperature determined in this study is lower than those shown in Table 6.1 for classrooms in tropical and sub-tropical climates.

The subjects' thermal preference temperature versus the thermal neutral temperature

Neutral thermal sensations are not always representing the ideal, optimal or preferred thermal state (Kwok. 1998; Wong and Khoo, 2003; Kwok and Chun, 2003 and Al-Mutawa *et al*. 2004), this finding was found through the different ventilation modes discussed earlier. The percentage of the students' votes who wanted to be cooler and those who wanted to be warmer according to the McIntyre thermal preference used in different ventilation modes in this study, were regressed and plotted against the classrooms operative temperature for the three different ventilation modes to investigate the students' preferred temperatures for each mode. Table 6.11 shows the differences between the thermal neutral temperatures and the preferred temperatures of both student genders under each ventilation mode. The intersection between the percentage of students' votes who wanted to be warmer and those who wanted to be cooler shown in Figures 6.47 and 6.48**,** represent the preferred temperatures by the younger and older subjects, respectively, during all three ventilation modes.

Table 6.11: Comparison between the neutral temperatures and the students' preferred temperatures under the three different ventilation modes

Children Age (years)	Ventilation Mode							
	Hybrid		Natural		Air-Conditioned		All Modes (Yearly Average)	
	NT (ºC)	PT (ºC)	NT (ºC)	PT (ºC)	NT (ºC)	PT (ºC)	NT (ºC)	PT (ºC)
6-10	21.5	20.6	21.0	19.8	23.4	22.0	22.0	20.8
11-17	21.2	20.1	21.3	20.3	23.2	22.0	21.9	20.8
All	21.4	20.4	21.2	20.1	23.3	22.0	22.0	20.8

NT: neutral temperature and PT: preferred temperature.

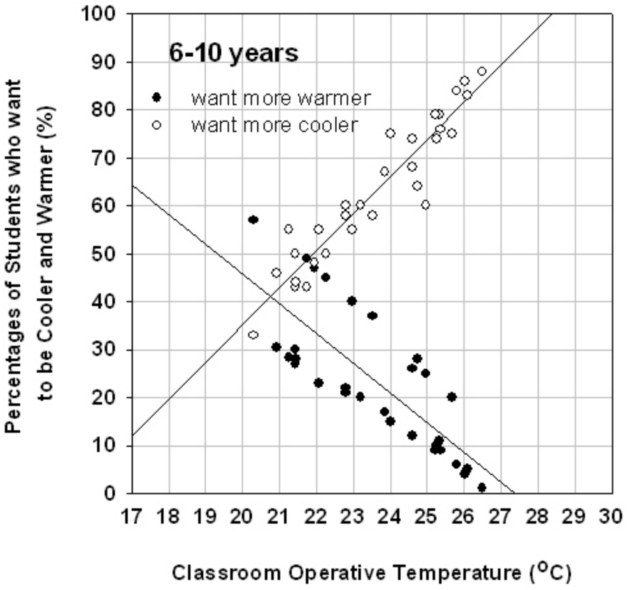

Figure 6.47: The preferred temperature due to the percentage of younger subjects who want to be cooler and warmer in all academic levels during all three ventilation modes

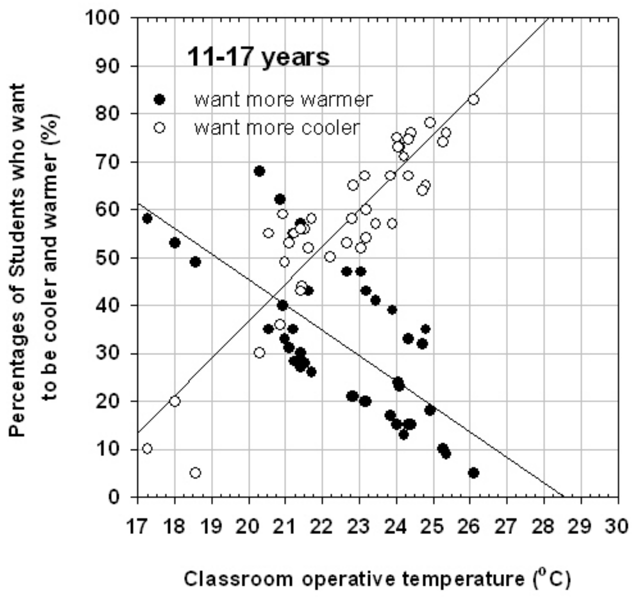

Figure 6.48: The preferred temperature due to the percentage of older subjects who want to be cooler and warmer in all academic levels during all three ventilation modes

From Table 6.11, it is clear that both age groups' preferred temperatures are below the neutral temperatures indicated for the three different ventilation modes. These findings are in agreement with the findings found in tropical and sub-tropical climates, (Kwok.

1998; Wong and Khoo, 2003; Kwok and Chun, 2003; Hwang *et al*., 2006 and Al-Mutawa *et al*. 2004). The yearly average difference between the preferred temperature (20.8^{o}C) and the neutral temperature (22.0^{o}C) averaged for both students age groups, is 1.2^{o}C. This difference suggested that the neutral thermal sensations do not always represent the ideal thermal state of occupants.

6.7.2 PMV model and young subjects

The AMV values was plotted and regressed against the PMV values for both age groups and for each ventilation mode as shown in Figure 6.49, to compare the differences in voting between the AMV and PMV of both age groups to investigate the applicability of PMV model to predict younger subjects' thermal sensation. From Figure 6.49, it can be seen that PMV-AMV relation along the different ventilation rate is almost the same for both age groups. The slight differences between their voting in the hybrid and nature ventilation modes can be related to the classrooms different thermal conditions, where this relation is identical during the same thermal conditions as the air-conditioned mode. This important finding confirm the applicability of the PMV model to predict the younger and older subjects' thermal sensations with the using the new designed thermal comfort questionnaire in chapter 4.

6.7.3 ASHRAE comfort zone versus Kuwait classrooms comfort zone

ASHRAE states that "a change of about 3 K in temperature is necessary to change a thermal sensation vote by one unit or temperature category", where the PMV range of -0.5 <PMV< +0.5 indicates 90% comfort satisfaction, ASHRAE (2009). The students' thermal comfort ranges according to their actual mean votes (AMV), within -0.5<AMV<+0.5 for both genders, are shown in Table 6.12, with yearly average clothing insulation values of 0.86 clo for age groups.

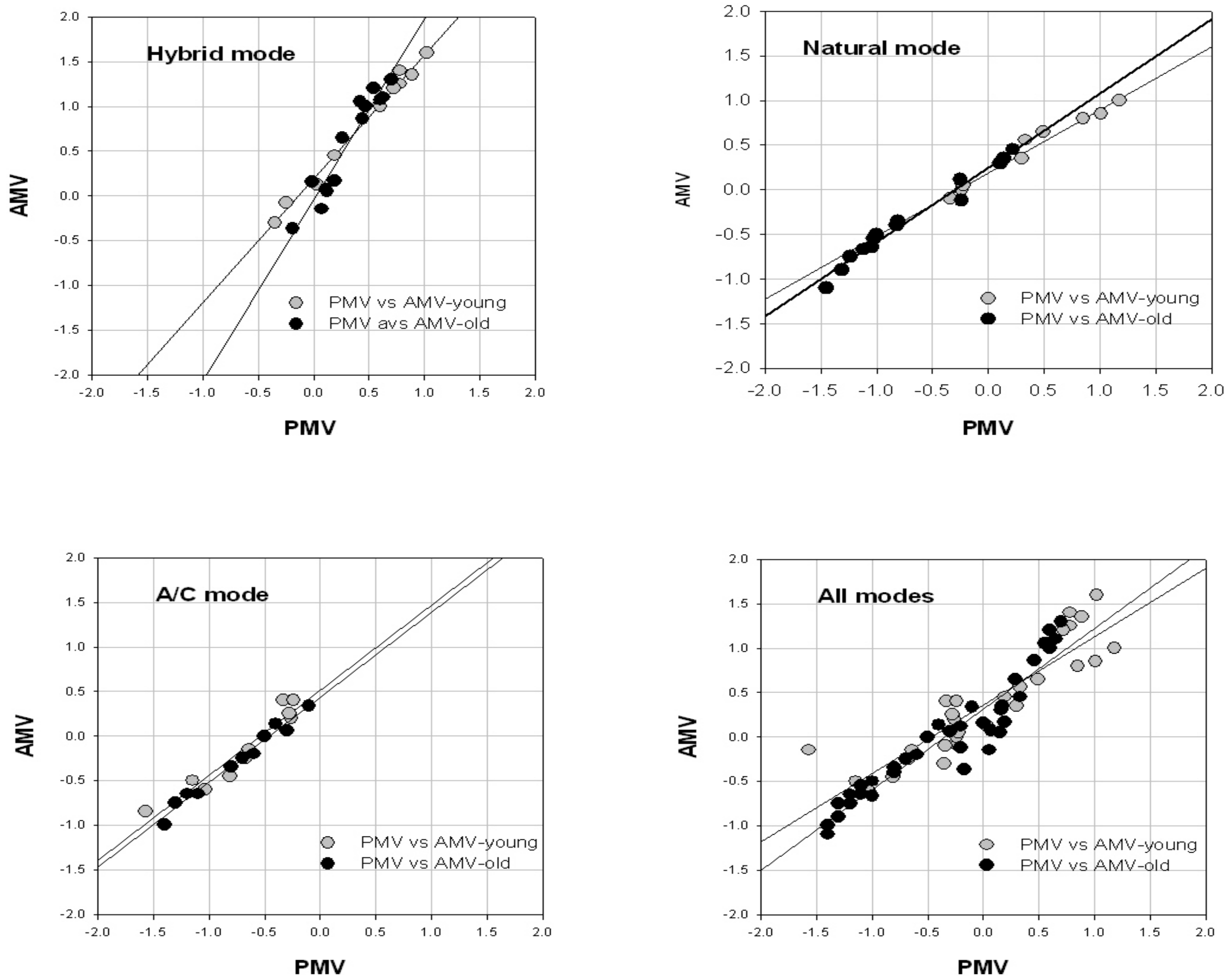

Figure 6.49: The relationship between PMV and AMV for the younger and older children during the different ventilation modes

Table 6.12: Thermal comfort ranges for both age groups under the three different ventilation modes. (0.86 clo for both age groups)

Both Genders	Ventilation Mode			
	Hybrid	Natural	Air-Conditioned	Yearly Average (All Modes)
Thermal Comfort Range (°C)	19.9 – 22.9	19.8 – 22.8	21.8- 24.8	20.4 – 23.4

The indoor thermal conditions or the comfort zones of ASHRAE 55 (2004) standard were reviewed and updated by many researchers, to specify the comfort zone acceptable by 80% of the occupants doing sedentary, or slightly more, activity with clothing insulation values of 0.5 clo and 1.0 clo.

By comparing the student's thermal comfort ranges in Table 6.12 with the thermal conditions or comfort zones presented by ASHRAE 55 standard, it is clear that the ASHRAE 55 standard comfort zones did not accurately cover the entire comfort zone of Kuwaiti students. The range of the upper and lower humidity levels of the ASHRAE 55 comfort zone is greater than that preferred by Kuwaiti people (Al-Mutawa *et al*., 2004). In addition, the recommended or preferred indoor relative humidity (50%) in Kuwait is determined to be slightly greater than that recommended by ASHRAE 55 standard (46%), (ASHRAE 55, 2004; Al-Mutawa *et al*., 2004, MEW/R-6, 2010 and MEW/R-7, 2010).

Figure 6.50 illustrates the ASHRAE comfort zone (black envelope); Kuwait schools comfort zone (black dashed envelope); while the yearly average comfort zone for Kuwaiti students is shown in the black box shape with an operative temperature range from 20.4°C to 23.4°C. Again, this range of thermal comfort is in agreement with Kuwait's Energy Code (inside design temperatures of 21.1°C and 23.9°C for winter and summer seasons, respectively) (MEW/R-6, 2010 and MEW/R-7, 2010).

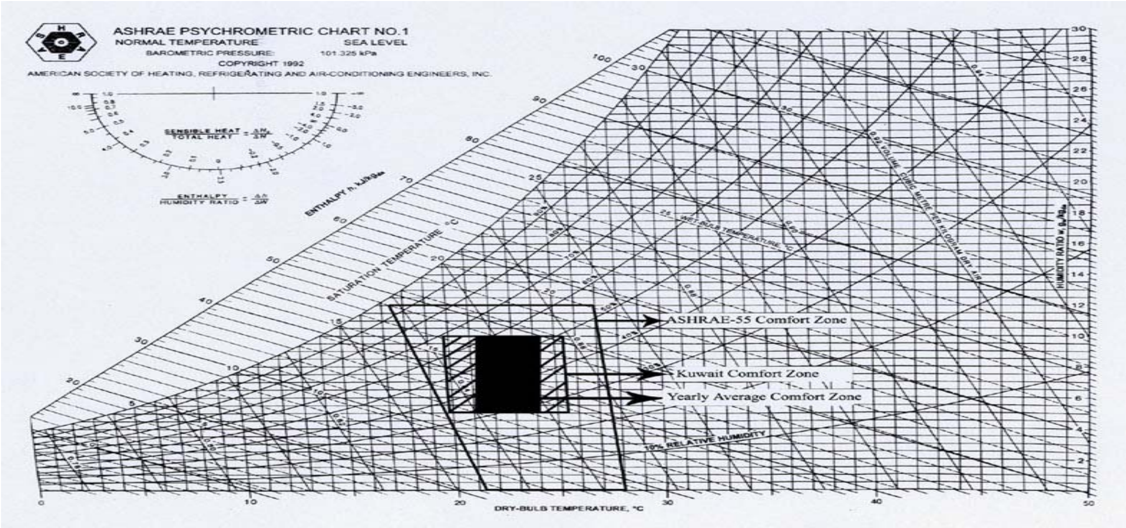

Figure 6.50: The ASHRAE psychrometric chart including the ASHRAE comfort zone (black envelope); Kuwait schools comfort zone (black dashed envelope) and the yearly average comfort zone for Kuwaiti students (black box shape)

6.7.4 Thermal comfort in Kuwait classrooms and energy conservation

The demand for electricity in Kuwait has been significantly increasing due to industrial; economical; urbanization developments and the increase in housing and public utilities. Because of the harsh climate in summer in Kuwait, most of this demand is extensively consumed by air-conditioning to provide acceptable indoor thermal comfort environment for occupants. The peak power consumption of air-conditioning systems reaches 70% of the total generated power during summer season. The Ministry of Electricity and Water (MEW) in Kuwait published in 1983 an energy conservation code (MEW/R-6, 2010) specifying the rules and regulations for designing air-conditioning systems under Kuwait's environmental conditions (MEW/R-7, 2010). According to this code, the recommended indoor and outdoor dry-bulb design temperatures are 23.9^{o}C and 48^{o}C, respectively, for Kuwait summer conditions.

The average student's neutral temperatures determined in this study in Kuwait classrooms during the different ventilation modes; air-conditioned ventilation mode (summer season); natural ventilation mode (winter season) and the hybrid ventilation mode have close agreement with the code's summer and winter design temperatures in Kuwait. On the other hand, the yearly average neutral temperature found in this study (21.9^{o}C) is less than the code's recommended summer designed temperature by about 2^{o}C. If adopted, this difference would be expected to increase the power plants loads and energy consumption in Kuwait classrooms by about 10% (MEW/R-6, 2010). In addition, providing temperatures that are preferred by the students, to meet their preferred thermal comfort conditions, could result in tremendously increasing the energy consumption inside Kuwait classrooms. This point must be studied further in the future in order to investigate the benefits of increasing the cooling loads and energy consumption on the student's learning performance, health and productivity.

6.7.5 Conclusions

- The combination of the three different ventilation mode shows that all the thermal comfort indices have under-predicted the student's along the ASHRAE.
- The PMV and ePMV indices have similar effects in Kuwait climate where the expectation level of the occupants is high.
- The PMV and ePMV models are the more appropriate thermal comfort indices to predict the thermal comfort sensations of the younger and older subjects in Kuwait classroom with the use of the new designed thermal comfort questionnaire, chapter 4, during the different ventilation modes throughout the academic year.
- This may be attributed to the domination of the air-conditioning system operation periods inside the classrooms, during the academic period, where it might suggest that the classroom environment during most of the whole academic year period, might still be considered as an air-conditioned mode instead of being a naturally-ventilated one, whereas the adaptive approach is more applicable to the naturally ventilated environments.
- The neutral temperatures of the younger and older subjects are 22.0^{o}C and 21.8^{o}C, respectively, during the whole academic year, which implies that there are no significant differences between both age groups regarding to the PMV-AMV differences between the two groups.
- The subject’s neutral temperature in air-conditioned environment is in agreement with other studies conducted for offices in Kuwait, for classrooms in Japan and Kuwait, and also with the inside design temperature conditions

required by the Kuwaiti's Energy Code (23.9^{o}C and 21.1^{o}C for summer and winter, respectively).

- The subject's yearly average neutral temperature (21.9^{o}C) under the three different ventilation modes in Kuwait is lower than that indicated for tropical and sub-tropical climatic zones, this may related to the higher insulation values worn by the subjects in Kuwait classrooms.
- The yearly average comfort zone for Kuwaiti subjects, according to their actual mean votes (AMV) within -0.5<AMV<+0.5 for both age groups, and with the yearly average clothing insulation values of 0.87 clo, have its operative temperature ranges from 20.4^{o}C to 23.4^{o}C., where this range of thermal comfort is also in agreement with Kuwait's Energy Code.
- Kuwaiti students preferred a yearly average temperature of (20.8^{o}C) which is 1.1^{o}C lower than their neutral temperature (21.9^{o}C). This difference suggested that the neutral thermal sensations do not always represent the ideal thermal state of occupants.
- The average student's neutral temperatures determined in this study in Kuwait classrooms during the different three ventilation modes are in close agreement with the code's summer and winter design temperatures in Kuwait, where the yearly average neutral temperature determined in this study (21.9^{o}C) is less than the code's recommended inside designed temperature by about 2^{o}C. This difference if adopted would be expected to increase the power plants loads and energy consumption in Kuwait classrooms by about 10%. In addition, providing temperatures that are preferred by the students, to meet their preferred thermal comfort conditions, could increase the energy consumption inside Kuwait classrooms. This point must be studied further in the future in order to investigate the benefits of increasing the cooling loads and energy consumption on the student's learning performance, health and productivity.

Chapter 7
Investigating the Relationship between the Ventilation Rates and the Students' Performance in Kuwait Classrooms during Different Ventilation Modes

7.1 Chapter Summary

The thermal comfort work reported in the previous chapters has been extended to include the influence of the ventilation modes on classroom air quality and its likely effect on pupil performance. In this field study, the CO_2 concentration levels have been investigated during natural and air-conditioned ventilation modes inside 10 elementary classrooms in 3 Kuwaiti school occupied by children in the 6-10 years age group. The findings showed that these classrooms have lower average CO_2 concentration levels (708 ppm) during their natural ventilation mode than that found for their air-conditioned mode (1596 ppm). Results suggested that the inappropriate selection of ventilation system type (wall-mounted split air-conditioning units) inside the classrooms is the main reason for the raised the CO_2 concentration levels. This latter type of ventilation system involves on air recirculation inside the occupied zone and provides no outside air (fresh air), except that from infiltration. Although this type of ventilation systems may have been specified to minimize energy consumption, it is not suitable for high occupancy zones like classrooms due to its inability to reduce the pollution level inside the classrooms, which may affect the children's health and performance.

According to the literature, reducing the CO_2 levels during the air-conditioned mode to the levels found during the natural ventilation mode (or standard levels) may increase the students' and staff's performance by at least 7% (Ito *et al.*, 2006; Murakami *et al.*, 2006; Wargocki and Wyon, 2006, 2007a and b; and Bako-Biro *et al*, 2007). Some remedial solutions were tested in this field study is an attempt to reduce classrooms CO_2 levels when operating in the air-conditioned mode and thus potentially enhance the students' and staffs' performance. Changing the existing air ventilation systems to central air-conditioned systems is one of these suggested solutions. In the meantime, we recommended that some means for fresh air make-up are arranged in these types of installation (e.g. partially open windows) and this has been communicated to the Kuwait Ministry of Education (MOE). However, more studies are needed to investigate the impact of this change on students' performance inside the classrooms together with implications for energy consumption and national costs.

7.2 Introduction

In recent years, indoor air quality (IAQ) has become an internationally recognized issue that has caught the attention of researchers and occupants toward improving the quality of air inside buildings. Indoor air quality (IAQ) is defined as the desire of humans to perceive the air as fresh and pleasant, with no negative impacts on their health and productivity; this is important in schools to enhance the children's learning and performance (Fanger, 2006). People, especially students, spend more than 90% of their life in indoor environments. Children in schools are usually taught in groups, and thus are exposed to indoor pollutant sources. Providing good indoor air quality is very important to them, where poor air quality can potentially affect the children's health, learning performance and student and staff's productivity (USEPA, 1996), which may have adverse consequences on the future of the children and the community. Investigating the indoor air and environmental quality in classrooms helps to characterize pollutant levels and provides the guidance to deliver good air quality conditions inside classrooms. Indoor air quality can be influenced by outdoor air pollution sources such as traffic, industrial, construction, and combustion activities (Wark and Warner, 1981), and indoor sources such as ventilation equipment, furniture, and human activities (number of students, lessons durations, breaks between lessons).

Research such as that of Daisey *et al*. (2003), and Mendell and Heath (2005) reviewed information presented by many recent studies about the relationship between the indoor air quality in classrooms, and the students' absence, health, or learning performance and productivity. Researchers realized that inadequate ventilation is a major factor affecting the student's health and performance. Abundant information has been provided by many studies about investigating the associations of students' health and learning performance with different environmental parameters such as the types of ventilation systems, ventilation rates, indoor temperature and humidity, concentrations of chemical and microbiological pollutants, and amount of daylight in classes (Pepler, 1968; Green, 1974, 1985; Norback *et al*., 1990; Ruotsalainen *et al*., 1995; Myhrvold *et al*., 1996; Myhrvold and Olsen, 1997; Smedje *et al*., 1997; Koo *et al*., 1997; Wålinder *et al*., 1997 a,b, 1998; Meyer *et al*., 1999; Lee and Chang, 1999; Åhman *et al*., 2000; Smedje and Norbäck, 2000; Heschong, 2002; Sahlberg *et al*., 2002; Shendell *et al*., 2004; Seppänen and Fisk, 2004; Griffiths and Eftekhari, 2008). Some of these studies have found an associative linkage between these environmental parameters and the students' health, attendance and performance.

7.2.1 The Effect of CO_2 Level on the Student's Learning Performance and Productivity

Carbon dioxide (CO_2) is one of the important indoor environmental parameters that must be controlled, where high CO_2 levels can affect the students' health, learning performance and productivity. Smedje *et al*. (1996) investigated the effects of indoor air quality in classrooms on the mental performance of secondary school pupils. They reported that the reduction in performance was related to low ventilation rates. Myhrvold *et al*. (1996) conducted a study to investigate the relationship between the CO_2 concentrations inside classrooms and pupils' health and performance. The authors demonstrated that reaction and performance tasks of pupils inside classrooms, according to the Swedish Performance Evaluation System Test (SPEST), was reduced at low ventilation rates (i.e., high CO_2 concentrations). A study was conducted by Coley *et al*. (2007) to investigate the effect of low ventilation rates on the cognitive function of a primary school class using standardized and computerized tests of cognitive functions. This study reported that at high CO_2 concentration levels in classrooms, the students' attention processes are scientifically slower, where the "power of attention" can decrease by 5% in increased level of CO_2. In a study conducted in Dutch primary schools, Dijken *et al*. (2005) found that the CO_2 level in 11 classrooms out of 12 were above the recommended CO_2 level of 1000 ppm. In one week study on naturally ventilated classroom during the heating season, Griffiths and Eftekhari (2008) investigated the ventilation rate by monitoring the CO_2 level inside the classroom and compared it to the existing guidelines. Although the thermal comfort inside the classroom was sometimes compromised, ventilation was shown in this classroom to be compatible with the guidelines. The authors noticed that the ventilation inside the classrooms was controlled by the teaching staff and the pupils according to their thermal comfort rather than the air quality. The CO_2 level measurements demonstrated that in order to maintain the CO_2 levels inside the classroom below 1500 ppm, as recommended by UK building Regulations, Part F (Building Bulletin 101, 2006), then the classrooms required more than just trickle ventilation. Another field study was conducted by Clements-Croome *et al*. (2008) in 20 primary schools in the UK to investigate the relationship between the IAQ and the ventilation rates on the pupils' health, well-being and performance. The authors found that CO_2 levels can rise to very high levels (about 4000 ppm), which is in agreement with the works of Awbi and Pay (1995) and Cole (2004), and that these high levels of CO_2 may adversely affect the pupils' learning. Most of the available data have shown that higher CO_2 concentrations in classrooms have been associated with increased frequency of health symptoms, increased students' absences, and decrease in learning performance of the school students and the students' and staff's productivity (Myhrovld and Olsen, 1997; Lee and Chang, 1999; Lugg and Batty, 1999; Carrer *et al*., 2002; Daisey *et al*., 2003 and Shendell *et al*., 2004).

7.2.2 Classroom Ventilation Rates and Student's Learning Performance and Productivity

Natural or mechanical ventilation provide means for reducing and diluting the concentrations levels of the indoor air pollution generated by the indoor pollutants. Inadequate ventilation in classrooms may have bad effects on the IAQ inside classrooms (Seppänen, 2003), where poor IAQ could have a negative impact on children's learning (Fanger, 2006). ASHRAE developed the ventilation standard ASHRAE 62 (2004), for many different kinds of buildings and spaces. A minimum ventilation rate of 7.5 L/s (15 ft^3/min) per occupant in classrooms is recommended in this standard, with a typical occupant density of 33 persons per 90 m^2 (1000 ft^2) and ceiling height of 3 m (10 ft). The current ASHRAE standard would require an air exchange rate of about 3 air changes per hour (ACH) for classrooms. Heating, ventilating and air conditioning (HVAC) systems are not only providing thermal comfort for occupants, but should also provide good IAQ by supplying and distributing adequate fresh air and removing pollutants. These systems may provide inadequate ventilation if they are not well designed or have installation problems or are poorly maintained.

Measuring the actual indoor CO_2 concentrations in any space or zone is an expensive and potentially problematic issue because they are a function of occupant and ventilation rate, where both are varying as a function of time (Daisey *et al*., 2003 and Shendell *et al*., 2004). For these reasons, ventilation rates in any space or zone can be inferred from the carbon dioxide measurements, where Lee and Chang (1999) and Daisey *et al*. (2003) stated that the indoor concentration of carbon dioxide (CO_2) has often been used as a surrogate for the ventilation rate per occupant, including in schools. In classrooms and offices, the source of CO_2 is the occupants' metabolic production, causing the indoor CO_2 concentrations to exceed outdoor concentrations. In addition, since the ventilation process is only a process for CO_2 removal, the ventilation rate of the outside air flow can be estimated if the CO_2 concentrations of the supply air or room air are known. ASHRAE Standard 62 (2004) expressed the difference between 'adequate' and 'inadequate' ventilation, by reporting that, for classrooms, the ventilation rate is inadequate if the indoor CO_2 concentration exceeds 1000 ppm during the school day, where as recommended by UK building Regulations, Part F (Building Bulletin 101, 2006) must be below 1500 ppm during the school day. From worldwide field studies about ventilation rates and the students' performance, Myhrvold and Olesen (1997) conducted a field study in 35 Norwegian classrooms to determine the students' concentration by measuring their reaction times with different ventilation rates. They found that by increasing the ventilation rate per person from 4 L/s to 12 L/s, the students' reaction times were 5.4% less (i.e. faster). In three learning performance studies conducted by Ito *et al*. (2006) and Murakami *et al*. (2006) in Japanese classrooms using three subjects groups (Theoretical, Memorization I and Memorization II), researchers found that by increasing the ventilation rate from 0.6 to 5 L/s per person, the learning performance was improved 5.5%. Wargocki and Wyon (2006; 2007a and b) investigated the impact of increasing the ventilation rate on the performance of 10 year old school children using parallel performance of tasks representing 8 different school work (from reading to mathematics). The authors found that by increasing the ventilation rate from 5 to 10 L/s, the school work performance improved by 15% and caused noticeable impairment in children's school performance and learning. In two UK classrooms, it was found that the pupils' work rate increased by 7% in the mathematical tests of addition and subtraction as a result of increasing the supplied fresh air from 0.3-5 to 13-16 L/s (Bako-Biro et al, 2007).

Based on the information reviewed, the main objectives of this part of the study reported here are:

- To measure and compare the indoor CO_2 concentrations in classrooms located in different regions in Kuwait equipped with two different types of ventilation modes (air-conditioned and natural ventilation modes)
- To compare these measurements with that found in ASHRAE standard 62 for classrooms and similar studies conducted elsewhere and reported in the literature.
- To investigate the potential impact of the CO_2 measurements on the students' performance and productivity according to the existing literature studies.
- If appropriate, suggest some remedial solutions to enhance the IAQ inside the classroom environment to enhance the students' and staff's performance.

7.3 Methodology

7.3.1 Study Background

Kuwait is a hot and dry country that lies between 28^o and 30^o N latitude and 45^o E longitude. Kuwait's environment is described as being very hot during summer where the temperature can reach 48^{o}C (July and August) in the afternoon and sometimes can exceed 55^{o}C. It has a desert climate which is characterized by the high percentage of sunshine, wide diurnal temperature extremes and little rainfall where the average summer relative humidity is about 18%, MD (2004). Therefore, most buildings extensively use air-conditioning systems during summer while in winter the weather is cold and dry and the air conditioning systems are not in use. The indoor design conditions in Kuwait are 24^{o}C and 50% relative humidity, MEW/R-7 (2010).

Most of the present school buildings in Kuwait are old (more than 30 years old) and were designed to be mechanically ventilated with ceiling fans. At the beginning of the 1990s, school buildings in Kuwait were extensively constructed or renovated. Two wall mounted split air-conditioning units (no outside fresh air) with typical filters type were installed in each classroom (each unit has two tons of refrigeration capacity), to provide comfortable thermal conditions and at the same time to save energy compared to central air-conditioning systems. Due to the lack of attention to the importance of the air quality inside the classrooms, these types of air-conditioning system were frequently installed may become a source of pollution due to air recirculation and low maintenance, and was have long and short term impacts on the students' and staff's health and performance. In addition, the control of those systems is not under the direct control of the students and the staff, and may have a negative effect on the student's health and comfort, and on the HVAC systems' energy consumption. Each school consists of not less than 20 classrooms in the different academic levels (elementary, intermediate and secondary), and each classroom has an average floor area of 56 m^2 and is of 3 m height, while it is sometimes occupied by more than 25 students.

The academic year in Kuwait lasts for nine months, and starts from the beginning of September and extends to the end of June, with about one month of school vacation in the winter (usually between January and February).

The question of indoor air conditions and quality in classrooms has to be seriously considered because children are still physically developing, where poor indoor air conditions and quality could affect the children's health and may indirectly affect their learning and performance – this may have detrimental consequences for them and society's future.

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7.3.2 Classrooms Selection and Data Collection

The field study was conducted in 10 elementary classrooms in a school located in a residential area, where the student's ages range from 6-10 years. The study was conducted in the presence of the teachers or some school administrators. The measurements were taken in two different ventilation modes (natural and air-conditioned modes) to investigate the effect of the different types of ventilation modes on the CO_2 concentrations inside the classrooms. The same classrooms were considered to ensure that they have the same infiltration and leakage conditions. The classrooms' indoor temperature and indoor and outdoor CO_2 concentrations, in addition to the ventilation rate were measured, where the outside temperature (T_{out}), wind speed (WS) and wind direction (WD) are collected from the meteorological department of the nearest meteorological station (airport station). The measured data for the naturally ventilated mode were collected during the period of March 1st- 15th, 2010, while the data for the air-conditioned ventilated mode were collected during the period of May 16th – 27th, 2010.These data correspond to that when those modes are normally used.

7.3.3 Objective Measurements

The measuring equipment consisted of a new Telaire 7001D sensor by the General Electric GE company (manufacturer's calibration) and was used to measure: indoor and outdoor CO_2 concentrations, scale ranging from 0-10000 ppm (accuracy of ±50 ppm and reliability of ±20 ppm); the equivalent ventilation rate based on the indoor/outdoor CO_2 differential readings (dCO_2); indoor temperature (±1^{o}C) and the relative humidity (±5%) inside the classrooms during the school day. The equipment was held manually and placed in six different locations, five locations inside the classroom at 1.5 m height close to the students' breathing level and not directly underneath the supply air diffusers, and one location outside the classrooms. The outdoor conditions were provided from the meteorological department of the nearest meteorological station (airport station). The equipment was held manually for 30 seconds before taking the measurements in each location. The measured data for the indoor and outdoor CO_2 concentrations were continuously monitored and recorded every 15 minutes time basis during the experiment. Results of this part of the study were compared to ASHRAE Standard 62 (2004) recommendations for CO_2 concentration level inside the classrooms and the required ventilation rate.

Based on the measured CO_2 data, the difference between the measured indoor and outdoor CO_2 concentrations (dCO_2) was calculated. The dCO_2 is only an approximate surrogate for ventilation rate because it is based on measurements made at a wide range of times throughout the school day.

7.4 Results and Discussion:

7.4.1 Effects of the Ventilation Mode on the CO_2 Levels inside Kuwait Classrooms

The average values for the inside and outside parameter, for the ten classrooms during a school day from 7:30 am to 14:00 pm, and for the different ventilation modes (natural and air-conditioned) are shown in Table 7.1. They are also illustrated in Figures 7.1 and 7.2 for naturally (NV) and air-conditioned (AC) ventilation modes, respectively. The ventilation rates were measured by the Telaire 7001D sensor according to the difference between the indoor and outdoor CO_2 concentrations (dCO_2). From Table 7.1, it is clear that during the air-conditioned (AC) mode inside the classrooms, the CO_2 concentration levels in the air-conditioned ventilated mode rose up rapidly to levels (average = 1596 ppm) higher than that found in the naturally ventilated classrooms (average = 721 ppm). The average ventilation rate during the natural ventilation (NV) was measured using the Telaire 7001D equipment by measuring the dCO_2 and was found to equal 8.7 L/s/p.

That is because in the natural ventilation mode the windows and doors of the classrooms are opened to provide airflows and high air change rates inside the classrooms for comfort conditions, whereas in the air-conditioned mode the windows and doors are closed, there is no fresh air make up with such split units, and thus these is no ventilation inside the classrooms, only re-circulation of room air. The only fresh air make up comes from the infiltration from the classroom cracks. Closing the classroom windows and doors in the air-conditioned mode is due to the regulation of the Ministry of Education regarding energy conservation and dust prevention inside the classrooms. The variations of the CO_2 concentration levels inside the 10 classrooms during the natural ventilation (NV) and air-conditioned ventilation (AC) modes are shown in Figures 7.1 and 7.2, respectively. From Figure 7.1, it is clear that due to the opening of the classrooms' windows and doors and the high fluctuation of the outside wind speed during this ventilation mode, the CO_2 levels in the NV mode are rapidly varying and fluctuated during the school day, where most of the maximum CO_2 peaks in the ten classrooms are about 1100 ppm (average maximum peaks = 1050 ppm) are within the recommended level of the standards.

Table 7.1: Measured CO_2 concentration levels, ventilation rates, and outdoor conditions for 10 classrooms in natural ventilation and air-conditioned modes during the school day

Classroom No.	Children's age (y)	Classroom Ventilation Type																		
		Natural									Air-Conditioned									
		$CO_{2,in}$ (ppm)			$CO_{2,out}$	VR	T_{in}	T_{out}	WS	WD	$CO_{2,in}$ (ppm)			$CO_{2,out}$	AR	T_{in}	T_{out}	WS	WD
		Min.	Max.	Avg.	(ppm)	(L/s/p)	(°C)	(°C)	m/s		Min.	Max.	Avg.	(ppm)	(L/s/p)	(°C)	(°C)	m/s	
C1	8	505	953	692	505	10.5	25	24	14	N	566	2344	1679	516	20	24	40	13	NW
C2	9	495	1113	770	471	7.7	27	26	12	NW	506	2031	1501	477	20	27	42	11	N
C3	10	509	987	696	452	9	24	27	12	N	495	2560	1760	445	20	22	42	13	NE
C4	7	494	971	684	511	10.3	25	26	8	N	577	1947	1456	419	20	25	44	6	NE
C5	6	491	1030	736	505	9.1	28	30	7	N	552	2424	1612	390	20	26	42	9	N
C6	6	510	1110	706	459	7.5	28	28	8	NW	520	2180	1571	493	20	21	39	7	NE
C7	8	502	1102	709	496	8	27	29	8	NW	489	2112	1510	401	20	23	40	14	N
C8	9	492	1103	743	515	7.7	30	30	7	N	583	2341	1677	375	20	20	37	15	N
C9	7	524	1215	762	464	6.5	29	31	7	N	559	2332	1747	450	20	23	39	14	N
C10	10	503	913	707	492	11.4	31	33	6	N	513	2011	1442	504	20	24	42	15	N
Average		503	1050	721	487	8.6	27	28	9	N	536	2121	1596	447	20	24	41	12	N

$CO_{2,in}$: indoor CO_2 concentration (ppm) during the school day; $CO_{2,out}$: outdoor CO_2 concentration (ppm) during the school day; VR: Ventilation Rate (L/s/p); AR: Air-recirculation Rate (L/s/p); T_{in}: indoor temperature (°C); T_{out}: outdoor temperature (°C); WS: daily average wind speed (m/s) and WD: wind direction.

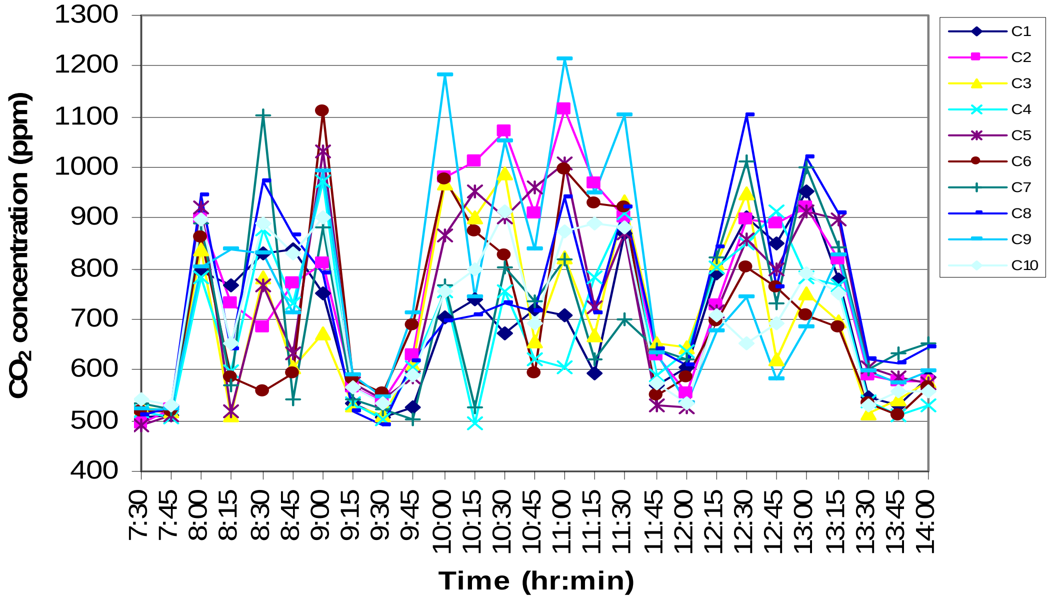

Figure 7.1: Variation of the CO_2 levels with time for the ten classrooms (C1-C10) under natural ventilation mode during a school day.

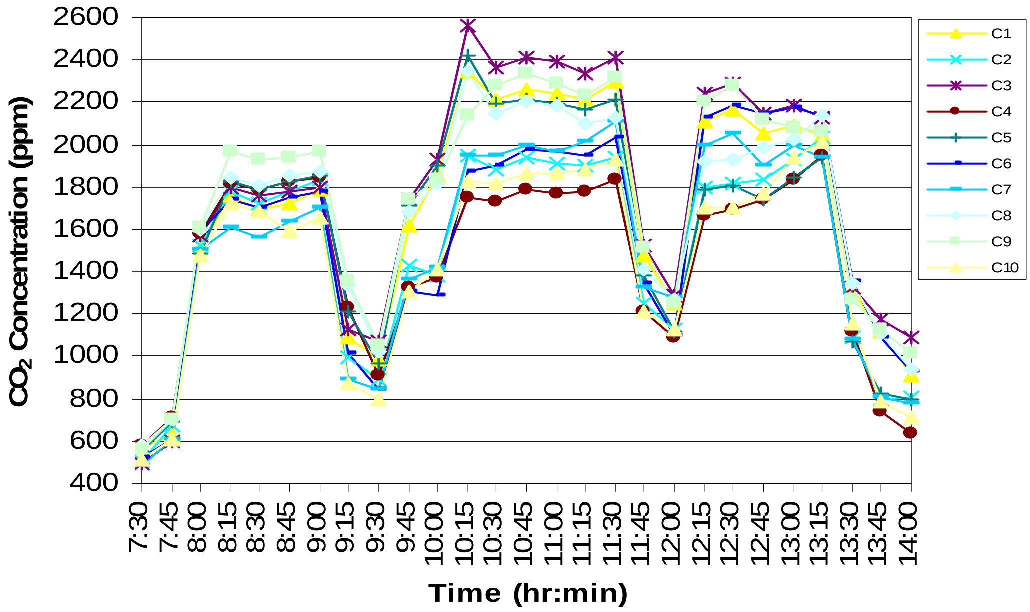

Figure 7.2: Variation of the CO_2 level with time for the ten classrooms (C1-C10) under air conditioned mode (wall-mounted split units) during a school day

During the AC mode, Figure 7.2, the CO_2 levels are raised rapidly in all of the ten classrooms due to the students' occupation in the classrooms, while the levels are decreased to lower levels during the breaks. After the breaks, the CO_2 levels reached high levels because of the students' high CO_2 production from the students' breathing due to their metabolism process. This high level of CO_2 concentration depends on the occupancy duration of the students inside the classrooms.

The comparison between the average CO_2 concentration level for the 10 classrooms during the natural and air-conditioned ventilation modes can be shown in Figure 7.3. The figure shows the high difference between the CO_2 levels inside the classrooms during the two ventilation modes.

Comparing the study findings with the recommended values of ASHRAE 62 Standard and the Kuwait Energy Code regarding the CO_2 concentration levels (1000 ppm) and the ventilation rates (7.5 L/s/p) inside classrooms, it is clear that the CO_2 concentration levels and the corresponding ventilation rate levels inside Kuwait classrooms during the natural ventilation mode meet the ASHRAE standard 62 recommendations, whereas they are not met when the classrooms are operated in the air-conditioned mode.

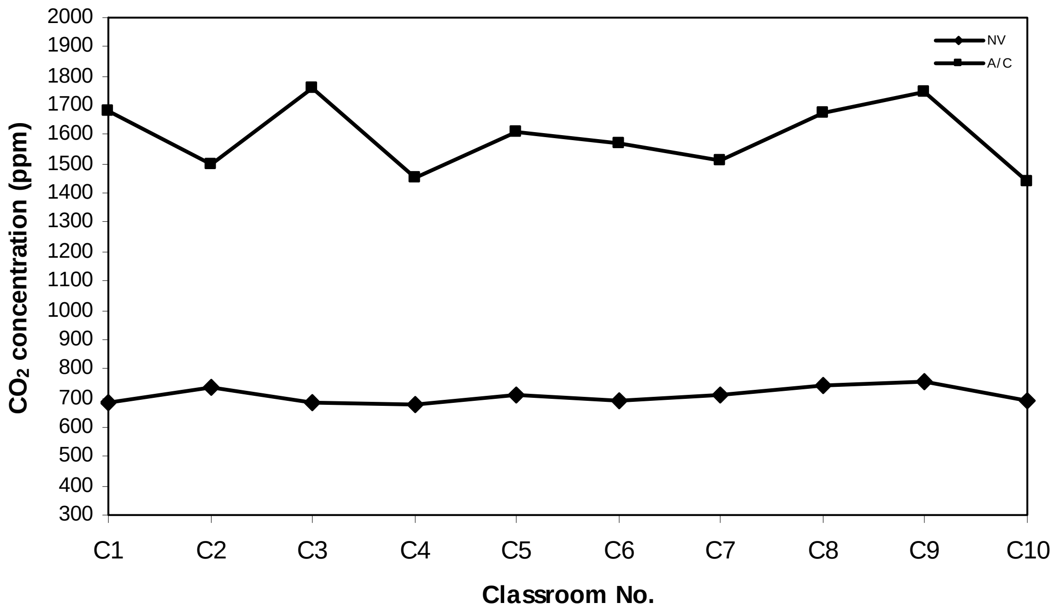

Fig.7.3: The average indoor CO_2 concentration level for the ten classrooms (C1-C10) under natural and air-conditioned ventilation modes

This can be explained by the inappropriate selection and design of the type of air-conditioning system (Lee and Chang, 1999; Corsi *et al.*, 2002; Shendell *et al.*, 2004and Mendell and Heath, 2005), where wall-mounted split units are used to cool and re-circulate, but not to ventilate, the air inside Kuwait classrooms. These types of systems are always recycling the inside air and do not provide an adequate amount of fresh air to the occupied zone which in turn increases the CO_2 levels the inside classrooms (Wong and Huang, 2004; Sekhar (2004) and Bako-Biro et al. 2007). This outcome creates a conflict with the Kuwait Energy Code which recommended 0.5 ACH (170 m^3/h) for classrooms (MEW/R-7, 2010), by using this type of ventilation system which involves no air change with the outside environment. These wall-mounted split units can provides good thermal comfort conditions in the classrooms and in addition aid energy saving by recycling the inside air. These types of systems might be suitable for zones that have low occupant density, such as residential building and offices, (less occupants to produce CO_2, in comparison to classrooms that have large number of occupants, and higher CO_2 concentrations), which means that using this type of system in classrooms may have negative impacts on the students' health and performance.

Figures 7.3 and 7.4 give an overview of the minimum, maximum, and average indoor CO_2 concentration levels in comparison with the average outdoor CO_2 concentration levels and the average ventilation rate for the ten classrooms during both naturally and air-conditioned ventilation modes, respectively. The findings are in agreement with that found by Lee and Chang (1999) regarding to the low CO_2 concentration levels in naturally ventilated classrooms than that found in air-conditioned classrooms.

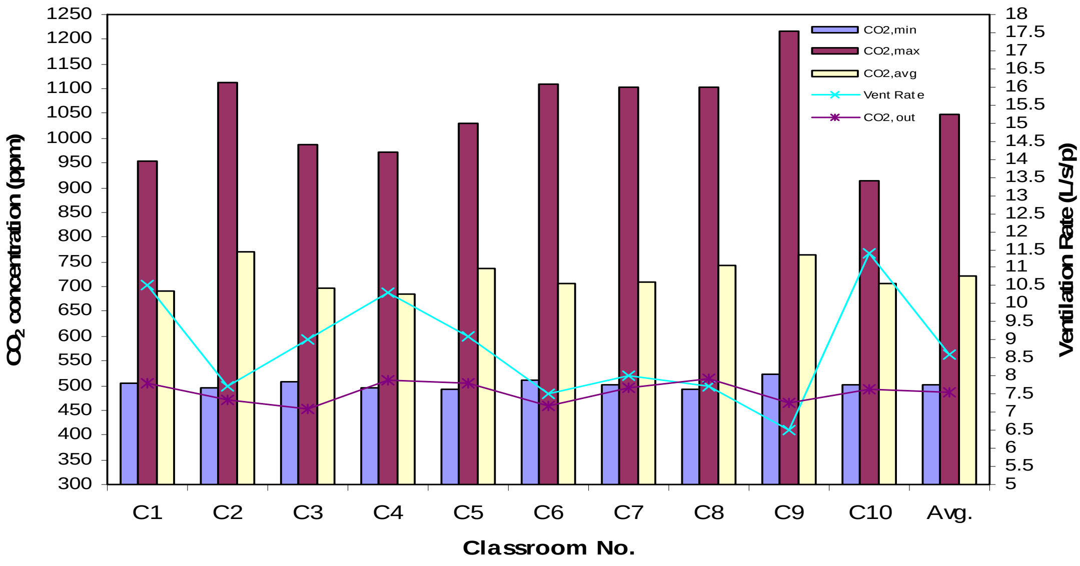

Figure 7.3: Classroom indoor maximum, minimum, average and outside CO_2 concentrations and the ventilation rate for each classroom under natural ventilation mode, and the overall average

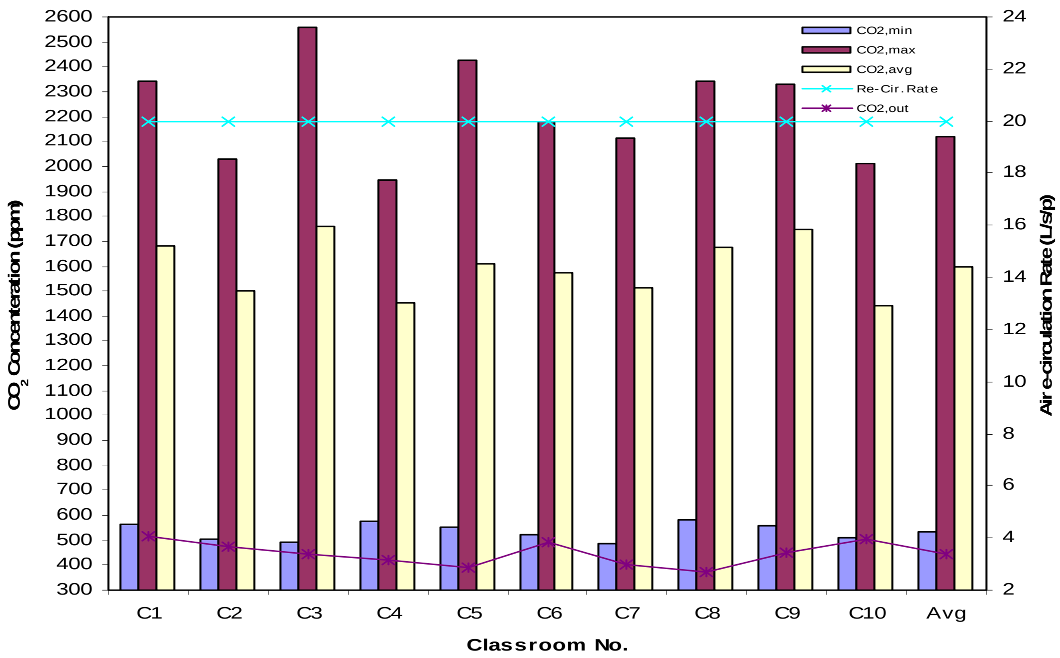

Figure 7.4: Classroom indoor maximum, minimum, average and outside CO_2 concentrations and the air re-circulation rate for each classroom under air-conditioned ventilation mode, and the overall average

7.4.2 Effect of the Outdoor Conditions on the Indoor Classroom Conditions

The school day in Kuwait starts at 7:30 am, with the lectures starting at 7:45 am. The elementary schools schedule consists as follows: start at 7:45 am with two continuous lectures, then a 30 minutes break at 9:00 am. It is then followed by three continuous lectures, then a 30 minutes morning break, which is followed by the last two continuous lectures. The duration of the school schedule is about 6 hours daily, where each lecture lasting for 40 minutes, with 5 minutes breaks between them for changing the lecturer. The average variation of the indoor and outdoor CO_2 concentrations for the ten classrooms on a typical school day during the natural ventilation and air-conditioned ventilation modes are shown in Figures 7.5 and 7.6, respectively.

In Figure 7.5 for natural ventilation mode, the CO_2 level rises due to students entering the classroom, and fluctuates until the end of morning break at 9:10, where the indoor CO_2 levels become close to the outdoor levels. This situation occurs also for the other lectures and breaks where the variations of the CO_2 concentrations levels depend on the occupied and break periods. This fluctuating variation of the CO_2 concentrations inside the classrooms is caused by closing and opening the classroom door or windows by the students according to the outdoor environment conditions (i.e. the high outside wind speed and dust …etc) during the school day, which offer different amounts of outside air to provide adequate air exchange rates that can be observed as a dilution of the indoor pollutants and CO_2 concentrations. The average CO_2 concentration levels for the classrooms in this ventilation mode are 708 ppm, which is in agreement with Lee and Chang (1999) findings for naturally ventilated classrooms. At the end of the school day and after students leave the classrooms; a noticeable rise in the outside CO_2 concentration levels occurs which might be related to the traffic emissions and other sources next to the school area (Lee and Chang, 1999), which usually increases during this time of the day.

The average variation of the CO_2 concentrations levels for the 10 classrooms during the school day in the air-conditioned mode is illustrated in Figure 7.6. From this figure, it is clear that at the beginning of the lectures and due to closing the windows and the door, the CO_2 concentrations levels rose rapidly to high levels (about 1800 ppm) and remains almost at the same level until the morning break. During the breaks and due to opening of the doors or windows by the students, the CO_2 level decreased to reach lower levels equal to the amount of fresh air entered to the classroom. In the following continuous lectures, the CO_2 levels increase to higher levels reaching more than 2100 ppm due to the generation of CO_2 by students. Again the CO_2 levels decrease to lower levels during the second break, and then rise up to higher levels in the last two continuous lectures, finally decreasing rapidly to lower levels at the end of the school day when the classrooms are unoccupied and the air-conditioning systems are shut down and the classrooms doors are opened. The average CO_2 concentration levels for the classrooms in this ventilation mode are found to be 1596 ppm. In this ventilation mode, the effect of the outside environmental conditions on the inside classrooms environment can only be noticed during the breaks.

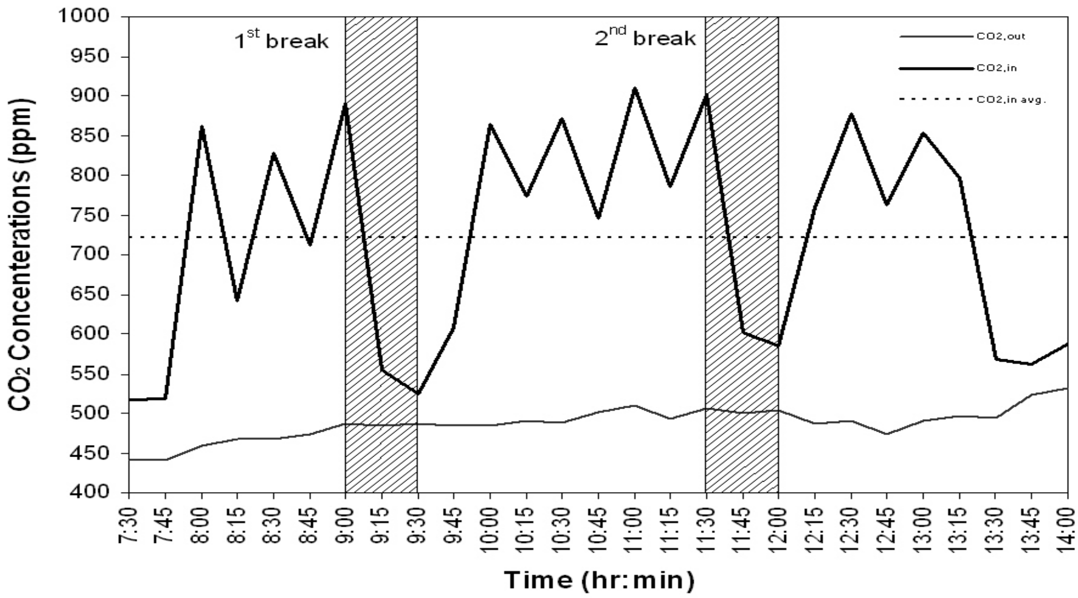

Figure 7.5: Average variation of CO_2 concentrations for the 10 classrooms with natural ventilation mode during a typical school day

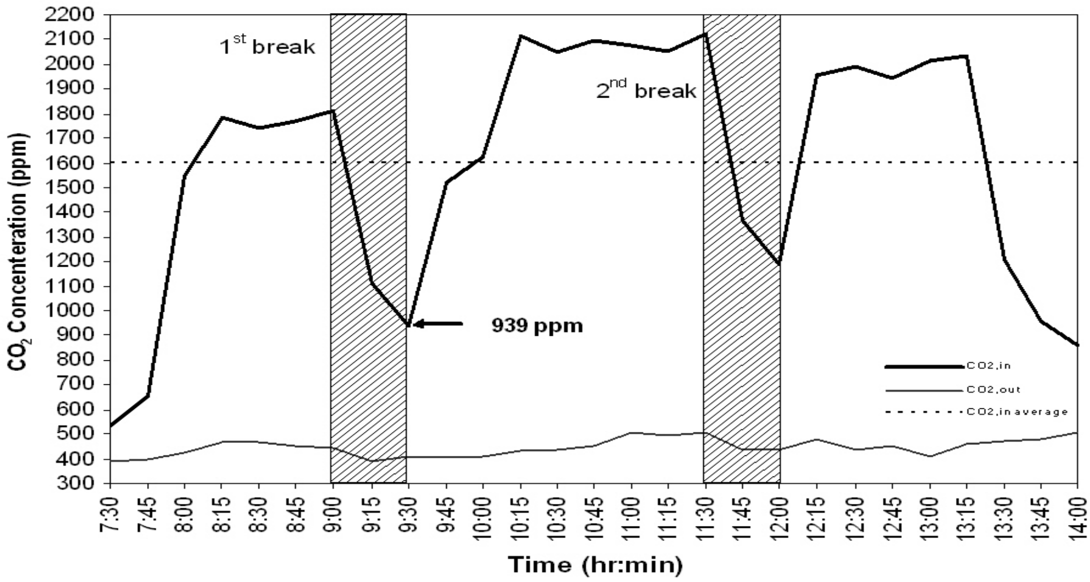

Figure 7.6: Average variation of CO_2 concentrations for the 10 classrooms with air-conditioned ventilation mode during a typical school day

This situation illustrates the relation between CO_2 concentrations inside the classrooms, the occupying periods by the students, and the air-conditioned system type employed, where inappropriate ventilation system types like that used in these Kuwait classrooms (wall-mounted split units) with large numbers of occupants and long occupying periods can result in unacceptably high CO_2 concentration levels. In the naturally ventilated mode and due to the opening of the classrooms' doors and windows, wind streams are entered to the classrooms delivering different amounts of sufficient fresh air that can provide adequate air exchange rates that can dilute the indoor pollutants and CO_2 concentrations The fluctuation of the CO_2 concentrations inside the classrooms during this mode depends on the amount of outside fresh air entered to the classroom, the number of the occupants and the occupancy period inside the classroom.

7.4.3 Effect of Ventilation Rates (CO_2 Levels) on the Students' and Staffs' Performance in Kuwait Classrooms

The measured data in Table 7.1 for the ten classrooms has shown that high CO_2 concentration levels during the AC mode and this can be attributed to the fact that windows and doors are kept closed and the ventilation is depending only on recycling the inside air with no outside fresh air make-up, leaving only infiltration as the route for any fresh air ingress, whereas in the natural ventilated mode, the classrooms' windows and doors are opened allowing fresh air to enter the classrooms. According to the ASHRAE 62-2004 standard, to reduce the average maximum CO_2 level (2121 ppm) of the 10 classrooms in the air-conditioned mode to meet the recommended (1000 ppm) requires the delivery of about 5.0 L/s/p of fresh air. According to the literature (Ito *et al*., 2006; Murakami *et al*., 2006; Wargocki and Wyon, 2006, 2007a and b; and Bako-Biro *et al*, 2007), achieving this difference can affect the students' and staffs' performance by increasing their performance by at least 7% during the air-conditioned mode. These results, which are in agreement with the findings of Wong and Huang (2004); Sekhar (2004) and Bako-Biro *et al*. (2007), emphasize that conditioning the classrooms using the existing type of ventilation system (wall-mounted split units) is not suitable with regard to the high student density inside the classroom.

7.5 Proposed Remedial Solutions to Reduce CO_2 Levels in Kuwait Classrooms

The CO_2 levels inside Kuwait classrooms, during natural ventilated (NV) mode, meet the recommended levels suggested by standards (<1000 ppm) as has been shown by this research this is clearly not the case in the air-conditioned mode, and thus some immediate remedial solutions are proposed to reduce the CO_2 levels in the air-conditioned (AC) mode in classrooms. Because air conditioning is essential in Kuwait due to the harsh weather in summer (hot and dry), these remedial solutions must be selected carefully, taking into consideration the thermal comfort of the students inside the classrooms. The suggested solutions are theoretically evaluated based on the observed rate of decrease in the average CO_2 levels (30 ppm/min) for the ten classrooms (deduced from Figure 7.6) during the school day breaks (9:00-9:30 am and 11:30-12:00 am) to reach the lowest observed CO_2 level (939 ppm).

7.5.1 Solution 1: Increasing the breaks

One immediate solution might be to increase the number of short breaks between the continuous lectures in addition to the main school day breaks. The numbers of the proposed short breaks are 4 short breaks with a period of 15 minutes (8:15-8:30; 10:00-10:15; 10:45-11:00 and 12:45-13:00) in addition to the two school day main breaks (9:00-9:30 and 11:30-12:00). The average CO_2 concentration levels during the school day were recalculated for the ten classrooms and the elevation of the CO_2 levels inside these classrooms is shown in Figure 7.7. The estimated average CO_2 level for the ten classrooms using this solution was found to be 1510 ppm during the school day. It can be seen that the 4 new short breaks do not bring CO_2 levels below the recommended 1000 ppm. Thus, increasing the number of breaks is likely to be an in ineffective to this problem.

7.5.2 Solution 2: Hybrid ventilation mode

Another proposed solution is to introduce a hybrid ventilation mode, i.e. switching between the AC and NV modes, with open doors and windows during the NV mode, during some parts of the school day. The natural ventilation mode is suggested to occur in three periods (7:45-9:30; 10:30-11:00 and 12:45-13:00), where the CO_2 level equal to 939 ppm (refer to Figure 7.6) will be the lowest suggested level and was taken as reference. The suggested periods during the school day have been selected in order not to harm the students' thermal comfort conditions. The resulting average CO_2 level due to this solution is 1420 ppm, where the CO_2 level during the hybrid mode for the ten classrooms is shown in Figure 7.8. It can be seen that CO_2 levels are brought below 1000 ppm for significant part of the morning period (8:00-9:30) making this a potentially viable solution compared with solution 1.

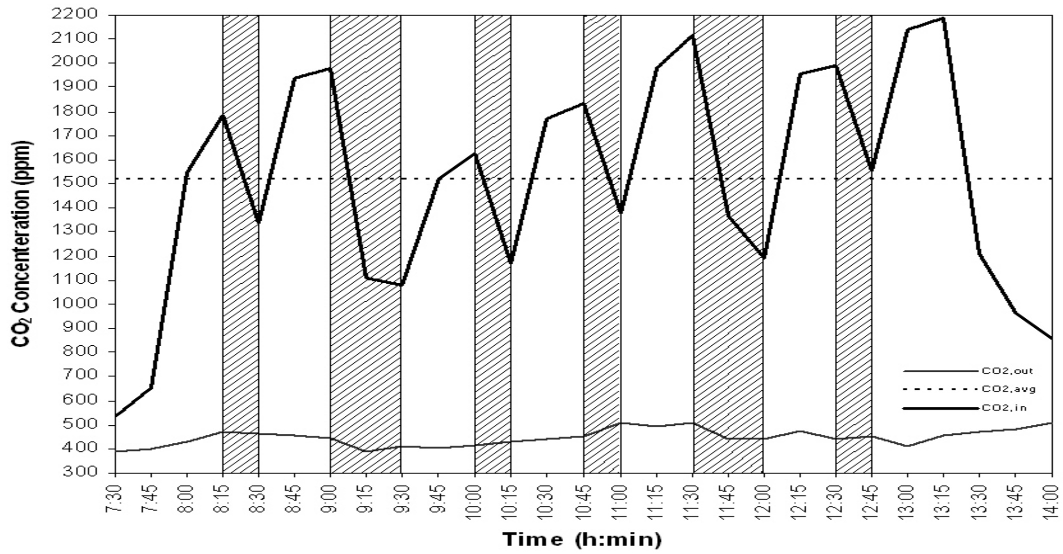

Figure 7.7: Average variation of CO_2 concentrations for the 10 classrooms with air-conditioned ventilation mode during the school day (Solution 1)

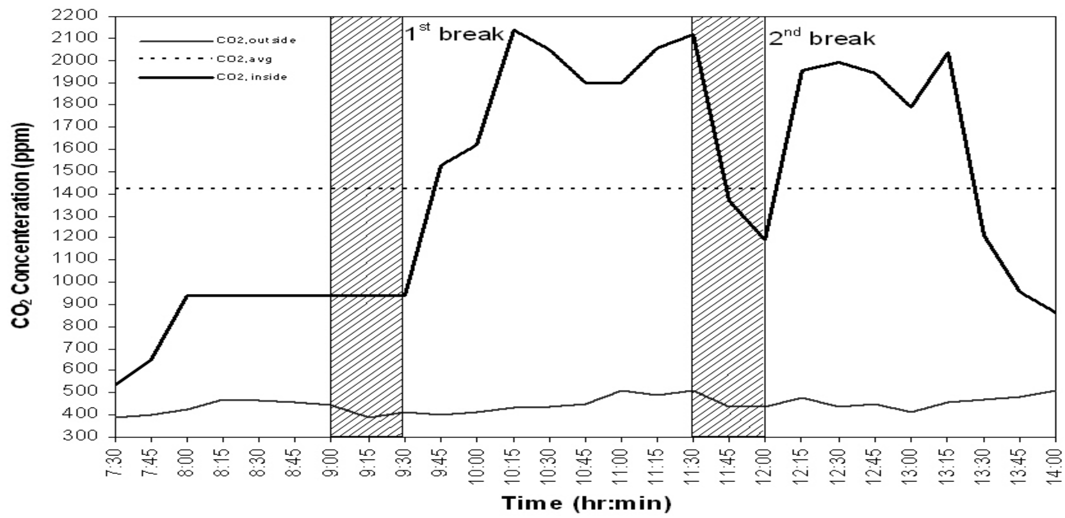

Figure 7.8: Average variation of CO_2 concentrations for the 10 classrooms with air-conditioned ventilation mode during the school day (Solution 2)

7.5.3 Solution 3: Changing the type of the AC system

Clearly the problem lies with the inappropriate choice of air-conditioning system for these kinds of application, so changing the AC system offers the most effective … Hence, the third proposed remedial solution to reduce the high CO_2 levels inside the classrooms is to change the existed ventilation system (wall-mounted split units) to central air conditioning systems or to same arrangement that allows adequate fresh air make up. Central air conditioning systems can provide amounts of adequate fresh air and air change rates to dilute and reduce the pollutants inside classrooms, in addition to reducing the CO_2 concentrations to the recommended levels (≤1000 ppm). Also, those types of systems can provide thermal comfort conditions for students inside classrooms. These conditions (low CO_2 levels and thermal comfort conditions) can be achieved while closing the classroom doors and windows. Finally, the central air conditioning systems will conform to Kuwait government regulations for ventilation rates (MEW/R-7, 2010) and energy conservation (MEW/R-6, 2010) inside classrooms with regard to students' thermal comfort (Al-Rashidi *et al*., 2010) in air-conditioned mode.

The description of the proposed remedial solution, expected CO_2 levels and the advantages and disadvantages of each solution are summarized in Table 7.2. From Table 7.2, it is clear that the proposed remedial solution No. (3) is the best choice as regards reducing the high levels of the CO_2 concentrations inside Kuwait classrooms, because of the more advantages it has compared with other solutions.

From the author's point of view, however, these are likely to be energy benefits, as well as cost benefits in refurbishment or new build or the increased energy consumption might be mitigated via some forms of cooling recover of or by evaporative cooling. Although Solution 3 is more costly and energy-intensive than the other solutions, the benefits of this choice for providing better indoor environments will be to enhance the students' and staff's health, performance and productivity. This point of view needs more future work regarding the cost and energy consumption inside Kuwaiti classrooms.

Finally, good IAQ in classrooms would enhance the classroom indoor environment and is likely to reduce the prevalence of diseases and the absence of the students and staff. This potentially may have very good returns on the national economy by saving of the medical treatment and the educational process expenses.

Table 7.2: Summary description of the suggested remedial solutions; expected CO_2 levels and the advantages and disadvantages of each solution

Solution No.	Solution Description	Expected CO_2 Level (ppm)	Advantages	Disadvantages
1	Breaks Increasing	1521	-Little reduction in CO_2 level	-May need to reschedule the lectures time or increase the school day time
2	Hybrid mode	1317	-Reduction in CO_2 level	-May need to reschedule the lectures time or increase the school day time -May have an effect on the students' thermal comfort
3	Changing the AC system type from wall-mounted split units to central air-conditioning systems	$\leq$1000	-Reduce the CO_2 levels to recommended standards levels -Provides adequate amount of fresh air and air exchange rates -Provides suitable thermal comfort conditions -Conserve energy consumption -Increase students' and staff's performance and productivity	-Increasing cost -Increasing energy consumption

7.6 Conclusions

This study has offered new information about the IAQ conditions inside Kuwait's school classrooms. The effect of the CO_2 concentration levels inside the classrooms, during the two ventilation modes (natural and air-conditioned modes), on the Kuwaiti students' performance and productivity among different student's ages has been estimated based on previous literature. The CO_2 concentration levels inside Kuwait classrooms during the air-conditioned ventilation mode have been found to be unacceptably high in comparison with recommended standards. Some remedial solutions were suggested to enhance and improve the IAQ inside the classrooms. Results suggested that new recommendations and guidelines are needed to be established to enhance and improve the environment inside Kuwait's classrooms for better IAQ and students' learning performance and productivity.

This study is a good foundation for future work related to indoor environment quality in Kuwait, especially to those interested in the indoor classroom environment. The findings of this study are being communicated to the Ministry of Education as a matter of urgency.

Chapter 8
Conclusions and Recommendations for Future Work

8.1 Chapter Summary

The literature reviews on thermal comfort and indoor air quality in classrooms have shown the lack of information about these two issues for the classrooms in Kuwait. The work of this thesis was conducted to cover some of these information and its impacts on student's health, performance and productivity in Kuwaiti classrooms. This chapter provides a review of the principle discussions and conclusions for the important findings in this thesis, and additional several suggested areas for future research are also presented.

8.2 Review of the work done

The thermal comfort and indoor air quality issues in classrooms have become a global point of interest for many researchers around the world due to their impacts on the student's health, learning performance and productivity. These impacts may have detrimental consequences on them and the society's future by decreasing the effectiveness and the quality of the educational process and increasing the health care expenses that can affect the national economy. Through the literature review of the thermal comfort (chapter 2) and indoor air quality (chapter 3) in classrooms, some lack of information was found. This lacked information were discussed and covered during the work of this thesis as summarized in the following paragraphs.

Although the first elementary years represent about 40% of the academic levels around the world, the literature review of the thermal comfort issue in classrooms (chapter 2) have shown a lack of information in investigating the thermal comfort conditions of the young children, especially from 6 to 10 years old. The reason of this shortage of information can be attributed to the difficulties that may face the children in understanding the concept of thermal comfort and the influences of the different thermal comfort variables on their thermal perception.

This information scarcity was treated in this thesis by designing and evaluating a new thermal comfort questionnaire (chapter 4) for gathering reported thermal comfort sensations from young children including children of age group from 6 to 10 years old. The idea of the new questionnaire is to design a thermal comfort questionnaire that can help the children from 6 to 10 years old to assess their thermal sensations but at the same time, it must have no effects or bias on the understanding of older age groups (11+).

Another point of needed information was raised through the literature, is that all the researchers were roughly estimating two of the basic thermal comfort variables for children measurements; the metabolic rate and the clothing insulation value, from the standard tables which are originally based on adult's measurements. This estimation may lead to some uncertainty due to using the standard tables to fit the children measurements. In this thesis the work was extended to investigate the applicability of using the standard tables to estimate the clothing insulation values for different children schoolwear used in Kuwait classrooms (chapter 5).

This estimation of the clothing insulation values were done by comparing different measurements methods, using thermal manikin; McCullough *et al*. (1985) regression equation, and the corrected McCullough et *al*. (1985) regression equation, as proposed by Havenith (2007). Additional procedure was followed in this thesis to investigate the effect of the insulation values on the different scholars' age groups by using the clothing temperature rating technique, McCullough *et al.* (2009) and compare the results to the scholars' comfort temperature found in recent field studies.

The metabolic rate of children in sedentary activity was investigated in this thesis, by comparing the effects of estimating the children's metabolic rates from the standard tables based on adult's measurements, and those estimated based on Havenith (2007) and Parsons (2003) recommendations, on the prediction of the thermal comfort sensation of children (PMV and PMV_{10}) during the field studies conducted in Kuwait classrooms among different ventilation modes (chapter 6).

All the previous studies found in the literature investigated the thermal comfort conditions in classrooms in tropical or hot humid climatic environments, while no studies have been done in classrooms in hot dry (desert) climatic environment like Kuwait classrooms, except by Al-Rashidi *et al.* (2009a, b and 2010) with regard to gender differences. The thermal sensations of the younger (6-10 years) and older (11-17 years) children were combined in these studies, where the age separation of subjects in this thesis can help to investigate if there is any difference in the thermal sensations of between the younger and older subjects.

After covering some of the needed information regarding the thermal comfort issue in classrooms, the reported results found (chapter 4 and 5) were used to conduct the thermal comfort study (chapter 6) to investigate the applicability of the different thermal comfort indices and equations to assess the younger and older subject's thermal sensations in Kuwait classrooms during different ventilation modes, hybrid; natural and air conditioned modes.

Regarding the literature review on indoor air quality in classrooms (chapter 3) and the lack of indoor air quality investigations found in Kuwait classrooms, the thesis work was extended to investigate the indoor air quality status in classrooms (chapter 7) by measuring the CO_2 concentrations levels in two different ventilation modes and compare them to that found in the standards. This indoor pollutant (CO_2) was chosen because the indoor concentration of CO_2 has often been used as a surrogate for the ventilation rate per occupant. The impacts of these CO_2 levels on the student's performance and productivity were investigated according to the existing literature studies. Some remedial solutions were suggested to enhance the IAQ inside the classroom environment in order to enhance the students' and staff's performance.

Based on the previous review of the work done in this thesis, some principal discussions and conclusions are reported in the next sections

8.3 Principal discussion

The new thermal comfort questionnaire (chapter 4) was designed by adding images and colours, while wording some of the questions used in the standard thermal comfort questionnaires. This procedure was done in accordance to the scientific and educational procedure used in children learning and education. Two thermal comfort field studies were conducted with two children age groups from 6 to 10 and 11 to 14 years old using the two types of questionnaires, the new designed (with colours and images) and the standard (no colours and images) questionnaires.

The differences between the responses of both age groups using both types of questionnaires were investigated and tested using a statistically model (z-test). The results suggested that the new designed thermal comfort questionnaire can help the children to assess their sensation in a better manner than that if the standard questionnaire was used. The new designed thermal comfort questionnaire has shown no effects or biasness on the older children. The new designed thermal comfort questionnaire can be considered as a new subjective assessment method that can support the thermal comfort standard by investigating the thermal comfort sensations of younger children age groups.

In respect to the measurements of the different schoolwear ensemble used in Kuwait classrooms, three methods were used to indicate and compare the thermal insulation values of different schoolwear ensembles worn by girls and boys in Kuwait classrooms during summer and winter seasons (chapter 5). These three methods ranges from using adult sized thermal manikins; estimating the thermal insulation values from the adults' data obtained in the standards tables; and using an adapted procedure using a regression equation to fit the children sizes from 6-17 years old. Results suggested that the clothing insulation values found from the measured and adapted data were similar to the adult's data in standards tables for the same summer and winter seasons ensembles.

The additional procedure to investigate the effect of the insulation values for the different scholars age groups using the clothing temperature rating technique showed that the temperature ratings of the clothing are close to, and in agreement with, the scholars' comfort temperature. An observed secular change in the children's heights and weights over the last few decades suggests that, for adolescents, the body surface areas are similar to those of adults. These findings have given evidence to support the applicability of using the adults' data in ASHRAE 55 and ISO 9920 standards to assess the thermal insulation values of different children clothing ensembles, provided that the garments and ensembles material and design are carefully selected.

A field study was conducted (chapter 6) to investigate the applicability of different thermal comfort indices for Kuwait classrooms along the academic year and under different ventilation modes to assess the thermal conditions for young (6-10 years) and old (11-17 years) children's age group during the school day. In this study, the new designed thermal comfort questionnaire and the clothing insulation values found in chapters 4 and 5 are used to collect the student's responses and calculating the PMV, ePMV and PMV_{10} thermal comfort indices, while measuring the thermal comfort variables at the same time.

Results have shown no difference in thermal sensations between younger and older students. The noticed differences between the actual mean votes of both age groups and that predicted by the different thermal indices used, suggested that all the investigated thermal comfort indices are predicting higher neutral temperatures than that predicted by the subject's actual mean votes (AMV) for both age groups during the three different ventilation modes. Results suggest that there is no difference in the neutral temperature between both age groups during the different ventilation modes, where the slightly difference in neutral temperature (about 0.2^{o}C during the different ventilation modes along the academic year), may related to the slightly difference in the insulation values of the schoolwear for each age group and the subjects' different classroom thermal conditions. This situation implies that the use of the new proposed thermal comfort questionnaire in chapter 4, helped the younger children to assess their sensation better as the older subjects.

Another important observation found that the metabolic rate of the younger children (6-10 year) is similar to those for older children (11-17 years old) and adults. This finding implies that the modification of reducing the metabolic rate of the adults to suit the younger ages, may not always be a right choice and may results in more inaccurate results, while during the different ventilation modes the of use the normal PMV model with the adult metabolic rate produce better predicted values.

The study showed the students' yearly average neutral temperature under different ventilations modes to be in agreement with the indoor design temperature set by the Energy Code of Kuwait. The yearly average comfort zone for Kuwaitis' students according to their actual mean votes (AMV) is ranged with an operative temperature range 20.9^{o}C - 23.8^{o}C, where this range of thermal comfort is also in agreement with Kuwait's Energy Code. Students in Kuwaiti's classrooms preferred temperature that is 1.3^{o}C lower than their neutral temperature along the three different ventilation modes. This difference suggested that the neutral thermal sensations do not always represent the ideal thermal state of occupants. Providing temperatures that are preferred by the students, to meet their preferred thermal comfort conditions, could increase the energy consumption inside Kuwait classrooms.

The adequacy of the ventilation rates have been investigated during naturally and air-conditioned ventilation modes (chapter 7) inside 10 elementary classrooms in Kuwait occupied by 6-10 years olds children age group by measuring the CO_2 concentration levels inside these classrooms. The findings showed that naturally ventilated classrooms have lower average CO_2 concentration levels (708 ppm) than air-conditioned classrooms (1596 ppm). The mean reason for the high CO_2 concentration in air conditioned classrooms is attributed to the improper selection of ventilation system type (wall-mounted split units) inside the classrooms. This type of ventilation system cools recirculated room air provides no outside air (fresh air), which is may not be appreciated for high occupancy zones like classrooms. Suitable means for fresh air provision must be made for this mode of operation.

According to the literature, an increase of 7% in the students' and staff's performance can be achieved when reducing the CO_2 levels during the air-conditioned mode to the levels found during the naturally ventilated mode (or standard levels). In this study, some remedial solutions were theoretically suggested to reduce the high CO_2 levels in air-conditioned classrooms which may enhance the students' and staffs' performance. The suggested solutions showed that changing the existed air ventilation systems to central air-conditioned systems with outside fresh air is a better appreciated solution.

8.4 Final Conclusions

An overall general conclusion points covering the work executed in this thesis are reported as follows:

- The use of the new proposed thermal comfort questionnaire and the addition of the images and colours can help younger children, 6-10 years old, to assess their thermal sensation better than of the standard questionnaire;
- The thermal insulation values of different schoolwear ensembles worn by girls and boys in Kuwait classrooms during summer and winter seasons are similar to the adult's data in standards tables for the same summer and winter seasons.
- The clothing temperature ratings are close to, and in agreement with, the scholars' comfort temperature.
- The PMV and ePMV indices are more appropriate to predict the younger and older student's thermal sensations in Kuwait classrooms under the three different ventilated environments than other thermal comfort indices.
- The neutral temperatures of the younger and older subjects in all three ventilation modes are the same and the yearly average neutral temperatures for both younger and older subjects have found to be equal to 21.9^{o}C, while the subjects' preferred temperature is found to be lower than neutral temperatures by about 1.3^{o}C.
- The yearly average comfort zone for Kuwaiti's students, according to their actual mean votes (AMV) within $-0.5<AMV<+0.5$ range, for both age groups, and with yearly average clothing insulation values of 0.86 clo, have its operative temperature ranges from 20.9^{o}C to 23.9^{o}C, where this range of thermal comfort is in agreement

with Kuwait's Energy Code (23.9°C and 21.1°C for summer and winter, respectively).

- The CO_2 concentration levels inside Kuwait classrooms during the air-conditioned ventilation mode are higher than that for natural ventilation mode. This is attributed to the improper selection of the air-conditioning system type (wall mounted split units) used in classrooms which cools recirculated room air provides no outside air (fresh air).
- The suggested remedial solutions to enhance and improve the IAQ inside classrooms, showed that changing the type of the existing air conditioning system to central air conditioning system is the most appreciated solution found, which can reduce the CO_2 concentration levels to meet the recommended levels.
- The latter data on CO_2 levels being above recommended values have been communicated to Kuwaiti government.

8.5 Future Research

Generally, the work done in this thesis have been considered as a good initial attempt to investigate the thermal comfort and indoor air quality issues in Kuwait classrooms, and studying their impacts on young children performance and productivity, in addition to their impacts on the energy consumption inside classrooms. Further research and investigations are needed of IAQ (CO_2 levels) in Kuwait classrooms to confirm the findings and scale the problem size which may lead to new policy and refurbishment of schools.

- The new proposed thermal comfort questionnaire, presented in this thesis, is considered a new subjective mean to help young children in assessing their thermal sensations toward their classrooms thermal environment. Additional future benefits are expected by modifying this new questionnaire (using boy or girl images with different uniforms) to assess the children thermal sensations in other environments such as schools, homes, vehicles …etc, with attention must be given to the language and cultural differences. The new proposed questionnaire could become a universal subjective tool without words, where this work is a step towards the "universal wordless" questionnaire.

- The estimation analysis, of the clothing insulation values for the different children school wears in Kuwait, can be extended to measure the insulation values of other different clothing ensembles (in regard to garments type, clothing style or fashion)wear by children such as daily house wears, and to indicate their temperature ratings.
- The thermal comfort study in this thesis considered to be the first study conducted to investigate the thermal sensations of school children in desert climate, where more studies related to children may be needed in other areas such as houses, vehicles …etc, with in same climate environments and the effects of these thermal environment on the quality of the occupant's life.
- The applicability of the different thermal comfort indices and equations can be extended to investigate the thermal comfort sensations in offices, houses and vehicles…..etc, in the hot and dry climates such as Kuwait climate.
- Attention to some adaptive opportunities such as the using of shade, fans, or opping the windows and doors, must give in the future design of the thermal environments in buildings to allow occupants to adjust their environment to reach their optimal thermal and IAQ conditions.
- The CO_2 concentration levels inside the classrooms have been used to indicate the adequacy of the indoor air ventilation, where more future research is needed regarding to the different indoor pollutants and their effects on the student's health, performance and productivity inside the classrooms, in addition to their effects on the energy consumption inside the classrooms.
- Generally, the results of this study suggested that new recommendations and guidelines are needed to enhance and improve the inside Kuwait's classrooms environment for better students' learning performance and productivity. This study is a good extension for future work related to indoor environment quality in Kuwait, especially to those interested in the indoor classroom environment.

Publications up to Date

Al-Rashidi, K.E., D.L. Loveday and N.K. Al-Mutawa, (2009a). Investigating the Applicability of Different Thermal Comfort Models in Kuwait Classrooms Operated in Hybrid Air-Conditioning Mode. *Sustainability in Energy and Buildings,* pp. 347-355.

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Appendix

The Proposed New Thermal Questionnaire (English and Arabic Versions)

School	Classroom	Remarks

1- How are you feeling the temperature in the classroom to be at this moment?

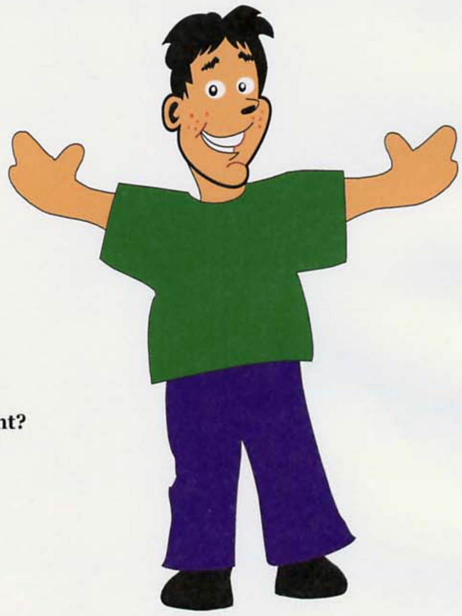
- I feel that the classroom temperature is __________

Cold	Cool	Slightly Cool	Neutral	Slightly Warm	Warm	Hot

2- Do you feel thermally comfortable now?

- I feel that I'm thermally __________

Comfortable	Uncomfortable	Very Uncomfortable



3- **Now, would you like to be** __________

Cooler	No Change	Warmer

4- **In general, how do you rate the classroom environment?**

- **I'm rate the classroom environment as** __________

Acceptable	Not Acceptable

5- **How do you feel about the air movement in the classroom?**

- **I feel that it is** __________

Breezy	Just right	Still

6- **How do you feel about the humidity in the classroom?**

- **I feel that it is** __________

Dry	Just right	Humid

مدرسة	صف	ملاحظات

1- ماهو شعورك تجاه درجة الحرارة في الفصل الآن؟

- أنا أشعر بأن درجة الحرارة في الفصل ________

حارة جداً	حارة	حارة قليلاً	متعادلة	باردة قليلاً	باردة	باردة جداً

2- هل تشعر بالراحة الآن؟

- أنا أشعر بأنني ________

مرتاح	غير مرتاح	غير مرتاح جداً

3- الآن، هل ترغب في أن تكون ________

أكثر دفئاً	بدون تغيير	أكثر برودة

4- بشكل عام، كيف تقيم البيئة المناخية في الفصل؟

- أنا أقيم البيئة المناخية الفصل بأنها ________

غير مقبولة	مقبولة

5- ماهو شعورك بالنسبة لحركة الهواء في الفصل؟

- أشعر بأنها ________

نسيم	جيدة	ساكنة

6- ماهو شعورك بالنسبة للرطوبة في الفصل ؟

- أشعر بأنها ________

جافة	جيدة	رطبة

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