ANALYZING THE EFFECTS OF THERMAL COMFORT AND INDOOR AIR QUALITY IN DESIGN STUDIOS AND CLASSROOMS ON STUDENT PERFORMANCE

A Master's Thesis

by

ALI RANJBAR

Department of
Interior Architecture and Environmental Design
İhsan Doğramacı Bilkent Üniversitesi
Ankara
July 2017

ANALYZING THE EFFECTS OF THERMAL COMFORT AND INDOOR AIR QUALITY IN DESIGN STUDIOS AND CLASSROOMS ON STUDENT PERFORMANCE

The Graduate School of Economics and Social Sciences
of
İhsan Doğramacı Bilkent University

by

ALI RANJBAR

In Partial Fulfillment of the Requirements for the Degree of
MASTER OF FINE ARTS

THE DEPARTMENT OF
INTERIOR ARCHITECTURE AND ENVIRONMENTAL DESIGN
İHSAN DOĞRAMACI BİLKENT UNIVERSITY
ANKARA

July 2017

I certify that I have read this thesis and have found that is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

Asst. Prof. Dr. Yasemin Afacan
Supervisor

I certify that I have read this thesis and have found that is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

Asst. Prof. Dr. Semiha Yılmazer
Examining Committee Member

I certify that I have read this thesis and have found that is fully adequate, in scope and in quality, as a thesis for the degree of Master of Fine Arts in Interior Architecture and Environmental Design.

Asst. Prof. Dr. Elif Güneş
Examining Committee Member

Approval of the Graduate School of Economics and Social Sciences

---

Prof. Dr. Halime Demirkan
Director

ABSTRACT

ANALYZING THE EFFECTS OF THERMAL COMFORT AND INDOOR AIR QUALITY IN DESIGN STUDIOS AND CLASSROOMS ON STUDENT PERFORMANCE

Ranjbar, Ali

MFA, Department of Interior Architecture and Environmental Design

supervisor: Assist. Prof. Dr. Yasemin Afacan

July 2017

The present study aims to evaluate the effects of the different ventilation modes on thermal comfort and indoor air quality in design studios and classrooms. It also investigates its associations with student performance. For this purpose, experimental and subjective measurements are used in both studio and classroom, in Interior Architecture and Environmental Design Department at Bilkent University, Ankara. CO2 concentration, indoor temperature and humidity values are collected in both winter and summer season under the three modes of ventilation: 1) without opening door and windows mode setting; (2) natural ventilation mode and (3) the mechanical TROX school-air unit mode. The thermal comfort and IAQ was investigated through CO2 concentration and temperature and humidity in these three different ventilation modes. Under these three modes in both seasons, student performance is assessed based on concentration and attention test results. Both experimental and subjective results have shown that the mechanical TROX school-air unit mode is the most satisfactory indoor environment in terms of standards, where the highest grade of students' concentration and attention are obtained.

Keywords: Classroom, indoor air quality (IAQ), studio, student performance, thermal comfort.

ÖZET

SINIF VE STÜDYOLARDAKİ ISIL KONFORUN VE İÇ MEKAN HAVA KALİTESİNİN ÖĞRENCİ PERFORMANSINA ETKİSİNİN ANALİZİ

Ranjbar, Ali

İç Mimarlık ve Çevre Tasarımı Yüksek Lisans Programı

Tez Danışmanı: Yrd. Doç. Dr. Yasemin Afacan

Haziran 2017

Bu çalışma, tasarım stüdyolarında ve sınıflarda farklı havalandırma koşullarının ısıl konfor ve iç mekan hava kalitesi üzerine etkilerini değerlendirmeyi amaçlamıştır. Aynı zamanda öğrenci performansıyla olan ilişkilerini de araştırır. Bu amaçla, Bilkent Üniversitesi İç Mimarlık ve Çevre Tasarımı Bölümünde hem stüdyo hem de sınıfta deneysel ve öznel ölçümler yapılmıştır. CO2 konsantrasyonu, iç sıcaklık ve nem değerleri, kış ve yaz sezonunda üç havalandırma koşulunda toplanmıştır: 1) kapı ve pencereleri açmadan olan koşul; (2) doğal havalandırma koşulu ve (3) mekanik TROX okul-hava cihazının kullanıldığı koşul. Isıl konfor ve iç mekan hava kalitesi, üç farklı havalandırma koşulunda CO2 konsantrasyonu, sıcaklık ve nem değerleri ile araştırıldı. Her iki mevsimdeki bu üç koşulda da öğrenci performansı yoğunlaşma ve dikkat testi sonuçlarına dayanarak değerlendirildi. Hem deneysel hem de öznel sonuçlar, mekanik TROX okul-hava cihaz koşulunun, öğrencilerin konsantrasyonunun ve dikkatinin en yüksek değerlerinin elde edildiği sınıf iç mekan

ortamı olduğunu göstermiştir.

Anahtar Kelimeler: Isıl konfor, iç mekan hava kalitesi, stüdyo, sınıf, öğrenci performansı.

ACKNOWLEDGEMENTS

Firstly, I would like to thank and express my gratefulness to my thesis supervisor, Asst. Prof. Dr. Yasemin Afacan, for her understanding, patience, and help in every situation. I would never be able to finish my thesis without her valuable guidance. It is an honor for me to be able to work with and learn from such a successful academician.

Secondly, I would like to thank to TROX TECHNIK, company to be sponsor for my thesis and installation of the air-handling unit. Especially I would like to thank to Ozan Atasoy, Cenani Bozkına, and S.Can Taşyürek.

I would like to thank my friends that supported me through this year. I am grateful for their support and encouragement. Especially to Arslan Moderres, Samad Nojavan, Ela Fasllija, Anıl Özdem, and Gonca Özger.

I would like to thank my family, without their endless and unconditional support, I would not be able to finish this thesis.

Lastly, I would like to thank to all of the participants of the survey. Without them, this research would not have been easily conducted and finished.

TABLE OF CONTENTS

ABSTRACT IV

OZET VI

ACKNOWLEDGEMENTS VIII

TABLE OF CONTENT IX

LIST OF TABLES XII

LIST OF FIGURES XVII

CHAPTER I: INTRODUCTION 1

1.1. Problem statement 1

1.2. Structure of thesis 2

CHAPTER II: LITERATURE REVIEW 3

2.1.What is thermal comfort? 3

2.1.1. Indicators 4

2.1.2. Building codes and regulations. 8

2.2.What is Indoor Air Quality (IAQ) 9

2.2.1. Indicators 10

2.2.2. Building codes and regulations 12

2.3. Recent studies on thermal comfort and IAQ 13

2.4. Ventilation modes and their importance 18

2.4.1. Natural ventilation mode 18

2.4.2. Mechanical ventilation mode…….19

CHAPTER III: HEALTH AND COMFORT IN SCHOOL BUILDING……...20

3.1. Co_2 level, ventilation rate and temperature in a classroom……20

3.2. Effect of thermal comfort and IAQ on student's attention and concentration……21

CHAPTER IV: METHODOLOGY ……...25

4.1. Research questions and hypotheses 25

4.2. Participants 26

4.3. Procedure 28

4.4. Instruments 31

CHAPTER V: DATA ANALYSES AND RESULTS ……..37

5.1. Experimental measurements: Thermal comfort and IAQ performance …38

5.1.1. Studio environment 38

5.1.1.1. Setting I: Without opening door and windows mode. 38

5.1.1.2. Setting II: Natural ventilation mode……..43

5.1.1.3. Setting III: Mechanical school-air unit mode ……..…….49

5.1.2. Classroom environment ……..….54

5.1.2.1. Setting I: Without opening door and windows mode.....54

5.1.2.2. Setting II: Natural ventilation mode…….60

5.1.2.3. Setting III: Mechanical school-air unit mode……67

5.2. Subjective measurements: Attention and concentration performance …72

5.2.1. Studio environment ……..72

5.2.1.1. Concentration performance under the three settings.76

5.2.1.2. Attention performance under the three settings.……...78

5.2.2. Classroom environment.....79

5.2.1.1. Concentration performance under the three settings.83

5.2.1.2. Attention performance under the three settings.……85

5.3. Discussion 86

5.3.1. Studio environment 87

5.3.2 Classroom environment.....90

5.3.3. Comparison of student performance in studio and classroom environment under the three settings 94

CHAPTER VI: CONCLUSION.....98

BIBLIOGRAPHY...…….....101

APPENDICES.....107

A. Survey 107

B. TROX school-air unit installation photos 110

C. Experimental measurement photos 114

LIST OF ABBREVIATIONS

IAQ: Indoor air quality

IEQ: Indoor environmental quality

iM: Metabolic rate

M: Metabolic heat production

PMV: Predicted mean vote

PPD: Predicted percentages of dissatisfaction

PPM: Per part millions

Rcl: Thermal resistance of clothing

tc: Operative comfort temperature

LIST OF TABLES

1. Predicted Distribution of sensation votes for given PMV values (ASHRAE standard, 2013). 6
2. ASHRAE Standard, recommendation for IAQ indicators, (ASHRAE Standard, 2013). 11
3. Number of participants for both season and both environments……27
4. Experimental measurement schedule on all settings. 29
5. Temperature values of studio environment in winter season under setting I mode. 38
6. Measured CO2 concentration, temperature and humidity values in setting I mode during the school day 40
7. Temperature values of studio environment in summer season under setting mode. 41
8. Measured CO2 concentration, temperature and humidity values in setting I mode during the school day. 43
9. Temperature values of studio environment in winter season under setting II mode. 44
10. Measured CO2 concentration, temperature and humidity values in setting II mode during the school day. 46
11. Temperature values of studio environment in winter season under setting II mode. 47

12. Measured CO2 concentration, temperature and humidity values in setting I mode during the school day 48
13. Temperature values of studio environment in winter season under setting III mode 49
14. Measured CO2 concentration, temperature and humidity values in setting III mode during the school day 51
15. Temperature values of studio environment in summer season under setting III mode. 52
16. Measured CO2 concentration, temperature and humidity values in setting III mode during the school day 54
17. Temperature values of classroom environment in winter season under setting I mode. 55
18. Measured CO2 concentration, temperature and humidity values in setting I mode during the school day 57
19. Temperature values of classroom environment in summer season under setting I mode 58
20. Measured CO2 concentration, temperature and humidity values in setting I mode during the school day 60
21. Temperature values of classroom environment in winter season under setting II mode 61
22. Measured CO2 concentration, temperature and humidity values in setting II mode during the school day 63
23. Temperature values of classroom environment in summer season under setting II mode.....64

24. Measured CO2 concentration, temperature and humidity values in setting II mode during the school day 66
25. Temperature values of classroom environment in winter season under setting III mode 67
26. Measured CO2 concentration, temperature and humidity values in setting III mode during the school day 69
27. Temperature values of classroom environment in summer season under setting III mode 70
28. Measured CO2 concentration, temperature and humidity values in setting III mode during the school day. 72
29. Demographic characteristics of the participants of winter season studio environment.....73
30. Demographic characteristics of the participants of summer season studio environment.....73
31. Mean comparison table among the three setting modes in winter season. 74
32. Mean comparison table among the three setting modes in summer season...74
33. Mean comparison table among the three settings in winter season 75
34. Mean comparison table among the three settings in summer season.....75
35. Mean comparison table among the three settings in winter season 75
36. Mean comparison table among the three settings in summer season.....76
37. Oneway ANOVA results of arithmetic concentration performance (Kraepelin test) in winter season 77
38. Oneway ANOVA results of arithmetic concentration performance, (Kraepelin test) in summer season 77

39. LSD test result of arithmetic concentration performance (Kraepelin test) in winter season 77
40. LSD test result of arithmetic concentration performance (Kraepelin test) in summer season 77
41. One-way ANOVA result of visual attention (Prague test) in winter season..78
42. One-way ANOVA result of visual attention (Prague test) in summer season78
43. LSD test result of visual attention (Prague test) in winter season.....78
44. LSD test result of visual attention (Prague test) in summer season 79
45. Demographic characteristics of the participants of winter season classroom environment.....80
46. Demographic characteristics of the participants of summer season classroom environment.....80
47. Mean comparison table among the three setting modes in winter season 81
48. Mean comparison table among the three setting modes in summer season...81
49. Mean comparison table among the three settings in winter season 82
50. Mean comparison table among the three settings in summer season.....82
51. Mean comparison table among the three settings in winter season 82
52. Mean comparison table among the three settings in summer season.....83
53. Oneway ANOVA results of arithmetic concentration performance (Kraepelin test) in winter season 84
54. Oneway ANOVA results of arithmetic concentration performance, (Kraepelin test) in summer season 84
55. LSD test result of arithmetic concentration performance (Kraepelin test) in winter season 84

56. LSD test result of arithmetic concentration performance (Kraepelin test) in summer season 84
57. One-way ANOVA result of visual attention (Prague test) in winter season..85
58. One-way ANOVA result of visual attention (Prague test) in summer season85
59. LSD test result of visual attention (Prague test) in winter season....86
60. LSD test result of visual attention (Prague test) in summer season 86
61. Comfort indicators of the studio environment among the three settings during the winter season 87
62. Comfort indicators of the studio environment among the three settings during the summer season 89
63. Comfort indicators of the classroom environment among the three settings during the winter season....91
64. Comfort indicators of the classroom environment among the three settings during the summer season 92

LIST OF FIGURES

1. Predicted percentages of dissatisfied (PPD) as function of predicted mean vote (PMV), (ASHRAE standard, 2013). 6
2. Operative comfort temperature function of clothing and activity, (ISO Standard 7730 ISO, 2005). 7
3. Insulation for clothing (INNOVA, 2002).....8
4. The relationship between temperature and the performance of office work (Seppanen et al., 2006) 16
5. The experimental relationship between classroom temperature and the performance of schoolwork (Wargocki and Wyon 2006).....16
6. Natural ventilation diagram, drawn by Ali Ranjbar, 2017. 18
7. Mechanical ventilation diagram, drawn by Ali Ranjbar, 2017 19
8. The experimental relationship between classroom temperature and the performance of schoolwork (Wargocki and Wyon, 2008).....24
9. The experimental relationship between outdoor air supply rate per child and classroom performance of schoolwork (Wargocki and Wyon, 2008) 24
10. FF101 room plan, not in scale drawn by Ali Ranjbar, 2017. 27
11. A panoramic photo of FF 101 room, taken by Ali Ranjbar, 2017 27
12. The three-dimensional drawing of FF 101 room, drawn by Ali Ranjbar, 2017. 28
13. Main conceptual procedure framework of the study.....29
14. Procedure diagram of the study for thermal comfort 31
15. BP 21 TROTEC, available at:

https://tr.trotec.com/ueruenler/haberler/genel-bakis/oelcuem-cihazlariniz-icin-sertifikali-guevenlik/ 32
16. BA 15 TROTEC, available at: https://tr.trotec.com/ueruenler/haberler/genel-bakis/oelcuem-cihazlariniz-icin-sertifikali-guevenlik/ 33
17. Co2 temp/RH Data logger CM 0019 http://www.co2meter.com/products/wireless-co2-temp-rh-environmental-logger.....34
18. Procedure diagram of the study for indoor air quality 35
19. TROX SCHOOLAIR, available online at: http://www.troxuk.co.uk/sill-and-under-sill-units/type-schoolair-b-8e32e6052d00629f 36
20. Type school air-B, available online at: http://www.troxuk.co.uk/downloads/f0b4a8c59e00315c/dezentrale-lueftung.pdf?type=product_inf 36
21. Psychometric chart of studio environment in winter season under setting I mode. 39
22. Variation of CO2, temperature and humidity levels with time for studio environment under setting I mode.....40
23. Psychometric chart of studio environment in summer season under setting I mode. 42
24. Variation of CO2, temperature and humidity levels with time for studio environment under setting I mode.....43
25. Psychometric chart of studio environment in winter season under setting II mode 45

26. Variation of CO2, temperature and humidity levels with time for studio environment under setting II mode. 46
27. Psychometric chart of studio environment in summer season under setting II mode. 47
28. Variation of CO2, temperature and humidity levels with time for studio environment under setting II mode 48
29. Psychometric chart of studio environment in winter season under setting III mode 50
30. Variation of CO2, temperature and humidity levels with time for studio environment under setting III mode 51
31. Psychometric chart of studio environment in summer season under setting III mode. 53
32. Variation of CO2, temperature and humidity levels with time for studio environment under setting III mode. 54
33. Psychometric chart of classroom environment in winter season under setting I mode. 56
34. Variation of CO2, temperature and humidity levels with time for classroom environment under setting I mode 57
35. Psychometric chart of classroom environment in summer season under setting I mode 59
36. Variation of CO2, temperature and humidity levels with time for classroom environment under setting I mode 60
37. Psychometric chart of classroom environment in winter season under setting II mode 62

38. Variation of CO2, temperature and humidity levels with time for studio environment under setting II mode 63
39. Psychometric chart of classroom environment in summer season under setting II mode.....65
40. Variation of CO2, temperature and humidity levels with time for classroom environment under setting II mode 66
41. Psychometric chart of classroom environment in winter season under setting III mode.....68
42. Variation of CO2, temperature and humidity levels with time for classroom environment under setting III mode.....69
43. Psychometric chart of classroom environment in summer season under setting III mode 71
44. Variation of CO2, temperature and humidity levels with time for classroom environment under setting III mode.....72
45. Variation of mean CO2 concentration of studio environment in the three settings, in winter season.....87
46. Variation of mean indoor air temperature of studio environment in the three settings, in winter season.....88
47. Variation of mean relative humidity of studio environment in the three settings, in winter season.....88
48. Variation of mean CO2 concentration of studio environment in the three settings, in summer season.....89
49. Variation of mean indoor air temperature of studio environment in the three settings, in summer season.....90

50. Variation of mean relative humidity of studio environment in the three settings, in summer season 90
51. Variation of mean CO2 concentration of classroom environment in the three settings, in winter season 91
52. Variation of mean indoor air temperature of classroom environment in the three settings, in winter season 91
53. Variation of mean relative humidity of classroom environment in the three settings, in winter season 92
54. Variation of mean CO2 concentration of classroom environment in the three settings, in summer season 93
55. Variation of mean indoor air temperature of classroom environment in the three settings, in summer season 93
56. Variation of mean relative humidity of classroom environment in the three settings, in summer season 94
57. The comparison of concentration performance scores in both studio and classroom environment regarding the winter season 95
58. The comparison of concentration performance scores in both studio and classroom environment regarding the summer season 95
59. The comparison of attention performance scores in both studio and classroom environment regarding the winter season. 96
60. The comparison of attention performance scores in both studio and classroom environment regarding the summer season 97

CHAPTER I

INTRODUCTION

In recent years, thermal comfort and indoor air quality has become the wide world well known issue, which get the researcher's attention, to improve interior living spaces. Indoor thermal comfort is define as the pleasant feeling about interior without any negative effect on occupants health and productivity. This topic get importance in school building since poor IAQ might potentially have negative effects on student's health and performance. Investigation on thermal comfort and IAQ deliver guideline to understand pollutant and their factor to have a better air quality condition inside classrooms.

1.1. Problem statement

In the scope of the literature review, it can be said that indoor environmental quality (IEQ) is the common used concept in order to enhance occupants living quality and health. It can be used in different era. One of the important aspects of IEQ is thermal comfort and IAQ, which considered in education facilities to improve student concentration and attention and it can be control by ventilation system. This study aims to analyze the effects of thermal comfort and indoor air quality in design studios and classrooms on student performance.

1.2. Structure of thesis

This thesis contains six chapters. In Chapter 1, a brief introduction is followed by the definition of the problem and structure of the thesis. In Chapter 2, first thermal comfort and IAQ are defined with their indicators, then recent studies on thermal comfort and IAQ are presented. Finally, the importance of interior ventilation and types are defined. Chapter 3 deals with the health and comfort in school building. This chapter covers the earlier studies on thermal comfort in classrooms and school buildings. In Chapter 4, methodology of the study is elaborated. First, research question of the study and hypotheses are given. Then, participants, tasks and procedure are explained respectively. In Chapter 5, results, which are obtained in both winter and summer, are presented under two main topics; experimental measurements and subjective measurements based on the three different ventilation settings: (1) without opening door and windows mode setting; (2) natural ventilation mode and (3) the mechanical school-air unit mode. Chapter 6 is the conclusion chapter.

LITERATURE REVIEW

2.1.What is thermal comfort?

Thermal comfort is “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ANSI/ASHRAE Standard 55, 2010). Thermal comfort is one of the most important parameters of indoor environmental quality. “Comfort is gained when body temperatures are held within narrow ranges, skin moisture is low, and the physiological effort of regulation is minimized” (Sarbu and Sebarchievici, 2013, 411). The term “thermal comfort” defines the psychological state of mind of an individual, and it comes into play when someone is feeling too hot or too cold. Air Conditioning Policy & Guidance (2013) states that thermal comfort is difficult to describe, and to provide comfortable environments; we should consider personal and environmental factors (Air Conditioning Policy & Guidance on Thermal Comfort, 2013, 2). The British Government’s The Health & Safety Executive (HSE) admits that the term ‘thermal comfort’ can be difficult to define. They suggest that the best one can hope to accomplish is a thermal environment that satisfies the majority of population in a given workplace (HSE, 2005). Another thing to note is that the HSE considers 80% of all occupants as a reasonable limit for the minimum number of people, who should be thermally comfortable in an environment (HSE, 2005). In addition, temperature, humidity, and radiant temperature known as environmental parameters

and the type of activity and clothing of occupant are known as personal parameters of thermal comfort (Atmaca and Yigit, 2011).

2.1.1. Indicators

There are two types of indicators: objective and subjective. The measurement of thermal comfort takes into account several objective parameters. The main factors that it is closely related with are temperature, humidity, ventilation rate, and air velocity. On the other hand, as mentioned before, thermal comfort is a state of mind and each society has their own comfort level such as weather condition geographical condition, and different psychological environment factors to be used for subjective measurements. When measuring the thermal comfort of a space, the tools utilized are the predicted percentages of dissatisfied (PPD) and predicted mean vote (PMV).

This master thesis looks at measurable objective indicators: Ventilation rate, Air circulation, Mean radiant temperature, Relative humidity, and Air velocity. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) defines these terms as follows:

Ventilation rate (l/s per person): “The volume of air passing into and out of the indoor environment per second” (ANSI/ASHRAE Standard 55, 2013).

Air-circulation rate (l/s per person): “Measurement of the amount of air per unit of time that flows from one part of space to another part” (ANSI/ASHRAE Standard 55, 2013).

Mean radiant temperature (°C): “The uniform surface temperature of an imaginary

black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space" (ANSI/ASHRAE Standard 55, 2013).

Relative humidity (%): "The ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature and the same total pressure" (ANSI/ASHRAE Standard 55, 2013), and

Air velocity (Cubic Feet per Minute - CFM): "Velocity is movement of sufficient air in a space, which can measure by quick spot from the air supply diffuser shows sufficient air entering the space or not" (ANSI/ASHRAE Standard 55, 2013).

For the subjective measurement, this thesis refers to P. O. Fanger's PMV/PPD (1971) model, which was later accepted as the standard for ISO certification. In this model, skin temperature quantifies the comfort level. EN ISO 10551 states that using a seven-point scale survey from cold (-3) to hot (+3) could identify the thermal sensation of participants. Moreover, "It is based on the assumption that people voting +2, +3, –2, or –3 on the thermal sensation scale are dissatisfied and on the simplification that PPD is symmetric around a neutral PMV" (ANSI/ASHRAE 1 Standard 55, 2013). (See Figure 1 and Table 1).

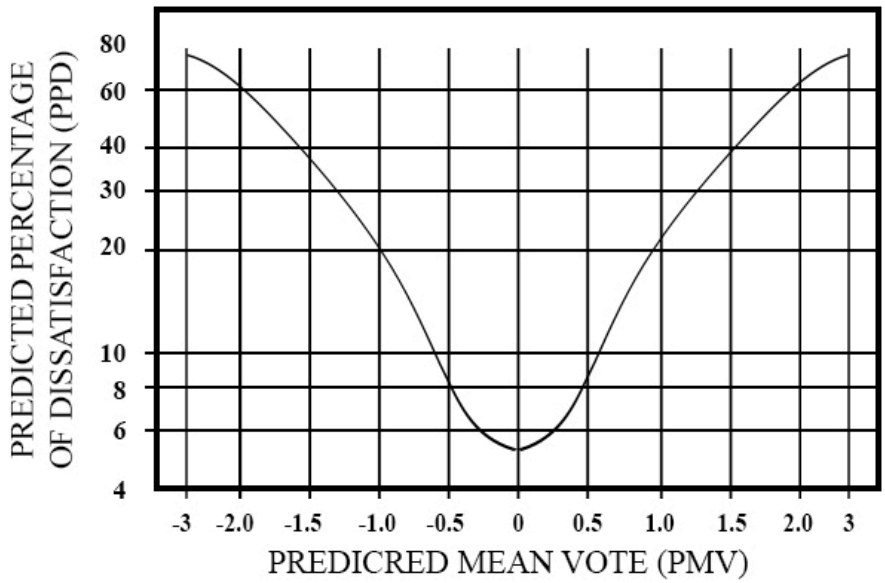


Figure 1: Predicted percentages of dissatisfied (PPD) as function of predicted mean vote (PMV), (ASHRAE standard, 2013).

Table 1: Predicted Distribution of sensation votes for given PMV values (ASHRAE standard, 2013).

PMV	**PPD**	**Persons Predicted to Vote %**		
		0	**-1, 0 or +1**	**-2, -1, 0, 1, or 2**
+2	75	5	25	70
+1	25	30	75	95
+0.5	10	55	90	98
0	5	60	95	100
-0.5	10	55	90	98
-1	25	30	75	95
-2	75	5	25	70

In another word, objective measurement is defined as the combination of environmental factors like temperature, humidity, and inlet heating source location in a space. Subjective measurement, however, is defined as an aggregation of individual

factors such as occupant clothing factor, and type of activity, which is related to how much each person exerts his or herself physically while working (HSE, 2005). Ioan and Călin (2013) mention that the main factors that influence the thermal equilibrium of the human body are:

- Body heat production, which depends on activity level and independent factors like sex, and age.
- Body heat loss, which depends on clothing.

Figure 2 is the representation of the values of operative comfort temperature "*tc* (corresponding to index PMV = 0), correlated to thermal resistance of clothing (*Rcl* and *Rh*), metabolic rate *iM* and metabolic heat production *M"* (ISO Standard 7730 ISO, 2005). Figure 3 represents the value of each clothing insulation for both summer and winter seasons.

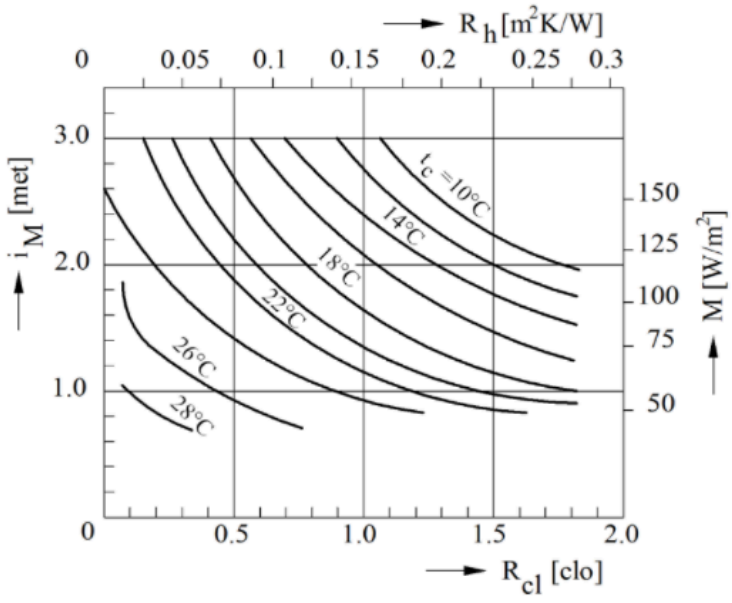


Figure 2: Operative comfort temperature function of clothing and activity,(ISO Standard 7730 ISO, 2005).

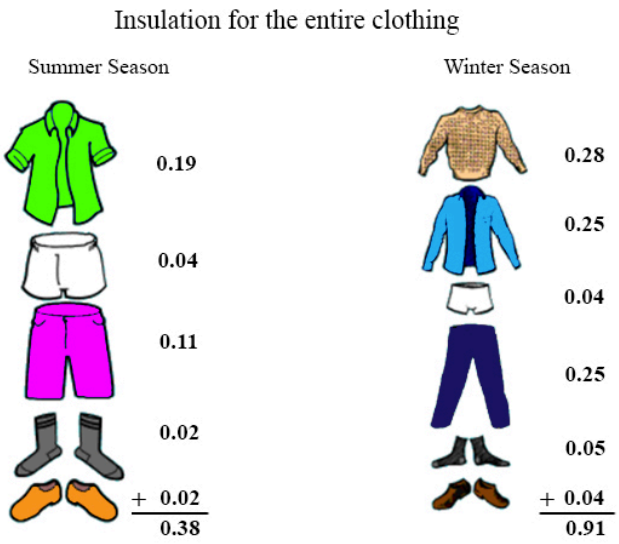


Figure 3: Insulation for clothing (INNOVA, 2002)

2.1.2. Building codes and regulations

With the importance of ventilation and indoor thermal comfort and the impact of these on occupants' health, many researchers began working on setting a standard on a worldwide scale. The most common used standard is the ASHRAE 55. ASHRAE 55 is a guideline, which gives us all sorts of values in different situations to keep the indoor thermal levels comfortable. The second standard is the European standard of EN ISO 7730. In this standard, thermal comfort, Ergonomics of the thermal environment, Analytical determination and interpretation of thermal comfort are calculated by using the PMV and PPD indices and local thermal comfort criteria. EN ISO 10551 provides the ergonomics of the thermal environment assessment of the influence of the thermal environment using subjective judgment scales. Also, other standards to take into consideration are the ISO 7933 and ISO 11079, which take a

close look on ergonomics of the thermal environment, analytical determination and interpretation of heat stress using of the predicted heat strain calculations.

- ASHRAE 55: Thermal comfort 2013
- EN ISO 7730: Thermal comfort 2013
- EN ISO 10551: 1995 Ergonomics of the thermal environment
- ISO 7933: 2004 Ergonomics of thermal environment
- ISO 11079: 2007 Ergonomics of thermal environment

2.2. What is IAQ?

IAQ is defined as the minimum ventilation requirements in building codes. Based on ASHRAE Standard 62.1, a good IAQ requires more than just the minimum ventilation rates. IAQ is also among the parameters of the indoor environmental quality (IEQ) alongside thermal comfort, lighting and acoustics, which has started to draw the attention of researchers and scientist in recent years. “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” (Fanger, 2006, 3). IAQ is a term that refers to “the quality of air within and around buildings, which has a direct relationship to the health and comfort of occupants of the building” (ANSI/ASHRAE Standard 62, 2010).

Gasses, including carbon dioxide CO2, radon, and volatile organic compounds (VOC) are the variables that affect the indoor air quality. In addition, Sarbu and

Sebarchievici (2013) claim that many factors including thermal adjustment, control of internal and external sources of pollutants, supplying of acceptable air, occupant activities and preferences, and proper operation and maintenance of building systems have an effect of thermal comfort and IAQ. Moreover, using different types of ventilation and filtration systems are the primary methods to increase indoor air quality (ANSI/ASHRAE Standard 62, 2013).

2.2.1. Indicators

IAQ is only one out of many factors that can contribute to the wellness of users in an indoor environment. There are also two types of indicator scales for IAQ, subjective and objective. Objective measurements are CO2 concentration level (ppm), indoor air temperature (°C), and relative humidity (%) (ANSI/ASHRAE Standard 62, 2013). Therefore, IAQ can be identified firstly by measuring the CO2 concentration level (ppm): this is the way to quantify the amount of gas by volume in the air. The unit of measurement is parts-per-million, that is the ratio between one gases to another in an exact volume of air. The second indicator is the indoor air temperature (°C). One definition of room temperature is that it is "the range of temperatures that people prefer for indoor settings, at which the air feels neither hot nor cold when wearing typical indoor clothing" (Webster, 2016). The third indicator is relative humidity (%). "The ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature and the same total pressure" (ANSI/ASHRAE Standard 55, 2013). In addition, the composition of living space air is different from the outdoors air in terms of (CO2) concentration.

Outside air has between 300 and 400 ppm of CO2 concentration. However, ASHRAE Standard recommends that in living spaces CO2 concentration level should not exceed 700 ppm above outdoors CO2 concentration level (ANSI/ASHRAE Standard 62, 2013). Air is considered contaminated when the CO2 concentration exceeds the range between 0.1 and 0.15 %. This corresponds to a concentration of 1000 ppm and 1500 ppm and becomes harmful to the body starting from a concentration of 2.5 %. (Sarbu and Sebarchievici, 2013).

On the other hand, as a subjective measurement element, using the seven-Likert scale questionnaire is recommended (EN ISO 10551). In this questionnaire, an answer of -3 signifies an unacceptable condition, and an answer of +3 signifies the acceptable condition (EN ISO 10551, European Standard). In other words, the primary factors, which affect the quality of air in a given space, are; temperature conditions and relative humidity, and the secondary factor are pollution in the air. However, as Jose (2010) mentions, the temperature is more effective than humidity in terms of the linear effect of acceptance of air quality (See Table 2).

Table 2: ASHRAE Standard, recommendation for IAQ indicators, (ASHRAE Standard, 2013).

	Operative Temperature	Acceptable Temperature	Humidity	CO_2 Concentration level
Winter Season	22 °C	20-23 °C	30-65 %	1000 ppm
Summer Season	24.5 °C	23-26 °C	30-65 %	1000 ppm

2.2.2. Building codes and regulations

As indoor air quality has the same importance as thermal comfort in interior spaces so it has some standards to define what acceptable indoor air quality is and how it should to be. The one of the common standards is an American standard ANSI/ASHRAE 61.1-2013 ventilation for acceptable indoor air quality, and ANSI/ASHRAE 61.2-2013 ventilation for acceptable indoor air quality in low-rise residential buildings. Another standard by European Committee for Standardization called Standard: CEN - CR 1752, considers the ventilation for buildings as a design criteria for the indoor environment. Also, ISO 16814: Building environment design- indoor environment- methods of expressing the quality of indoor air for human occupancy, and NTP 243: Indoor air quality are the other standard which we take in consideration in this study.

- ANSI/ASHRAE 61.1-2013, ventilation for acceptable indoor air quality.
- ANSI/ASHRAE 61.2-2013 ventilation for acceptable indoor air quality in low-rise residential buildings.
- CEN CR 1752: ventilation for buildings.
- ISO 16814: 2008 Building environment design- indoor environment- methods of expressing the quality of indoor air for human occupancy.
- NTP 243: Indoor air quality

2.3. Recent Studies on Thermal Comfort and IAQ

The population of the world is rapidly growing. This growth is leading to an increase in the urban density of buildings. Therefore, the growing population will need more indoor spaces for various reasons and uses. The American Environmental Protection Agency (EPA) notes that architects and engineers looking for ways to improve environmental comfort while improving the performance of buildings should consider that people spend anywhere between 80% to 90% of their time in indoor environments (Environmental Protection Agency, 2014, 2). Thermal comfort and IAQ are topics, which draw the attention of many researchers, and many studies have been conducted in this area in recent years. On the other hand, conservation of energy in buildings is one of the best ways to reduce emission of greenhouse gases. Therefore, how thermal comfort and air quality conditions should be controlled in buildings, in order to achieve reduced energy consumption and higher indoor air quality is the primary concern of researchers in this field.

The idea of ventilation was first brought up by the work of Lavoisier in 18th century, who stated that it is not oxygen but rather carbon dioxide that is the most important factor on whether the indoor air quality is bad or not (Lavoisier, 1798). Tredgold (1836) published the first estimate of the minimum quantity of ventilating air needed. Approximately a hundred years later from Lavoisier, Pettenkofer (1862) found that biological contaminants from the human body contribute to indoor air quality more than CO2 does. He believed, as did Saeltzer (1872) and others, that CO2 was a useful surrogate for vitiated air (Janssen, 1999).

Based on early studies, in 1913 the New York State Ventilation Commission was

founded to ensure ventilation requirements were met in public buildings. Lehmberg, Yaglou, and their colleagues (1930) conducted chamber experiments in which occupants' body odor levels were considered as a factor for the ventilation rate level. This research results showed that "8 L/s per person controlled these odors to levels that weren't objectionable to persons entering the space from clean air environments" (Lehmberg andYaglou, 1930). Fanger in 1970 started to develop the first classic steady-state model for air-condition based on a heat balance model of the human body (Fanger, 1970). Later on, "those rates were 2.5 L/s m^2 in offices and 7.6 L/s m^2 in public buildings including schools, which convert to 50 L/s per person in offices and 22 L/s in classrooms based on the default occupancy densities in ASHRAE Standard 62.1-2013" (Persily, 2015, 63-64). Later, Billing and his colleagues (1970) suggested 15 L/s per person ventilation rate or higher as the optimum level. These rates are also used in the law model in American Society of Heating and Ventilating Engineers (ASHRAE) standard 62.1 2013. In other words, the development of ventilation rate and IAQ standards began with the publication of ASHRAE Standard 62-1973, Standards for Natural and Mechanical Ventilation (ASHRAE standard 62, 1973).

These numbers have been changed as time went on, "In lecture halls with fixed seats, with a much higher occupant density, the outdoor air requirement is 4.0 L/s per person. Moreover, the default value for the IAQ in a classroom is minimum value of five L/s per person, increasing to maximum value of 20 L/s per person. And twice these rate for smoking spaces" (Persily, 2015). These requirements are same in the latest version of the standard, 62.1-2013 (ASHRAE, 2013). Something else to

consider is that the “physical factors may modify the body response to indoor pollutants by interacting with it or have a direct effect on the occupants” (Levin, 1995). Another study on improvement on concentration by Wyon (1996) showed that “individual control equivalent to ±3 K would be expected to improve the performance of mental tasks requiring concentration by 2.7%” (Wyon, 1996).

Study by Wyon et al. (1975) shows that no difference was found in performance of two settings of thermal neutrality with different temperature and clothing: 0.6 clo at 23 °C and 1.15 clo at 19°C. In other words, there is no difference in thermal satisfaction between low temperature, high clothing insulation setting and high temperature, low clothing insulation setting (Wyon, 1975). Other studies on cold climates by Seppanen and Fisk (2004) stated that low ventilation rate with high indoor temperature results in low air quality for that space (Haverinen, et al, 2014). In addition, “this degree of individual control (±3 K) would be expected to improve the group mean performance of routine office tasks by 7%”. Figure 4 shows the effects of temperature on performance, documented in the literature (Seppanen, Fisk and Lei 2006). Figure 5 shows an experimental relationship between the performance of office work and thermal discomfort (Wargocki and Wyon, 2006).

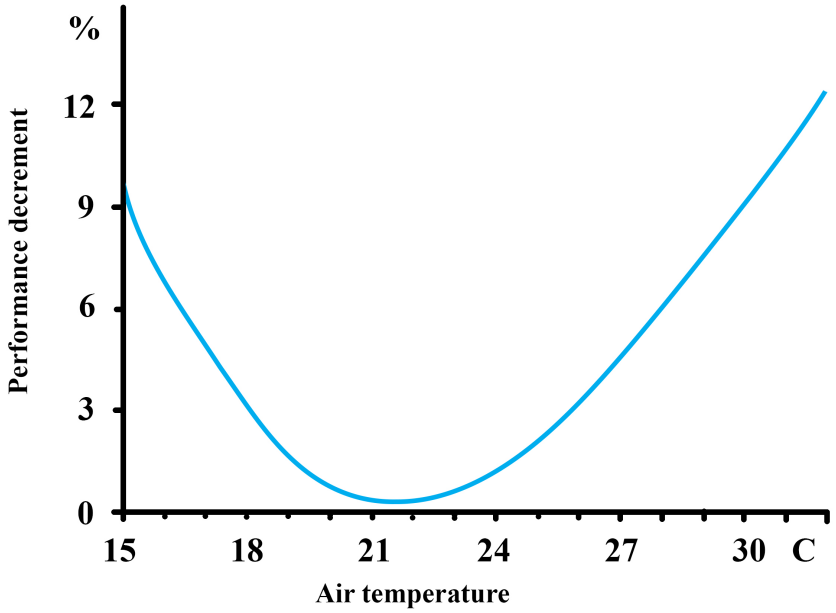


Figure 4: The relationship between temperature and the performance of office work (Seppanen et al., 2006)

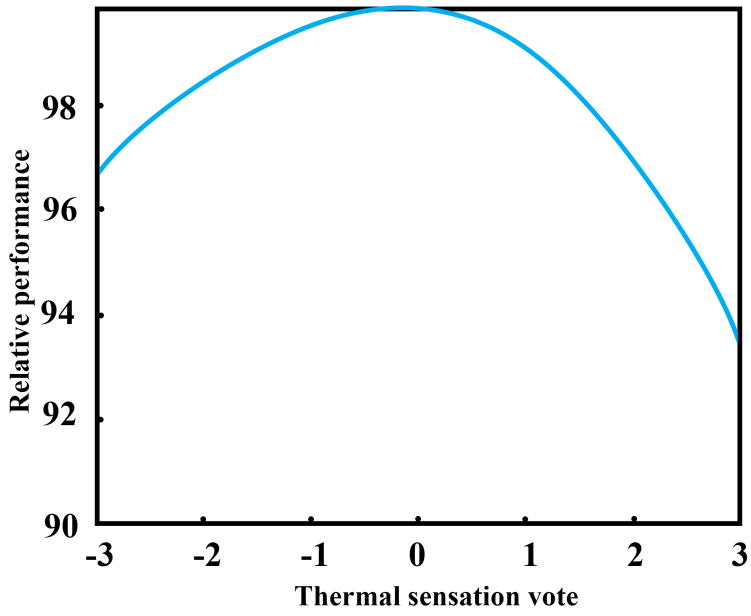


Figure 5: The experimental relationship between classroom temperature and the performance of schoolwork (Wargocki and Wyon 2006).

According to Seppanen et al. (2006), the impact of ventilation on worker performance is significant and they reported that statistically significant improvements in performance for ventilation rates up to 15 L/s. (Seppanen et al., 2006). A Swedish experimental study (2008) recommended both sufficient air exchange and an air-conditioned building for a better classroom indoor air quality and thermal comfort (Norback and Nordstrom, 2008). “Increased accuracy in the Tsai-Partington test indicates raised arousal, which improves concentration and would thus be expected to benefit rule-based logical thinking” (Tham and Willem, 2010).

An ensuing study (Fisk, et al, 2011) concluded that higher ventilation rates (25 L/s per person) have a reducing effect on sick building syndrome (SBS) in office buildings. The same study also points out that, “The air change rates above 0.5 h^{-1} are associated with reduced symptoms of asthma and allergies.” (Fisk, et al, 2011). Frontczak and Wargocki (2011) stated that the participants in this study rated the thermal comfort as the most important condition for improving satisfaction with the indoor environment and providing control over the indoor condition improves their thermal comfort. In addition, “There are differences in thermal acceptability for users of naturally ventilated buildings compared to users of buildings with air-conditioning” (Rupp, Lamberts, Vásquez, 2015).

2.4. Ventilation Modes and Their importance

In order to reach acceptable levels of IAQ and thermal comfort, diverse ventilation modes are required. Ventilation of indoor spaces allows us to control and keep CO_2 levels and fresh air levels in balance. Ventilation modes are divided into two main modes: natural ventilation and mechanical ventilation.

2.4.1. Natural ventilation mode

Natural ventilation is the process of supplying air to and removing air from an indoor space without using mechanical systems (Linden, 1999). In this case, smart architectural design leads the air to move inside the building and replace exhausted air with fresh air by designing the openings in appropriate dimensions and orientation in cross façades according to wind directions. The raising concerns about cost and environmental use of energy have increased the use of natural ventilation definitely to provide improved IAQ in a cost-effective and sustainable manner. Figure 6 illustrates a basic room diagram for natural ventilation.

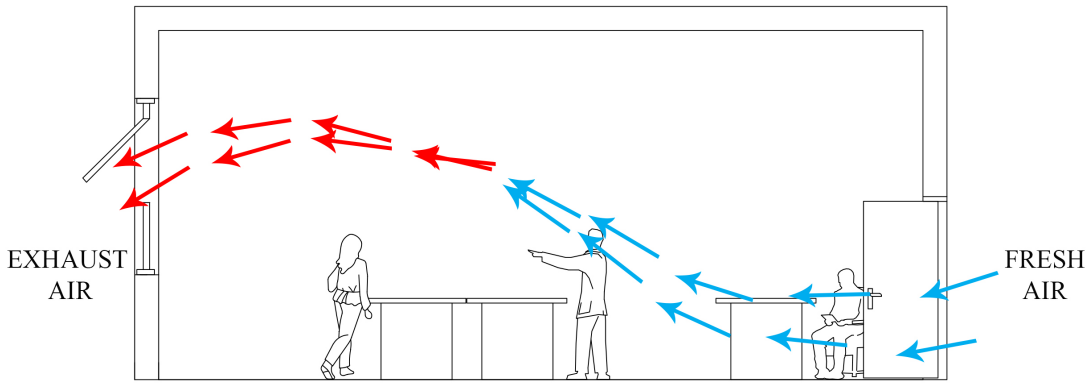


Figure 6: Natural ventilation diagram, drawn by Ali Ranjbar, 2017.

2.4.2. Mechanical ventilation mode

"Mechanical ventilation is the medical term for artificial ventilation where mechanical means are used to assist or replace spontaneous breathing" (Linden, 1999). The machine programmed to meet the demand of any kind of space according to the up to date standards. It manages the air input and outputs and automatically controls the carbon dioxide concentration level inside the environment. Figure 7 illustrates a basic room diagram for mechanical ventilation mode.

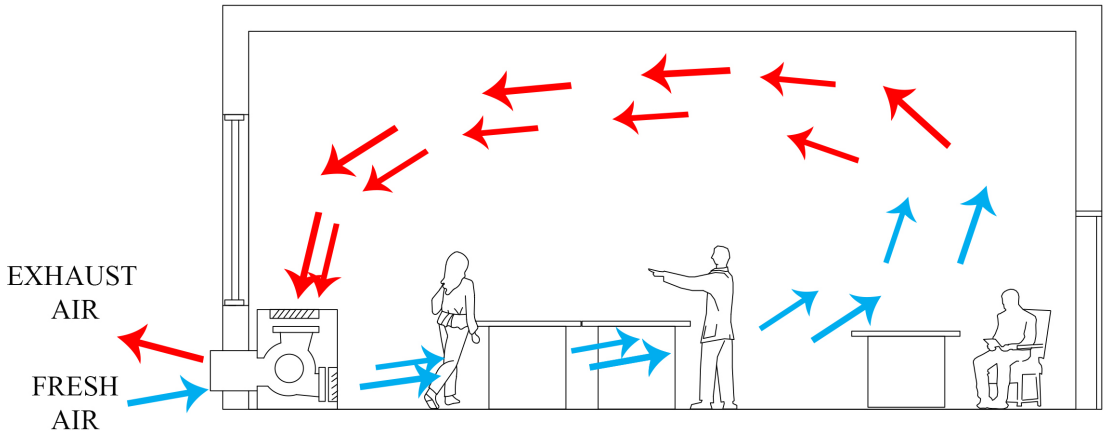


Figure 7: Mechanical ventilation diagram, drawn by Ali Ranjbar, 2017

CHAPTER III

HEALTH AND COMFORT IN UNIVERSITY BUILDINGS

3.1. CO2 level, ventilation rate and temperature in a classroom

Universities are places where most of the young population is in during the daytime. Many researchers mention university environments as the most crucial indoor environments to ensure student's health, effective learning and wellbeing (Diapouli, 2008; Dorizas, 2013; Silvers, 1994). The New York State Ventilation Commission was formed in 1913 to determine ventilation requirements in schools and other public buildings. The results of research by Andrew persily (2015) conclude that five L/s to 7.5 L/s per person was the acceptable limit for classrooms. Those rates were 2.5 L/s m^2 in offices and 7.6 L/ s m^2 in public buildings including schools, which translates to 22 L/s per person in classrooms based on the population of occupancy in space and used in ASHRAE standard (ASHRAE Standard 62.1-2013). The ventilation rate per person and the indoor CO2 concentration are related based on a single-zone mass balance of CO2. ASHRAE 62-1989 eliminated the distinction between smoking and non-smoking spaces, requiring eight L/s per person of outdoor air in a classroom. The 2001 versions of ASHRAE standard changed the ventilation requirements to include both an outdoor air requirement per person, and an outdoor air requirement per unit floor area. The default value for the lowest class of IAQ is five L/s per person, increasing to 20 L/s per person for the highest class. The rates for smoking spaces are twice those for non-smoking. "Measuring the actual indoor CO2

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, 2003). According to Al-Rashidi, Loveday and Al-Mutawa (2012), "high CO2 concentration levels in classrooms can affect students' health, learning performance and productivity" (p.3). In classrooms, the source of CO2 is the occupants' metabolic production, causing the indoor CO2 concentrations to exceed outdoor concentrations. An average individual with normal activity produces 20 liters (0.02 m3) of CO2 in an hour, so the density of crowding can affect CO2 concentration level (ppm) in space. Therefore, the 1000-ppm concentration of CO2 is acceptable level as the minimum level in an indoor environment (Bulut, 2012). In order to provide that level, "the ventilation system controls the level of CO2 in the air (pre-person 25-85 m3/hour) according to a number of people in space" (Bulut, 2012).

3.2. Effect of thermal comfort and IAQ on students' attention and concentration

Several studies have shown that poor IAQ and inadequate ventilation rate can also be linked to reducing academic achievements and general performance of schoolwork (Mendell and Heath, 2005; Wargocki et al. 2005; Wargocki and Wyon, 2007). It is believed that poor indoor environmental quality (IEQ) in schools may result in illness leading to student absenteeism, as well as adverse health symptoms, and decreased academic performance (Eide, et al, 2010, Fitzgerald, et al, 2010; Eliseeva, et al, 2013; Mendell, 2005). "An earlier study of one hundred elementary schools from two school districts in the Southwest United States found that 87% of

classrooms studied (one classroom per school) had ventilation rates below 7.1 l/s per person" (Haverinen-Shaughnessy, Moschandreas and Shaughnessy, 2011), which is the minimum ventilation rate according to ASHRAE standard 2013. A later study by Shaughnessy et al. (2014) found the same result that there is a linear association between classroom ventilation rates and students' academic achievement within the range of 0.9-7.1 l/s per person.

Investigation of the effects of classroom IAQ on the mental performance of high school students by Smedje et al. (1996) reported that the reduction in performance is related with low ventilation rates. "The main idea of classroom ventilation is to provide indoor environmental conditions that reduce the risk of health problems among occupants and minimize their discomfort in order to eliminate any negative effects on learning" (Sarbu and Pacurar, 2015). However, low ventilation rates in classrooms have been also associated with lower student attention and concentration. (Mishra and Ramgopal, 2015). The poor indoor environment in classrooms may be linked to many factors, such as inadequate levels of ventilation as well as to the lack of necessary resources for the suitable operation and maintenance of facilities. The study by Wargocki and Wyon (2007) showed that improving ventilation rates improves performance in a classroom environment. Feeling too cold or too warm will negatively affect the performance, though the effects are not symmetrical around thermal neutrality and they are somewhat skewed toward a slightly cool sensation. (Jensen, 2007; Lan, 2011; Roelofsen, 2001). Therefore, a lower environmental quality will cause reduced performance.

Three field studies were conducted in Denmark using mechanical ventilation (Wargocki & Wyon, 2008). In these studies, ventilation rate was improved from 3 to 9 L/S person, the outcome shows that increasing outdoor air supply improved the performance of students by 4 in a numerical and 2 in a language-based task, and there is a significant reduction on the percentage of errors on the numerical task (Wargocki & Wyon, 2008). The study by Shaughnessy et al, (2015) includes of 70 schools in Southwestern US 2008-2009 school year. Monitoring done for 27 of the elementary schools during the following school year (2009-2010) showed that the classroom ventilation rate and temperature, as well as hygiene of the high contact surfaces appear to be important IEQ variables, potentially related to student health and/or academic performance. The results showed that heating, ventilation, and air conditioning, as well as surface cleaning comprises the fundamental operational strategies for adjusting the school environment to improve health and academic performance of students (Shaughnessy et al. 2015). The conclusion was that doubling the outdoor air supply improved schoolwork by 8% overall, and by 14% for the task. Holmberg and Wyon (1969) report that by reducing temperature to 20 °C, the performance of two arithmetical and two language-based tests improved significantly. In addition, the improvement was always in terms of speed of performance, not accuracy. Figure 8 explains the average magnitude of the effects as a function of temperature. In addition, there is only a negligible effect recognized on errors in these setting, as shown in Figure 9. Wargocki and Wyon (2008) emphasized "there is not only the bioeffluents emitted by occupants, but also the emissions from materials have negative impact on performance" (10). In addition, the research by Satish et al. (2012) supports the idea of high CO2 leading to decreased performance. They found in their experiment of 3000 ppm CO2 to emphasize the negative effect of

high CO2 level on performance (Satish et al. 2012).

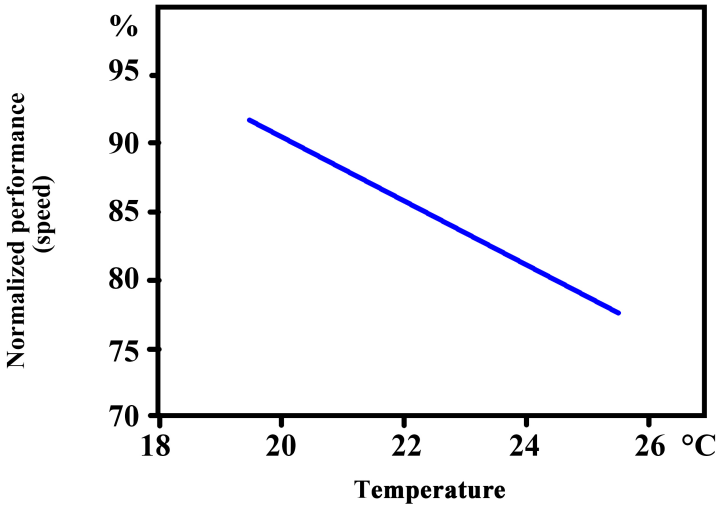


Figure 8: The experimental relationship between classroom temperature and the performance of schoolwork (Wargocki and Wyon, 2008).

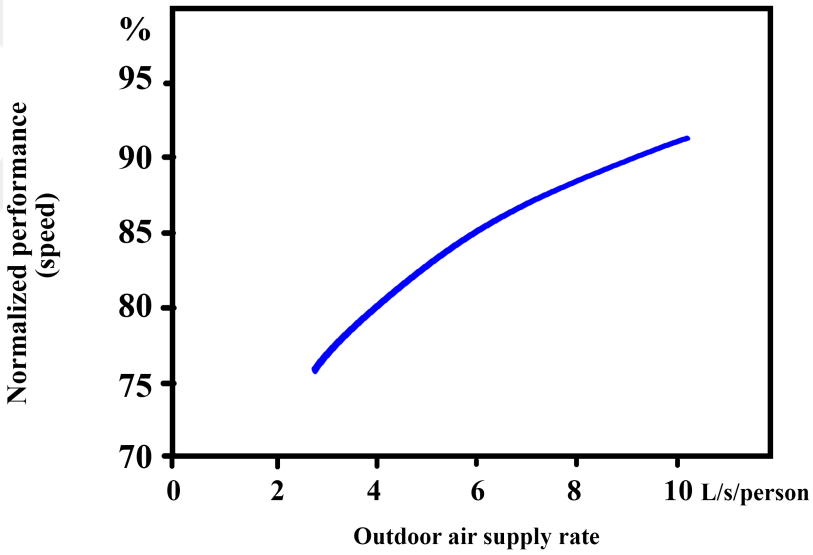


Figure 9: The experimental relationship between outdoor air supply rate per child and classroom performance of schoolwork (Wargocki and Wyon, 2008)

CHAPTER IV

METHODOLOGY

4.1. Research questions and hypotheses

The thesis has the following research questions:

R1: What are the effects of different ventilation modes on thermal comfort and IAQ of a design studio/classroom?

R2: How are thermal comfort and IAQ levels of a design studio /classroom associated with students' performance?

The thesis grouped the hypotheses under two groups. The two hypotheses related to thermal comfort are as follows:

H1: Increasing ventilation rate (5 l/s person<VR<7 l/s person) improves student performance.

H2: There is a statistically significant relationship between thermal comfort within the comfort zone and student performance.

The other two hypotheses related to IAQ are as follows:

H3: Increasing supplied fresh air from 0.3-5 to 13-16 l/s causes improvement on students' performance.

H4: Overloaded Co_2 concentration (above 1000 ppm) in design studios causes a decrease in student concentration and attention

4.2. Participants

Bilkent University, Department of Interior Architecture and Environmental Design was chosen as the location of the experiment. The department building, FF building, is a complex building, which contains many classrooms and design studios on each floor. The chosen room for the experiment setting is a newly furbished room called FF 101room, which is located on the first floor of the building. Selected studio has equipped with school air ventilation unit. The room is 125.6 square meter and is a high ceiling (3.6 m) design studio with three window façades. The reasons of selecting this room are as follows: Figure 10 illustrates the floor plan of the room. FF 101 Studio is furnished with 32 regular drawing tables and 32 adjustable chairs, one desktop computer, one projector, and wall mounted display setting panels from sound absorption fabric material, which also serve to keep acoustic comfort. On the other hands, the classroom volume satisfied the optimum value for the required IAQ rate in terms of number of students. Figure 11 illustrates the panoramic photograph of the studio. Figure 12 is the three-dimensional model of the studio, which is drawn by the author.

Participants of the study are 3rd-year undergraduate students of the Department of Interior Architecture and Environmental Design. 22 students are selected for a studio environment from a studio course ‘IAED 301 interior design studio’ for winter season and the same 16 students from ‘IAED 302 interior design studio ’ for summer season. For the classroom environment, 100 students are selected from the course ‘IAED 342 Sustainable Design for Interiors’ for both winter and 50 students from same course for summer seasons (See table 3).

Table 3: Number of participants for both season and both environments of study.

Season	Number of students	
	Studio	Classroom
Winter season	22	100
Summer season	16	50

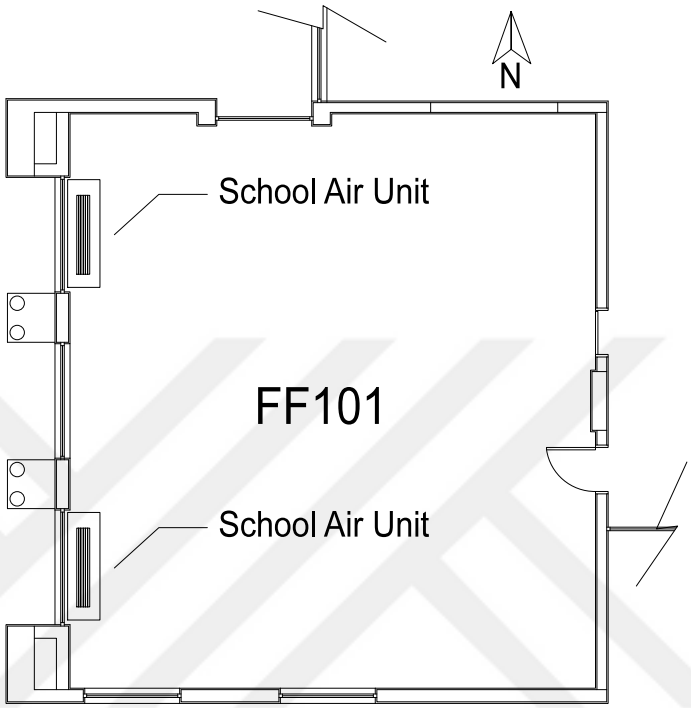


Figure 10: FF101 room plan, not in scale drawn by Ali Ranjbar, 2017.

Figure 11: A panoramic photo of FF 101 room, taken by Ali Ranjbar, 2017

Figure 12: The three-dimensional drawing of FF 101 room, drawn by Ali Ranjbar, 2017.

4.3. Procedure

This thesis used both objective and subjective indicators to assess the thermal comfort and IAQ of the experiment room, FF 101. This study is composed of two phases: one is winter season phase and second is the summer setting phase. Winter season phase was conducted on November 2016 and February 2017 and the summer season phase was conducted on April 2017. (See Table 4) Each phase has three experimental conditions, in every which both objective and subjective measurements of thermal comfort and IAQ of the room are repeated. Figure 13 illustrates the main conceptual procedure framework of this thesis. Table 4 explains the date of experimental measurement in studio and classroom on both seasons.

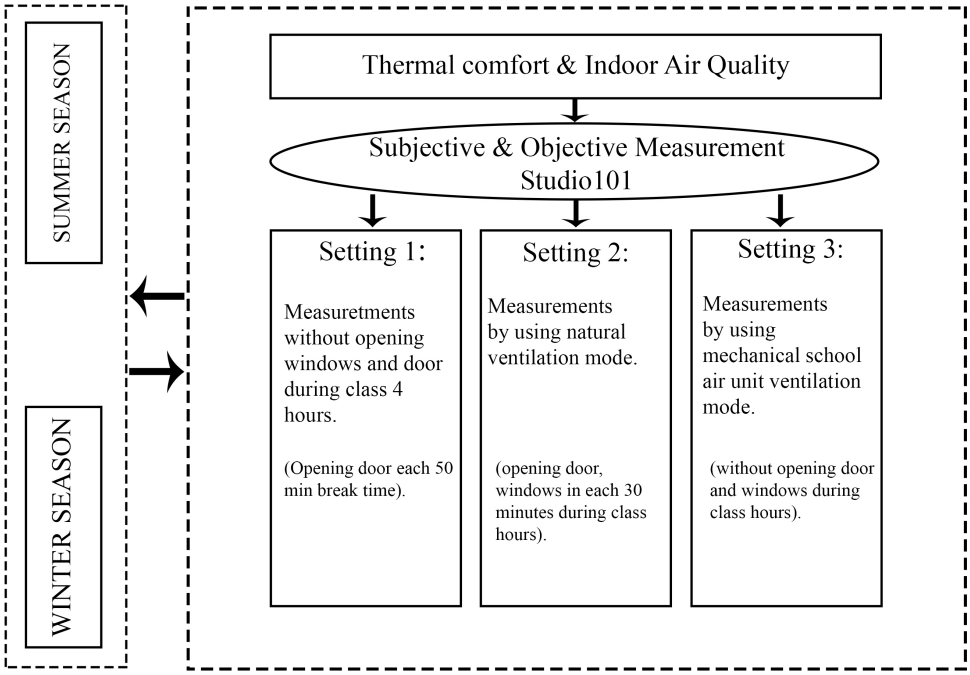


Figure 13: Main conceptual procedure framework of the study.

Table 4: Experimental measurement schedule on all settings.

	Winter Season		**Summer Season**	
	Studio	**Classroom**	**Studio**	**Classroom**
Setting I	1Nov 2016	6Feb 2017	4April 2017	3April 2017
Setting II	15Nov 2016	20Feb 2017	18April 2017	17April 2017
Setting III	29Nov 2016	6March 2017	2May 2017	1May 2017

Setting 1 is a none ventilation setting, which means that during the class hours neither door nor windows are open so ventilation happened by door trace and windows leak, except break times. The aim of the Setting 1 is to understand the general condition of air in FF 101. The objective measurements, CO2 concentration, temperature, humidity, monitor and record by digital measurement devices during 3

hours of the studio class and 2 hours of the lecture class. Then the subjective measurement, the questionnaire and performance tests, was conducted in the last 20 minutes of each class hour.

Setting 2 is a natural ventilation setting, which means that fresh air comes to space by opening the door and three cross windows in specific time periods in specific time duration (each 30 minutes, 5 minutes). The aim of setting 2 is to specify the amount of fresh air moving inside the room and circulation of the air inside the room in specific times. In addition, the objective measurements was monitored and recorded by digital measurement devices, as same as in Setting 1. Then, the same subjective measurements were also conducted in the last 20 minutes of each class time.

Setting 3 is a mechanical ventilation setting which means that none of the door and window opening were used for ventilation purposes, as same as setting 1 except using School Air –B. School Air –B is an air conditioning machine to meet the demand of the fresh air coming to space and to circulate fresh air in desired time and speed. During the Setting 3 the School Air –B software was also used to monitor the changing IAQ levels, CO2 and humidity, which gives the real-time information on diverse IAQ levels within the room. Again, the subjective measurements are conducted in last 20 minute of the class hour.

4.4. Instruments

Using different measurement tools to calculate thermal comfort and IAQ level separately can benefit the investigation. See Figure 14 Procedure diagram of the study for thermal comfort and Figure 18 Procedure diagram of the study for indoor air quality.

For the thermal comfort subjective measurements, a 7-point Likert scale (-3 is for cold, and +3 is for hot) questionnaire, which is recommended by the EN ISO 10551 is used. The questionnaire includes three sections (See Appendix A). In the first section, the demographic information of the participants are asked, such as age, gender, hours spent in the room, and their seating placement. In the second section, participants are asked to rate their thermal comfort level using 7-point likert scale questionnaire.

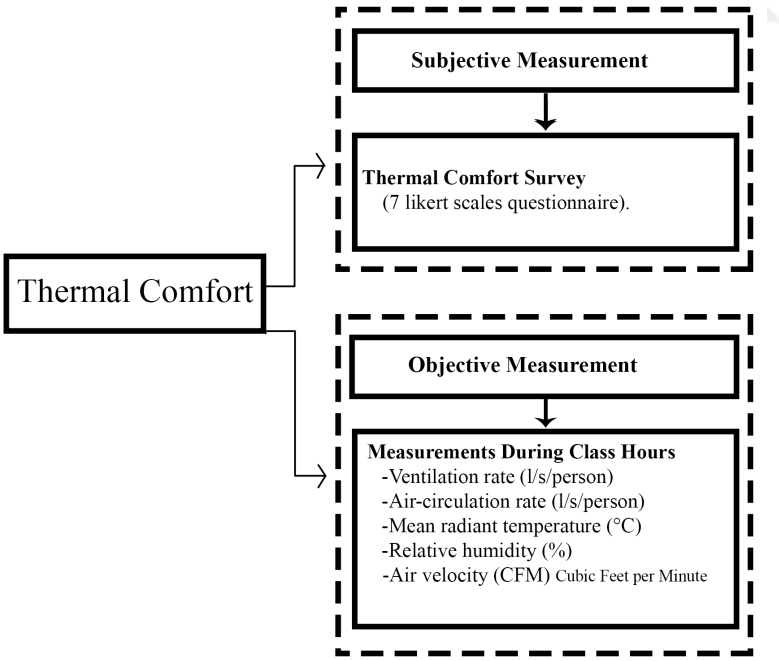


Figure 14: Procedure diagram of the study for thermal comfort

The digital measurement tools did objective measurements. First, Laser Pyrometer, BP 21 (Infrared thermometer) from TROTEC Company is used in the measurement of the radiant temperature. The device can measure the surface temperatures and has the measurement range of -35 C to +800 C, the accuracy of +_ 1% of the measurement value, and optical resolution of 12:1. Figure 15 illustrates the device.

Figure 15: BP 21 TROTEC available at: https://tr.trotec.com/ueruenler/haberler/genel-bakis/oelcuem-cihazlariniz-icin-sertifikali-guevenlik/

Another device is Flexible Thermo Anemometer, BA 15 by TROTEC Company, which is used to measure air speed, ventilation rate, and air circulation. The device can measure the amount of air that passes through its fan. In addition, it displays the result in full four digits of air velocity in m/s, and temperature °C. Figure 16 illustrates the device.

Figure 16:BA 15 TROTEC, available at: https://tr.trotec.com/ueruenler/haberler/genel-bakis/oelcuem-cihazlariniz-icin-sertifikali-guevenlik/

IAQ subjective measurement conduct by 7-likert scales placed in questionnaire sheet on section 3. In this section, participants are asked to rate their indoor air quality level in 7 scales from -3 very strongly dissatisfaction to +3 very strongly satisfaction. In addition, the subjective measurement continues by two performance tests. The first test is called Kraepelin test, which measures the arithmetic concentration, performance speed, and task performance accuracy. The second test called Prague test, which measures the attention of the participants on visual memories, targeting selective attention, and the perception of fixed discrimination. To sum up, in both tests the total number of answering, wrong answering, and missing the correct answers is considered in the calculation on software called SPSS during analyze statistically between settings.

Next phase is objective measurements, which done by several digital measurement tools same as thermal comfort. CO2 temp/RH Data logger CM 0019 is the device, which able to measure and monitor real time using computer software of CO2 (ppm) concentration level, humidity (%) level, and temperature (°C) level (See Figure 17).

Figure 17: Co2 temp/RH Data logger CM 0019

http://www.co2meter.com/products/wireless-co2-temp-rh-environmental-logger

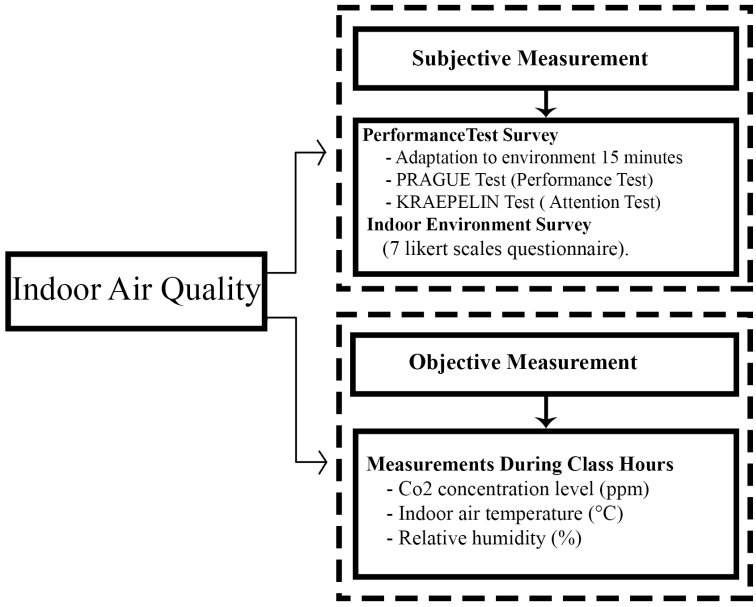


Figure 18: Procedure diagram of the study for indoor air quality

The last instrument to be used is TROX SCHOOLAIR-B the mechanical ventilation and filtration machine. The machine is capable of recognizing IAQ indicators in real time, filtration and recirculating of indoor air of the space, and if existing air has higher values according to update standard indicators value, the machine replaces the exhausted air of indoor with fresh air from outdoor. This feature of the device helps to keep indoor air fresh, clean, and in balance during occupant mode because building can breath simulataneous by help of mechanical ventilation (See Figure 19 and 20).

Figure 19: TROX SCHOOLAIR, available online at:

http://www.troxuk.co.uk/sill-and-under-sill-units/type-schoolair-b-8e32e6052d00629f

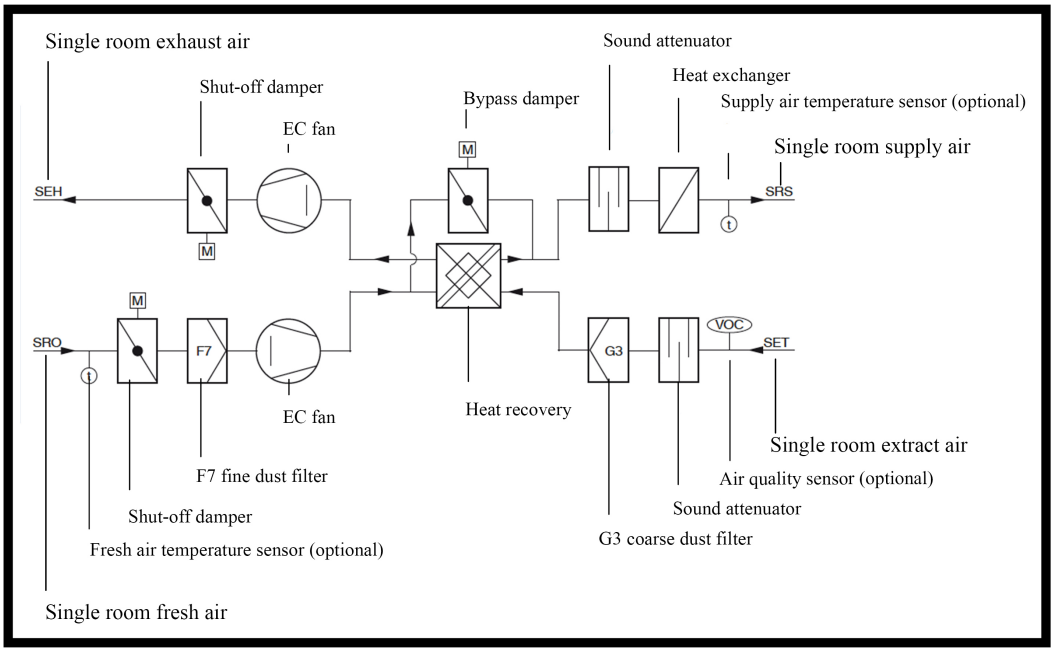


Figure 20: Type SCHOOLAIR-B, available online at:

http://www.troxuk.co.uk/downloads/f0b4a8c59e00315c/dezentrale-lueftung.pdf?type=product_info

CHAPTER V

DATA ANALYSES AND RESULTS

The results obtained from the experimental and subjective test measurements of the three different ventilation modes in both winter and summer seasons of the 2016-2017 academic year were discussed below. In both experimental and subjective measurements, first studio environment, and then classroom environment were described with reference to the winter and summer season, respectively. Measurements indicated that in both environments, the setting with mechanical school air unit ventilation was the most effective in terms of thermal comfort and IAQ performance. Moreover, this setting has also a greater influence on the attention and concentration performance of the students positively. The following two sub-sections give detailed explanations and the third subsection gives a summarized discussion of the results.

5.1. Experimental measurements: Thermal Comfort and IAQ Performance

5.1.1. Studio environment

5.1.1.1. Setting I: Without opening door and windows mode

Winter season experimental measurements of studio environment were started with the first week of November. 3-hours studio measurement without opening door and windows (except 10 minutes break times after every 30 minutes) was conducted during a school day from 13:40 h to 16: 40 h. Table 5 illustrates the results of the thermal comfort with the airflow values and temperature values of each wall of the studio room. As shown in the table, the mean radiant temperature was measured as 22.8 °C and mean airflow as 0.45 M/S.

Table 5: Temperature values of studio environment in winter season under setting I mode.

Air flow	**(M/S)**
Door	0.9 M/S
Window	0.0 M/S
Temperature	**(°C)**
Wall 1	24.9 °C
Wall 2	23.7 °C
Wall 3	20.9 (C
Wall 4	21.8 °C
Floor	23 °C
Ceiling	23.4 °C
Mean radiant temperature	22.8 °C
Outdoor	15 °C (cloudy)

The measured temperature values in winter were also inserted into the psychometric chart of the thermal comfort simulation CBE Thermal Comfort Tool, which is available in the online website of http://comfort.cbe.berkeley.edu/. This chart is significant in terms of showing whether the obtained values are within the comfort zone or not. In Figure 21, it was shown that the measurements values of 0.53 as PMV is higher than the value of -0.5<x<+0.5 for PMV with the sensation values of slightly warm, 27.5 °C as indoor temperature .As illustrated in Figure 21, the results of this setting do not comply with ASHRAE Standard 55-2013 and EN ISO 7730.

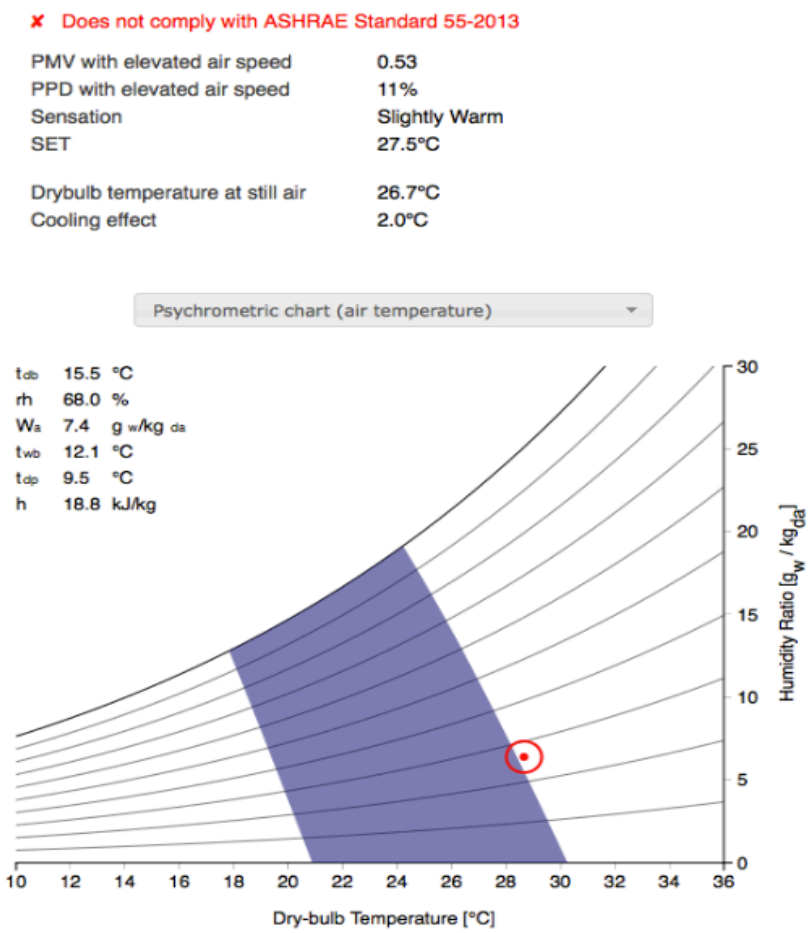


FIGURE 21: Psychometric chart of studio environment in winter season under setting I mode.

The measurement results of IAQ for the same studio environment were given in Figure 22. The measured mean value of the CO2 concentration was 1119 ppm with the humidity level of 26.22 % (See Figure 22 and Table 6). As shown in the Figure 22, the maximum CO2 peaks were about 1400 ppm while the minimum humidity level was about 24%. The CO2 levels were broken after the 30 minutes breaks, and then reached to higher levels because of CO2 production of students.

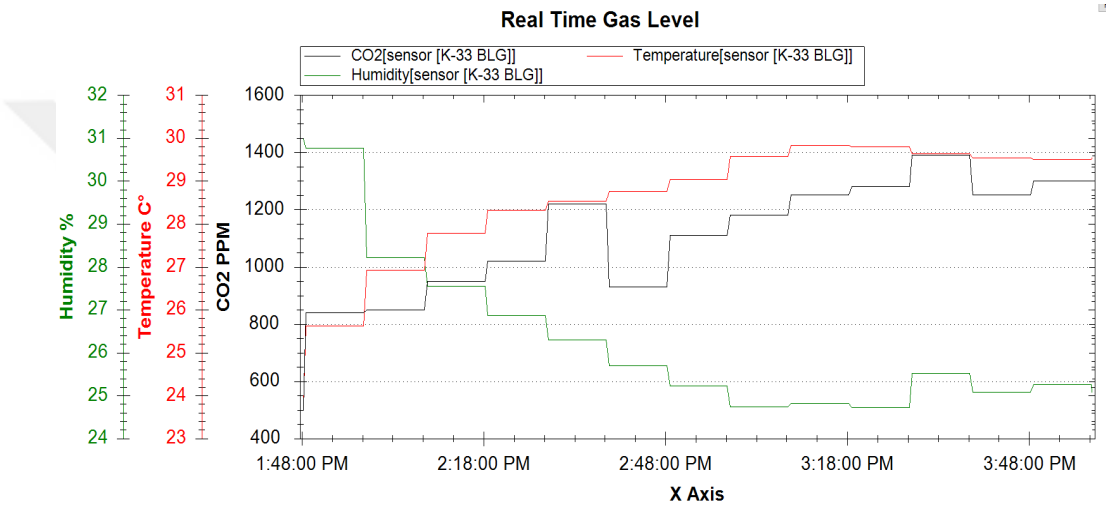


Figure 22: Variation of CO2, temperature and humidity levels with time for studio environment under setting I mode.

Table 6: Measured CO2 concentration, temperature and humidity values in setting I mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1390 ppm	1119 ppm	500 ppm
Temperature (°C)	29.45°C	28.66°C	23.76°C
Humidity (%)	30.97 %	26.22 %	24.71 %

Coming to summer results of the studio environment, which conducted on the first week of April 2017, the temperature values were given in Table 7. The mean radiant temperature was measured as 24.4 °C. Different than the winter season, the values were higher. However, like in winter season, according to these results, the thermal comfort of the studio environment was not within the recommended zone of the ASHRAE Standard 55-2013 and EN ISO 7730, as well. In Figure 23, it was shown that the measurements values of -0.68 as PMV and 23 °C as the indoor temperature with the sensation of slightly cool.

Table 7: Temperature values of studio environment in summer season under setting mode.

Air flow	**(M/S)**
Door	0.4 M/S
Window	0.0 M/S
Temperature	**(°C)**
Wall 1	25.5 °C
Wall 2	24.6 °C
Wall 3	23.0 °C
Wall 4	24.0 °C
Floor	24.0 °C
Ceiling	25.5 °C
Mean radiant temperature	24.4 °C
Outdoor	16 °C (cloudy)

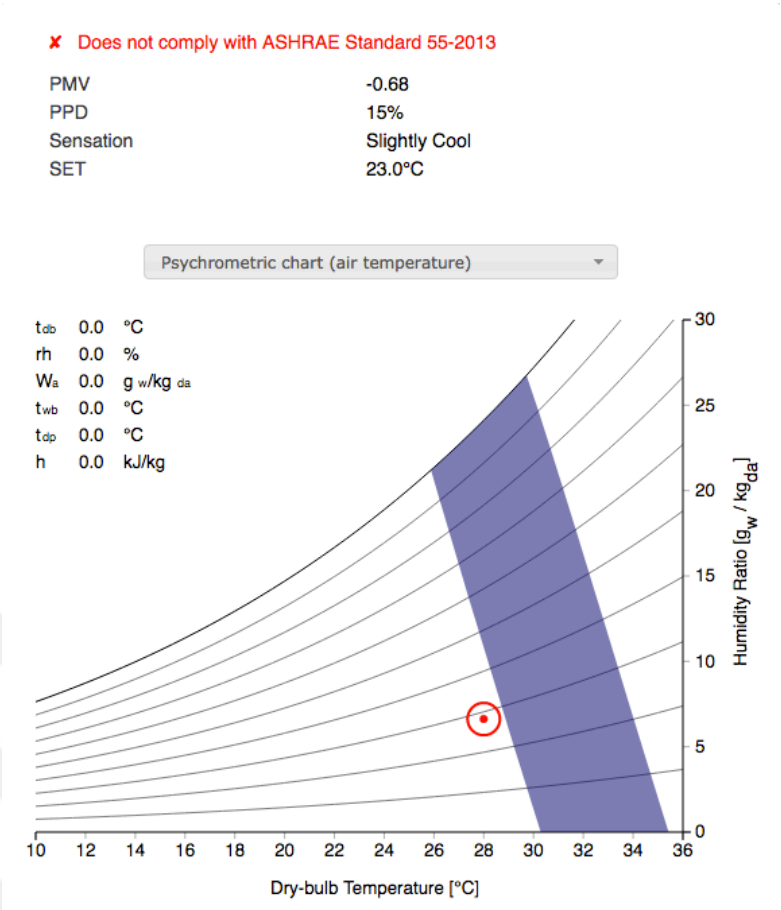


Figure 23: Psychometric chart of studio environment in summer season under setting I mode.

The IAQ results in summer season differed than the winter results in terms of humidity levels (Figure 24 and Table 8). As shown in Figure 24, it was clear that the humidity levels were increasing along temperature values in summer season, because the radiators were in the off-mode. There was a sudden rise in CO2 levels around 3.00 pm (reaching almost 3000 ppm, above ASHRAE 61.1 standards) because of the increase in student occupation during the critique times. Table 8 gave the maximum and minimum values of CO2 concentration, temperature and humidity values.

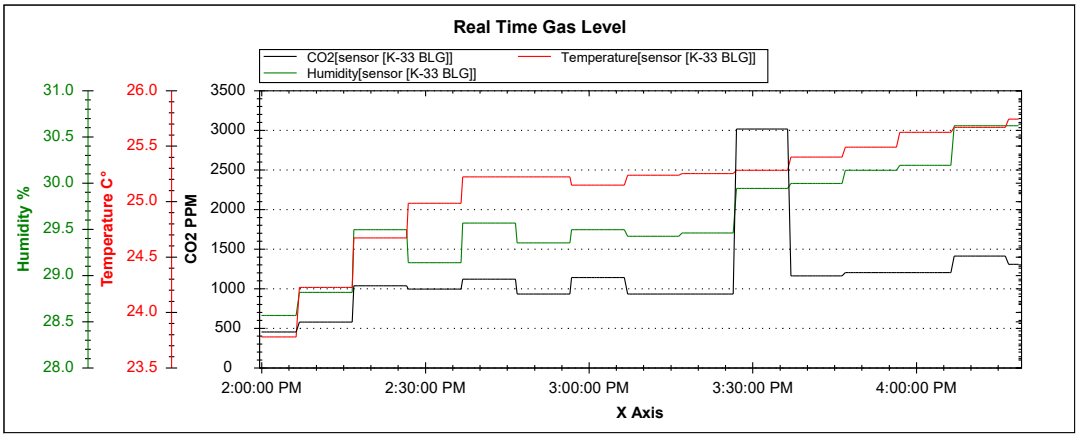


Figure 24: Variation of CO2, temperature and humidity levels with time for studio environment under setting I mode.

Table 8: Measured CO2 concentration, temperature and humidity values in setting I mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	3000 ppm	1250 ppm	500 ppm
Temperature (°C)	23.50°C	24.66°C	25.70°C
Humidity (%)	30.50 %	29.44 %	26.56 %

5.1.1.2. Setting II: Natural ventilation mode

Winter season experimental measurements of second setting of in studio environment were started with the third week of November. Three-hours studio measurement of cross-ventilated through the door and three windows (5 minutes in each 30 minutes) was conducted during a school day from 13:40 pm to 16:40 pm. Table 9 illustrates the outcomes of the thermal comfort with the airflow values and temperature values of each wall of the studio environment. As displayed in the table 9, the mean radiant temperature was measured as 22.8 °C and mean airflow as 0.5 M/S.

Table 9: Temperature values of studio environment in winter season under setting II mode.

Air flow	**(M/S)**
Door	0.3 M/S
Window	0.7 M/S
Temperature	**(°C)**
Wall 1	26.1 °C
Wall 2	25.7 °C
Wall 3	23.4 °C
Wall 4	25.7 °C
Floor	25.1 °C
Ceiling	26.2 °C
Mean radiant temperature	22.8 °C
Outdoor	11 °C (cloudy)

The measured temperature values of second setting in winter were also inserted into the same psychometric chart of the thermal comfort simulation CBE Thermal Comfort Tool as setting one. This chart is significant in terms of demonstrating whether the achieved values are within the comfort zone or not. In Figure 25, it was shown that the measurements values of 0.33 as PMV is between the value of -0.5<x<+0.5 for PMV with the neutral sensation values, 26.8 °C as indoor temperature .As illustrated in Figure 25, the results of second setting winter season do comply with ASHRAE Standard 55-2013 and EN ISO 7730.

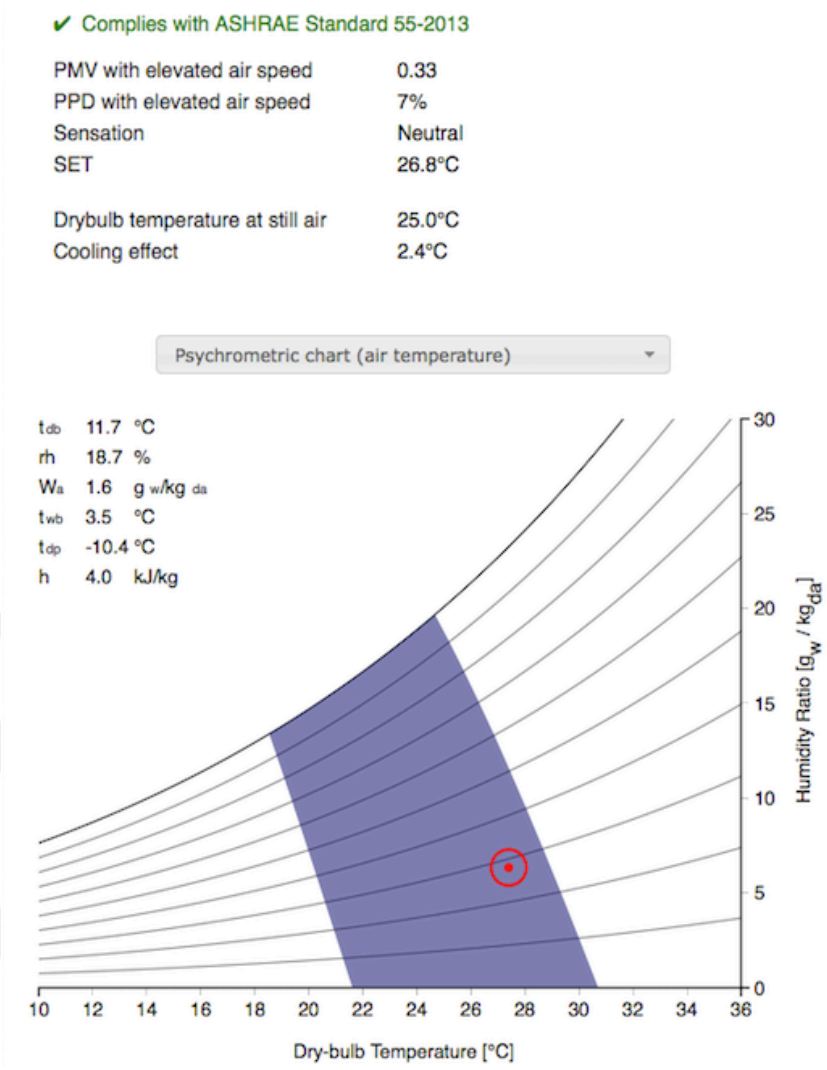


Figure 25: Psychometric chart of studio environment in winter season under setting II mode.

The measurement results of IAQ for the same studio environment were given in Figure 26. The measured mean value of the CO2 concentration was 1068 ppm with the humidity level of 28.06 % (See Figure 26 and Table 10). As shown in the Figure 26, the maximum CO2 were about 1268 ppm whereas 23.56% recorded as the minimum humidity level. The CO2 concentration were moved in between the narrow range of 1000 ppm and 1200 ppm, then drop to 868-ppm minimum measured value of CO2, which is related to number of student at that time.

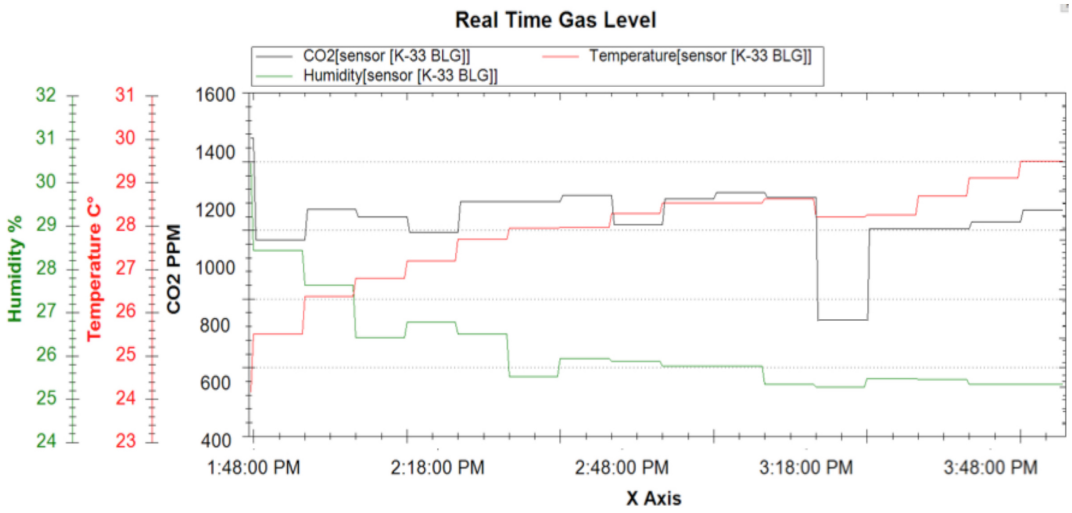


Figure 26: Variation of CO2, temperature and humidity levels with time for studio environment under setting II mode.

Table 10: Measured CO2 concentration, temperature and humidity values in setting II mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1268 ppm	1068 ppm	868 ppm
Temperature (°C)	30.5°C	27.44°C	23.8°C
Humidity (%)	33.89 %	28.06 %	23.56 %

Summer season measurements of second setting in the studio environment have been started on third week of April 2017. The temperature values were given in Table 11. The mean radiant temperature was measured as 25.2 °C. Unlike the winter season, the values were much higher. However, according to these outcomes, the thermal comfort of the studio environment was within the recommended zone of the ASHRAE standards. In Figure 27, it was represented that the measurements values of -0.48 as PMV and 23.4 °C as the indoor temperature with the sensation of neutral.

Table 11: Temperature values of studio environment in winter season under setting II mode.

Air flow	(M/S)
Door	0.4 M/S
Window	1.3 M/S
Temperature	**(°C)**
Wall 1	26.4 °C
Wall 2	25.7 °C
Wall 3	23.6 °C
Wall 4	26.2 °C
Floor	23.5 °C
Ceiling	26.3 °C
Mean radiant temperature	25.2 °C
Outdoor	16 °C (cloudy)

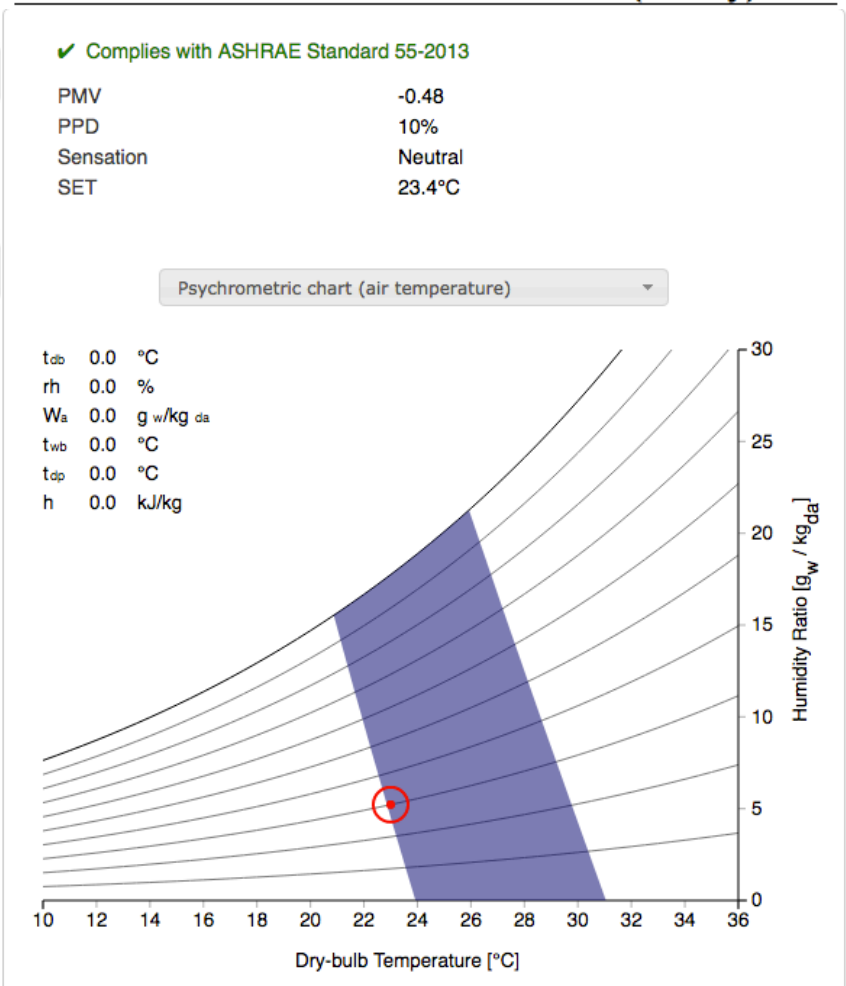


Figure 27: Psychometric chart of studio environment in summer season under setting II mode.

The IAQ results in summer season differed than the winter results in terms of temperature levels (Figure 28 and Table 12). As shown in Figure 28, it was clear that the humidity levels and temperature values in summer season were decreasing, because no heating system were running during summer season. As illustrated in Figure 28, the temperature, humidity and CO2 levels were within the control limits; with a continuous increase of CO2 levels and sudden breaks of every 40 minutes break. Table 12 gave the maximum and minimum values of CO2 concentration, temperature and humidity values.

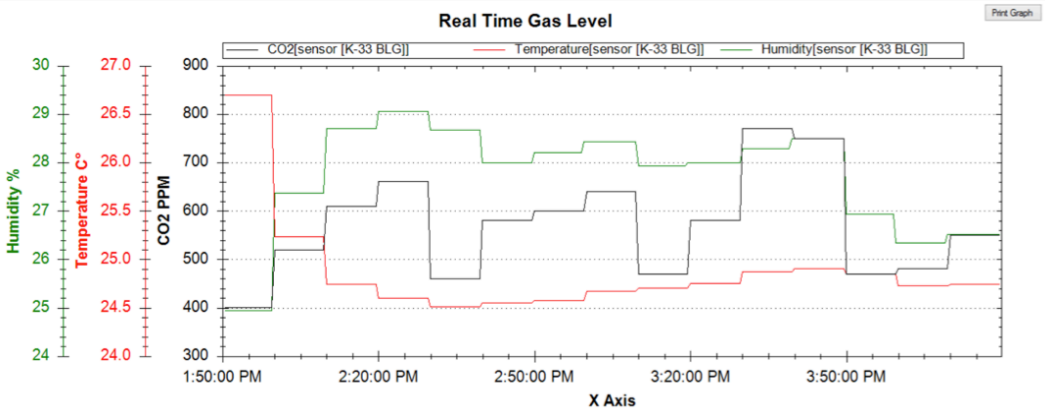


Figure 28: Variation of CO2, temperature and humidity levels with time for studio environment under setting II mode.

Table 12: Measured CO2 concentration, temperature and humidity values in setting I mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	765 ppm	582 ppm	400 ppm
Temperature (°C)	26.50°C	25.50°C	24.30°C
Humidity (%)	29.20 %	27.25 %	25.3 %

5.1.1.3. Setting III: Mechanical school-air unit mode

Third setting experimental measurements of winter season in studio environment were started with the first week of December. Three-hours studio measurement by using TROX school air-B unit (Mechanical ventilated) conducted during a school day as same as previous two settings. Table 13 illustrates the results of the thermal comfort with the airflow and temperature values of each wall surfaces of the studio environment. As presented in the Table 13, the mean radiant temperature was recorded as 21.5 °C and mean airflow as 0.85 M/S including mean airflow of 0.25 with a ventilation unit of TROX school air unit,

Table 13: Temperature values of studio environment in winter season under setting III mode.

Air flow	**(M/S)**
Door	1.3 M/S
Window	0.4 M/S
Temperature	**(°C)**
Wall 1	23.3 °C
Wall 2	21.8 °C
Wall 3	17.5 (C
Wall 4	21.5 °C
Floor	21.9 °C
Ceiling	23.4 °C
Mean radiant temperature	21.5 °C
Outdoor	0 °C (cloudy)

The measured temperature values in winter were also inserted into the same psychometric chart of the thermal comfort simulation CBE Thermal Comfort Tool. This chart was shown that the measurements values of -0.25 as PMV that is in between value of -0.5<x<+0.5 for PMV with the sensation values of neutral, 24.3 °C as indoor temperature. As demonstrated in Figure 29, the outcomes comply with ASHRAE Standard 55-2013 and EN ISO 7730.

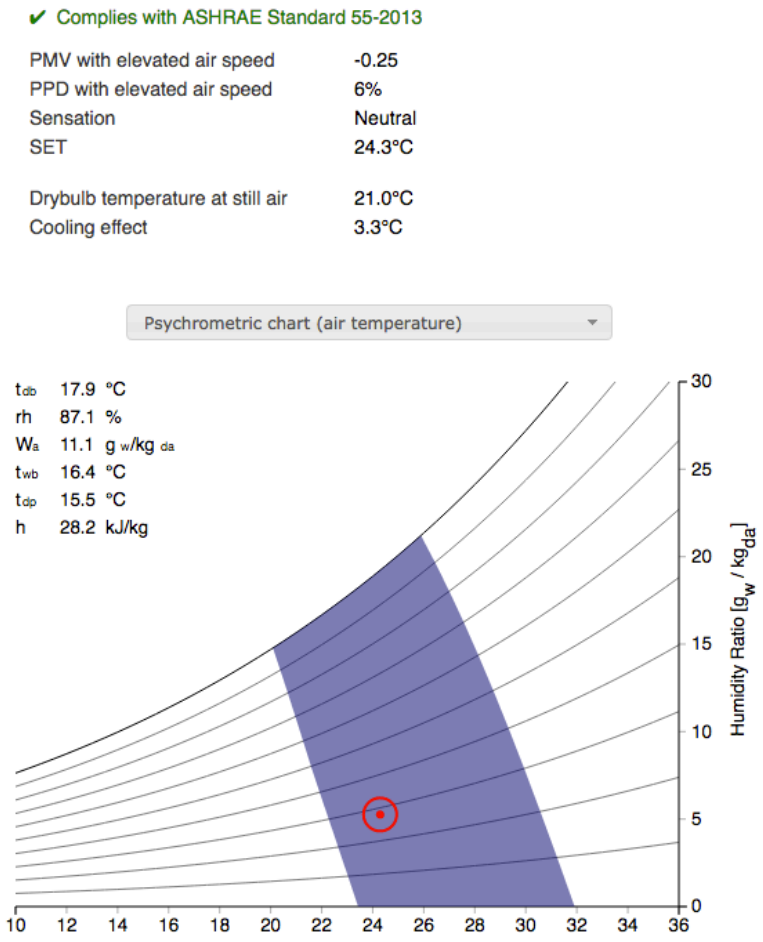


Figure 29: Psychometric chart of studio environment in winter season under setting III mode.

The measurement results of IAQ for the same studio environment were given in Figure 30. The measured mean value of the CO2 concentration was 985 ppm with

the humidity level of 27.98 %, and mean value of 24.29 °C (See Figure 30 and Table 14). As shown in the Figure 30, the maximum CO2 were about 1100 ppm with the minimum humidity level of the 26.96%. The variation in indoor relative air humidity was within the limits according to the requirements of EN ISO 7730 standard and decreased constantly during the 3 hours because of the ventilation unit. The CO2 levels were changing inconstantly because of the change in number of the students that were irregularly going in and out from the studio and respectively. The temperature had a greater increase from 21 °C to 25 °C in the first two hours and then maintained an approximately constant value of 25.5 °C.

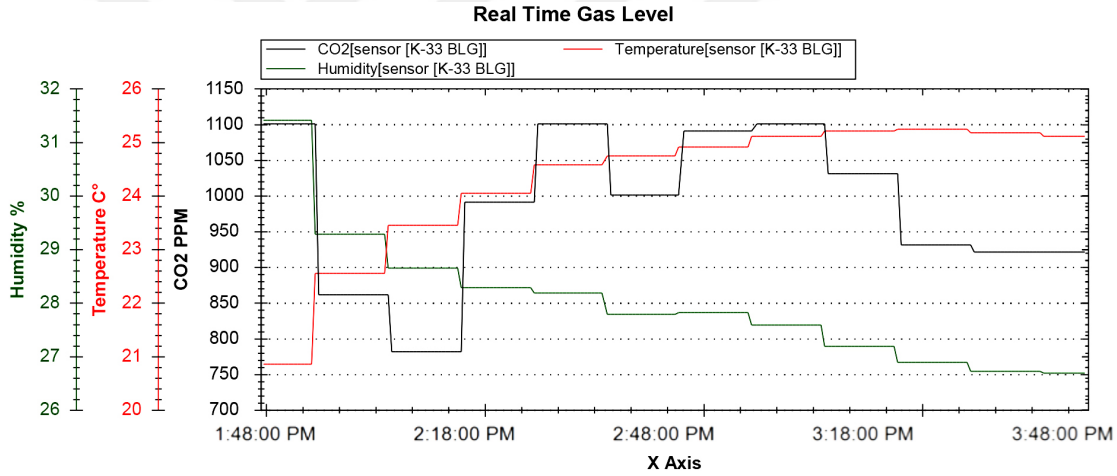


Figure 30: Variation of CO2, temperature and humidity levels with time for studio environment under setting III mode.

Table 14: Measured CO2 concentration, temperature and humidity values in setting III mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1100 ppm	985 ppm	780 ppm
Temperature (°C)	25.24°C	24.29°C	20.48°C
Humidity (%)	31.4 %	27.98 %	26.69 %

Summer season measurements of the studio environment were conducted on the first week of May 2017. The results are given in Table 15. The mean radiant temperature was measured as 25.1 °C. Unlike the winter season, the temperature values were higher in summer season. However, in summer season, according to recorded outcomes, the thermal comfort of the studio environment was within the recommended zone of the ASHRAE Standard 55-2013 and EN ISO 7730 with the help of TROX school air unit. In Figure 31, the measurements were presented in values of -0.29 as PMV and 23.7 °C as the indoor temperature.

Table 15: Temperature values of studio environment in summer season under setting III mode.

Air flow	**(M/S)**
Door	0.0 M/S
Window	0.4 M/S
Temperature	**(°C)**
Wall 1	25.3 °C
Wall 2	25.0 °C
Wall 3	24.1 (C
Wall 4	25.0 °C
Floor	24.6 °C
Ceiling	26.6 °C
Mean radiant temperature	25.1 °C
Outdoor	16 °C (cloudy)

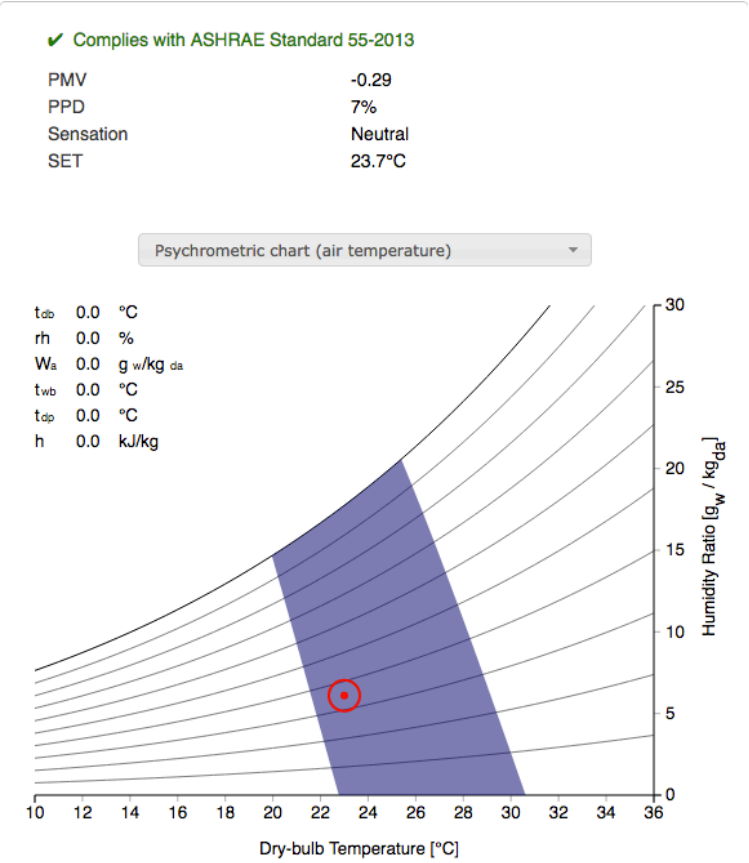


Figure 31: Psychometric chart of studio environment in summer season under setting III mode.

The IAQ results in summer season differed than the winter results in terms of higher humidity levels (Figure 32 and Table 16). As shown in Figure 32, it was clear that the humidity levels and temperature values increased in summer season, however they were still within the limits of the requirements. The influence of TROX school air unit was very clear on CO2 concentration. Although CO2 concentartion level was increasing with the three hours, it was reached to a final value of approximately 650 ppm, which is a very acceptable value in ASHRAE 61.1.

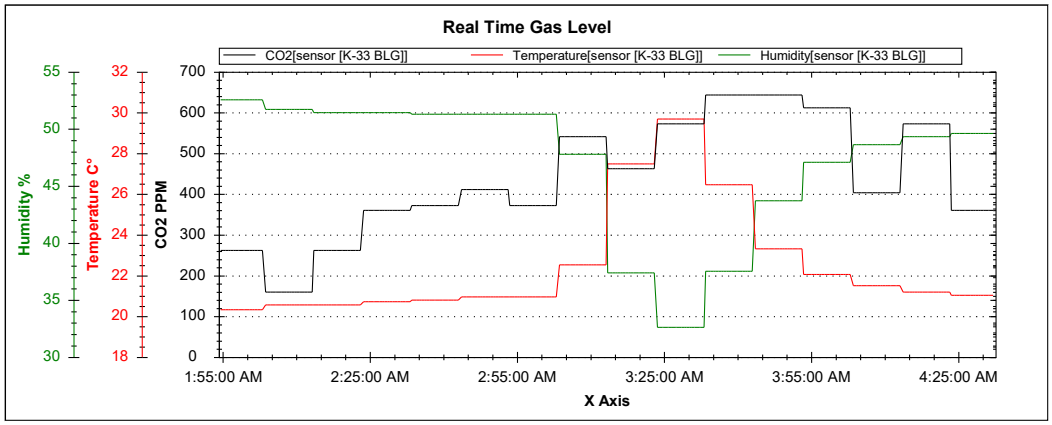


Figure 32: Variation of CO2, temperature and humidity levels with time for studio environment under setting III mode.

Table 16: Measured CO2 concentration, temperature and humidity values in setting III mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	665 ppm	472 ppm	280 ppm
Temperature (°C)	29.00 °C	24.75 °C	20.50°C
Humidity (%)	51.00 %	41.25 %	26.69 %

5.1.2. Classroom environment

5.1.2.1. Setting I: Without opening door and windows mode

Experimental measurements of classroom environment were started with the winter season, in the first week of February 2017. 2-hours classroom measurement without opening door and windows (except 10 minutes break times after every 30 minutes) was conducted during a school day from 8:40 Am to 10: 40 Am. Table 17 demonstrated the results of the thermal comfort with the airflow and temperature

values of each wall of the classroom. As shown in the table, the mean radiant temperature was measured as 23.0 °C and mean airflow as 0.4 M/S.

Table 17: Temperature values of classroom environment in winter season under setting I mode.

Air flow	**(M/S)**
Door	0.8 M/S
Window	0.0 M/S
Temperature	**(°C)**
Wall 1	24.5 °C
Wall 2	22.4 °C
Wall 3	20.5 °C
Wall 4	23.8 °C
Floor	21.9 °C
Ceiling	25.1 °C
Mean radiant temperature	23.0 °C
Outdoor	-3 °C (cloudy)

The measured values in terms of temperature and air flow in winter season were also inserted into the psychometric chart of the thermal comfort simulation CBE Thermal Comfort Tool, in order to observe whether the achieved values are within the comfort zone or not. According to Figure 33, the measurements values of -0.63 as PMV was higher than the value of -0.5<x<+0.5 for PMV with the sensation values of slightly cool, 23.7 °C as indoor temperature .As illustrated in Figure 33, the results of this setting do not comply with ASHRAE Standard 55-2013 and EN ISO 7730.

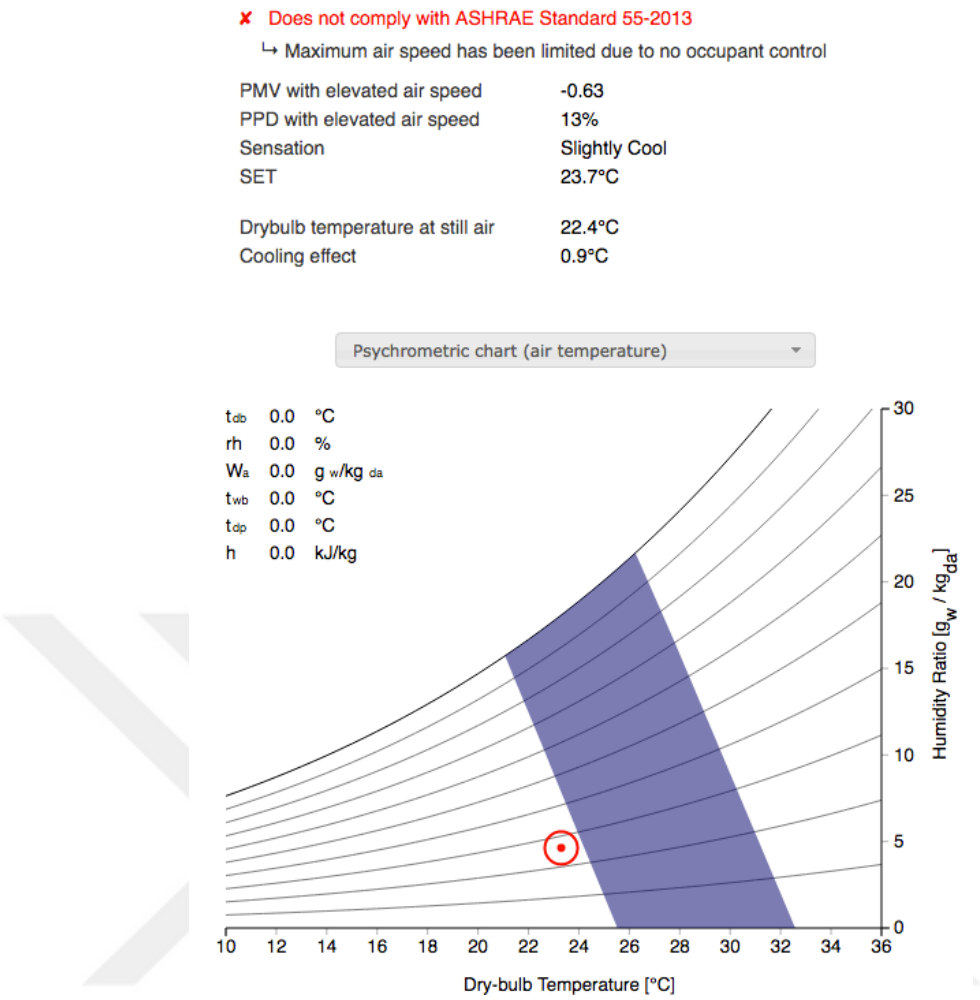


FIGURE 33: Psychometric chart of classroom environment in winter season under setting I mode.

The measurement results of IAQ for the same classroom environment were given in Figure 34. The measured mean value of the CO2 concentration was 1472 ppm with the humidity level of 26.14 % (See Figure 34 and Table 18). As shown in the Figure 34, the maximum CO2 peaks were about 2050 ppm while the minimum humidity level was about 23.89%. As shown in Figure 34, the CO2 concentration increased continuously because of the lack of ventilation during the class hours.

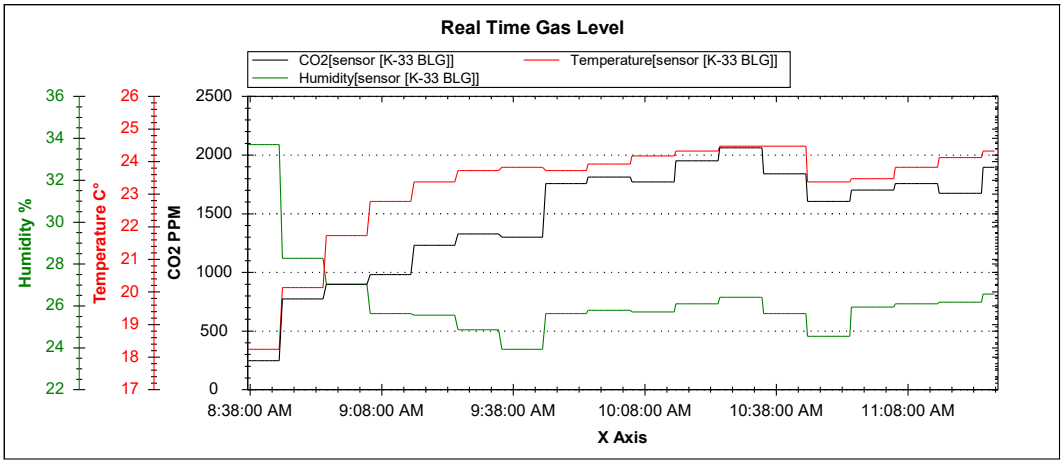


Figure 34: Variation of CO2, temperature and humidity levels with time for classroom environment under setting I mode.

Table 18: Measured CO2 concentration, temperature and humidity values in setting I mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	2050 ppm	1472 ppm	240 ppm
Temperature (°C)	24.32 °C	23.23 °C	18.22 °C
Humidity (%)	33.63 %	26.14 %	23.89 %

The summer measurements of the classroom environment in setting I conducted in the first week of April 2017. The temperature values were given in Table 19. The mean radiant temperature was measured as 23.5 °C. The similarities between both season can be recognized in terms of surface temperature. However, like in winter season, according to these results, the thermal comfort of the classroom environment was not within the recommended zone of the ASHRAE Standard 55-2013 and EN ISO 7730. In Figure 35, it was shown that the measurements values of -0.56 as PMV and 22.9 °C as the indoor temperature with the sensation of slightly cool.

Table 19: Temperature values of classroom environment in summer season under setting I mode.

Air flow	**(M/S)**
Door	0.4 M/S
Window	0.0 M/S
Temperature	**(°C)**
Wall 1	25.5 °C
Wall 2	23.0 °C
Wall 3	22.6 °C
Wall 4	24.5 °C
Floor	21.5 °C
Ceiling	24.0 °C
Mean radiant temperature	23.5 °C
Outdoor	13 °C (cloudy)

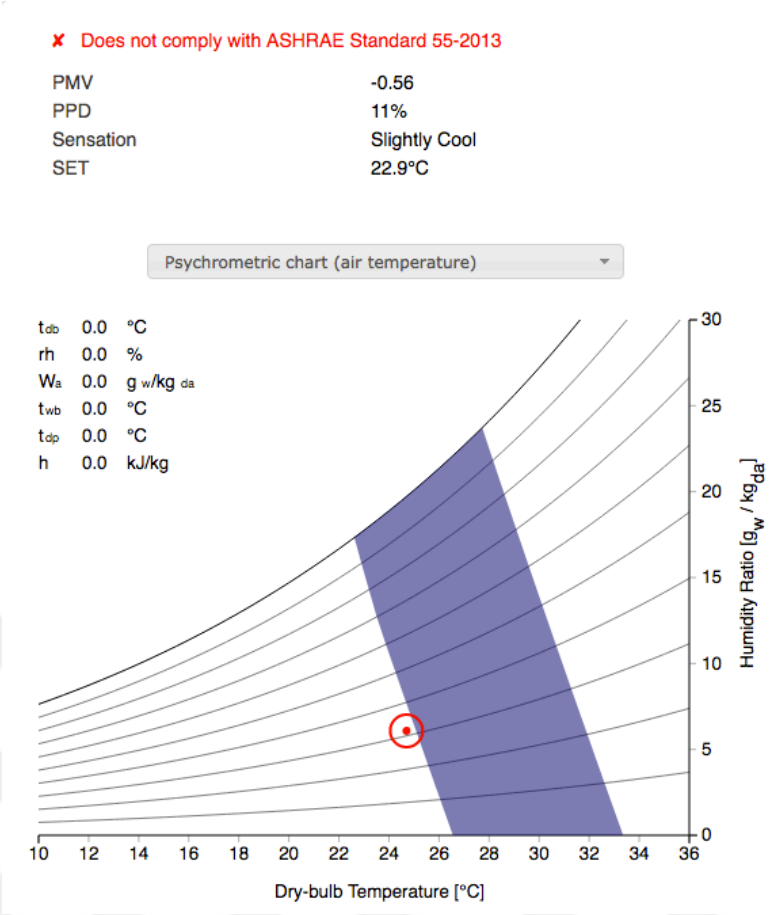


Figure 35: Psychometric chart of classroom environment in summer season under setting I mode.

The IAQ results in summer season were also close to the winter season results except C02 concentration levels (Figure 36 and Table 20). As shown in Figure 34, the IAQ indicators were increasing with time, and at the end of class they reached the maximum level above the standards. These increases showed that the exhausted air was incarcerated in to the classroom. Table 20 gave the maximum and minimum values of CO2 concentration, temperature and humidity values.

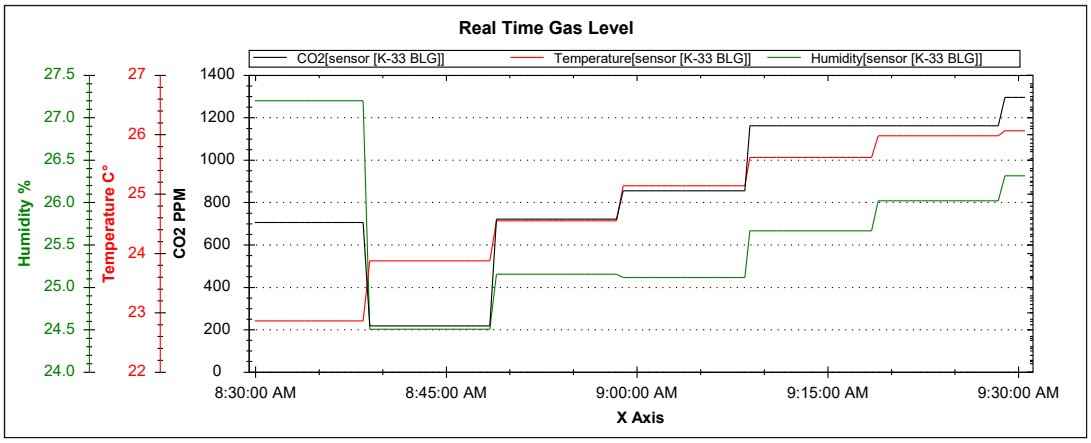


Figure 36: Variation of CO2, temperature and humidity levels with time for classroom environment under setting I mode.

Table 20: Measured CO2 concentration, temperature and humidity values in setting I mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1300 ppm	1000 ppm	700 ppm
Temperature (°C)	26.70°C	24.70°C	22.70°C
Humidity (%)	37.20 %	31.80 %	26.40 %

5.1.2.2. Setting II: Natural ventilation mode

The natural ventilation setting of winter season experimental measurements of classroom environment was started with the third week of February 2017. Two-hours classroom measurement of natural ventilation mode (5 minutes in each 30 minutes) was conducted during a same school day from 8:40 pm to 10:40 pm. Table 21 illustrated the outcomes of the thermal comfort with the airflow values and temperature values of each wall of the classroom environment. As displayed in the Table 21, the mean radiant temperature was measured as 24.6 °C and mean airflow as 1.0 M/S.

Table 21: Temperature values of classroom environment in winter season under setting II mode

Air flow	**(M/S)**
Door	0.8 M/S
Window	1.2 M/S
Temperature	**(°C)**
Wall 1	25.2 °C
Wall 2	24.0 °C
Wall 3	22.1 °C
Wall 4	27.7 °C
Floor	23.8 °C
Ceiling	25.3 °C
Mean radiant temperature	24.6 °C
Outdoor	2 °C (cloudy)

Using the same psychometric chart of the thermal comfort simulation CBE Thermal Comfort Tool brought the outcomes, which present in Figure 35. The results shown that the measurements values of -0.12 as PMV is between the value of -0.5<x<+0.5 for PMV with the neutral sensation values, and 25.1 °C as indoor temperature. As illustrated in Figure 37, the results of second setting winter season comply with ASHRAE Standard 55-2013 and EN ISO 7730.

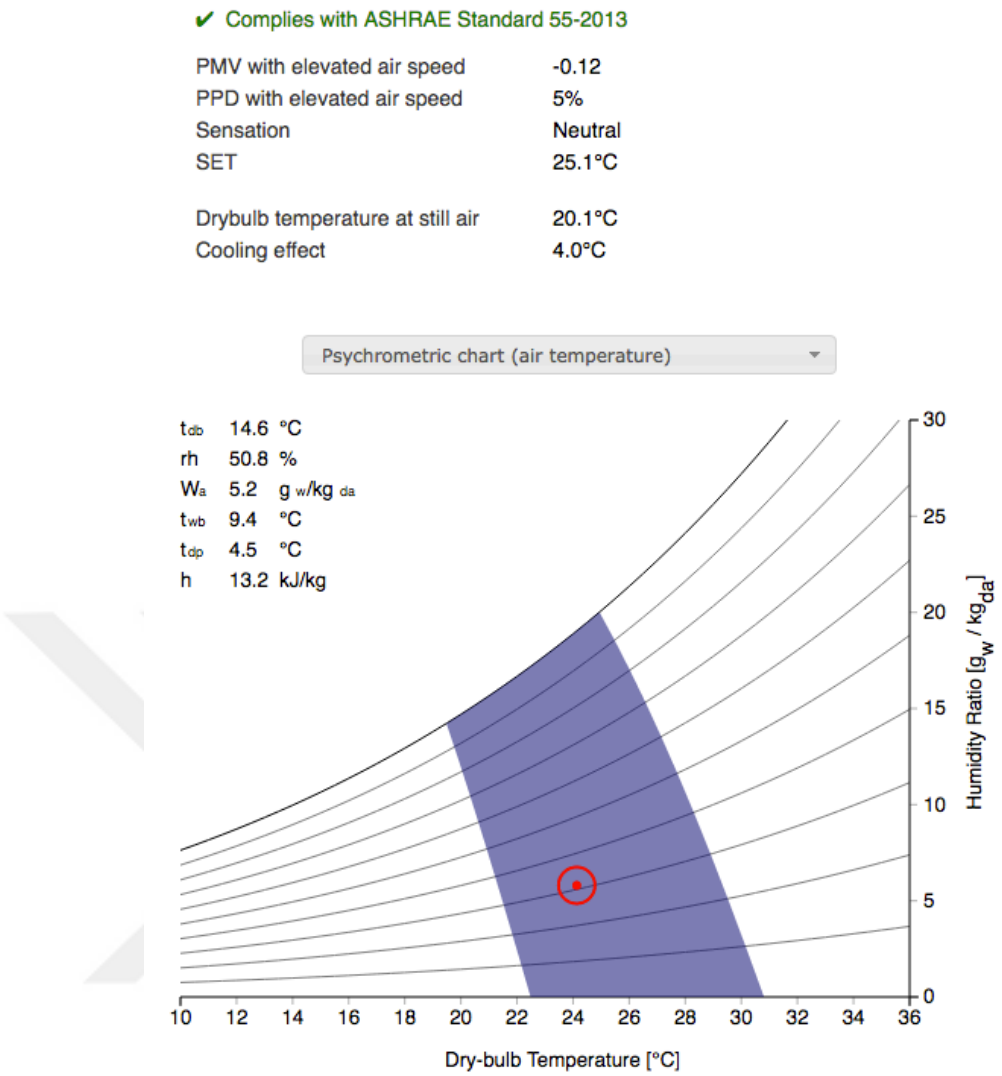


Figure 37: Psychometric chart of classroom environment in winter season under setting II mode.

The IAQ measurement results for the same classroom environment were presented in Figure 36. The measured mean value of the CO2 concentration was 1031 ppm with the humidity level of 31.24 % (See Figure 38 and Table 22). As shown in the Figure 36, the maximum CO2 were about 1600 ppm whereas 29.4% recorded as the minimum humidity level. According to Figure 38, there were declines in temperature values, CO2 concentration and humidity levels in each hour related to natural

ventilation break times. Table 22 displayed the maximum and minimum values of temperature, CO2 concentration and humidity values.

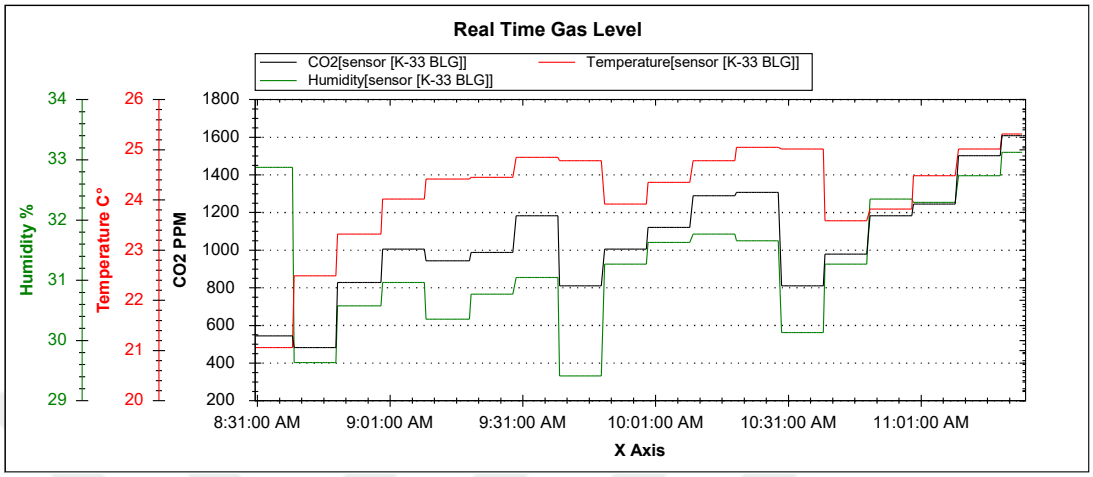


Figure 38: Variation of CO2, temperature and humidity levels with time for studio environment under setting II mode.

Table 22: Measured CO2 concentration, temperature and humidity values in setting II mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1600 ppm	1031 ppm	480 ppm
Temperature (°C)	25.31 °C	24.13 °C	21.03°C
Humidity (%)	33.1 %	31.24 %	29.4 %

The summer season measurements of setting II in classroom environment were conducted in the third week of April 2017. The temperature and airflow values were given in Table 23. The mean radiant temperature was measured as 24.0 °C. Different than the winter season, the values of air movement in the space were higher. According to these results, the thermal comfort of the classroom environment was at the border of the recommended zone of ASHRAE Standard 55-2013 and EN ISO

7730. In Figure 39, it was shown that the measurements values of -0.45 as PMV and 23.3 °C as the indoor temperature with the sensation of neutral.

Table 23: Temperature values of classroom environment in summer season under setting II mode.

Air flow	**(M/S)**
Door	1.3 M/S
Window	1.7 M/S
Temperature	**(°C)**
Wall 1	25.8 °C
Wall 2	25.0 °C
Wall 3	22.4 °C
Wall 4	24.3 °C
Floor	22.3 °C
Ceiling	24.6 °C
Mean radiant temperature	24.0 °C
Outdoor	7 °C (cloudy)

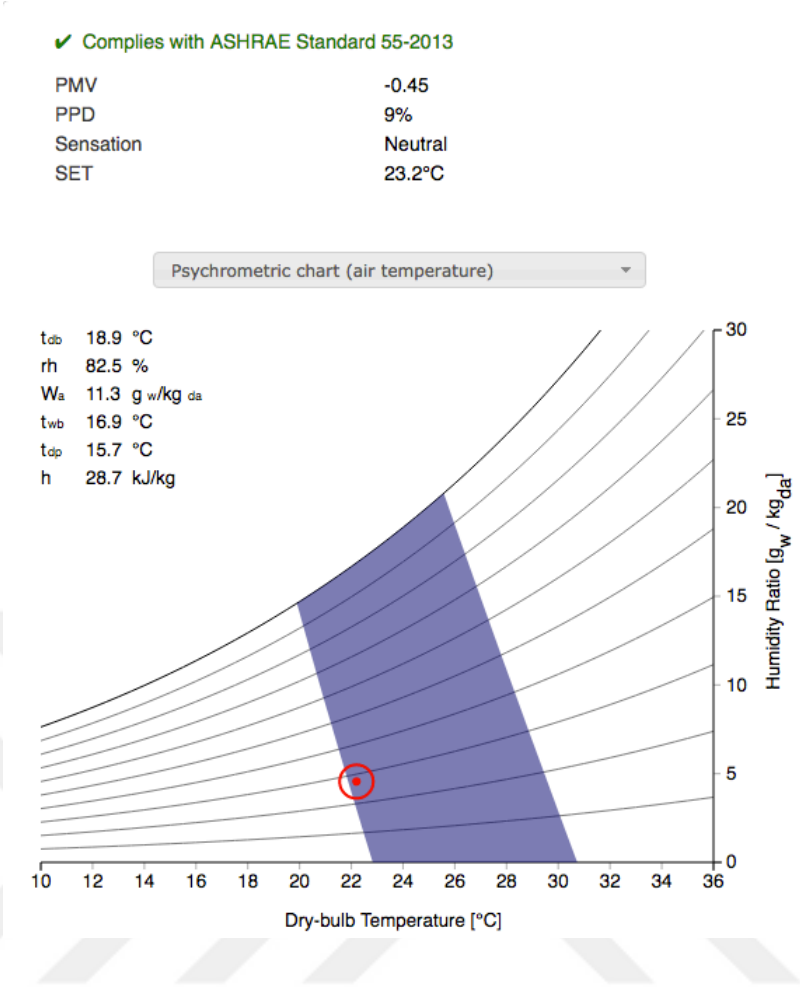


FIGURE 39: Psychometric chart of classroom environment in summer season under setting II mode.

According to the IAQ results in summer season, for the first thirty minutes there was a decrease in CO2 concentration and humidity levels compared to the winter season results because there was no heating system running during summer season (Figure 40 and Table 24). However, after thirty minutes, there was a constant increase in both CO2 concentration and humidity levels. The temperature values were low at the first ten minutes, but then they increased constantly within the two hours. Table 24 presented the maximum and minimum values of CO2 concentration, temperature and humidity values.

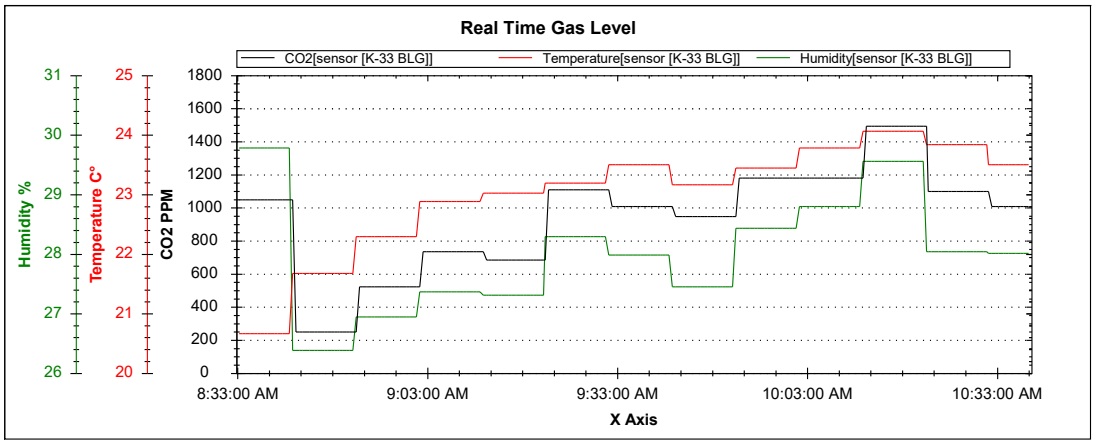


Figure 40: Variation of CO2, temperature and humidity levels with time for classroom environment under setting II mode.

Table 24: Measured CO2 concentration, temperature and humidity values in setting II mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1500 ppm	900 ppm	300 ppm
Temperature (°C)	24.10°C	22.20°C	20.30°C
Humidity (%)	29.30 %	27.90 %	26.50 %

5.1.2.3. Setting III: Mechanical school-air unit mode

The winter season experimental measurements of setting III in classroom environment were started with the fourth week of February 2017 and conducted during a school day from 8:40 Am to 10:40 Am. Table 25 illustrates the results of the thermal comfort with the airflow values and temperature values of each wall of the classroom. As shown in the table, the mean radiant temperature was measured as 23.3 °C and mean airflow as 0.15 M/S plus mean airflow of 0.25 M/S according to TROX school air unit out let.

Table 25: Temperature values of classroom environment in winter season under setting III mode.

Air flow	**(M/S)**
Door	0.3 M/S
Window	0.0 M/S
Temperature	**(°C)**
Wall 1	24.7 °C
Wall 2	23.4 °C
Wall 3	22.5 °C
Wall 4	24.2 °C
Floor	21.3 °C
Ceiling	24.2 °C
Mean radiant temperature	23.3 °C
Outdoor	3 °C (cloudy)

The recorded temperature values in winter season were inserted into the psychometric chart of the thermal comfort simulation CBE Thermal Comfort. In Figure 41, it was shown that the measurements values of 0.31 as PMV is between the value of -0.5<x<+0.5 for PMV with the sensation values of neutral, 26.7 °C as

indoor temperature. As illustrated in Figure 41, the results of this setting comply with ASHRAE Standard 55-2013 and EN ISO 7730.

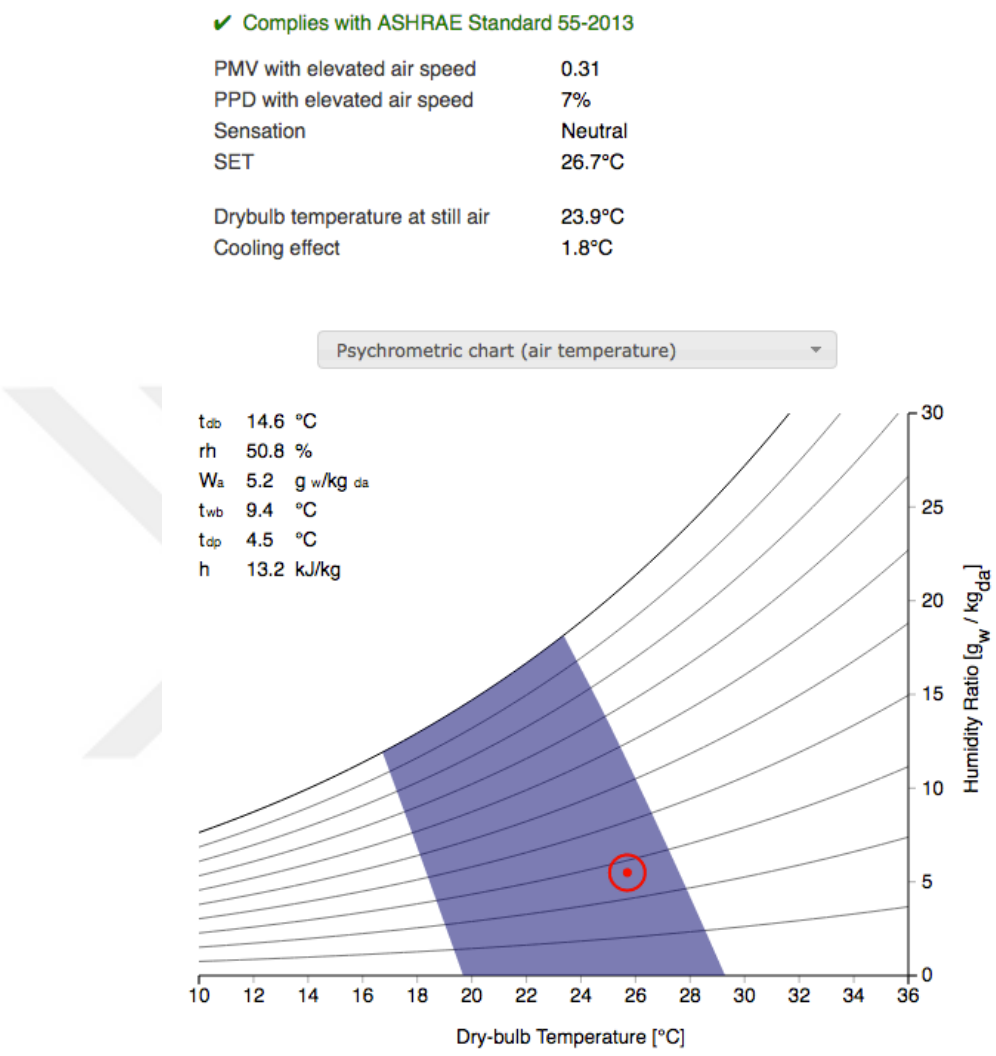


Figure 41: Psychometric chart of classroom environment in winter season under setting III mode.

The measurement results of IAQ for the same classroom environment were given in Figure 39. The measured mean value of the CO2 concentration was 799 ppm with the humidity level of 26.83 % (See Figure 42 and Table 26). As shown in the Figure 42 and table 26, the maximum CO2 peaks were about 1050 ppm while the minimum

humidity level was about 28%. The CO2 levels were moved up then it fixed between 800 ppm and 1000 ppm with the help of the TROX school air unit.

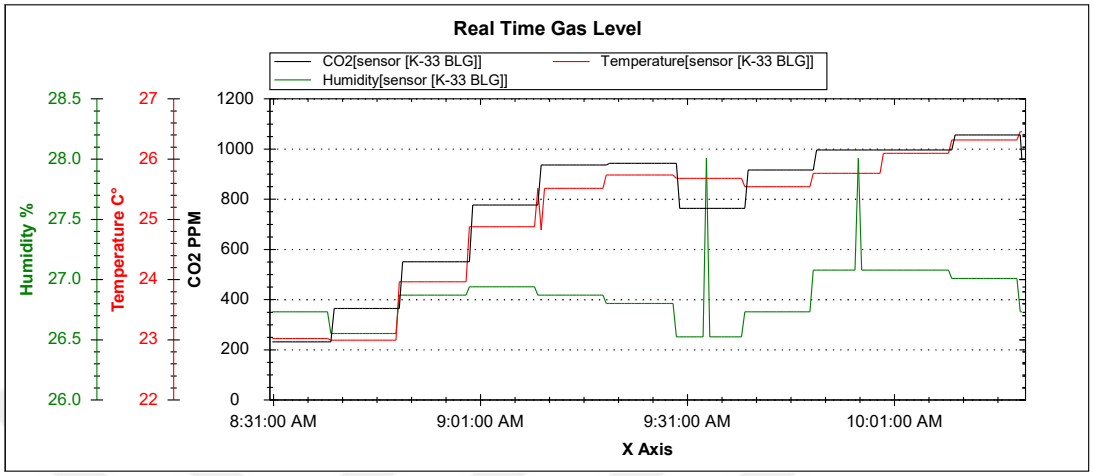


Figure 42: Variation of CO2, temperature and humidity levels with time for classroom environment under setting III mode.

Table 26: Measured CO2 concentration, temperature and humidity values in setting III mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	1050 ppm	799 ppm	230 ppm
Temperature (°C)	26.45°C	25.70°C	22.99°C
Humidity (%)	28.00%	26.83%	26.51%

Moving to summer season results of the classroom environment that were conducted in the first week of May 2017; the temperature values were given in Table 27. The mean radiant temperature was recorded as 23.3 °C. Different than the winter season, the environment had cool and tolerable. Therefore, same as winter season of the third setting, according to these results, the thermal comfort of the classroom environment was within the recommended zone of the ASHRAE 55 and EN ISO 7730 standards,

as well. Figure 43 presented that the measurements values of -0.24 as PMV and 23.7 °C as the indoor temperature.

Table 27: Temperature values of classroom environment in summer season under setting III mode.

Air flow	**(M/S)**
Door	0.3 M/S
Window	0.2 M/S
Temperature	**(°C)**
Wall 1	23.7 °C
Wall 2	22.3 °C
Wall 3	21.3 °C
Wall 4	22.7 °C
Floor	22.8 °C
Ceiling	24.2 °C
Mean radiant temperature	23.3 °C
Outdoor	13°C (cloudy)

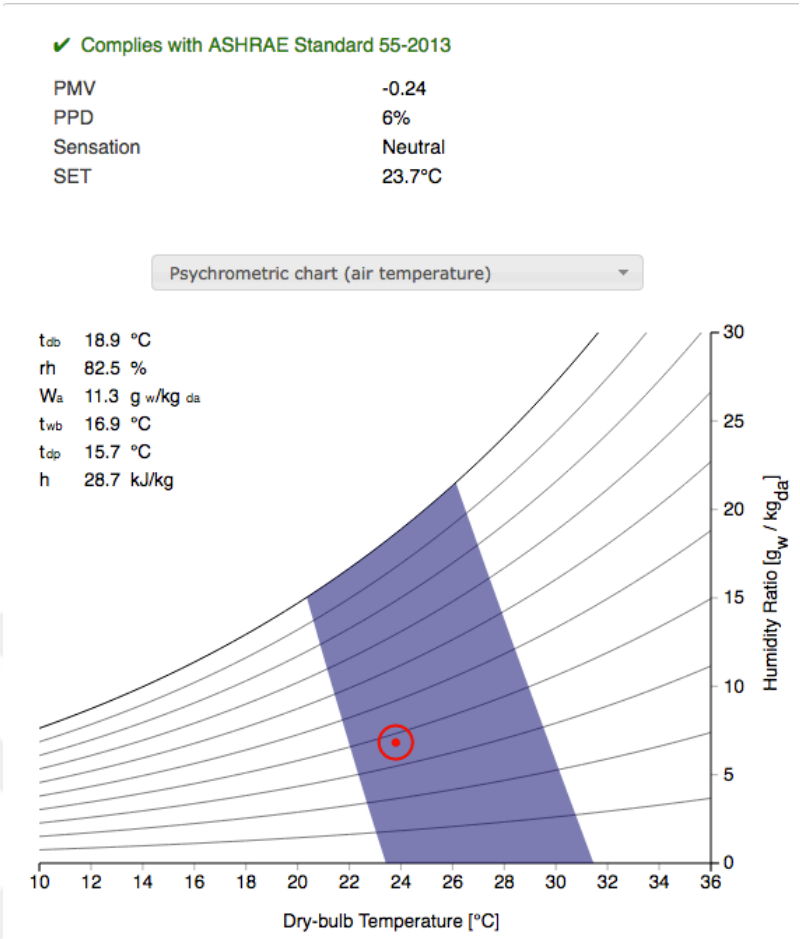


Figure 43: Psychometric chart of classroom environment in summer season under setting III mode.

The IAQ results in summer season have the less CO2 concentration level and high humidity levels comparing to the winter results of same setting (Figure 44 and Table 28). As shown in Figure 44, all indicators increased in the first hour of class, however, then after 9:40 am all indicators increased by less. It can be noticed that TROX school air unit influenced the environmental quality and made balance between CO2 concentration and temperature values. Table 28 displayed the maximum and minimum values of CO2 concentration, temperature and humidity values.

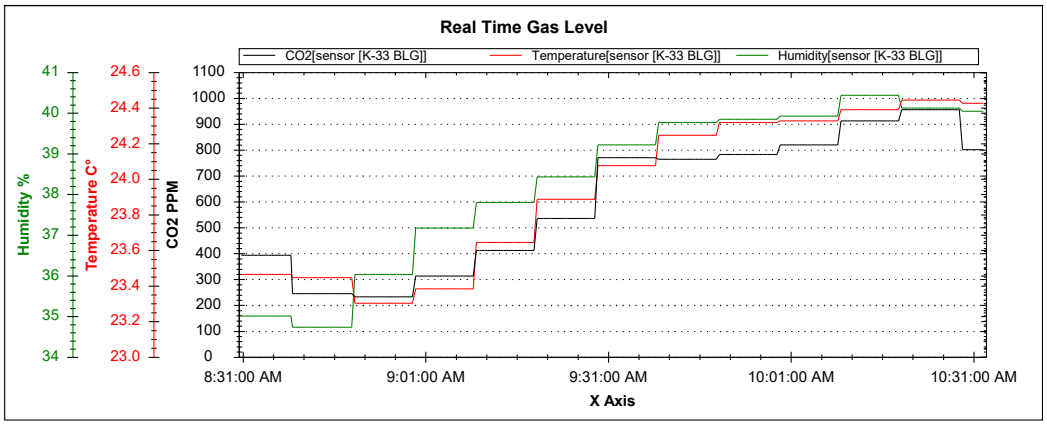


Figure 44: Variation of CO2, temperature and humidity levels with time for classroom environment under setting III mode.

Table 28: Measured CO2 concentration, temperature and humidity values in setting III mode during the school day.

	MAX. Value	MEAN Value	MIN. Value
Co_2 Concentration (ppm)	970 ppm	600 ppm	230 ppm
Temperature (°C)	24.40°C	23.80°C	23.30°C
Humidity (%)	40.10 %	37.20 %	34.30 %

5.2. Subjective Measurements

5.2.1. Studio Environment

The demographics of the participants attending to the subjective measurements in winter season and summer season under three setting modes were given in Table 29 and 30. According to the results, winter season had 19 female students and 3 male students between the age ranges of 18-25. All of the participants were spending at least 5 hours per week in the studio. On the other hand, summer season had 13

female students and 3 male students between age ranges of 18-25 who spent more then 10 hours per week in studio.

Table 29: Demographic characteristics of the participants of winter season studio environment.

Characteristics	Category	Frequency	Percentage
Gender	Female	19	86.4
	Male	3	13.6
Age	18-25	21	95.5
	25-30	1	4.5
Spending Hours	1-4 hours per week	-	-
	5-10 hours per week	12	54.5
	More then 10 hours per week	10	45.5
Seating Location	Near wall 1	-	-
	Near wall 2	3	13.6
	Near wall 3	8	34.4
	Near wall 4	4	18.2
	Center	7	31.8

Table 30: Demographic characteristics of the participants of summer season studio environment.

Characteristics	**Category**	**Frequency**	**Percentage**
Gender	Female	13	81.3
	Male	3	18.8
Age	18-25	16	100
	25-30	0	0.00
Spending Hours	1-4 hours per week	1	6.3
	5-10 hours per week	2	12.5
	More then 10 hours per week	13	81.3
Seating Location	Near wall 1	1	6.3
	Near wall 2	3	18.8
	Near wall 3	4	25.0
	Near wall 4	4	25.0
	Center	4	25.0

Table 31 and Table 32 illustrated the perceived thermal comfort feeling of the participants in both seasons. According to the tables, in setting I mode, without opening door and windows, participants felt warm and uncomfortable in both seasons, whereas in the second setting and third setting, natural ventilation mode and mechanical school-air unit mode, mean values of the participants were so close, and they felt comfortable. The IAQ satisfaction results of the participants were given in Table 33, 34 and Table 35, 36. According to the results, the participants are most satisfied with the air quality of the studio environment in setting III, mechanical school-air unit mode.

Table 31: Mean comparison table among the three setting modes in winter season.

Settings	How do you feel now?	How do you find thermal comfort of the classroom?	How do you prefer thermal comfort of the classroom to be?
Non ventilated setting	1.09	.59	.95
Natural ventilated setting	.45	.41	.18
School Air ventilated setting	-.14	-.27	.95

Table 32: Mean comparison table among the three setting modes in summer season.

Settings	How do you feel now?	How do you find thermal comfort of the classroom?	How do you prefer thermal comfort of the classroom to be?
Non ventilated setting	1.31	1.44	1.38
Natural ventilated setting	.56	.38	.25
School Air ventilated setting	.00	.25	.13

Table 33: Mean comparison table among the three settings in winter season.

Settings		Is the thermal comfort of environment acceptable?	Is the thermal comfort of environment tolerable?
Non ventilated setting	Mean	4.45	4.64
Natural ventilated setting	Mean	4.50	4.45
School Air ventilated setting	Mean	4.41	4.27

Table 34: Mean comparison table among the three settings in summer season.

Settings		Is the thermal comfort of environment acceptable?	Is the thermal comfort of environment tolerable?
Non ventilated setting	Mean	4.25	4.63
Natural ventilated setting	Mean	4.75	5.00
School Air ventilated setting	Mean	3.94	3.94

Table 35: Mean comparison table among the three settings in winter season

Settings		How satisfied are you with AQ of your workspace	Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?	How satisfied are you with cleaning service provided for your workspace?
Non ventilated setting	Mean	3.86	3.95	4.64
Natural ventilated setting	Mean	3.86	3.77	4.50
School Air ventilated setting	Mean	3.82	4.23	4.50

Table 36: Mean comparison table among the three settings in summer season.

Settings		How satisfied are you with AQ of your workspace	Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?	How satisfied are you with cleaning service provided for your workspace?
Non ventilated setting	Mean	4.69	5.31	5.44
Natural ventilated setting	Mean	4.63	4.81	4.69
School Air ventilated setting	Mean	2.75	3.38	3.94

5.2.1.1. Concentration Performance under the Three Settings

The outcomes of analysis of variance (ANOVA) test demonstrated statically significant differences between the groups, according to F value of 2.999 at the significant level of 0.057, for winter season (See table 37) and F value of 14.542 at the significant level of 0.000 for summer season (See Table 38). However, the further analysis of ANOVA with LSD test for both season have shown that, there was a significant statistical difference between setting I and setting II, and between setting I and setting III, but there is not a statistical difference between setting II and III (See table 39 and 40), which means that the participants concentration performance did not differed statistically under setting II, natural ventilation mode, and setting III, mechanical school-air unit mode.

Table 37: Oneway ANOVA results of arithmetic concentration performance (Kraepelin test) in winter season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2462.182	2	1231.091	2.999	.057
Within Groups	25865.409	63	410.562		

Table 38: Oneway ANOVA results of arithmetic concentration performance, (Kraepelin test) in summer season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8951.625	2	4475.813	14.542	.000
Within Groups	13850.687	45	307.793		

Table 39: LSD test result of arithmetic concentration performance (Kraepelin test) in winter season.

Multiple Comparisons

(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-12.818*	6.109	.040	-25.03	-.61
	School Air ventilated setting	-13.091*	6.109	.036	-25.30	-.88
Natural ventilated setting	Non ventilated setting	12.818*	6.109	.040	.61	25.03
	School Air ventilated setting	-.273	6.109	.965	-12.48	11.94
School Air ventilated setting	Non ventilated setting	13.091*	6.109	.036	.88	25.30
	Natural ventilated setting	.273	6.109	.965	-11.94	12.48

*. The mean difference is significant at the 0.05 level.

Table 40: LSD test result of arithmetic concentration performance (Kraepelin test) in summer season.

Multiple Comparisons

(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-28.875*	6.203	.000	-41.37	-16.38
	School Air ventilated setting	-29.063*	6.203	.000	-41.56	-16.57
Natural ventilated setting	Non ventilated setting	28.875*	6.203	.000	16.38	41.37
	School Air ventilated setting	-.188	6.203	.976	-12.68	12.31
School Air ventilated setting	Non ventilated setting	29.063*	6.203	.000	16.57	41.56
	Natural ventilated setting	.188	6.203	.976	-12.31	12.68

*. The mean difference is significant at the 0.05 level.

5.2.1.2. Attention Performance under the Three Settings

This part continues with Visual Attention Test (Prague test). The result of ANOVA showed statically significant differences between groups, according to F value of 9.843 at the significant level of 0.000 for winter season, and F value of 9.843 at the 0.000 significant level for summer season (See table 41 and 42). Moreover, the difference between groups according to LSD test results show that in both season there is a statistically significant difference between groups. Similar to the concentration performance results, attention performance of the participants did not differ when setting II and setting III were compared (See table 43 and 44).

Table 41: One-way ANOVA result of visual attention (Prague test) in winter season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	481.121	2	240.561	9.898	.000
Within Groups	1531.136	63	24.304		

Table 42: One-way ANOVA result of visual attention (Prague test) in summer season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	439.292	2	219.646	9.843	.000
Within Groups	1004.187	45	22.315		

Table 43: LSD test result of visual attention (Prague test) in winter season.

Multiple Comparisons

(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-5.409*	1.486	.001	-8.38	-2.44
	School Air ventilated setting	-6.000*	1.486	.000	-8.97	-3.03
Natural ventilated setting	Non ventilated setting	5.409*	1.486	.001	2.44	8.38
	School Air ventilated setting	-.591	1.486	.692	-3.56	2.38
School Air ventilated setting	Non ventilated setting	6.000*	1.486	.000	3.03	8.97
	Natural ventilated setting	.591	1.486	.692	-2.38	3.56

*. The mean difference is significant at the 0.05 level.

Table 44: LSD test result of visual attention (Prague test) in summer season.

Multiple Comparisons						
(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-4.313*	1.670	.013	-7.68	-.95
	School Air ventilated setting	-7.375*	1.670	.000	-10.74	-4.01
Natural ventilated setting	Non ventilated setting	4.313*	1.670	.013	.95	7.68
	School Air ventilated setting	-3.063	1.670	.073	-6.43	.30
School Air ventilated setting	Non ventilated setting	7.375*	1.670	.000	4.01	10.74
	Natural ventilated setting	3.063	1.670	.073	-.30	6.43

*. The mean difference is significant at the 0.05 level.

5.2.2. Classroom Environment

The demographics of the participants attending to the subjective measurements in winter season and summer season under the three setting ventilation modes were given in Table 45 and 46. As shown in the results, winter season had 84 female students and 16 male students between the age ranges of 18-25. The participants were spending mostly at least 1-4 hours per week in the classroom. On the other hand, summer season had 41 female students and nine male students between the same age ranges of 18-25 who is spend 1-4 hours per week in classroom.

Table 45: Demographic characteristics of the participants of winter season classroom environment.

Characteristics	Category	Frequency	Percentage
Gender	Female	84	88
	Male	16	12
Age	18-25	88	88
	25-30	12	12
Spending Hours	1-4 hours per week	52	52
	5-10 hours per week	17	17
	More then 10 hours per week	31	31
Seating Location	Near wall 1	3	3
	Near wall 2	27	27
	Near wall 3	26	26
	Near wall 4	27	27
	Center	17	17

Table 46: Demographic characteristics of the participants of summer season classroom environment.

Characteristics	Category	Frequency	Percentage
Gender	Female	41	82
	Male	9	18
Age	18-25	45	90
	25-30	5	10
Spending Hours	1-4 hours per week	28	56
	5-10 hours per week	12	24
	More then 10 hours per week	10	10
Seating Location	Near wall 1	3	6
	Near wall 2	17	34
	Near wall 3	10	20
	Near wall 4	11	22
	Center	9	18

The perceived thermal comfort feeling of the participants in both seasons illustrated in tables 47 and 48. According to the tables, in setting I mode, without opening door and windows, participants prefer to have much more warmer environment in both seasons, whereas in the second setting and third setting, natural ventilation mode and mechanical school-air unit mode, mean values of the participants were so close to neutral value, and they felt comfortable. The IAQ satisfaction results of the participants were given in Tables 49, 50, 51 and 52 for both seasons. According to the results, the participants in all the three setting have been satisfied. However, the participants are most satisfied with the air quality of the classroom environment in setting III, mechanical school-air unit mode.

Table 47: Mean comparison table among the three setting modes in winter season.

Settings	How do you feel now?	How do you find thermal comfort of the classroom?	How do you prefer thermal comfort of the classroom to be?
Non ventilated setting	.05	-.05	1.11
Natural ventilated setting	-.12	.12	.70
School Air ventilated setting	-.08	.09	.57

Table 48: Mean comparison table among the three setting modes in summer season.

Settings	How do you feel now?	How do you find thermal comfort of the classroom?	How do you prefer thermal comfort of the classroom to be?
Non ventilated setting	.44	.46	.60
Natural ventilated setting	.02	.02	.48
School Air ventilated setting	.16	.20	.56

Table 49: Mean comparison table among the three settings in winter season.

Settings	Is the thermal comfort of environment acceptable?	Is the thermal comfort of environment tolerable?
Non ventilated setting	4.06	4.43
Natural ventilated setting	4.54	4.60
School Air ventilated setting	4.75	4.76

Table 50: Mean comparison table among the three settings in summer season.

Settings	Is the thermal comfort of environment acceptable?	Is the thermal comfort of environment tolerable?
Non ventilated setting	5.22	5.24
Natural ventilated setting	4.70	5.04
School Air ventilated setting	4.38	4.50

Table 51: Mean comparison table among the three settings in winter season

Settings	How satisfied are you with AQ of your workspace	Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?	How satisfied are you with cleaning service provided for your workspace?
Non ventilated setting	3.62	4.23	4.91
Natural ventilated setting	4.25	4.47	4.37
School Air ventilated setting	4.46	4.71	4.73

Table 52: Mean comparison table among the three settings in summer season.

Settings	How satisfied are you with AQ of your workspace	Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?	How satisfied are you with cleaning service provided for your workspace?
Non ventilated setting	4.54	4.90	4.50
Natural ventilated setting	4.58	4.64	4.90
School Air ventilated setting	4.16	4.58	4.62

5.2.1.1. Concentration Performance under the Three Settings

The outcomes of ANOVA test demonstrated statically significant differences between the groups, according to F value of 19.399 at significant level of 0.000, for winter season (See table 53) and the F value of 22.503 at significant level of 0.000 for summer season (See Table 54). However, the further analysis of ANOVA with LSD test for both season have shown that, there was a significant statistical difference between setting I and setting II, and between setting I and setting III, but there is not a statistical difference between setting II and III (See table 55 and 56), which means that the participants concentration performance did not differed statistically under setting II, natural ventilation mode, and setting III, mechanical school-air unit mode.

Table 53: Oneway ANOVA results of arithmetic concentration performance (Kraepelin test) in winter season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	73034.087	2	36517.043	19.399	.000
Within Groups	559081.710	297	1882.430		

Table 54: Oneway ANOVA results of arithmetic concentration performance, (Kraepelin test) in summer season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	43231.293	2	21615.647	22.503	.000
Within Groups	141202.040	147	960.558		

Table 55: LSD test result of arithmetic concentration performance (Kraepelin test) in winter season.

Multiple Comparisons

(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-26.530*	6.136	.000	-38.61	-14.45
	School Air ventilated setting	-37.090*	6.136	.000	-49.17	-25.01
Natural ventilated setting	Non ventilated setting	26.530*	6.136	.000	14.45	38.61
	School Air ventilated setting	-10.560	6.136	.086	-22.64	1.52
School Air ventilated setting	Non ventilated setting	37.090*	6.136	.000	25.01	49.17
	Natural ventilated setting	10.560	6.136	.086	-1.52	22.64

*. The mean difference is significant at the 0.05 level.

Table 56: LSD test result of arithmetic concentration performance (Kraepelin test) in summer season.

Multiple Comparisons

(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-35.740*	6.199	.000	-47.99	-23.49
	School Air ventilated setting	-36.280*	6.199	.000	-48.53	-24.03
Natural ventilated setting	Non ventilated setting	35.740*	6.199	.000	23.49	47.99
	School Air ventilated setting	-.540	6.199	.931	-12.79	11.71
School Air ventilated setting	Non ventilated setting	36.280*	6.199	.000	24.03	48.53
	Natural ventilated setting	.540	6.199	.931	-11.71	12.79

*. The mean difference is significant at the 0.05 level.

5.2.1.2. Attention Performance under the Three Settings

The ANOVA results of the Visual Attention Test (Prague test) showed statistically significant difference between groups according to F value of 16.978 at the significant level of 0.000 for winter season and F value of 2.912 at the significant level for summer season (See table 57 and 58). Moreover, the difference between groups according to LSD test results showed that in winter season there was a statistically significant difference between groups. Similar to the concentration performance results, attention performance of the participants did not differ when setting II and setting III were compared (See table 59 and 60). However, summer season have the different results on LSD test. The significance level of 0.096 between setting I and setting II, and significance level of 0.504 between setting II and setting III demonstrated that there was a significant statistical difference between setting I and setting III, but there is not a statistical difference between setting I and II, and Setting II and III.

Table 57: One-way ANOVA result of visual attention (Prague test) in winter season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1517.007	2	758.503	16.978	.000
Within Groups	13269.030	297	44.677		

Table 58: One-way ANOVA result of visual attention (Prague test) in summer season.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	275.080	2	137.540	2.912	.058
Within Groups	6943.880	147	47.237		

Table 59: LSD test result of visual attention (Prague test) in winter season.

Multiple Comparisons						
(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-3.010*	.945	.002	-4.87	-1.15
	School Air ventilated setting	-5.500*	.945	.000	-7.36	-3.64
Natural ventilated setting	Non ventilated setting	3.010*	.945	.002	1.15	4.87
	School Air ventilated setting	-2.490*	.945	.009	-4.35	-.63
School Air ventilated setting	Non ventilated setting	5.500*	.945	.000	3.64	7.36
	Natural ventilated setting	2.490*	.945	.009	.63	4.35

*. The mean difference is significant at the 0.05 level.

Table 60: LSD test result of visual attention (Prague test) in summer season.

Multiple Comparisons						
(I) Settings	(J) Settings	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Non ventilated setting	Natural ventilated setting	-2.300	1.375	.096	-5.02	.42
	School Air ventilated setting	-3.220*	1.375	.020	-5.94	-.50
Natural ventilated setting	Non ventilated setting	2.300	1.375	.096	-.42	5.02
	School Air ventilated setting	-.920	1.375	.504	-3.64	1.80
School Air ventilated setting	Non ventilated setting	3.220*	1.375	.020	.50	5.94
	Natural ventilated setting	.920	1.375	.504	-1.80	3.64

*. The mean difference is significant at the 0.05 level.

5.3. Discussion

Based on the above experimental and subjective results, all the four hypotheses of the thesis are supported. H1, which is 'İncreasing ventilation rate (5 l/s person<VR<7 l/s person) improves student performance' is accepted. H2, which is 'there is a statistically significant relationship between acceptable thermal comfort level and student performance' is accepted. The other two hypotheses related to IAQ, H3 'increasing supplied fresh air from 0.3-5 to 13-16 l/s causes improvement on students' performance' and H4 'Overloaded CO2 concentration (above 1000 ppm) in design studios causes a decrease in student concentration and attention' are also supported with the obtained results.

5.3.1. Studio Environment

Thermal comfort's indicators and CO2 concentration values of the studio environment among the three settings during the winter season were compared. Table 61 illustrated the values among these three settings. According to the experimental results of the studio environment during the winter season under three ventilation modes, the CO2 concentration and temperature values in setting I and setting II were above the recommended standards, whereas in setting III the values were closer to the ASHRAE Standard 55-2013 and EN ISO 7730 (Figure 45 and Table 61).

Table 61: IAQ indicators of the studio environment among the three settings during the winter season.

	Setting I	Setting II	Setting III
CO2 Concentration	1119(ppm)	1068(ppm)	986(ppm)
Temperature	28.66°C	27.44°C	20.48°C
Humidity	26.22%	28.06%	26.69%

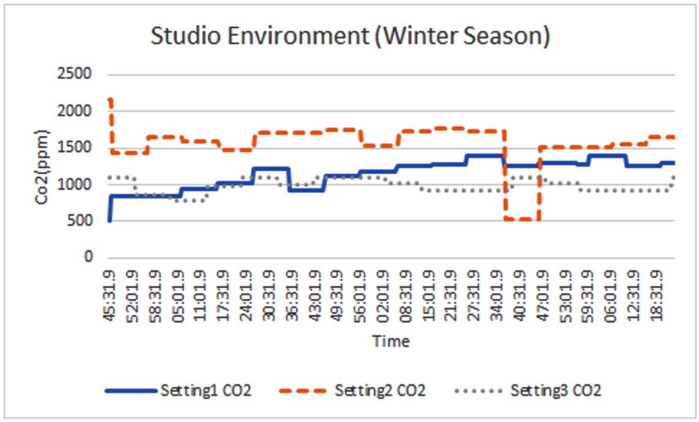


Figure 45: Variation of mean CO2 concentration of studio environment in the three settings, in winter season.

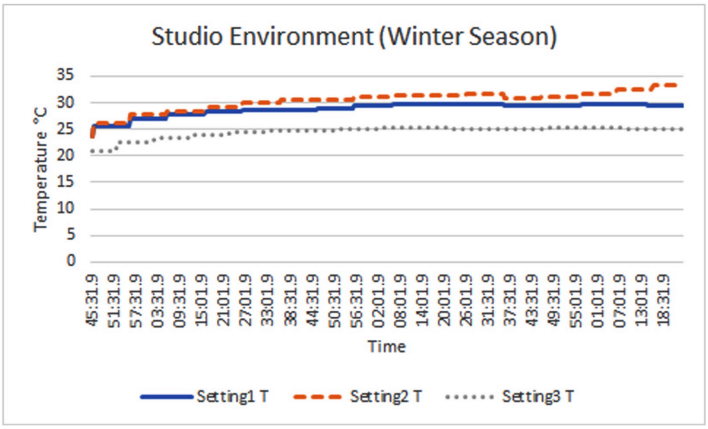


Figure 46: Variation of mean indoor air temperature of studio environment in the three settings, in winter season.

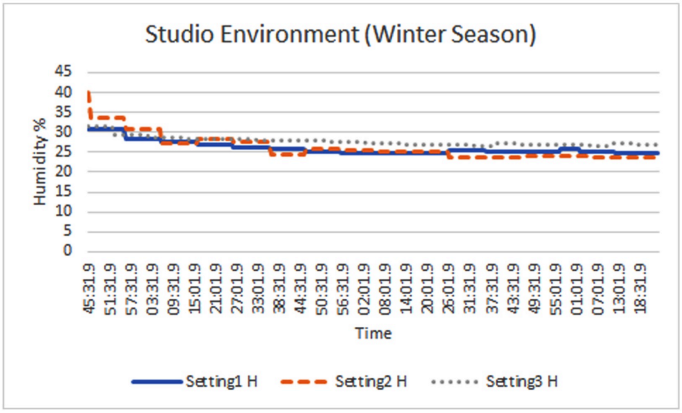


Figure 47: Variation of mean relative humidity of studio environment in the three settings, in winter season.

Coming to the studio environment experimental measurements during the summer season under the same three settings, Table 62 illustrated the comparison values among these three settings. As shown in Figure 48, only in setting I CO2 concentration values were above the required values, which are 1000 ppm. In setting

II and III, the CO2 concentration values were below the 1000ppm, where as the temperature values were higher in all the three settings. The outdoor air temperature influenced only setting I and setting II, because the TROX school air system was running in Setting III. The relative humidity was within the comfort range in all the three settings (Figure 48, 49 and 50).

Table 62: IAQ indicators of the studio environment among the three settings during the summer season.

	Setting I	Setting II	Setting III
CO2 Concentration	1250(ppm)	582(ppm)	472(ppm)
Temperature	24.64°C	25.5°C	24.75°C
Humidity	29.44%	27.25%	27.25%

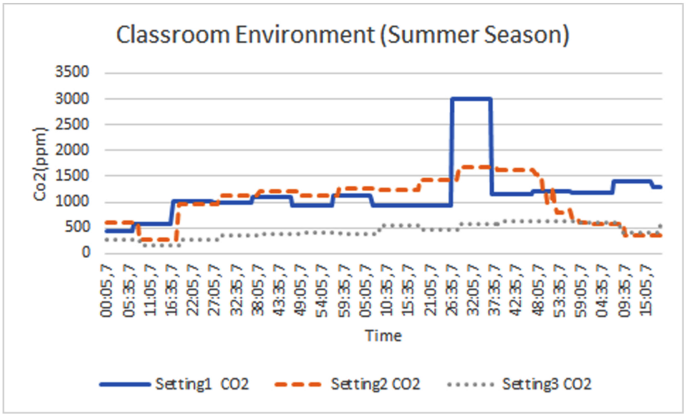


Figure 48: Variation of mean CO2 concentration of studio environment in the three settings, in summer season.

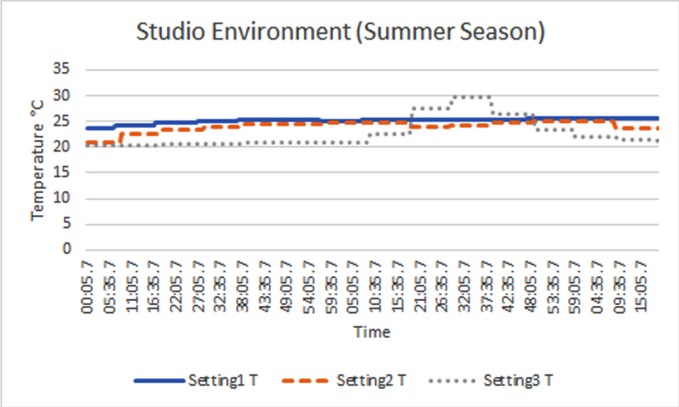


Figure 49: Variation of mean indoor air temperature of studio environment in the three settings, in summer season.

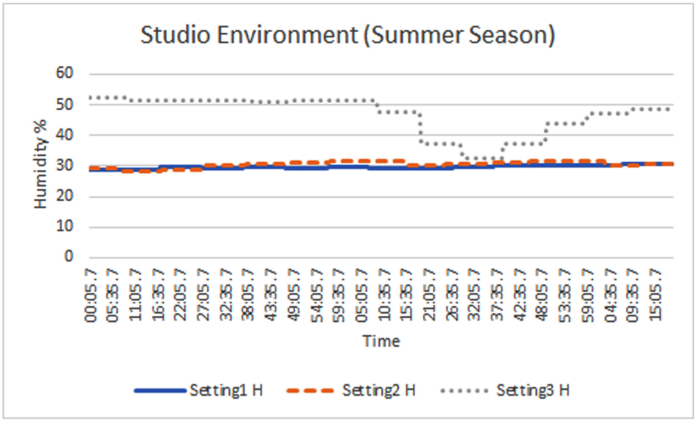


Figure 50: Variation of mean relative humidity of studio environment in the three settings, in summer season.

5.3.2 Classroom Environment

Table 63 illustrated the CO2 concentration, temperature and humidity values during the winter season in the three settings. According to the results, setting I had higher CO2 concentration values compared to the other two settings. All the values in the setting II and setting III during the winter season had the values within the comfort standards of the ASHRAE Standard 55-2013 and EN ISO 7730 (Figure 51,52, and 53).

Table 63: IAQ indicators of the classroom environment among the three settings during the winter season.

	Setting I	Setting II	Setting III
CO2 Concentration	1472(ppm)	1031(ppm)	799 (ppm)
Temperature	23.23°C	24.13 °C	25.70 °C
Humidity	26.14%	31.24 %	26.83 %

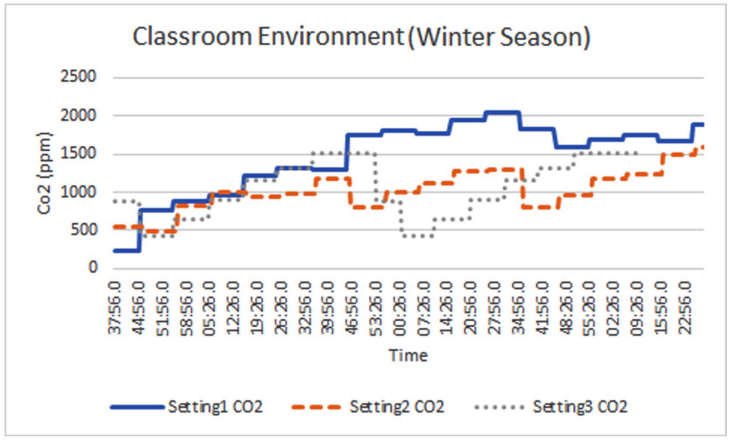


Figure 51: Variation of mean CO2 concentration of classroom environment in the three settings, in winter season.

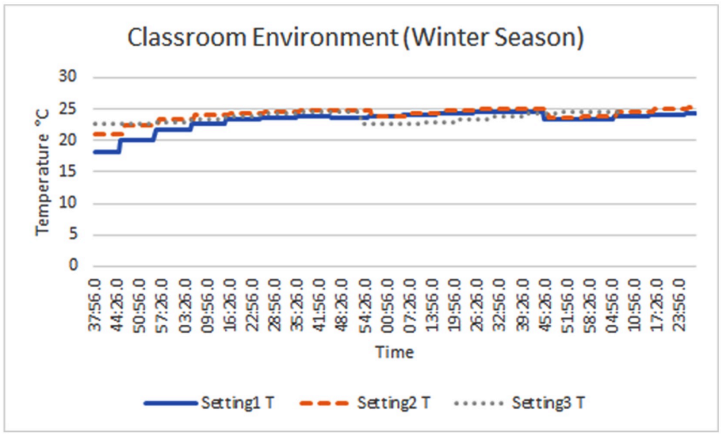


Figure 52: Variation of mean indoor air temperature of classroom environment in the three settings, in winter season.

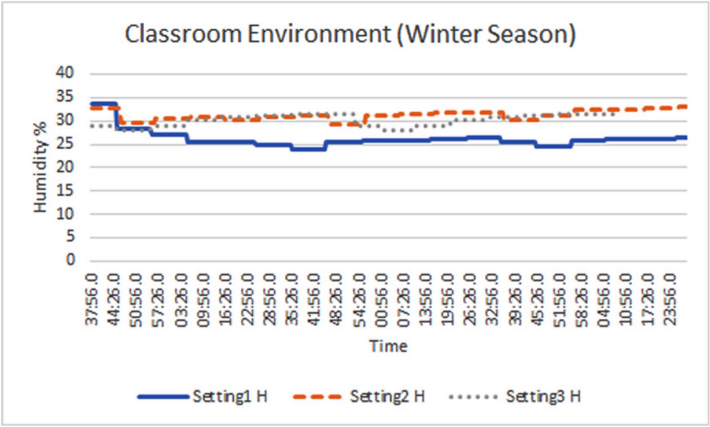


Figure 53: Variation of mean relative humidity of classroom environment in the three settings, in winter season.

Table 64 illustrated summer results under the same three settings mode. Although setting I had the maximum values for all the indicators compared to the other two settings, all the values under three settings complied with the ASHRAE Standard 55-2013 and EN ISO 7730 (Figure 54, 55 and 56). However, the concentration and attention test results of the students in setting III, with 600 ppm CO2 concentration value, 23.80 °C temperature, and 34.30% humidity, achieved higher number of correct answers, which means TROX school air unit had positive effects on student performance.

Table 64: IAQ indicators of the classroom environment among the three settings during the summer season.

	Setting I	Setting II	Setting III
CO2 Concentration	1000 (ppm)	900 (ppm)	600 (ppm)
Temperature	24.70 °C	22.20 °C	23.80 °C
Humidity	31.80 %	27.90 %	34.30 %

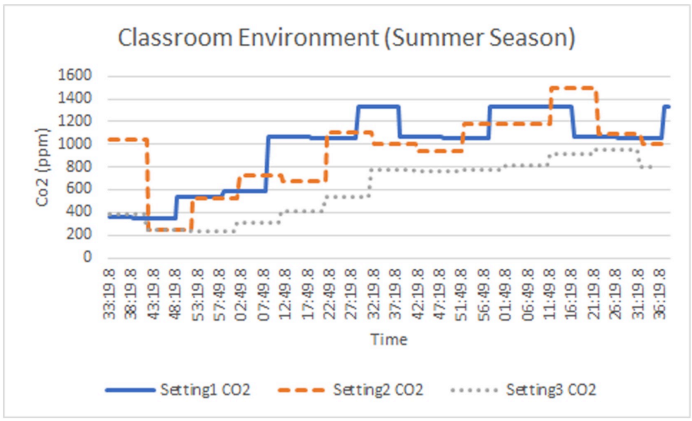


Figure 54: Variation of mean CO2 concentration of classroom environment in the three settings, in summer season.

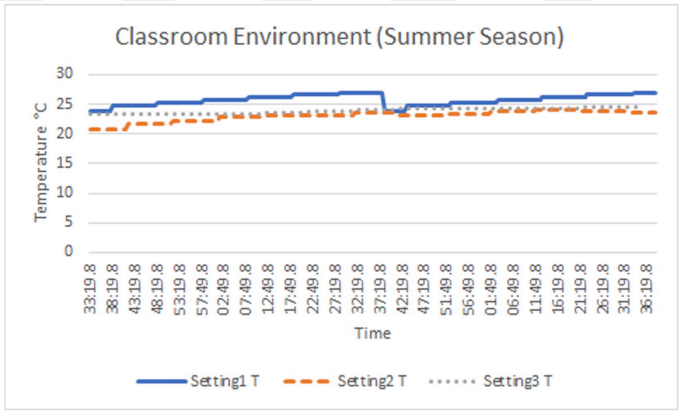


Figure 55: Variation of mean indoor air temperature of classroom environment in the three settings, in summer season.

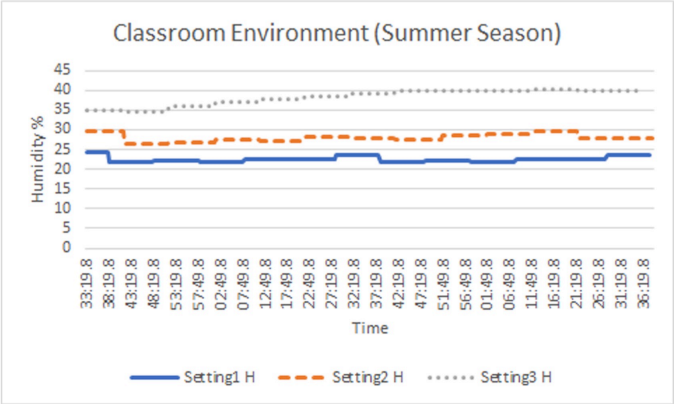


Figure 56: Variation of mean relative humidity of classroom environment in the three settings, in summer season.

5.3.3. Comparison of Student Performance in Studio and Classroom Environment under the Three Settings

Figure 54 illustrated the comparison of concentration performance scores in both studio and classroom environment regarding the winter season. Among the three settings, the number of correct answers to the test was highest in setting III Figure 57, which means that good thermal comfort and air quality had influence on concentration performance of the students. Coming to summer season, in both studio and classroom environments setting II and setting III had the close mean values of correct answers compared to setting I (Figure 58). In both season, both environments showed that TROX school air ventilation setting had the positive affects on student concentration in terms of task work performance. The difference between winter and summer in setting II in both studio and classroom setting resulted from the outside temperature. In setting II during summer season, higher values of student concentration performance was observed for the same indoor temperature. The

natural air ventilation mode through windows and doors affected the ability of student concentration performance.

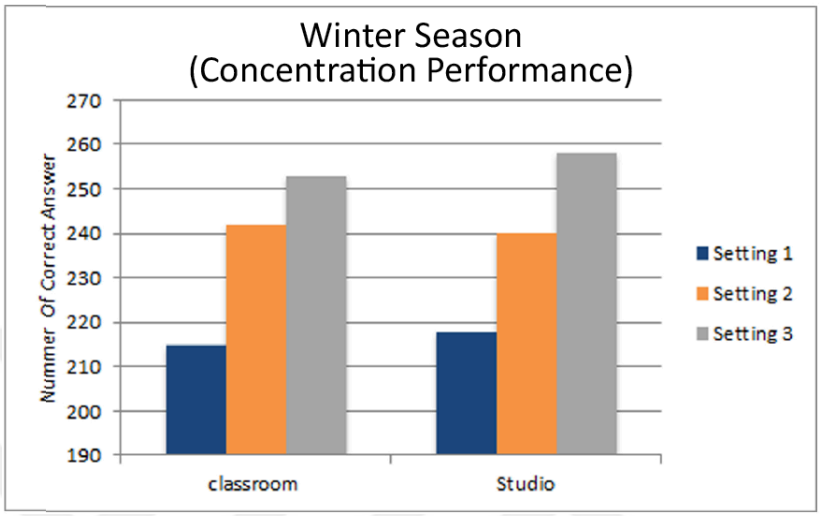


Figure 57: The comparison of concentration performance scores in both studio and classroom environment regarding the winter season.

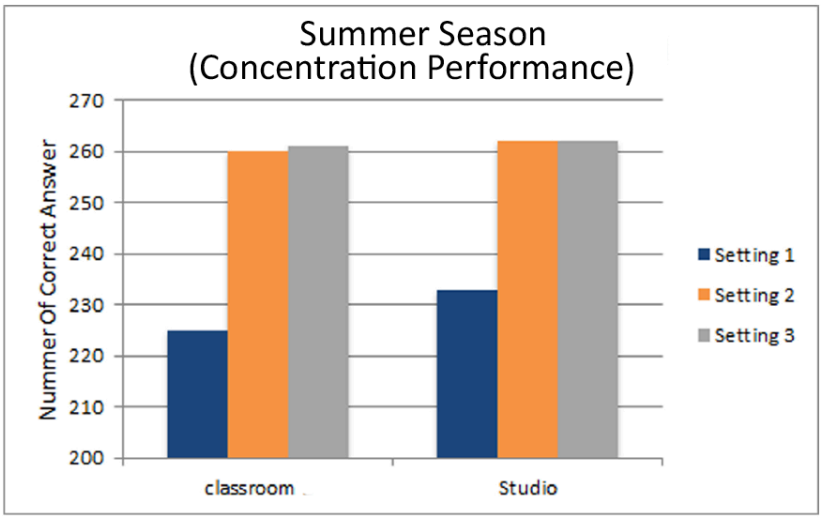


Figure 58: The comparison of concentration performance scores in both studio and classroom environment regarding the summer season.

The results of the attention test showed that in studio and classroom environment during the both seasons, the attention test scores were increased from setting I to setting III (Figure 59 and 60). Similar to the concentration scores, the highest number of correct answers was achieved in setting III, which was the mechanical ventilation mode with TROX school air unit.

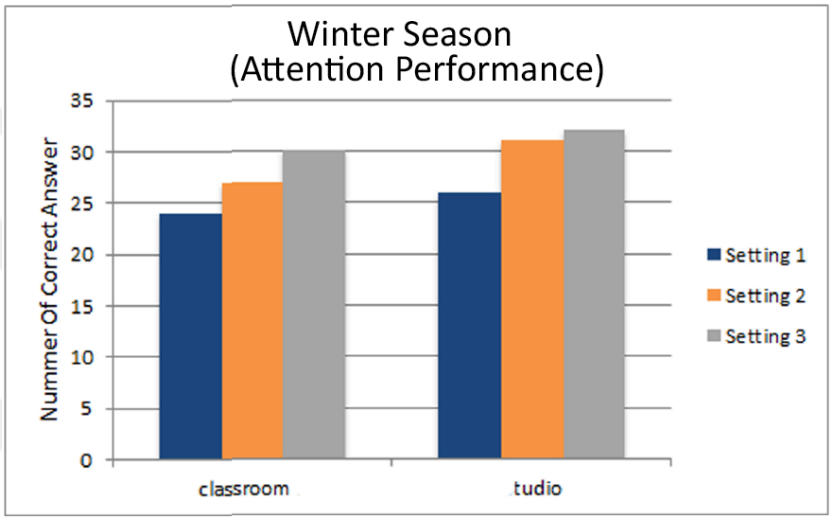


Figure 59: The comparison of attention performance scores in both studio and classroom environment regarding the winter season.

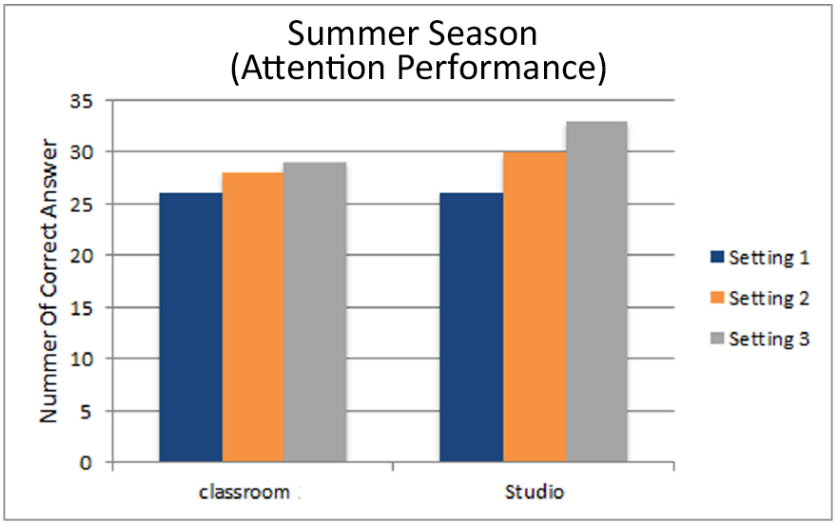


Figure 60: The comparison of attention performance scores in both studio and classroom environment regarding the summer season.

CHAPTER VI

CONCLUSION

People spend more than 80% of their time in indoor environments, such as in schools, offices, and shops. Universities are the places, where most of the young population spends their daytime. Thus, “university environments are the most crucial indoor environments to ensure student’s health, effective learning and well-being (Silvers, 1994; Diapouli, 2008; Dorizas, 2013). This study investigated the effects of different ventilation modes on students’ performance. It measured experimentally the thermal comfort and IAQ of both a design studio environment and a classroom environment under three different ventilation modes. The experimental results were in line with the literature review. As mentioned in the literature review, the study by Wargocki & Wyon (2008) showed that increasing outdoor air supply enhance the student performance on numerical and language-based task, also the percentage of error on numerical task significantly reduced in that case. Satish et al. (2012) also mentioned that the CO2 overload in interior leads to decrease attention and has negative effects on performance. Moreover, according to the subjective outcomes of the study, both the studio and classroom environment with TROX school-air unit (Mechanical ventilation) had highest performance scores compared to other two ventilation modes. In the absence of a mechanical air-conditioning system, the performance decreased in both environments and seasons. On the other hands, both

studio and classroom environments have a slight difference on survey and experimental measurements' result. The reason is the low population density with more time durations in studio environment, compared to classroom environment, where there is a high population density with the less spending hours. Therefore, there is a significant relationship between number of occupants and spending hours in studio.

More specifically, this study assumed that the increasing ventilation rate (5 l/s person<VR<7 l/s person) would improve student performance. In addition, there is a statistically significant relationship between thermal comfort within the comfort zone and student performance. As mentioned in the result section, the high ventilation rate was in TROX school-air ventilation setting with the higher range of thermal comfort level, next one was setting 2 with natural ventilation setting, and last one non ventilation setting.

On the other hand, increasing supplied fresh air from 0.3-5 to 13-16 l/s causes improvement on students' performance. Furthermore, overloaded CO2 concentration (above 1000 ppm) in design studios decreases student's concentration and attention. As mentioned in the result section, the higher amount of fresh air provided by TROX school-air ventilation unit. As a result, the higher IAQ provided in setting 3 (mechanical ventilation), setting 2 natural ventilation have the average value of IAQ and setting 1 non ventilation setting has less range of IAQ (See Appendix A4, A5). According to the results of statistical analysis and experimental measurements, the study suggests the following three key guidelines that should be considered for improving thermal comfort and IAQ in art classrooms:

1. Cleaning and maintenance of space have importance beside the volume and orientation. Also, openings should be arranged in an appropriate dimensions and orientations.

2. Thermal comfort indicators within comfort zone should be considered according to the different climates and cultures.

3. Indoor air quality should be considered with the student numbers and time durations of the lectures in addition to the standards in terms of CO2 concentration, temperature, and humidity.

There were also a few limitations, which influenced this study. First, all the measurements were taken in the same room. However, different orientation, size, shape and façade design could affect the thermal comfort and indoor air quality. Moreover, not having the equal number of gender of participants could be also limited the study in terms of analyzing gender differences.

Further research could be conducted in other art schools as well, with different number and grade of students. Future studies could also include analyzing the effects of indoor air quality in primary schools. Since providing better thermal and air quality conditions in classrooms would be cost-effective, developing sustainable strategies becomes essential.

BIBLIOGRAPHY

ASHRAE. ANSI/ASHRAE Standard 62.1 (2013). Ventilation for acceptable indoor air quality. *Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers*, Inc.

Al-Rashidi, K., Loveday, D., & Al-Mutawa, N. (2012). Impact of ventilation modes on carbon dioxide concentration levels in Kuwait classrooms. *Energy and Buildings*, *47*, 540-549. doi:10.1016/j.enbuild.2011.12.030

BATES, M. E., & LEMAY, E. P. (2004). The d2 Test of Attention: Construct validity and extensions in scoring techniques. *Journal of the International Neuropsychological Society*, *10*(03), doi:10.1017/s135561770410307x

BATES, M. E., & LEMAY, E. P. (2004). The d2 Test of Attention: Construct validity and extensions in scoring techniques. *Journal of the International Neuropsychological Society*, *10*(03). doi:10.1017/s135561770410307x

d2 Test of Attention. (1998). *PsycTESTS Dataset*. doi:10.1037/t03299-000

Daisey, J. M., Angell, W. J., & Apte, M. G. (2003). Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air*, *13*(1), 53-64. doi:10.1034/j.1600-0668.2003.00153.x

Diapouli, E., Chaloulakou, A., Mihalopoulos, N., & Spyrellis, N. (2007). Indoor and outdoor PM mass and number concentrations at schools in the Athens area. *Environmental Monitoring and Assessment*, *136*(1-3), 13-20. doi:10.1007/s10661-007-9724-0

Diapouli, E., Chaloulakou, A., & Spyrellis, N. (2007). Indoor and Outdoor

Particulate Matter Concentrations at Schools in the Athens Area. *Indoor and Built Environment*, *16*(1), 55-61. doi:10.1177/1420326x06074836

Dorizas, P., Kapsanaki-Gotsi, E., Assimakopoulos, M., & Santamouris, M. (2013). Correlation of Particulate Matter with Airborne Fungi in Schools in Greece. *International Journal of Ventilation*, *12*(1), 1-16. doi:10.1080/14733315.2013.11683998

Eide, E. R., Showalter, M. H., & Goldhaber, D. D. (2010). The relation between children's health and academic achievement. *Children and Youth Services Review*, *32*(2), 231-238. doi:10.1016/j.childyouth.2009.08.019

Eide, E. R., Showalter, M. H., & Goldhaber, D. D. (2010). The relation between children's health and academic achievement. *Children and Youth Services Review*, *32*(2), 231-238. doi:10.1016/j.childyouth.2009.08.019

Haverinen-Shaughnessy, U., Moschandreas, D. J., & Shaughnessy, R. J. (2010). Association between substandard classroom ventilation rates and students' academic achievement. *Indoor Air*, *21*(2), 121-131. doi:10.1111/j.1600-0668.2010.00686.x

Haverinen-Shaughnessy, U., Shaughnessy, R. J., Cole, E. C., Toyinbo, O., & Moschandreas, D. J. (2015). An assessment of indoor environmental quality in schools and its association with health and performance. *Building and Environment*, *93*, 35-40. doi:10.1016/j.buildenv.2015.03.006

Linden, P. F. (1999). THE FLUID MECHANICS OF NATURAL VENTILATION. *Annual Review of Fluid Mechanics*, *31*(1), 201-238. doi:10.1146/annurev.fluid.31.1.201

Linden, P. F. (1999). THE FLUID MECHANICS OF NATURAL

VENTILATION. *Annual Review of Fluid Mechanics*, *31*(1), 201-238. doi:10.1146/annurev.fluid.31.1.201

Mendell, M. J., & Heath, G. A. (2005). Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air*, *15*(1), 27-52. doi:10.1111/j.1600-0668.2004.00320.x

Mishra, A. K., & Ramgopal, M. (2015). A comparison of student performance between conditioned and naturally ventilated classrooms. *Building and Environment*, *84*, 181-188. doi:10.1016/j.buildenv.2014.11.008

Mishra, A. K., & Ramgopal, M. (2015). A comparison of student performance between conditioned and naturally ventilated classrooms. *Building and Environment*, *84*, 181-188. doi:10.1016/j.buildenv.2014.11.008

Norbck, D., & Nordstrm, K. (2008). An experimental study on effects of increased ventilation flow on students perception of indoor environment in computer classrooms. *Indoor Air*, *18*(4), 293-300. doi:10.1111/j.1600-0668.2008.00530.x

Persily, A. (2015). Challenges in developing ventilation and indoor air quality standards: The story of ASHRAE Standard 62. *Building and Environment*, *91*, 61-69. doi:10.1016/j.buildenv.2015.02.026

Sarbu, I., & Pacurar, C. (2015). Experimental and numerical research to assess indoor environment quality and schoolwork performance in university classrooms. *Building and Environment*, *93*, 141-154. doi:10.1016/j.buildenv.2015.06.022

Satish, U., Mendell, M. J., Shekhar, K., Hotchi, T., Sullivan, D., Streufert, S., &

Fisk, W. (. (2012). Is CO2 an Indoor Pollutant? Direct Effects of Low-to-Moderate CO2 Concentrations on Human Decision-Making Performance. *Environmental Health Perspectives*. doi:10.1289/ehp.1104789

Scherer, G. (2015). Conference Report - 7th International Conference on Indoor Air Quality and Climate (Indoor Air 96) July 21-26, 1996, Nagoya, Japan. *Beiträge zur Tabakforschung / Contributions to Tobacco Research*, *17*(1). doi:10.2478/cttr-2013-0649

Seppanen, O. A., & Fisk, W. J. (2004). Summary of human responses to ventilation. *Indoor Air*, *14*(s7), 102-118. doi:10.1111/j.1600-0668.2004.00279.x

Seppanen, O., Fisk, W. J., & Lei, Q. H. (2006). Ventilation and performance in office work. *Indoor Air*, *16*(1), 28-36. doi:10.1111/j.1600-0668.2005.00394.x

Shaw, E. (1972). Thermal Comfort: analysis and applications in environmental engineering, by P. O. Fanger. 244 pp. DANISH TECHNICAL PRESS. Copenhagen, Denmark, 1970. Danish Kr. 76, 50. *The Journal of the Royal Society for the Promotion of Health*, *92*(3), 164-164. doi:10.1177/146642407209200337

Silvers, A., Florence, B. T., Rourke, D. L., & Lorimor, R. J. (1994). How Children Spend Their Time: A Sample Survey for Use in Exposure and Risk Assessments. *Risk Analysis*, *14*(6), 931-944. doi:10.1111/j.1539-6924.1994.tb00062.x

Simons, E., Lin, S., & Hwang, S. (2009). The Impact of School Building Conditions on Student Absenteeism and Performance in Upstate New York. *Journal of Allergy and Clinical Immunology*, *123*(2), S21-S21. doi:10.1016/j.jaci.2008.12.094

Sleegers, P., Moolenaar, N., Galetzka, M., Pruyn, A., Sarroukh, B., & Van der Zande, B. (2012). Lighting affects students' concentration positively: Findings from three Dutch studies. *Lighting Research & Technology*, *45*(2), 159-175. doi:10.1177/1477153512446099

Stabile, L., Dell'Isola, M., Frattolillo, A., Massimo, A., & Russi, A. (2016). Effect of natural ventilation and manual airing on indoor air quality in naturally ventilated Italian classrooms. *Building and Environment*, *98*, 180-189. doi:10.1016/j.buildenv.2016.01.009

Sundell, J., Levin, H., Nazaroff, W. W., Cain, W. S., Fisk, W. J., Grimsrud, D. T., Weschler, C. J. (2011). Ventilation rates and health: multidisciplinary review of the scientific literature. *Indoor Air*, *21*(3), 191-204. doi:10.1111/j.1600-0668.2010.00703.x

Tham, K. W., & Willem, H. C. (2010). Room air temperature affects occupants' physiology, perceptions and mental alertness. *Building and Environment*, *45*(1), 40-44. doi:10.1016/j.buildenv.2009.04.002

Turunen, M., Toyinbo, O., Putus, T., Nevalainen, A., Shaughnessy, R., & Haverinen-Shaughnessy, U. (2014). Indoor environmental quality in school buildings, and the health and wellbeing of students. *International Journal of Hygiene and Environmental Health*, *217*(7), 733-739. doi:10.1016/j.ijheh.2014.03.002

Wassenberg, R., Hendriksen, J. G., Hurks, P. P., Feron, F. J., Keulers, E. H., Vles, J. S., & Jolles, J. (2008). Development of Inattention, Impulsivity, and Processing Speed as Measured by the d2 Test: Results of a Large Cross-sectional Study in Children Aged 7–13. *Child Neuropsychology*, *14*(3), 195-210. doi:10.1080/09297040601187940

Webster, J. (2016). creolization. *Oxford Classical Dictionary*. doi:10.1093/acrefore/9780199381135.013.6981

WYON, D. P., FANGER, P. O., OLESEN, B. W., & PEDERSON, C. J. (1975). The Mental Performance of Subjects Clothed for Comfort at Two Different Air Temperatures. *Ergonomics*, *18*(4), 359-374. doi:10.1080/00140137508931470

APPENDICES

A. SURVEY

A1. Thermal Comfort and Indoor Air Quality Survey

Thermal Comfort & Indoor Air Quality Survey

The aim of this survey is to rate your thermal comfort and Indoor air quality level in your workpace. This survey will not be shared with public. Data is going to be used in the department of interior architecture and environmental design master thesis.

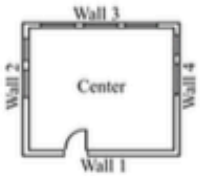
Section 1:

1. What is your age?
2. What is your gender? ☐ Male ☐ Female
3. How many hours do you spend in this design studio?

☐ 1 - 4 hours per week ☐ 5 -10 hours per week ☐ More than 10 hours per week

4. Where is your workplace location in the studio?

☐ Near wall 1 ☐ Near wall 2 ☐ Near wall 3 ☐ Near wall 4 ☐ Center part of studio



Section 2:

Please rate your thermal comfort level using 7 likert scale .

Thermal comfort	Cold / Hot -3 -2 -1 0 +1 +2 +3
1. How do you feel now?	☐☐☐☐☐☐☐
2.How do you find thermal comfort of the classroom?	☐☐☐☐☐☐☐
3. How do you prefer thermal comfort of the classroom to be?	☐☐☐☐☐☐☐
4. Is the thermal comfort of environment acceptable?	Unacceptable / Acceptable -3 -2 -1 0 +1 +2 +3 ☐☐☐☐☐☐☐
5. Is the thermal comfort of environment tolerable?	Non-tolerable / Tolerable -3 -2 -1 0 +1 +2 +3 ☐☐☐☐☐☐☐

Section 3:

Please rate your indoor air quality level using 7 likert scale .

Indoor Air Quality	Very strongly dissatisfied / Very strongly satisfied -3 -2 -1 0 +1 +2 +3
1. How satisfied are you with the air quality in your workspace?	☐☐☐☐☐☐☐
2. Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?	☐☐☐☐☐☐☐
3. How satisfied are you with cleaning service provided for your workspace?	☐☐☐☐☐☐☐

A2. Arithmetic Concentration Test (Kraepelin test)

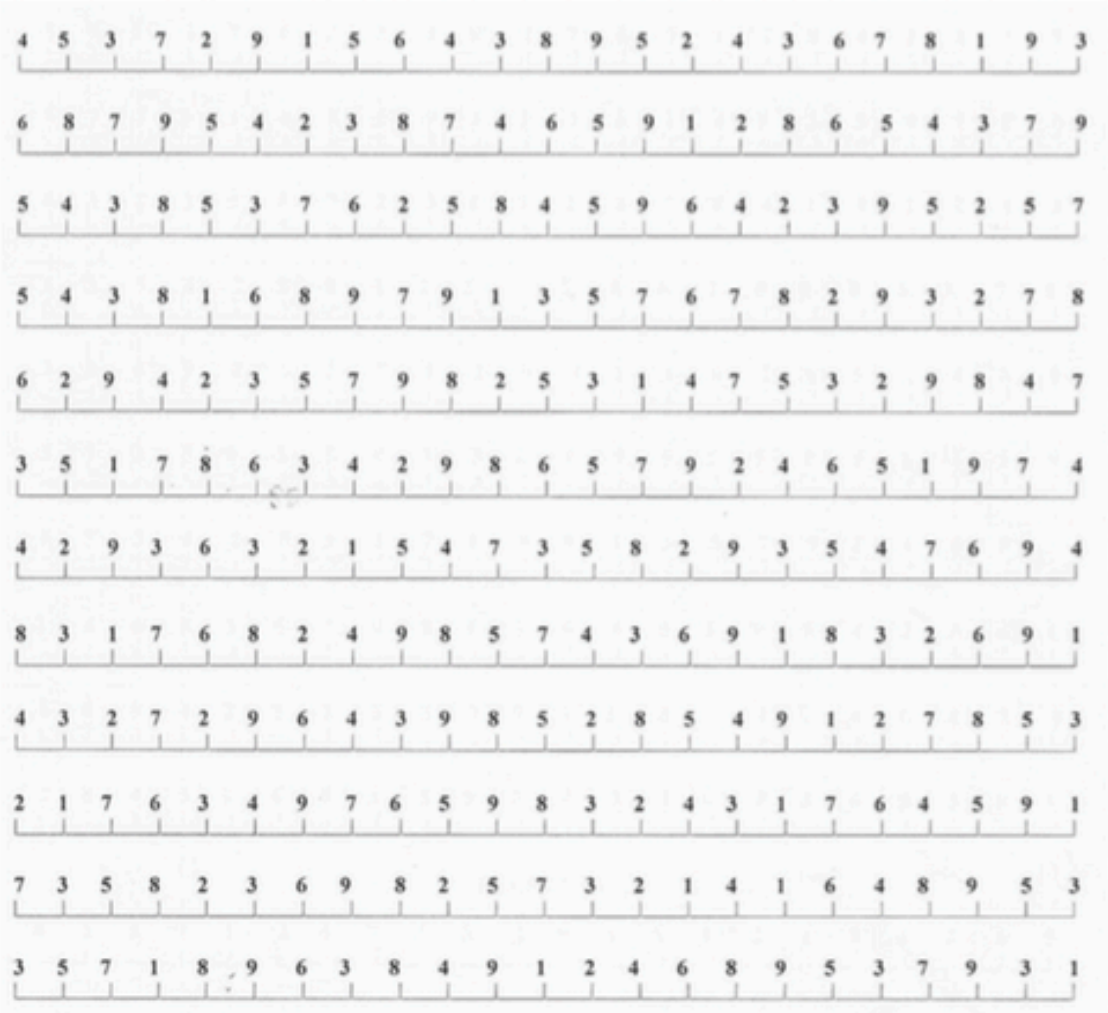
KRAEPELIN Test (Arithmetic test)

Performance speed and task performance accuracy

Solving mode:
If the second number from the pair is smaller than the first, it is subtracted from the first (-). If the second number from the pair is higher than the first, the two numbers assemble (+).

Attention! Do not make the calculation write only the sign of operation between the two numbers.

Time to solve: 10 min.



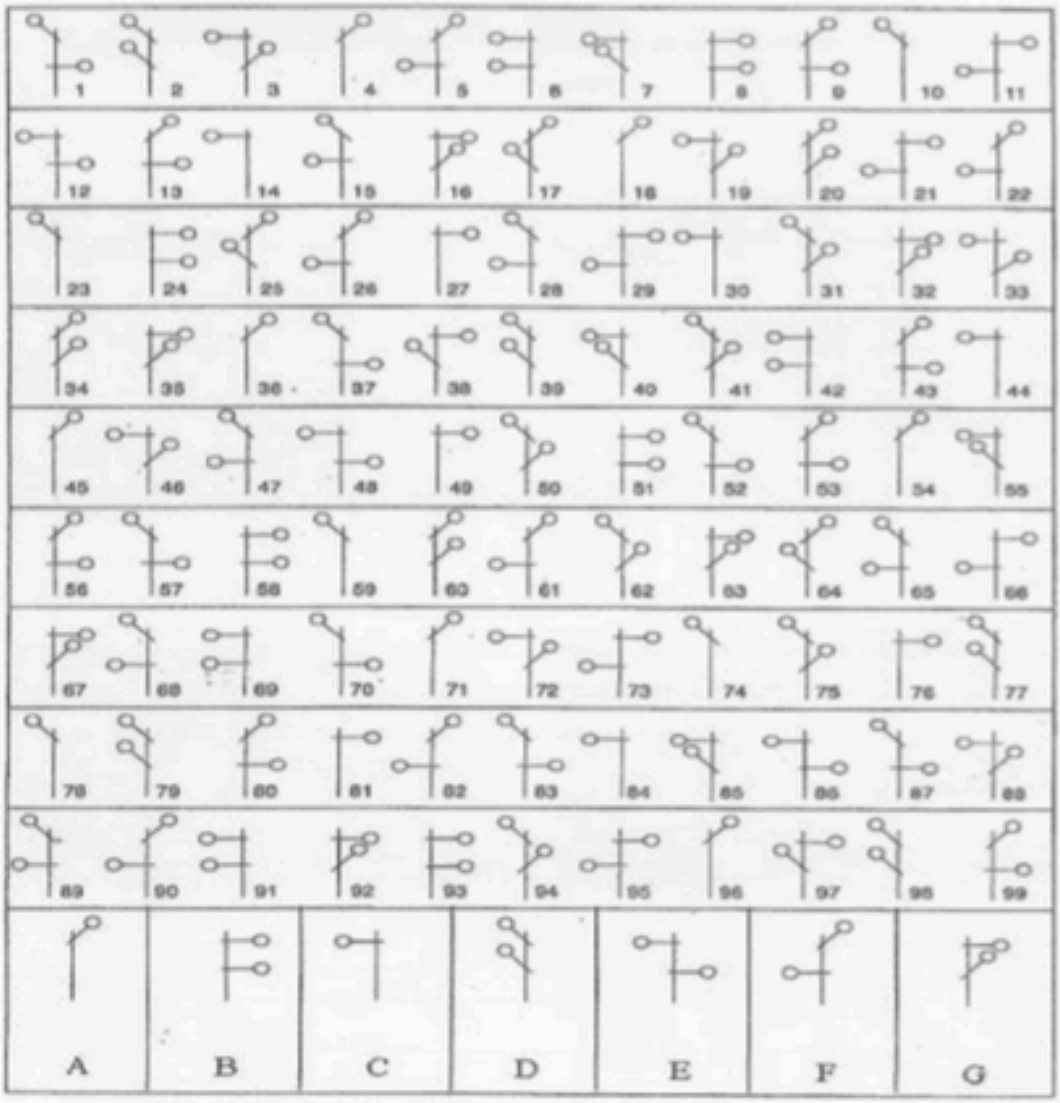
A3. Visual attention Test (Prague test)

PRAGUE test (Attention tests)

Attention tests require concentration and targeting selective attention, the visual memory and the perception of fixed discrimination.

Solving mode:
At the bottom of the page, you have some rectangles and each has a traffic light with one or two branches. The branches are straight or oblique, in one sense or another. They are similar to the model at the top. You will find 99 traffic lights. The task is to take them in the order written - reading (up-down, left-right) - and compare each traffic light with the models. You cross the number that accompanies the traffic light in the model box, which looks similar. There are traffic lights that do not look similar to any of the models and skips them.

Time to solve: 10 min.



A4: Results of subjective, objective, and concentration tests for both environments (Winter season).

			M.R.T	Air Flow	CO2	Temperature	Humidity	Kraeplin	Prague
Winter Season	Studio Environment	Setting 1	22.8°C	0.45	1119	28.66°C	26.22	218/264	26/36
		Setting 2	22.8°C	0.5	1068	27.44°C	28.06	240/264	31/36
		Setting 3	21.5°C	0.75	986	20.48°C	26.69	258/264	32/36
	Classroom Environment	Setting 1	23.0°C	0.4	1472	23.23°C	26.14	215/264	24/36
		Setting 2	24.6°C	1	1031	24.13°C	31.24	242/264	27/36
		Setting 3	23.3°C	0.15	799	25.70°C	26.83	253/264	30/36

A5: Results of subjective, objective, and concentration tests for both environments (Summer season).

			M.R.T	Air Flow	CO2	Temperature	Humidity	Kraeplin	Prague
Summer Season	Studio Environment	Setting 1	24.4°C	0.2	1250	24.64°C	29.44	233/264	26/36
		Setting 2	25.2°C	0.75	582	25.50°C	27.25	262/264	30/36
		Setting 3	25.1°C	0.2	472	24.75°C	27.25	262/264	33/36
	Classroom Environment	Setting 1	23.5°C	0.2	1000	24.70°C	31.80	225/264	26/36
		Setting 2	24.0°C	1.5	900	22.20°C	27.90	260/264	28/36
		Setting 3	23.3°C	0.25	600	34.30°C	34.30	261/264	29/36

ISI KAYBI ÇİZELGESİ

Proje no :
Proje adı : Bilkent
Konu : Isı Kaybı Hesabı

Sayfa no : 1
Revizyon : 0
Tarih : Pazartesi, 30 Mayıs, 2016
Hesaplayan : Agah ARIK
Kontrol : BAHRİ TÜRKMEN

DİZAYN BİLGİLERİ

Şehir adı	Dış hava sıcaklığı (°C)	Rüzgar durumu	İşletme durumu
Ankara	-12 °C	Rüzgarlı	2. işletme

HESAP DEĞERLERİ

FF101 **SINIF** **20 °C**

İşr.	Yön	Gen. W(m)	Uzn. L(m)	Yük. H(m)	Alan A(m2)	Adet	Çıkan A(m2)	Net Alan	K (Watt/m2K)	tr-to dt(°C)	Kxdt	Q Kısmi	ZD (%	Z W	ZH (%	Z	Toplam Q(Watt)
Dp2	K		2.00	3.60	7.20	1		7.20	2.100	32	67.20	484					
Dd1	K	0.25	5.70	3.75	21.37	1	7.20	14.18	1.000	32	31.90	452					
Dp1	B		2.35	3.60	8.46	3		25.38	2.100	32	67.20	1,706					
Dd1	B	0.25	12.40	3.75	46.50	1	25.38	21.12	1.000	32	31.90	674					
Dp2	G		2.00	3.60	7.20	2		14.40	2.100	32	67.20	968					
Dd1	G	0.25	11.30	3.75	42.38	1	14.40	27.98	1.000	32	31.90	893					
Dd1	D	0.25	3.53	3.75	13.24	1		13.24	1.000	32	31.90	422					
												5,599	15	0	5	1.20	6,719

Qfuga = (axl) x R x H x (ti-td) x Ze
60 x 0.9 x 0.97 x 32 x 1.2 = 2,011

8,730

B. TROX school-air unit installation photos. (September 2016)

Photo 1: Unboxing the TROX school-air unit.

Photo 2: locating the TROX school-air unit.

Photo 3: installation of the TROX school-air unit to the plumping system of building.

Photo 4: Air input and output from windows.

Photo 5: Studding the electric power system of unit.

Photo 6: Electronic circuit of TROX school-Air unit.

Photo 7: Installation of electrical wiring and control panel of unit.

Photo 8: Finish the process of installation and automation.

Measurement set up on FF 101 Studio.

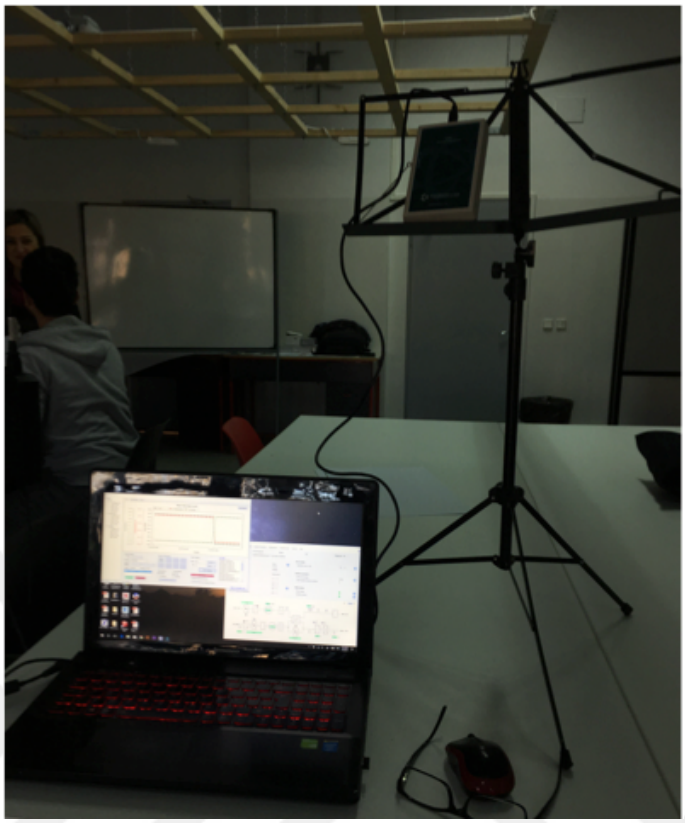


Photo 9: Measurement set up of IAQ on site.

Photo 10: ventilation through door and windows.

Photo 11: Air flow measurement device