



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

بسم الله الرحمن الرحيم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



MONA MAGHRABY



**NUMERICAL INVESTIGATION OF
FLOW PATTERNS AND THERMAL COMFORT INSIDE AIR-
CONDITIONED CLASSROOM**

By

Eng. Mahmoud Mohamed Ahmed Abdelmaksoud Abu-Saad

**A Thesis Submitted to the Faculty of
Engineering at Cairo University in Partial
Fulfilment of the Requirements for the Degree of
MASTER OF SCIENCE**

In

MECHANICAL POWER ENGINEERING

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020**

**NUMERICAL INVESTIGATION OF
FLOW PATTERNS AND THERMAL COMFORT INSIDE AIR-
CONDITIONED CLASSROOM**

By

Eng. Mahmoud Mohamed Ahmed Abdelmaksoud Abu -Saad

**A Thesis Submitted to the Faculty of
Engineering at Cairo University in Partial
Fulfilment of the Requirements for the Degree of
MASTER OF SCIENCE**

In

MECHANICAL POWER ENGINEERING

Under Supervision of

Prof. Dr. Essam E. Khalil
Professor
Mechanical Power Department
Faculty of Engineering
Cairo University

**Dr. Gamal Abd El moniem
El-Hariry**
Associate Professor
Mechanical Power Department
Faculty of Engineering
Cairo University

Dr. Eslam Said Abdelghany
Assistant Professor
Mechanical Power Department
Institute of Aviation Engineering
and Technology

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020**

NUMERICAL INVESTIGATION OF FLOW PATTERNS AND THERMAL COMFORT INSIDE AIR-CONDITIONED CLASSROOM

By

Eng. Mahmoud Mohamed Ahmed Abdelmaksoud Abu -Saad

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

In

MECHANICAL POWER ENGINEERING

Approved by the
Examining Committee

Prof. Dr. Essam E. Khalil

Thesis Main Advisor

Prof. Dr. Sami Murad Morkus

Internal Examiner

Prof. Dr. Osama Ezzat Abdel-Latif

External Examiner

-Prof. of Mechanical Power Engineering, Faculty of Engineering at (Shoubra),
Benha University

**FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020**

Engineer's Name: Mahmoud Mohamed Ahmed
abdel maksoud abu saad
Date of Birth: 20/2/1992
Nationality: Egyptian
E-mail: Mn_Mn61881@yahoo.com
Phone: 01064670724
Address: Desouk_ kafr al- sheikh
Registration Date: 1/10/2015
Awarding Date: 15 / 2 /2020
Degree: Master of Science
Department: Mechanical power



Supervisors:

Prof. Dr. Essam E. Khalil
Prof. Dr. Gamal Abd El moniem
Dr. Eslam Said Abdelghany

Examiners:

Prof. Dr. Osama Ezzat Abdel-Latif (External examiner)
Prof. Dr. Sami Murad Morkus (Internal examiner)
Prof. Dr. Essam E. Khalil (Thesis main advisor)

Title of Thesis:

NUMERICAL INVESTIGATION OF FLOW PATTERNS AND THERMAL
COMFORT INSIDE AIR-CONDITIONED CLASSROOM

Key Words:

Thermal comfort; flow pattern; air- conditioning

Summary:

In this thesis we will concern primarily with simulation of airflow pattern, carbon dioxide dispersion, and thermal comfort inside an educational classroom in Institute of Aviation Engineering and Technology, which is located on the second floor of the building of architecture, Hall 3201. An experimental investigation on the same classroom was accomplished which aims to validate the used CFD code and a Good the agreement is found among both predictions. These investigations included the measurements of relative humidity, and temperature, which were done using (Elcometer 319 Dewmeter gauge). The study is employed using CFD simulation techniques as embedded in the commercially available CFD code (FLUENT 19). The domain assembly case was finally discretized into 4,444,200 averaged tetrahedral elements. The thesis is keen to numerically investigate influence of changing the type of air outlet on the distribution of air and the thermal comfort for the occupants inside the teaching space and choosing the best design of air conditioning inside the classroom, this could be expressed concerning with only three different types of air outlet which are square diffuser, swirl diffuser, and round diffuser.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and cited them in the references section.

Name:

Date:

Signature:

Acknowledgments

With the name of ALLAH, I started this research hoping that it accelerates the wheel of progress in this field.

I would like to express my sincere appreciation and infinite thanks to **Professor Dr. Essam E. Khalil**, professor of mechanical power- faculty of engineering–Cairo University, who gave me a great scientific support and guidance to make a progress in my research. Besides, having severe admiration of his gigantic experience and unlimited co-operation and efforts of helping me to introduce this research in the best.

I would also like to acknowledge the help rendered to me by, **Dr. Gamal El-Hariry and Dr. Eslam Said Abdelghany** as advisors, they provided me valuable suggestions and guidance during my study. I appreciate their encouragement, guidance and cooperation through my whole thesis work.

In addition, I cannot express; in words; the support of **my parents**, and my sisters. Their insight and wisdom have been invaluable.

To all my team and my friends: thank you very much for what you have done for me. I thank you all for the companionship that made this journey much easier. In fact, I do not need to list your names because I am sure that you know who you are.

Table of Contents

DISCLAIMER	I
ACKNOWLEDGMENTS	II
TABLE OF CONTENTS	III
LIST OF TABLES	VI
LIST OF FIGURES	VII
ABSTRACT	XIX
CHAPTER 1 : INTRODUCTION	1
1.1. THERMAL COMFORT	1
1.2. FACTORS INFLUENCING THERMAL COMFORT	1
1.2.1. Air Temperature	2
1.2.2. Radiant Temperature	2
1.2.3. Air Velocity	2
1.2.4. Relative Humidity	2
1.2.5. Clothing Insulation	3
1.2.6. Metabolic Heat	3
1.3. MODELS OF THERMAL COMFORT	3
1.3.1. PMV/PPD Method	3
1.3.2. Adaptive Comfort Model	5
1.4. ROOM AIR DISTRIBUTION SCHEMES	6
1.5. VENTILATION SYSTEMS	6
1.6. THESIS OUTLINES	7
CHAPTER 2 : LITERATURE REVIEW	8
2.1 PAPERS CONCERNED WITH FLOW INVESTIGATIONS IN ENCLOSED SPACE.	8
2.2 OBJECTIVE OF PRESENT WORK	19
CHAPTER 3 : GOVERNING EQUATION	20
3.1. FLUID ELEMENT FOR CONSERVATION LAWS	20
3.2. CONTINUITY EQUATION	20
3.3. MOMENTUM CONSERVATION EQUATIONS	21
3.4. ENERGY CONSERVATION EQUATION	22
3.5. TURBULENCE MODELLING	23
3.6. THE STANDARD K - E MODEL	24
3.7. CONVECTIVE HEAT AND MASS TRANSFER MODELING IN THE STANDARD K – E MODEL	25
3.8. SEGREGATED SOLUTION ALGORITHM	25
3.9. DISCRETIZATION SCHEME	26

CHAPTER 4 : VALIDATION	28
4.1. DESCRIPTION OF CLASSROOM SPACE CONFIGURATION	28
4.2 BOUNDARY CONDITIONS	29
4.3 MEASURING INSTRUMENTS.....	30
4.4 MEASURING LOCATIONS.....	30
4.5 EXPERIMENTAL PROCEDURE.....	32
4.6 EXPERIMENTAL RESULTS.....	33
4.7 EVALUATION OF CFD MODELLING VALIDATION.....	35
4.8 MESH INDEPENDENCE TEST.....	37
4.9 VALIDATION RESULTS	37
4.9.1 Temperature results	38
4.9.2 Relative humidity results.....	43
CHAPTER 5 : MODELING OF AIRFLOW CHARACTERISTICS INSIDE CLASSROOM.....	49
5.1 CASE STUDIED SPECIFICATION	49
5.2 BOUNDARY CONDITION	53
5.3 EFFECT OF OCCUPANTS	56
5.4 CASE MESHING	58
5.5 MESH INDEPENDENCE TEST.....	61
5.6 MODELLING OF OCCUPANT	62
5.7 MODELLING OF DIFFERENT TYPES OF AIR OUTLET.....	63
5.7.1 Modelling of square diffuser	63
5.7.2 Modelling of swirl diffuser.....	63
5.7.3 Modelling of round diffuser	64
5.8 PLANES THAT SHOWS RESULTS	64
5.9 CASE STUDIES.	66
5.9.1 Results of Modeled Case Studies	66
5.9.1.1 Four - way square diffuser	66
5.9.1.1.1 Case 1 ($\theta=30^\circ$).....	67
5.9.1.1.2 Case 2 ($\theta=45^\circ$).....	77
5.9.1.1.3 Case 3 ($\theta=60^\circ$).....	87
5.9.1.1.4 Case 4 ($V=3.5\text{m/s}$, $\theta=30^\circ$).....	97
5.9.1.1.5 Case 5 ($V=4\text{ m/s}$, $\theta=30^\circ$).	106
5.9.1.1.6 Case 6($V=5\text{m/s}$, $\theta=30^\circ$).....	115
5.9.1.2 Swirl diffuser	124
5.9.1.2.1 Case 7 ($V=3\text{m/s}$).....	124
5.9.1.2.2 Case 8 ($V=4\text{m/s}$).....	134
5.9.1.2.3 Case 9 ($V=5\text{m/s}$).....	143
5.9.1.2.4 Case 10 ($V=6\text{m/s}$)	153
5.9.1.3 Round diffuser	162
5.9.1.3.1 Case 11($V=3\text{m/s}$)	163
5.9.1.3.2 Case 12 ($V=4\text{m/s}$)	172
5.9.1.3.3 Case 13 ($V=5\text{m/s}$)	182
CHAPTER 6 : CONCLUSIONS AND SUGGESTED FUTURE WORK.....	192
6.1 CONCLUSIONS OF PRESENT WORK.....	192

6.2 RECOMMENDATIONS FOR FUTURE WORK	193
REFERENCES	194
APPENDIX A	أ
APPENDIX B.....	ث
الملخص	أ

List of Tables

Table 2.1: List of results of PMV, PPD, and CO ₂ concentration for the different cases, [13].	9
Table 4. 1 Measurements Lines Coordinates	32
Table 4. 2 Measurements in the plane $x = 1.62$ m.....	33
Table 5 1: Summary of different cases.....	54
Table 5 2: occupant data.....	62
Table A. 1: Typical Metabolic Heat Generation for Various Activities [32].....	أ
Table A.2: Typical lighting data for various applications [37].	ب
Table A.3: recommended Heat gain from typical different equipment [38]......	ت
Table C. 1: Standard composition of dry air (detailed analysis) [33].	ث
Table B. 2: four-way engineering performance data [34].	ج
Table B. 3: four-way square diffuser engineering performance data [35].	ح
Table B. 4: circular diffuser engineering performance data [35].	خ
Table B. 5: swirl diffuser engineering performance data [36].	د

List of Figures

Fig 1. 1 : Factors influencing thermal comfort,[2]	2
Fig 1. 2: Two alternative thermal comfort representations for PMV / PPD, [9]. (a)Relative humidity chart related to temperature. , (b) Psychometric chart.	5
Fig 1. 3: Adaptive chart due to ASHRAE Standard 55, [5].	5
Figure 1.4: Supply and return / extract basic room ports, [10].....	6
Figure 2. 1. The domain of case study configuration Modeled by ANSYS 15, [13].	9
Fig.2. 2. Geometry model, [14].	10
.....	10
Fig 2.3: a. Occupant gratification about temperature; b. Occupant satisfaction about air speed, [14].	10
Figure 2. 4 Configuration of model space with a symmetry wall, [17].....	12
Figure 2. 6 Swirl inlet diffuser Simulation, [17].	12
Figure 2. 7: Geometry & border conditions for the tested room, [18].	13
Figure 2.8: Show the teaching space geometry, [19].	14
Figure 2.9: Geometry of the teaching space and the 4-way air-conditioner, [20].	14
Figure 2.10: Location of measuring points in theatre, [21].	15
Figure 2. 11: Experimental setup. a) Schematic of the office room; b) Haiku ceiling fan, [22].	16
Figure 2.12: Measurement points for three rotational speeds (72 rpm, 124 rpm, and 182 rpm), [22].	16
Figure 2. 13: The investigated environment, [23]: (a) Exterior wall of the examined classroom measurement points (b) Classroom plan measurement point (c) A view of classroom during the experimental campaign.	17
Figure 2. 14: Room model: a) simulation model; b) mesh implemented, [23].	17
Figure 2.15: Thermal field within room: 8 Am., 12 pm., 3 pm., 5 p.m. and 6 pm, [23].	18
Figure 2. 16: Velocity profile within room: 3 pm. and 5 pm, [23].	18
Figure 2. 17: The model room for air- Conditioning & ventilation cases, [24].	19
Figure 3.1: Fluid element for conservation, [26].	20
Figure 3.2: Stress components on the three faces of the fluid element. [26].	21
Figure.3. 3: Typical point velocity measurement in turbulent flow, [27].	23
Figure 3.4: Flowchart for the segregated solver, [27].	26
Figure-3.5: Types of grid (a) structured grid, (b) unstructured, [25].	27
Fig 4. 1: exterior and interior views of classroom.....	28
Fig 4. 2: classroom space configuration	29
Fig 4. 3: boundary condition of classroom.....	29
Fig 4. 4 Elcometer 319 Dewmeter.....	30
Fig 4. 5: (a) plane of measurement (b) points of measurement plane.	31
Fig 4. 6 photos of classroom during measurements.	33
Fig 4.7 Validation process.	36
Fig 4. 8 Mesh Geometry using different mesh size	37
Fig 4.9 Temperature at line (1) [measurements versus numerical results].....	38
Fig 4. 10 Temperature at line (2) [measurements versus numerical results].....	38
Fig 4.11 Temperature at line (3) [measurements versus numerical results].....	39
Fig 4.12 Temperature at line (4) [measurements versus numerical results].....	39

.....	40
Fig 4. 13 Temperature at line (5) [measurements versus numerical results].....	40
.....	40
Fig 4. 14 Temperature at line (6) [measurements versus numerical results].....	40
Fig 4. 25 Temperature at line (7) [measurements versus numerical results].....	41
.....	41
Fig 4. 16 Temperature at line (8) [measurements versus numerical results].....	41
Fig 4. 17 Temperature at line (9) [measurements versus numerical results].....	42
Fig 4. 18 Temperature at line (10) [measurements versus numerical results].....	42
Fig 4. 19 Relative humidity at line (1) [measurements versus numerical results]	43
Fig 4. 20 Relative humidity at line (2) [measurements versus numerical results]	43
Fig 4. 21 Relative humidity at line (3) [measurements versus numerical results]	44
Fig 4. 22 Relative humidity at line (4) [measurements versus numerical results]	44
Fig 4. 23 Relative humidity at line (5) [measurements versus numerical results]	45
Fig 4. 24 Relative humidity at line (6) [measurements versus numerical results]	45
Fig 4.25 Relative humidity at line (7) [measurements versus numerical results]	46
Fig 4.26 Relative humidity at line (8) [measurements versus numerical results]	46
Fig 4.27 Relative humidity at line (9) [measurements versus numerical results]	47
Fig 4. 28 Relative humidity at line (10) [measurements versus numerical results]	47
Fig 5. 1: interior and exterior views of the classroom: (a) Front view for the building (b) Side view of the building(c) Photos of the classroom from the inside.....	52
Fig 5. 2: classroom space configuration.	53
Fig 5. 3: Indoor initial & boundary conditions for classroom.	54
Fig 5. 4: Mean temperature of skin as a function in activity level, [30].	57
Fig 5. 5: Rate of CO ₂ generation from human at various activities, [1].	58
Fig 5.7 Meshing processed using ANSYS 19	60
Figure 5. 8 Mesh Geometry using a different mesh size	61
Figure 5. 9 Modelling of occupant	62
Figure 5. 10 modelling of square diffuser	63
.....	63
Figure 5. 11 modelling of swirl diffuser.....	63
Figure 5. 12 modelling of round diffuser	64
Figure 5. 13 Horizontal contour at Y=1.1m	64
.....	65
Figure 5. 14 Vertical contour at X=1. 2m	65
Figure 5. 15 Vertical contour at X=1.62m	65
Fig 5.16: Classroom space configuration for square diffuser.....	66
.....	67
Fig 5.17: direction of air flow outlet for a square diffuser ($\theta=30^\circ$).....	67
Fig 5. 18: Temperature horizontal contour at (Y=1.1m)	67
Fig 5. 19: Temperature vertical contour at (X=1.62 m)	68
Fig 5.20: Temperature vertical contour at (X=1.2m)	68
Fig 5. 21: Velocity horizontal contour at (Y=1.1 m).....	69
Fig 5. 22: Velocity vertical contour at (X=1.62 m)	69
Fig 5. 23: Velocity vertical contour at (X=1.2m).....	70
Fig 5. 24: Relative humidity horizontal contour at (Y=1.1 m).....	70
Fig 5. 25: Relative humidity vertical contour at (X=1.62 m).....	71
.....	72
Fig 5. 27: CO ₂ concentration horizontal contour in ppm at (Y=1.1 m).....	72