COMPUTATIONAL FLUID DYNAMICES (CFD) OF THERMAL COMFORT IN UNIVERSITY LIBRARY ENVIRONMENT

By

Eng. Hassan Ahmed Yasen Ali

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

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2019

COMPUTATIONAL FLUID DYNAMICES (CFD) OF THERMAL COMFORT IN UNIVERSITY LIBRARY ENVIRONMENT

By

Eng. Hassan Ahmed Yasen Ali

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

Under Supervision of

Prof. Dr. Mahmoud A. Fouad
Professor Mechanical Power
Department Faculty of
Engineering
Cairo University

Dr. Ahmed Mahmoud Abouzaid
Assistant Professor
Mechanical Power Department Faculty
of Engineering
Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2019

COMPUTATIONAL FLUID DYNAMICES (CFD) OF THERMAL COMFORT IN UNIVERSITY LIBRARY ENVIRONMENT

By

Eng. Hassan Ahmed Yasen Ali

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. Mahmoud A. Fouad	**Thesis Main Advisor**
Prof. Dr. Mustafa Abdul-Hameed Rizq	**Internal Examiner**
Prof. Dr. Mohammed Fayek Abed Rabbo	**External Examiner**

Professor, Mechanical Power Engineering Department Faculty of Engineering, Benha University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2019

Engineer: Hassan Ahmed Yasen Ali

Date of Birth: 14/01/1983

Nationality: Iraqi

E-mail: hassan.alahmed@yahoo.com

Phone: (+2) 01064212253

Address: 12 Abou El-Wafa St, Al-Haram, Cairo, Egypt

Registration Date: 01/03/2017

Awarding Date: / / 2019

Degree: Master of Science

Department: Mechanical Power Engineering

Supervisors: **Prof. Dr.** Mahmoud A. Fouad

Dr. Ahmed Mahmoud Abouzaid

Examiners: **Prof. Dr.** Mahmoud A. Fouad (Thesis main advisor)

Prof. Dr. Mustafa Abdul-Hameed Rizq (Internal examiner)

Prof. Dr. Mohammed Fayek Abed Rabbo (External examiner)

Professor, Mechanical Power Engineering Department, Benha University

Title of Thesis:

"COMPUTATIONAL FLUID DYNAMICES (CFD) OF THERMAL COMFORT IN UNIVERSITY LIBRARY ENVIRONMENT"

Key Words:

(CFD, thermal comfort, Library, air distribution, air change rate)

Summary:

The present thesis is devoted to numerical investigation that change in the angles of air throwing, air change per hour (ACH), also numbers, positions and dimensions of air extract grilles are studied to revealed the impact on the overall comfort levels for people. The study is carried out using (CFD) simulation techniques as entrenched in the commercially available CFD code (FLUENT 19). The CFD modelling techniques solved the continuity, momentum and energy conservation equations in addition to comfort parameters PMV and PPD based on Fanger's model and RNG k – ε model equations for turbulence closure. The results had shown the best configuration among the other configurations when eleven supply grilles distributed uniformly on ceiling with angle of throwing air is (15º) with horizontal, and four extract grilles distributed uniformly on the edges of the ceiling, at ACH=6.

DISCLAIMER

I hereby declare that this thesis is my own original work and that no part of it has been

Submitted for a degree of qualification at any other university or institute.

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

Name: Date:

Signature:

Dedication

With all love, devotion, and dedication, I dedicate this work to my parents, my wife and my son in Iraq. For their endless support.

ACKNOWLEDGMENT

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. Mahmoud A. Fouad**, 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 way.

I would also like to acknowledge the help rendered to me by, **Dr. Ahmed Mahmoud Abouzaid** as advisor, 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, my brother, my sister, my wife and my son. 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 much easier.
Last, but not least, I dedicate this research to my home country, Iraq.

Table of Contents

SUBJECT	PAGE
DISCLAIMER ……..	i
DEDICATION ……..	ii
ACKNOWLEDGEMENT……...	iii
TABLE OF CONTENTS…….	iv
LIST OF TABLES…….	x
LIST OF FIGURES…….....	xi
SYMBOLS AND ABBREVIATIONS ……..	xviii
NOMENECLATURE…….	xviii
GREEK LETTERS…….……	xix
SUPERSCRIBTS AND SUBSCRIBTS…….……	xx
ABBREVIATIONS……...	xv
ABSTRACT……...	xvi

CHAPTER 1 INTRODUCTION

1.1	Background…….	1
1.2	Thermal Comfort Factors …….....	2
1.2.1	Air temperature ……..……..	2
1.2.2	Air velocity ……..	2
1.2.3	Humidity ……..	2
1.2.4	Mean Radiant Temperature (MRT) ……	3
1.2.5	Clothing Insulation (Clo) …….	4
1.2.6	Metabolic Rate ……..……	4
1.2.7	Heat generated by lighting ……...…….	5
1.3	Other Thermal Comfort Assessment Tools…….……..	5

1.3.1 Predictive Mean Vote (PMV)…… 5
1.3.2 Predicted Percentage Dissatisfied (PPD) …… 6
1.4 Fanger's Contributions in Thermal Comfort …… 6
1.5 Air Exchange Rate (ACH) …… 7
1.6 Current Thesis Objective …….. 8
1.7 Present Work..…….. 8

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction …….. 9
2.2 Previous work …….. 9
2.3 Relations between Previous Work and Present Work ……. 16

CHAPTER 3 MATHEMATICAL MODELLING & GOVERNING EQUATIONS

3.1 Introduction ……..... 17
3.2 Governing Equations …… 18
3.2.1 Mass Conservation ……... 18
3.2.2 Momentum Equation …… 18
3.2.3 Energy Equation ……... 20
3.3 Turbulence Modelling ……..... 20
3.3.1 Selection a Turbulence Model …… 21
3.3.2 The k - ε Models …….. 22
3.3.3 The RNG k - ε Model…… 22
3.3.3.1 Equations of transport for the RNG k - ε Model ……. 23
3.3.3.2 Effective Viscosity Modeling …….. 23
3.3.3.3 RNG Swirl Modification ……. 24
3.3.3.4 Estimating the Inverse Effective Prandtl Numbers ……. 24

3.3.3.5 The R_ϵ Term in the ϵ Equation …….. 25
3.3.3.6 Constants of Model …….. 26
3.4 Treatments Near-Wall Treatments for Wall-Bounded Turbulent Flows …. 26
3.4.1 Standard Wall Functions …….. 27
3.5 Grid Generation and Mesh Criteria ……. 31
3.6 Discretization and Mathematical Modelling …… 32
3.6.1 Introduction …….. 32
3.6.2 Solution Algorithm …….. 32
3.6.3 Pressure Interpolation Schemes …… 33
3.6.4 Pressure-Velocity Coupling …… 33
3.6.4.1 SIMPLE algorithm (for steady state calculations) ……. 33
3.6.4.2 PISO algorithm (for unsteady calculations) ……. 34

CHAPTER 4 NUMERICAL VALIDATION

4.1 Introduction …….. 35
4.2 Flow Patterns in Rooms ……... 35
4.2.1 Liu, J. et al. Work ……. 35
4.2.2 Zhang, W. and Chen, Q. Work ……. 39
4.3 Conclusions …….. 44

CHAPTER 5 MODELING OF AIR FLOW CHARACTERISTICS IN LIBRARY

5.1 Introduction …….. 45
5.2 Case Studied Specification ……..... 45
5.3 Case Meshing ……... 48
5.4 Library Indoor Space Environment Boundaries ……... 49
5.5 Effect of Students or Researchers.…… 53
5.5.1 Modeling of Chosen Configurations …… 55

5.5.1.1 Configuration 1 …… 55
5.5.1.2 Configuration 2 …… 55
5.5.1.3 Configuration 3 …… 56
5.5.1.4 Configuration 4 …… 56
5.5.1.5 Configuration 5 …… 56
5.5.1.6 Configuration 6 …… 56
5.5.1.7 Configuration 7 …… 56
5.5.1.8 Configuration 8 …… 57
5.5.1.9 Configuration 9 …… 57
5.5.1.10 Configuration 10 …… 57
5.5.1.11 Configuration 11 …… 58
5.5.1.12 Configuration 12 …… 59
5.5.1.13 Configuration 13 …… 59
5.5.1.14 Configuration 14 …… 59
5.5.1.15 Configuration 15 …… 60
5.5.1.16 Configuration 16 …… 60
5.5.1.17 Configuration 17 …… 61
5.5.1.18 Configuration 18 …… 61
5.5.2 Planes that Used to Show Results …… 62
5.5.3 Results of Modeled Case Studies …… 64
5.5.3.1 First configuration …… 64
5.5.3.2 Second configuration …… 69
5.5.3.3 Third configuration …… 73
5.5.3.4 Fourth configuration …… 77
5.5.3.5 Fifth configuration …… 81
5.5.3.6 Sixth configuration …… 85

5.5.3.7 Seventh configuration …… 89
5.5.3.8 Eighth configuration ……..…… 92
5.5.3.9 Ninth configuration ……..…… 96
5.5.3.10 Tenth configuration ……..…… 116
5.5.3.11 Eleventh configuration ……..……...… 121
5.5.3.12 Twelfth configuration ……..…. 126
5.5.3.13 Thirteenth configuration ……..…… 132
5.5.3.14 Fourteenth configuration ……..…… 137
5.5.3.15 Fifteenth configuration ……..…….. 142
5.5.3.16 Sixteenth configuration ……..……..…… 147
5.5.3.17 Seventeenth configuration ……..……..…..… 152
5.5.3.18 Eighteenth configuration ……..…… 157
5.6 Overview…… 162

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 Introduction ……..... 163
6.2 Conclusions ……..... 163
6.3 Recommendations for Future Work ……. 164

References ……. 165
APPENDICES ……... 168
Appendix A …… 168
Appendix B ……...…. 169
Appendix C …… 170

List of Tables

TABLE	DESCRIPTION	PAGE
Table 2.1	Neutral/comfort temperature in each climate zone ……..	15

Table 3. 1: The most common models for turbulence 21
Table 3. 2 : Indicates a comparison between two different turbulence models at same interval size. [28] 21

Table 5.1:	Summary of the different configurations ……	54

List of Figures

Figure 1. 1: New Library of Alexandria, Egypt [2] 1
Figure 1. 2: RH and Comfort. [3] 3
Figure 1. 3: Mean radiant temperature [5]. 3
Figure 1. 4: Various insulations of clothing (in Clo unit). [7] 4
Figure 1. 5: Scale of activity level (In Met units). [8] 5
Figure 1. 6: The recommended range of PMV-PPD relation by ISO. [13] 7
Figure 1. 7: Air exchange into space. [15] 7

Figure 2. 1: 3D view of office space-case study [16] 10
Figure 2. 2: Indoor initial and boundary conditions for Al-Masa'a space. [17] 10
Figure 2. 3: Multifunction hall-case study [18] 11
Figure 2. 4: library constructed using Industrialized Building System (IBS), case study [20] 12
Figure 2. 5: Configuration (1) without presence of people [22] 13
Figure 2. 6: Configuration (1) Temperature contours (K), vertical plane at (Y= 7 m). [22] 13
Figure 2. 7: Configuration (1) Temperature contours (K), vertical plane at (Y= 4 m). [22] 14
Figure 2. 8: 3D view of DIMO'S gymnasium [23] 14
Figure 2. 9: Geometry of the lecture room and the 4-way air-conditioner [26]. 16

Figure 3. 1: Flow chart CFD analysis process. 17
Figure 3. 2: Stress components on the six faces of the fluid element. 18
Figure 3. 3 : Typical point speed measurement in flow of turbulent 20
Figure 3. 4: Comparison between two different turbulence models and measured air velocity. [31] 22
Figure 3. 5: Near-Wall Treatments in FLUENT 27
Figure 3. 6: Solution Algorithm. 33

Figure 4. 1: Room isometric view, [29]. 35
Figure 4. 2: Ground position of vertical poles for air velocity comparison, [29]. 36
Figure 4. 3: Comparison between measured and simulation velocity profiles at point one (P1) 37
Figure 4. 4: Comparison between measured and simulation velocity profiles at (P2) 37
Figure 4. 5: Comparison between measured and simulation velocity profiles at (P3) 38
Figure 4. 6: Geometry for the mixed convection case, [30]. 39
Figure 4. 7: Comparison between measured and predicted static temperature (ºC) along the center section (Y=0.502m) 40

Figure 4. 8**:** Comparison between measured and predicted static temperature (ºC) along the center section (X= 0.502m) 41
Figure 4. 9: Comparison between measured and predicted average v-velocity (m/s) along the center section (Y=0.502m) 42
Figure 4. 10: Comparison between measured and predicted average u-velocity (m/s) along the center section (X= 0.502m) 43

Figure 5.1: Central Library of Cairo University…….. ……. 45
Figure 5.2 : Meshing processed with ANSYS 19…….. 48
Figure 5.3**:** Comparing velocity magnitude at a horizontal line at (X= 8, Y= 13.35 m) with high Z=1.1m using different mesh sizes…… 48
Figure 5.4**:** Human geometry & arrangement inside Library…… 49
Figure 5.5**:** Positions and shapes of supply and extract (top view)……... 49
Figure 5.6: Indoor initial and boundary conditions for Library……..... 50
Figure 5.7**:** Indoor initial and boundary conditions for library……. 50
Figure 5.8**:** Mean skin temperature as a function in activity level, [34]…… 54
Figure 5.9**:** Rate of CO_2 generation from human at various activities, [5]……. 54
Figure 5.10: configuration 1…….. 55
Figure 5.11: Configuration 10…… 58
Figure 5.12: Configuration 11…… 58
Figure 5.13: Configuration 12…….. 59
Figure 5.14: Configuration 16…… 60
Figure 5.15: Configuration 17…… 61
Figure 5.16: Configuration 18…… 62
Figure 5.17**:** Horizontal plane at Z =1.1 m……. 62
Figure 5.18**:** Vertical plane (on mouth of students) at Y =5.26 m……. 63
Figure 5.19**:** Vertical plane (on 3 supply grilles) at Y =4.37 m……. 63
Figure 5.20**:** Temperature (°C) horizontal contour at (Z=1.1m)…… 64
Figure 5.21: Velocity (m/s) horizontal contour at (Z=1.1 m)…… 64
Figure 5.22: Relative humidity (%) horizontal contour at (Z=1.1 m)…… 64
Figure 5.23: PMV horizontal contour at (Z=1.1 m)……. 65
Figure 5.24: PPD horizontal contour at (Z=1.1 m)…… 65
Figure 5.25: CO_2 concentration horizontal contour in ppm at (Z=1.1 m)……. 65
Figure 5.26**:** Temperature (°C) vertical contour at (Y=5.26 m)…… 65
Figure 5.27**:** Velocity (m/s) vertical contour at (Y=4.37 m)…….. 66
Figure 5.28**:** Velocity (m/s) vector plane at (Y=4.37 m)…….. 66
Figure 5.29**:** Relative humidity (%) vertical contour at (Y=5.26 m)…….. 66
Figure 5.30: PMV vertical contour at (Y=5.26 m)……. 66
Figure 5.31: PPD vertical contour at (Y=5.26 m)……. 67
Figure 5.32**:** CO_2 concentration vertical contour in ppm at (Y=5.26 m)…… 67
Figure 5.33**:** Temperature (°C) horizontal contour at (Z=1.1m)…… 69
Figure 5.34: Velocity (m/s) horizontal contour at (Z=1.1 m)…… 69