NUMERICAL INVESTIGATION OF CONDITIONED AIR DISTRIBUTION INSIDE A NEW METRO CAR IN EGYPT

By

Eng. Mostafa Mahmoud Ahmed Abd-Allah

A Thesis Submitted to the Faculty of Engineering at Cairo University in Partial Fulfilment of the Requirements for the Degree of MASETER OF SCINCE

In

MECHANICAL POWER ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

NUMERICAL INVESTIGATION OF CONDITIONED AIR DISTRIBUTION INSIDE A NEW METRO CAR IN EGYPT

By

Eng. Mostafa Mahmoud Ahmed Abd-Allah

A Thesis Submitted to the Faculty of Engineering at Cairo University in Partial Fulfilment of the Requirements for the Degree of MASETER OF SCINCE

In

MECHANICAL POWER ENGINEERING

Under Supervisor of

Dr. Gamal El-Hariry

Associate Professor
Mechanical Power Department
Faculty of Engineering
Cairo University

Dr. Ahmed M. Abouzaid

Lecturer
Mechanical Power Department
Faculty of Engineering
Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

NUMERICAL INVESTIGATION OF CONDITIONED AIR DISTRIBUTION INSIDE A NEW METRO CAR IN EGYPT

By

Eng. Mostafa Mahmoud Ahmed Abd-Allah

A Thesis Submitted to the Faculty of Engineering at Cairo University in Partial Fulfilment of the Requirements for the Degree of MASETER OF SCINCE

In

MECHANICAL POWER ENGINEERING

Under Supervisor of

Assoc.Prof.Dr.Gamal A.Hariry **Thesis Main Advisor**
Mech.power Dept., Faculty of Eng., Cairo Univ.

Prof.Dr.Sayed A.Kasseb **Internal Examiner**
Mech.power Dept., Faculty of Eng., Cairo Univ.

Prof.Dr.Eed A.Abdel-Hadi **External Examiner**
Mech.power Dept.,Shobra Faculty of Eng., Benha Univ.

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2019

Engineer's Name: Eng. Mostafa Mahmoud Ahmed Abd-Allah

Date of Birth: 07/12/1987

Nationality: Egyptian

E-mail: Engmost2009@yahoo.com

Phone: 01229067347

Address: 7, Gamal Abd-Elnaser .,St,Ehwa,Bani-Suief.

Registration: 1/3/2014

Awarding Date: 2019

Degree: Master of Science

Department: Mechanical Power Department

Supervisors: Assoc.Prof.Dr. Gamal A.Hariry

Dr. Ahmed M. Abouzaid

Examiners:

Prof.Dr.Eed A.Abdel-Hadi	(External Examiner)
Prof.Dr.Sayed A.Kasseb	(Internal Examiner)
Assoc.Prof.Dr.Gamal A.Hariry	(Thesis Main Advisor)

Title of Thesis: NUMERICAL INVESTIGATION OF CONDITIONED AIR DISTRIBUTION INSIDE A NEW METRO CAR IN EGYPT.

Key Words: Metro car; Computational fluid dynamic (CFD); European Standard EN-14750-1:2006; Thermal comfort; PMV.

Summary:

Egypt expands in updating the old metro cars by new conditioned metro cars to achieve best thermal comfort of passengers inside the vehicle. Using FLUENT (ANSYS 16), the best temperature and flow distributions for both seated and standing people inside the metro car are obtained when air incident by angle 75^{o} (case 2) with respect to horizontal axis giving acceptable results with respect to rolling stocks European standards EN 14750-1:2006 and it gives the best thermal comfort for both seated and standing people based on PMV model even with high PMV value from 1 to 2.5 which gives best thermal comfort when distribute the same number of inlet air vents as a modified model with PMV from 0.6 to 1.5 .

Disclaimer

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

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

Name: Date:

Signature:

ACKNOWLEDGEMENT

I hereby would like to express my deep gratitude and thanks to Dr. Gamal El-Hariry and Dr. Ahmed M.Abouzaid for their support, continuous encouragement and distinctive supervision throughout the course of this work. They helped providing me with up to date technical references that were of great help in the present work.

Also, I cannot express; in words; my thanks and gratitude to my Family for their great and continuous help and support they provided me to finish this work in a suitable form.

Nevertheless, I cannot forget the support of my bosses in my work for their encouragement and giving me all time I needed in the scope of work.

LIST OF CONTENTS

SUBJECT	PAGE
CONTENTS	I
LIST OF FIGURES	V
LIST OF TABLES	XII
SYMBOLS AND ABBREVIATIONS	XIV
ABSTRACT	XVIII

CHAPTER 1 INTRODUCTION

1.1 General	1
1.2 Present Work	4
1.3 Thesis Layout	5

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction	7
2.2 General cases	7

CHAPTER 3 GOVERNING EQUATIONS

3.1 Governing Equations 36
3.2 Turbulence model 37
3.2.1 K- ε model 37
3.2.2 K-ω model 40

CHAPTER 4 NUMERICAL INVESTIGATION PRINCIPLES

4.1 CFD Validation 43
4.2 Three Dimensional Modeling 45
4.3 Mesh Size 45
4.4 Model Description 45
4.5 Boundary Condition: 46
4.5.1 Inlet and Outlet Air Conditions 46
4.5.2 Walls: 47
4.5.3 Solution Algorithm 47
4.6 Modeled Case Studies 48
4.7 Results of Case Studies 50
4.7.1 Case 1 50
4.7.2 Case 2 59
4.7.3 Case 3 69
4.7.4 Case 4 72
4.7.5 Case 5 80
4.7.6 Mesh independency Test 88
4.7.7 Results of Average temperatures and Velocities 89
for Previous Cases Studied

4.7.8 The Best Temperature and Air Flow Distributions case study 91

4.8 Validation Results of case 2 with European 93
Standard EN-14750-1:2006[2]

4.9 The Best Thermal Comfort Case Study 95

4.9.1 Fanger's Model 96

4.9.1.1 Introduction 96

4.9.1.2 The comfort equation 97

4.9.1.3 Heat balance 97

4.9.1.4 Sweat rate and skin temperature for comfort 99

4.9.1.5 Predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) 99

4.9.2 PMV for the previous five studied cases 101

4.9.2.1: PMV for seated people at height y=1.1 m 101

4.9.2.2: PMV for standing people at height y=1.7 m 104

4.9.3 The Best Thermal comfort Case 107

4.10 New Modified Model 108

4.10.1 Seated People 109

4.10.2 Standing People 113

4.10.3 Both Seated and Standing People 119

4.10.4 Standing People at corners 122

4.10.5 Results of Modified Model 124

CHAPTER 5 CONCLUSIONS AND SUGGESTED FUTURE WORK

5.1 Introduction 126

5.2 Conclusion of the present work 126

5.3 Recommendations for Future work 128

REFERENCES 129

ANNEX

Annex A Acceptance criteria of new metro conditioned cars with respect to European standard EN 14750-1:2006 of Cairo metro company 132

Annex B Solar radiation calculation of the designer 135

LIST OF FIGURES

FIGURE	DESCRIPTION	PAGE
1.1	Old metro cars	1
1.2	New metro cars in first old line	2
2.1	Temperature gradients distribution at height of 1.25 m above the floor (moving phase)	8
2.2	Temperature gradients distribution at height of 1.75 m above the floor (moving phase)	8
2.3	Temperature gradients distribution at height of 1.25 m above the floor (traffic stop phase)	9
2.4	Temperature gradient distribution at height of 1.75 m above the floor (traffic stop phase)	9
2.5	Scheme of the experimental measurement points	10
2.6	Comparison of simulation and measurements (horizontal temperatures)	12
2.7	Comparison of simulation and measurements (vertical temperatures)	12
2.8	Absolute value of the velocity vector in m/s along the width of the vehicle in a height of 1000 mm: -1300 mm is left wall, + 1300 mm is the right wall	13

2.9	First class compartment of a regional train with an implemented virtual surface displaying the velocity vectors of the air flow. The small velocity of 0.01 m/s is displayed blue, the higher velocity of 0.8 m/s is colored red	14
2.10	Tram model view	15
2.11	Inlets and exhausts openings for part 1	15
2.12	Passenger's distribution in car C1	16
2.13	Selected horizontal and vertical planes	17
2.14	Velocity fields for plane X1 (case 1)	18
2.15	Velocity fields for plane X2 (case 1)	19
2.16	Velocity fields for plane X1 (case 3)	20
2.17	Velocity fields for plane X2 (case 3)	20
2.18	Temperature fields in the horizontal plane at +1.1 m, cases (1-4)	21
2.19	Temperature fields at vertical planes X1, X2, X3, and X4 for Case 3	22
2.20	The CFD geometrical model of passenger train	25
2.21	Velocity streamlines at zero degree	26
2.22	Velocity streamlines at 15 degree	27
2.23	Velocity streamlines at 25 degree	28
2.24	List of the investigated cases	29
2.25	Predicted streamlines emerging from inlet surfaces and surface temperature distribution for the reference case	30

2.26	Velocity and temperature distribution in the cross-section of row 6 for the reference case	31
2.27	Predicted streamlines emerging from inlet surfaces and surface temperature distribution for the TI case	31
2.28	Velocity and temperature distribution in the cross-section of row 6 for the TI case	32
2.29	Predicted streamlines emerging from inlet surfaces and surface temperature distribution for the MB case	33
2.30	Velocity and temperature distribution in the cross-section over row 6 for the MB case	33
2.31	The train model	34
2.32	Contour of velocity fields on cross section	35
3.1	Fluid element and coordinate system used in the conservation laws	36
4.1.	Temperture fields on cross section	43
4.2	Temperture curves at height 1.6 m	44
4.3	The velocity gauges for same 10 chain points at 1.6 m	44
4.4	Metro car model view	46
4.5	Solution Algorithm	48
4.6	The four different studied sections.	50
4.7	Temperature contours (^{o}C) (case 1.a), horizontal plane at y=1.1 m	51
4.8	Velocity contours (m/s) (case 1.a), horizontal plane at y=1.1 m	52

4.9	Temperature contours (^{o}C) (case 1.b), vertical plane at z=0.3 m	53
4.10	Velocity contours (m/s) (case 1.b), vertical plane at z=0.3 m	54
4.11	Temperature contours (^{o}C) (case 1.C), horizontal plane at y=1.7 m	55
4.12	Velocity contours (m/s) (case 1.c), horizontal plane at y=1.7 m	56
4.13	Temperature contours (^{o}C) (case 1.d), vertical plane at z=1.2 m	57
4.14	Velocity contours (m/s) (case 1.d), vertical plane at z=1.2 m	57
4.15	Velocity contours (m/s) (case 1.e), vertical plane at x=11 m	58
4.16	Temperature contours (^{o}C) (case 1.e), vertical plane at x=11 m	59
4.17	Temperature contours (^{o}C) (case 2.a), horizontal plane at y=1.1 m	60
4.18	Velocity contours (m/s) (case 2.a), horizontal plane at y=1.1 m	61
4.19	Temperature contours (^{o}C) (case 2.b), vertical plane at z=0.3 m	62
4.20	Velocity contours (m/s) (case 2.b), vertical plane at z=0.3 m	63
4.21	Temperature contours (^{o}C) (case 2.c), horizontal plane at y=1.7 m	64
4.22	Velocity contours (m/s) (case 2.c), horizontal plane at y=1.7 m	65
4.23	Temperature contours (^{o}C) (case 2.d), vertical plane at z=1.2 m	66
4.24	Velocity contours (m/s) (case 2.d), vertical plane at z=1.2 m	67
4.25	Velocity contours (m/s) (case 2.e), vertical plane at x=11 m	68
4.26	Temperature contours (^{o}C) (case 2.e), vertical plane at x=11 m	68
4.27	Temperature contours (^{o}C) (case 3.a), horizontal plane at y=1.1 m	69
4.28	Temperature contours (^{o}C) (case 3.c), horizontal plane at y=1.7 m	70
4.29	velocity contours (m/s) (case 3.e), vertical plane at x=11 m	71

4.30	Temperature contours (^{o}C) (case 3.e), vertical plane at x=11 m	71
4.31	Temperature contours (^{o}C) (case 4.a), horizontal plane at y=1.1 m	72
4.32	Velocity contours (m/s) (case 4.a), horizontal plane at y=1.1 m	73
4.33	Temperature contours (^{o}C) (case 4.b), vertical plane at z=0.3 m	74
4.34	Temperature contours (^{o}C) (case 4.c), horizontal plane at y=1.7 m	75
4.35	Velocity contours (m/s) (case 4.c), horizontal plane at y=1.7 m	76
4.36	Temperature contours (^{o}C) (case 4.d), vertical plane at z=1.2 m	77
4.37	Velocity contours (m/s) (case 4.d), vertical plane at z=1.2 m	78
4.38	Velocity contours (m/s) (case 4.e), vertical plane at x=11 m	79
4.39	Temperature contours (^{o}C) (case 4.e), vertical plane at x=11 m	79
4.40	Temperature contours (^{o}C) (case 5.a), horizontal plane at y=1.1 m	80
4.41	Velocity contours (m/s) (case 5.a), horizontal plane at y=1.1 m	81
4.42	Temperature contours (^{o}C) (case 5.b), vertical plane at z=0.3 m	82
4.43	Temperature contours (^{o}C) (case 5.c), horizontal plane at y=1.7 m	83
4.44	Velocity contours (m/s) (case 5.c), horizontal plane at y=1.7 m	84
4.45	Temperature contours (^{o}C) (case 5.d), vertical plane at z=1.2 m	85
4.46	Velocity contours (m/s) (case 5.d), vertical plane at z=1.2 m	86
4.47	velocity contours (m/s) (case 5.e), vertical plane at x=11 m	87
4.48	Temperature contours (^{o}C) (case 5.e), vertical plane at x=11 m	87
4.49	Shape of mesh cells	88
4.50	Temperature gradient at a horizontal line for different mesh interval sizes	89