AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
MECHANICAL POWER DEPARTMENT

EFFECT OF SOME DESIGN PARAMETERS ON AIR TEMPERATURE DISTRIBUTION IN THE HIGHLY COOLED AIR CONDITIONING SYSTEMS

A THESIS
SUBMITTED FOR THE PARTIAL FULFILLMENT OF MASTER DEGREE IN MECHANICAL ENGINEERING
By

Eng. Asmaa Fathy Ahmed Gad El-Rab
BSc. In Mechanical Power Engineering 2009

Supervisors

Prof. Dr. Raouf Nassif Abdelmessih
Mechanical Power Eng. Department
Faculty of Engineering
Ain Shams University

Prof. Dr. Gamil Wissa Younan
Mechanical Power Eng. Department
Faculty of Engineering
Ain Shams University

Dr. Ehab Mouris Mina

Mechanical Power Eng. Department
Faculty of Engineering
Ain Shams University

Cairo, 2019

EXAMINERS COMITTEE

The under designed certify that they have read and recommended to the Faculty of Engineering, Ain Shams University for acceptance a thesis entitled by **"Effect of some design parameters on air temperature distribution in the highly cooled air conditioning systems".** Submitted by **Asmaa Fathy Ahmed Gad El-Rab**, in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Power Engineering.

	Name	Signature
1.	**Prof. Dr. Ramadan Yousef Sakr** Banha University Cairo, Egypt	(……)
2.	**Prof. Dr. Hanan Mostafa Kamal Sabry** Ain Shams University Cairo, Egypt	(……)
3.	**Prof. Dr. Raouf Nassif Abdel-Messih** Ain Shams University Cairo, Egypt	(……)
4.	**Prof. Dr. Gamil Wissa Younan** Ain Shams University Cairo, Egypt	(……)

STATEMENT

This dissertation is submitted to Ain Shams University in fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

The work included in this thesis was made by the author during the period from May- 2015 to May-2019 at the Mechanical Power Engineering Department, Ain Shams University. No part of this thesis has been submitted for degree or qualification at any other university or institute.

Date:

Signature:

Name: Asmaa Fathy Ahmed

ABSTRACT

Title: The Effect of Some Design Parameters on Air Temperature Distribution in Highly Cooled Air System.

Description: Highly cooled air distribution systems offer the thermal comfort at lower operating and primary costs when compared to the conventional air system. Supply air to the conditioned space at lower temperatures ranging from 5 to 10ºC resulting in lower air volume flow rates by about 30% compared with that required for the conventional air conditioning systems, which supply air to the conditioned space at temperatures ranging from 13 to 18 ºC.

Consequently, the reduced air flow rates required smaller air ducts, smaller air handling units (AHUs), reduced fan energy consumption. For the improvements in indoor air quality, better results have been detected. It is strongly recommended carrying out life cycle analysis of using highly cooled air distribution systems versus conventional systems.

But the highly cooled air systems don't much established because of some concerns such the condensation on surfaces and the fear from cold drafts formation which affect the human comfort. Review of the previous researches submitted in the field of highly cooled air and air temperature distribution and related indoor quality and feeling comfort. Computational Fluid Dynamics (CFD) governing equations and solution methods are explained in different turbulence modeling are represented. This research introduces a comparison between the comfort attained using highly-cooled and conventional air-conditioning systems using CFD simulation inside a 2-D room with height of 2.8 m and width of 2.9 m. The supply temperature for the conventional system is selected to be 13 and 8ºC for the highly cooled air system. Several arrangements of the supply return combination as well as the ceiling curvature were assessed using the air diffusion performance index, ADPI. Internal loads represented in constant heat flux from walls, ceiling and floor. Successful supply of the highly cooled air directly to the space at 8 ºC with a good mixing between the highly cooled air system and the room air streams. Results of each case figured and discussed through the specified air temperature and velocity contours and estimating the air diffusion performance index (ADPI)

from the effective draft temperature (EDT) contours.

ACKNNOWLEDGMENTS

First of all, I would like to thank God for giving me the strength and courage to do this work and made everything is possible for me. My deepest respect and gratitude are due to my **Prof. Dr. Raouf Nassif Abdelmessih** for his effective guidance and massive support in each step of this research.

I would like to thank Prof. **Dr. Gamil Wissa Younan** for his accurate scientific review of the thesis and his assistantship.
Thanks to **Dr. Ehab Mouris Mina** for his great effort, his expensive time and his unique scientific advices.

Thanks are also due to the technical staff of the Mechanical Power Engineering Department, Faculty of Engineering, Ain Shams University, for their help.

I would like to thank ***my parents*** for everything and for supporting me in each step in life. Finally, I would like to express my appreciation to my ***husband*** for his support during the period of this research.

Asmaa Fathy
2019

TABLE OF CONTENETS

PREFACE		**I**
EXAMINER COMITTE		**II**
STATEMENTS		**III**
ABSTRACT		**IV**
ACKNOWLEGMENTS		**V**
TABLE OF CONTENTS		**VI**
LIST OF FIGURES		**VII**
LIST OF TABLES		**VIII**
NOMENCLATURE		**IX**
INTROCDUCTION		**X**
CHAPTER 1	**HIGHLY COOLED AIR SYSTEM**	**1-9**
	1.1. Difference between the highly cooled air system and the conventional system	**1**
	1.2. Economical benefits of the highly cooled air system	**1**
	1.3. Reducing supply air temperature and the efficiency of the highly cooled air system	**2**
	1.3.1. Achieving environmental comfort	**3**
	1.3.2.Working thermal storage	**3**
	1.4. Problems accompanying to the operation of the highly cooled air distribution system	**4**
	1.5. Thermal comfort	**5**
	1.6. Environmental comfort evaluation	**7**
	1.7. Conclusion and current research	**8-9**
	1.7.1. Conclusions	**8**
	1.7.2. Current research	**9**
CHAPTER 2	**LITERATURE REVIEW**	
	2.1.Introduction	**10**
	2.2.Review of previous work	**10**
	2.3.Conclusion	**32**
CHAPTER 3	**VALIDATION OF THE**	**33-48**

NUMERICAL TECHNIQUE

3.1.Introduction **34**

3.2.The governing equations **35**

3.2.1.Conservation of mass **36**

3.2.2.Conservation of momentum **37**

3.2.3.Conservation of energy **38**

3.2.4.Turbulence modeling equations **39-42**

3.3.Validation of the numerical technique **42**

3.3.1. Comparison between the previous similar researches and their results **43**

3.3.2. Comparison between the numerical and Restivo's experimental results **46**

3.3.2.1. Comparison between restivo's experimental work results and the numerical simulation results at x=3m **46**

3.3.2.2. Comparison between experimental work results and the numerical simulation results at x=6m restivo's **46**

3.4. Conclusion **49**

CHAPTER 4 RESULTS AND DISCUSSION

4.1. Introduction **50**

4.2. Load analysis and solution methodology **51**

4.3. The effect of decreasing supply air temperature **53**

4.4. The effect of supply/return arrangements changing **62**

4.4.1. Low side supply air inlet and a high side air exit at the opposite wall **62**

4.4.2. Low side supply air inlet and a high side air exit at the same wall **70**

4.5. The effect of ceiling shape changing (vault ceiling) **78**

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1.Introduction **85**

5.2.Conclusions **86**

5.3.Recommendations for later work **87**

REFERENCES **89-91**

LIST OF FIGURES

Figure (1-1)	Acceptable range of operative temperature and humidity (ANSI/ASHRAE Standard 55-2004)	6
Figure (1-2)	Air speed required to offset increased temperature (ANSI/ASHRAE Standard 55-2004)	7
Figure (2-1)	Nozzle diffuser used in Knebel and John case Knebel, D.E. and John, D.A. (1993)	11
Figure (2-2)	Test room layout (a) elevation, (b)side view, (c) plan view and (d) 3-D room geometry (Salah, 2013)	12
Figure (2-3)	(a) position of the lamp cells on the floor and (b) pictures of the lamp cell (Salah, 2013)	13
Figure (2-4)	(a) the pulsating mechanism and (b) the stepper motor (Salah, 2013)	13
Figure (2-5)	The Y-shape duct splitter (Salah, 2013)	14
Figure (2-6)	Schematic diagram of temperature meters used in the experiment (Salah, 2013)	15
Figure (2-7)	(a) test room isometric view, (b) plan view and (c) side view (Salah, 2013)	16
Figure (2-8)	experiments data (Salah, 2013)	17
Figure (2-9)	Test results (Salah, 2013)	17
Figure (2-10)	Measured heat gain and heat extraction rates (Salah, 2013)	18
Figure (2-11)	Performance index for temperature homogeneity inside the occupied space (Salah, 2013)	19
Figure (2-12)	Performance index, (a) for 480W experiments and (b) for 1040W experiments (Salah, 2013)	20
Figure (2-13)	Temperature profiles for steady flow at room load 1040W, (a) angle-5, (b) angle-1, (c) level [A] at 249cm from the floor, (d) the three different levels at where the air temperature were measured, (e) level [D] at 180cm from the floor and (f) level [H] at 88cm from the floor (Salah, 2013)	21
Figure (2-١٤)	Temperature profiles for pulsating flow at room load	22

	1040W and rotational speed of 6rpm, (a) angle-5, (b) angle-1, (c) level [A] at 249cm from the floor, (d) the three different levels at where the air temperature were measured, (e) level [D] at 180cm from the floor and (f) level [H] at 88cm from the floor (Salah, 2013)	
Figure (2-1٥)	a- 2D room used in the numerical study, b- the constructed grid (Youssef et al., 2018)	24
Figure (2-1٦)	Temperature contours clipped between 295 K to 299 K, (a) supply air temperature at 14°C, (b) supply air temperature at 10°C and (c) supply air temperature at 6°C (Youssef et al., 2018)	26
Figure (2-17)	Velocity vectors, a- supply air temperature at 14°C, b- supply air temperature at 10°C and c- supply air temperature at 6°C (Youssef et al., 2018)	26
Figure (2-1٨)	EDT contours clipped between -1.7°C to +1.1°C, (a) supply air temperature at 14°C, (b) supply air temperature at 10°C and (c) supply air temperature at 6°C (Youssef et al., 2018)	27
Figure (2-1٩)	Velocity profiles near the ceiling (u at Y/L = 0.99) at different supply velocity cases (Youssef et al., 2018)	28
Figure (2-٢٠)	(a) Physical model of the investigated office with rectangular ceiling air distributer, (b) the investigated office with the double louver wall air outlet (Zhu, 2006)	29
Figure (2-٢١)	(a) The airflow directions of the rectangular ceiling air distributer, (b) the airflow directions of the double louver wall air outlet (Zhu, 2006)	30
Figure (2-٢٢)	Temperature distribution results (a) The rectangular ceiling air distributer case, (b) The double louver wall air outlet case (Zhu, 2006)	31
Figure (2-٢٣)	Velocity contours (a) The rectangular ceiling air distributer case, (b) The double louver wall air outlet case (Zhu, 2006)	31
Figure (3-1)	Three dimensions of fluid dynamics (Anderson, 1995)	34

Figure (3-2)	Restivo's rectangular cavity geometry used for forced convection (Kayne, 2012)	45
Figure (3-3)	Comparison between the Restivo's experimental and a numerical simulation results at x = 3m	48
Figure (3-4)	Comparison between the Restivo's experimental and a numerical simulation results at x = 6m	49
Figure (4-1)	Supply air angle (θ)	50
Figure (4-2)	The four different studied cases in the current research, (a) case (1), (b) case (2), (c) case (3) and (d) case (4)	52
Figure (4-3)	(a) 2-D room used in case (1) and (b) the constructed meshing grid	53
Figure (4-4)	Case (1) temperature contours ranged from 22ºC to 26ºC (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	55
Figure (4-5)	Case (1) predicted velocity contours (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	56
Figure (4-6)	Case (1) EDT contours clipped from -1.7 to +1.1 (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	57
Figure (4-7)	Processed image used in ADPI measuring by MATLAB for case (1) as an example	59
Figure (4-8)	Case (1) comparison between highly cooled air and conventional system results summary supplying air at four different angles	61
Figure (4-9)	(a) 2-D room used in case (2) numerical study and (b) the constructed meshing grid	62
Figure (4-10)	Case (2) temperature contours clipped from 22ºC to 26ºC (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	63
Figure (4-11)	Case (2) velocity contours (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	65

Figure (4-12)	Case (2) EDT contours clipped between -1.7 and +1.1 at (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	66
Figure (4-13)	Case (2) comparison between highly cooled air and conventional system results summary supplying air at four different angles	69
Figure (4-14)	(a) 2-D room used in case (3) study and (b) the constructed meshing grid	70
Figure (4-15)	Case (3) temperature contours clipped from 22ºC to 26ºC (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	72
Figure (4-16)	Case (3) velocity contours (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	73
Figure (4-17)	Case (3) EDT contours clipped between -1.7 and +1.1 at (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	74
Figure (4-18)	Case (3) comparison between the highly cooled air and the conventional system results summary supplying air at four different angles	77
Figure (4-19)	2-D room used in case (4) numerical study	78
Figure (4-20)	Case (4) temperature contours clipped from 22ºC to 26ºC (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	80
Figure (4-21)	Case (4) velocity contours (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	81
Figure (4-22)	Case (4) EDT contours clipped between -1.7 and +1.1 at (a) at θ = 0°, (b) at θ = 22.5°, (c) at θ = 45° and (d) at θ = 60° respectively	82
Figure (4-23)	Case (4) numerical comparison between highly cooled air and conventional system results summary supplying air at four different angles	84

LIST OF TABLES

Table (1-1)	Comparison between the conventional and the highly cooled air systems for 1 ton of refrigeration sensible load	2
Table (3-1)	Comparison between the previous experimental researches and their results	43-44
Table (4-1)	Case (1) comparison between the highly cooled and the conventional system results summary supplying air at four different angles	60
Table (4-2)	Case (2) comparison between the highly cooled and the conventional system results summary supplying air at four different angles	67
Table (4-3)	Comparison between the computed results from case (2) and case(3) simulations both with using the highly cooled air conditioning system	75
Table (4-4)	Comparison between case (3) and case (4) results both with using the highly cooled air conditioning system	79

INTRODUCTION

Research Background and Problem statement

The aim of the air conditioning in any building implies the control of indoor environment for comfort of human beings or for the proper performance of some industrial or scientific process. Thermal comfort is achieved through a combination of several objective and subjective operational factors. Objective factors include air purity, air movement, temperature, air velocity and relative humidity. In addition there is also subjective factors such as clothing and metabolic rate. These factors should be controlled within the limits imposed by the design specification. The installed air conditioning system should achieve high levels of comfort, indoor air quality with reducing project first and running cost. Nowadays, this trend is commercially considerable, especially with the global continuous increasing rate in energy cost. For the previous reasons, reduction in the supply air temperature could be a solution that reduce energy usage while assuring comfort. This reduction in supply temperature is known in the HVAC profession as highly cooled system. These systems uses supply air at (5°C to 10 °C) as opposed to the conventional system (from 13 to 17°C).

Research Problem

Studying the effect of reducing the supply air temperature, Supply/return arrangements changing, supply air angle changing, and the effect of using the vault ceiling on comfort and power usage.

Keywords: Comfort, Energy Usage, Temperature distribution, Velocity field, CFD, HVAC.

Research Hypothesis and Questions

The use of highly cooled air reduces the amount of pumped air for the same cooling load. This will reduce the pumping power and consequently the energy use. The research question is to check that comfort is attained and compare the percentage reduction in pumped air. This investigation (Comfort and amount of flow needed) is done for several cases of supply /return arrangements. The