



Ain Shams University  
Faculty of Engineering  
Department of Architectural Engineering

تكامل أنظمة التظليل مع الواجهات المزدوجة المتهواة طبعياً لتحسين الأداء الحراري في المباني الفندقية بالقاهرة الكبرى

## **Integrating Shading Systems with Naturally Ventilated Double Skin Facades for Enhancing Thermal Performance in Hotel Buildings of Greater Cairo.**

A Thesis Presented in Partial Fulfillment of the Requirements for Master of Science Degree in  
Architecture

**Abdulrahman Ayman Fahmy Salem**  
BSc. of Architecture 2015 – Ain Shams University

Supervised by:  
**Professor Dr. Morad Abdelkader Abdelmohsen**  
Professor of Architecture and Environmental Control  
Ain Shams University

**Professor Dr. Hanan Mostafa Kamal Sabry**  
Professor of Architectural Design and Environmental Control  
Ain Shams University

**Professor Dr. Ahmed Atef Eldesouky Faggal**  
Professor of Architecture and Environmental Control  
Ain Shams University



## Statement

---

This thesis is submitted to Ain Shams University for the M.Sc. degree in Architecture.

The work included in this thesis was carried out by the researcher at the Department of Architecture, Faculty of Engineering, Ain Shams University, and During the Period from December July 2016 to July 2019.

No Part of this thesis has been submitted for a degree of a qualification at any other university or institute.

Name	Abdulrahman Ayman Fahmy Salem
Signature	
Date	

## Board of Examiners

---



### **Integrating Shading Systems with Naturally Ventilated Double Skin Facades for Enhancing Thermal Performance in Hotel Buildings of Greater Cairo.**

A Thesis Presented in Partial Fulfillment of the Requirements for Master of Science Degree in Architecture

By

**Abdulrahman Ayman Fahmy Salem**

Board	Signature
<b>Professor Dr. Ahmed Reda Abdeen</b> Professor of Architecture and Environmental Control, Department of Architecture - Faculty of Engineering, Cairo University.	
<b>Professor Dr. Mostafa Refat Ismaeil</b> Professor of Architecture and Environmental Control, Department of Architecture - Faculty of Engineering, Ain Shams University.	
<b>Professor Dr. Morad Abdelkader Abdelmohsen</b> Professor of Architecture and Environmental Control, Department of Architecture - Faculty of Engineering, Ain Shams University.	
<b>Professor Dr. Hanan Mostafa Kamal Sabry</b> Professor of Architecture and Environmental Control, Department of Architecture - Faculty of Engineering, Ain Shams University.	

Date of research:

- Approval stamp:
- Date of approval:
- Faculty board approval:
- University board approval:



## Acknowledgements

---

*At first, I would love to thank Allah for helping me through the hard times and for rewarding me with such a milestone in my academic life which I hope could help researchers and students locally and worldwide in the future.*

*I would also love to show my sincere gratitude for the dear professor Morad Abdulqader whose guidance and information have always been valuable and respected.*

*To the dear professor Hanan Sabry, this work would have never been completed, without your patience, guidance and knowledge all the way. No words can describe how grateful and lucky I am to be a student of yours.*

*To the dear professor Ahmed Faggal, your endless encouragement, knowledge and support were always a push up. I would like to thank you from my heart.*

*To my father, mother and aunt, thank you for always being beside me and never giving up on me in the hardest times and for your encouragement and love.*

*To my precious wife, thank you for helping me in every stage and every step I take in my life. You have always been special.*

*Also, I would like to thank my brother, sister, Amer and Ayman (my dearest friends) as well for their encouragement and support.*

*To FEDA staff and graduates, mentioning Prof. Yasser Mansour, Dr. Ashraf Nessim, Dr. Mohamed Steit, Dr. Amal Shamseldin, Dr. Moataz Abdulfattah, Architect Mohamed Abdelmohsen, Architect Hisham Bahaa, Architect Helal Shawky, Architect Sayed Samir and Architect Bassant Alaa, I would like to thank you all for your valuable information and help whenever I needed them. Your existence in my life is a precious gift from Allah.*

## Abstract

---

The research aimed at evaluating the efficiency of integrating shading devices with naturally ventilated walls on thermal performance and indoor ventilation rates of a generic five stars hotel double room in Greater Cairo. This research is composed of 4 chapters. Chapter 1 and 2 studied theoretically and analytically naturally ventilated walls and shading devices' working principle, types and how they work in hot arid climates. Also, the parameters of shading devices and naturally ventilated walls were discussed and some parameters were determined to be used in the comparative analysis which took place in chapters 3 and 4. In chapter 3, Cairo's weather was analyzed and moreover a reference case was modeled and tested using Computational Fluid Dynamics simulations. In chapter 4 the results of three more cases were introduced and compared analytically. Those cases are: naturally ventilated wall case, and two cases of integration of shading devices with naturally ventilated wall one with shading devices near the outer skin and one near the inner skin.

The research focused on the extreme conditions of Cairo's climate and the study was made in the day with the highest temperature in summer in South orientation and the hours of the study were the hours which had the highest operative temperature at day and night. Three floors were chosen for the study which were decided to be at the beginning of the building (5<sup>th</sup> floor), at the middle of the building (20<sup>th</sup> floor) and the last floor (35<sup>th</sup> floor). The study was done on South, West, East and North orientations and the research revealed that naturally ventilated walls which depend on stack effect, as a working principle, could achieve reasonable ventilation rates and could lower down operative temperature of the room both at day at night.

The research revealed also that integrating shading devices with naturally ventilated walls could affect cavity's overheating problem positively especially when placing shading devices near the outer skin. The techniques were compared to a single skin façade reference case using the outputs of EnegyPlus as a Computation Fluid Dynamics (CFD) simulation engine to study the efficiency of all techniques on thermal comfort and flow rate using only convective cooling strategy. CFD simulations showed that integrating shading devices with naturally ventilated walls while placing shading devices near the outer skin could enhance thermal comfort and ventilation rates in South, West and East orientations. This technique could lower down the room's operative temperature (OT) by 1.85 Celsius degrees in West façade when compared to ambient temperature. Also, air velocity (AV) values could

reach an average of 0.041 m/s in all orientations which is close to comfort zone. The results also showed that placing shading devices near the inner skin could lead to higher operative temperatures at West orientation only at day and night while the difference in other orientations was not significant but gave advantage to the case where shading devices are placed near outer skin over this case because at higher floors the operative temperature were higher with a difference that could reach 1.57 Celsius degrees. Regarding ventilation rates, the case where shading devices were placed near the outer skin always showed better performance than when shading devices were near the inner skin. Average age of air<sup>1</sup> was significantly lower also in this case.

On the other hand, using naturally ventilated walls alone could enhance thermal performance and ventilation rates in North where an operative temperature difference between the room and ambient air could reach 1.79 Celsius degrees and a maximum value of air velocity could reach 0.041 m/s.

The results give promising indication that although the room couldn't reach comfort zone, it still could have a lower operative temperature than single skin façade case by 2.85 Celsius degrees at South which is considered a significant result gathered with the significant result regarding age of air which was enhanced. More studies on the parameters of shading devices coupled with the introduction of a forced air flow in the cavity need to be investigated.

---

<sup>1</sup> Definition in table 3-4 – Page 87.



## Table of Contents

---

Acknowledgements.....	IV
Abstract.....	V
Table of Contents.....	VII
List of Figures .....	XI
List of Tables .....	XV
List of Abbreviations .....	XVI
Keywords.....	XVI
Glossary.....	XVI
Overview.....	XXI
Problem Statement.....	XXII
Aim .....	XXII
Objectives: .....	XXII
Methodologies.....	XXII
Scope and Limitations.....	XXIII
Chapters' Overview .....	XXIII
Chapter 1: Integrating Shading Devices with Naturally Ventilated Double Skin Facades .....	3
1.1 Introduction.....	3
1.2 Double Skin Facades (DSF).....	4
1.2.1 Definition .....	7
1.2.2 Functions of DSF .....	8
1.2.2.1 Natural Ventilation.....	8
1.2.2.2 Heat Gain Control .....	8
1.2.2.3 Daylighting .....	10
1.2.3 DSF Components .....	11

1.2.3.1	Inner and Outer Façade .....	11
1.2.3.2	Façade Cavity.....	12
1.2.3.3	Openings .....	12
1.2.3.4	Shading Devices.....	13
1.2.4	DSFs Classification.....	14
1.2.4.1	Based on Air Flow Origin:.....	14
1.2.4.2	Based on the driving force of air flow (Ventilation Type):.....	15
1.2.4.3	Based on the Function of the Cavity:.....	15
1.2.4.4	Based on Compartmentalization: .....	16
1.3	Naturally Ventilated Walls.....	21
1.3.1	Natural ventilation performance of double skin facades.....	22
1.3.2	Naturally Ventilated Walls Working Principle .....	22
1.3.2.1	Aerophysics.....	22
1.3.2.2	Forms of Heat Transfer through a Double Skin Facade.....	25
1.3.2.3	Quality of Indoor Space .....	26
1.3.3	Naturally Ventilated Walls in Hot Arid Climates .....	27
1.4	Integrating Shading Devices with Naturally Ventilated Walls .....	30
1.4.1	Integrated Shading Devices Working Principle:.....	30
1.4.1.1	Influence of Cavity-Integrated Shading Devices on Thermal Performance of DSF and Indoor Spaces .....	31
1.4.1.2	Influence of Cavity-Integrated Shading Devices on Airflow of Ventilated DSFs .....	32
1.5	Summary and Conclusion .....	33
Chapter 2 - Design Parameters of Naturally Ventilated Walls and Integrated Shading Devices .....		38
2.1	Introduction.....	38
2.2	Design Parameters of Naturally Ventilated Walls .....	38
2.2.1	Factors Affecting Natural Ventilation of Naturally Ventilated Walls	38
2.2.2	Design Parameters of Naturally Ventilated Walls .....	42
2.2.2.1	Cavity:.....	42
2.2.2.2	Openings Principles: .....	45

2.2.2.3	Air Intakes and Extracts .....	48
2.2.2.4	Material Choice .....	49
2.3	Design Parameters of Shading Devices .....	53
2.3.1	Shading Devices Position .....	54
2.3.2	Inclination Angle of Shading Devices .....	54
2.3.3	Shading Devices Material .....	56
2.4	Summary and Conclusion .....	59
Chapter 3 – CFD Simulation Analysis .....		66
3.1	Introduction .....	66
3.2	Climate Description of Egypt .....	68
3.2.1	Weather Data File .....	68
3.2.2	Cairo’s Weather Analysis .....	69
3.2.2.1	Temperature .....	69
3.2.2.2	Solar Radiation .....	70
3.2.2.3	Wind Velocity .....	70
3.2.2.4	Relative Humidity .....	70
3.3	Selected Energy Modeling Software .....	71
3.4	Reference Case Specifications .....	72
3.4.1	Reference Case Geometry .....	72
3.4.2	Parameters of the Hotel Room (Reference Case): .....	74
3.4.3	Reference Case Modeling .....	76
3.4.3.1	Modeling the Repeated Units .....	76
3.4.3.2	Modeling the Unit to Be Thermally Studied .....	77
3.4.3.3	Unit Activity Template .....	78
3.5	Choosing CFD Simulations’ Floors .....	78
3.6	Thermal Simulation .....	78
3.7	CFD Simulation .....	80
3.8	Evaluation Criteria and Measurement Units .....	81
3.9	CFD Simulations Results for Reference Case .....	82
3.9.1	CFD Simulation Results for Reference Case at 2 PM .....	82
3.9.2	CFD Simulation Results for Reference Case at 6 PM .....	85

3.10	Summary and Conclusion .....	87
Chapter 4 – CFD Simulations’ Results .....		91
4.1	Introduction.....	91
4.2	Naturally Ventilated Wall’s Specifications.....	93
4.2.1	Naturally Ventilated Wall Geometry: .....	93
4.2.2	Naturally Ventilated Wall Parameters: .....	94
4.2.3	Unit Materials’ Template: .....	94
4.3	CFD Simulations Results for Naturally Ventilated Wall (Case 2).....	95
4.3.1	CFD Simulations Results for Naturally Ventilated Wall at 2 PM ...	96
4.3.2	CFD Simulations Results for Naturally Ventilated Wall at 6PM ....	98
4.4	Shading Devices Specifications.....	102
4.4.1	Shading Devices Geometry.....	104
4.4.2	Shading Devices Modeling .....	104
4.5	CFD Simulations Results for Integration of Shading Devices with Naturally Ventilated Wall (Case 3).....	106
4.5.1	CFD Simulations Results for Integrating Shading Devices with Naturally Ventilated Wall (Case 3) at 6 PM .....	108
4.6	CFD Simulations Results for Integration of Shading Devices with Naturally Ventilated Wall (Case 4).....	112
4.6.1	CFD Simulations Results for Integrating Shading Devices with Naturally Ventilated Wall (Case 4) at 2 PM .....	112
4.6.2	CFD Simulations Results for Integrating Shading Devices with Naturally Ventilated Wall (Case 4) at 6 PM .....	115
4.7	Cavity’s Operative Temperature Results’ Discussion .....	119
4.8	Results’ Conclusion .....	120
4.9	Summary and Conclusion: .....	133
Conclusion .....		138
Future Research Work .....		141
References.....		144

## List of Figures

---

Figure 1-1- Double Skin Facades – Passive Cooling Strategy .....	6
Figure 1-2 Heat Transfer through a Single Pane of Glass .....	8
Figure 1-3 Heat Transfer through a Double Skin Facade .....	9
Figure 1-4- Double Skin Façade Components ( <a href="https://bergami.it/facciata-ventilata-hi-tec-cose-le-principali-tipologie-esistenti/vetro/">https://bergami.it/facciata-ventilata-hi-tec-cose-le-principali-tipologie-esistenti/vetro/</a> Last visit: 22-7-2018) .....	12
Figure 1-5- Shading Devices Integrated with Double Skin Facades ( <a href="http://udis-tmc.blogspot.com/2011/09/skin-of-architecture-double-skin-3.html">http://udis-tmc.blogspot.com/2011/09/skin-of-architecture-double-skin-3.html</a> Last Visit: 22-7-2018) .....	13
<i>Figure 1-6 Double Skin Façade Types Based on Air Flow Origin (Yellamraju, V., 2004, Evaluation And Design Of Double-Skin Facades For Office Buildings In Hot Climates)</i> .....	14
Figure 1-7 Façade Type - DSF Schematic Drawing .....	17
Figure 1-8 Corridor Type - DSF Schematic Drawing.....	17
Figure 1-9 Shaft Type - DSF Schematic Drawing .....	18
Figure 1-10 Box-Window Type DSF Schematic Drawing .....	18
Figure 1-11- Different Models (Alahmed, Z., 2013, Double-Skin Façade in Hot-Arid Climates Computer Simulations to Find Optimized Energy and Thermal Performance of Double Skin Facades).....	19
Figure 1-12- Building Plan Designed for Simulation by Rezazadeh, N., et al (Thermal Behavior of Double Skin Facade in Terms of Energy Consumption in the Climate of North of Iran-Rasht).....	20
Figure 1-13 Recommended R-values for building envelope's elements (Heinberg, 2007) .....	24
Figure 1-14- Heat Transfer and Air Movement in Double Skin Facades (Mostafa M., et al., 2016).....	26
Figure 1-15 DSF with Dividing Plates and Grilles. (Hashemi, et al., 2010).....	31
Figure 2-1 Acceptable Range of Operative Temperature and Humidity for Spaces Satisfying above Criteria (ASHRAE, Standard 55, 2004).....	41
Figure 2-2- Naturally Ventilated Walls Parameters (Urban D., et al, Assessment of Sound Insulation of Naturally Ventilated Double Skin Facades (2016).....	42
Figure 2-3- Section Showing Chimney Added to DSF (Khakazar, G., 2014, Evaluation of Facade Performance, in Terms of Thermal Comfort for Health Center Building, EMU) .....	44

Figure 2-4-Annual Cooling Loads for 1 floor Corridor Façade (Torres, M., Et Al, 2007, Double Skin Façades – Cavity and Exterior Openings Dimensions for Saving Energy on Mediterranean Climate).....	47
Figure 2-5- Annual Cooling Loads for Multistorey Façade (Torres, M., Et Al, 2007, Double Skin Façades – Cavity and Exterior Openings Dimensions for Saving Energy on Mediterranean Climate).....	48
Figure 2-6 Spectral Transmittance of Clear and Tinted Glass (Chaiyapinunt, S., et al, 2005) .....	50
Figure 2-7 Spectral Transmittance of Clear Glass for Different Pane Thicknesses. (Chaiyapinunt, S., et al, 2005) .....	50
Figure 2-8- Annual Cooling Loads for Different Glazing Types (Hamza, N., 2008, Double Versus Single Skin Facades in Hot Arid Areas) .....	52
Figure 2-9- Shading Devices Vocabulary (DesignBuilder).....	53
Figure 2-10- Air Temperature of Horizontal Shading Devices (a) and Vertical Shading Devices (b) (Reference: Lee, J., et al, A Study of Shading Device Configuration on the Natural Ventilation Efficiency and Energy Performance of a Double Skin Façade).....	55
Figure 2-11- Cavity Alternatives Shading Devices. (Reference: Barbosa, S., Thermal Comfort in Naturally Ventilated Buildings with Double Skin Façade under Tropical Climate Conditions: The Influence of Key Design Parameters) .....	58
Figure 3-1 Simulation Phases Diagram .....	67
Figure 3-2- Köppen Geiger's Climate Classification, 2017, Google Earth Pro.....	68
Figure 3-3- Temperature Range Chart for Cairo (Climate Consultant 6.0).....	69
Figure 3-4- Radiation Range Chart for Cairo (Climate Consultant 6.0).....	70
Figure 3-5- Wind Velocity Range in Cairo (Climate Consultant 6.0) .....	70
Figure 3-6- Relative Humidity in Cairo, Egypt ( <a href="https://www.weather-atlas.com/en/egypt/cairo-climate?c,mm,mb,km">https://www.weather-atlas.com/en/egypt/cairo-climate?c,mm,mb,km</a> , last visit: 16-8-2018).....	71
Figure 3-7- Perspective of the Reference Case - Thermal Study Unit – Typical Floor No. 35.....	72
Figure 3-8- Perspective of the Repeated Rooms in Reference Case's Curtain Wall Facade (Left) and Repeated Thermal Study Unit – Typical Floor No. 35 (Right) ..	73
Figure 3-9 Plan of Reference Case (Left) and Section (A-A) Passing through Plan (Right).....	73
Figure 3-10- Single Skin Facade (Reference Case) .....	74
Figure 3-11 Reference Case Wall's Detail .....	75
Figure 3-12- Model of Study Unit on DesignBuilder .....	77
Figure 3-13- Chimney Detail .....	78
Figure 3-14- Average Site Year Temperature.....	79
Figure 3-15- Temperature Records on the 23rd of August in South Orientation ....	79
Figure 3-16- Temperature Records on the 23rd of August in North Orientation ....	79
Figure 3-17- Temperature Records on the 23rd of August in East Orientation .....	79
Figure 3-18- Temperature Records on the 23rd of August in West Orientation.....	80

Figure 3-19- Average Operative Temperatures in Reference Case at 2 PM in C° ..	82
Figure 3-20 Average Air Velocities in Reference Case at 2 PM in m/s .....	83
Figure 3-21 Average Age of Air in Reference Case at 2 PM in Seconds .....	84
Figure 3-22 Average Operative Temperatures in Reference Case at 6 PM in C° ....	85
Figure 3-23 Average Air Velocities in Reference Case at 6 PM in m/s .....	86
Figure 3-24 Average Age of Air in Reference Case at 6 PM in Seconds .....	87
Figure 4-1 Simulation Phases Diagram .....	92
Figure 4-2- Perspective of the Repeated Rooms in a Shaft-Box Type Naturally Ventilated Wall (Left) and Repeated Thermal Study Unit – Typical Floor No. 35 (Right) .....	93
Figure 4-3 Plan of Naturally Ventilated Wall Case (Left) and Section (A-A) Passing through Plan (Right) .....	93
Figure 4-4- Model of Naturally Ventilated Wall Used in Research .....	94
Figure 4-5- Naturally Ventilated Wall Detail .....	95
Figure 4-6 Average Operative Temperatures in Case 2 at 2 PM in °C .....	96
Figure 4-7- Average Air Velocities in Case 2 at 2 PM in m/s .....	97
Figure 4-8 Average Age of Air in Case 2 at 2 PM in Seconds .....	98
Figure 4-9 Average Operative Temperatures in Case 2 at 6 PM in °C .....	99
Figure 4-10 Average Air Velocities in Case 2 at 6 PM in m/s .....	100
Figure 4-11 Average Age of Air in Case 2 at 6 PM in Seconds .....	101
Figure 4-12- Model of Naturally Ventilated Wall with Shading Slats near Outer Skin .....	103
Figure 4-13- Model of Naturally Ventilated Wall with Shading Slats near Inner Skin .....	103
Figure 4-14- Shading Devices Separation Distance Study .....	104
Figure 4-15- Case 3 (Near Outer Glazing) .....	105
Figure 4-16- Case 4 ( Near Inner Glazing) .....	105
Figure 4-17 Average Operative Temperatures in Case 3 at 2 PM in C° .....	106
Figure 4-18- Average Air Velocities in Case 3 at 2 PM in m/s .....	107
Figure 4-19 Average Age of Air in Case 3 at 2 PM in Seconds .....	108
Figure 4-20 Average Operative Temperatures in Case 3 at 6 PM in C° .....	109
Figure 4-21 Average Air Velocities in Case 3 at 6 PM in m/s .....	110
Figure 4-22 Average Age of Air in Case 2 at 6 PM in Seconds .....	111
Figure 4-23 Average Operative Temperatures in Case 4 at 2 PM in C° .....	113
Figure 4-24- Average Air Velocities in Case 4 at 2 PM in m/s .....	114
Figure 4-25 Average Age of Air in Case 4 at 2 PM in Seconds .....	115
Figure 4-26 Average Operative Temperatures in Case 4 at 6 PM in C° .....	116
Figure 4-27 Average Air Velocities in Case 4 at 6 PM in m/s .....	117
Figure 4-28 Average Age of Air in Case 4 at 6 PM in Seconds .....	118
Figure 4-29 Average OT Difference between Case 2 and Case 1 at 2 PM .....	122
Figure 4-30 Average OT Difference between Case 2 and Case 1 at 6 PM .....	122
Figure 4-31 Average OT Difference between Case 3 and Case 2 at 2 PM .....	123