



Alexandria University
Faculty of Fine Arts
Dept. of Architecture
Post-graduate Studies

Energy-Efficient Building Envelope Design Using Computer-Based Measurements.

تصميم غلاف المبنى المرشد للطاقة باستخدام قياسات الحاسب الآلى

PhD Degree Thesis
Presented By:

Architect / Khaled Mohamed Farid Mohamed Mohamed El-Deeb
Assistant Lecturer in the Department of Architecture
Faculty of Fine Arts – Alexandria University

Under Supervision of :
Prof. Dr. Hoda Abd El-Kader Azzam
Professor of Architecture
Faculty of Fine Arts – Alexandria University

Assistant Prof. Dr. Abbas Mohamed El-Zafarany
Assistant Professor of Architecture
Faculty of Regional Planning – Cairo University



Alexandria University
Faculty of Fine Arts
Dept. of Architecture
Post-graduate Studies

Energy-Efficient Building Envelope Design Using Computer-Based Measurements.

تصميم غلاف المبنى المرشد للطاقة باستخدام قياسات الحاسب الآلى

PhD Degree Thesis
Presented By:

Architect / Khaled Mohamed Farid Mohamed Mohamed El-Deeb

Assistant Lecturer in the Department of Architecture
Faculty of Fine Arts – Alexandria University

SUPERVISORS:

Prof. Dr. Hoda Abd El-Kader Azzam

Professor of Architecture
Faculty of Fine Arts – Alexandria University

Assistant Prof. Dr. Abbas Mohamed El-Zafarany

Assistant Professor of Architecture
Faculty of Regional Planning – Cairo University



Alexandria University
Faculty of Fine Arts
Dept. of Architecture
Post-graduate Studies

Energy-Efficient Building Envelope Design Using Computer-Based Measurements.

تصميم غلاف المبنى المرشد للطاقة باستخدام قياسات الحاسب الآلى

PhD Degree Thesis
Presented By:

Architect / Khaled Mohamed Farid Mohamed Mohamed El-Deeb
Assistant Lecturer in the Department of Architecture
Faculty of Fine Arts – Alexandria University

EXAMINATION COMMITTEE

Prof. Dr. Magdi Mohamed Moussa.

Professor in the Department of Architecture, Former Dean of Faculty of Fine Arts.
Faculty of Fine Arts – Alexandria University.....(Member and Chairman).

Prof. Dr. Hoda Abd El-Kader Azzam.

Professor in the Department of Architecture,
Faculty of Fine Arts – Alexandria University.....(Supervisor).

Prof. Dr. Ahmed Ahmed Fekry.

Professor in the Department of Architecture,
Faculty of Engineering – Cairo University.....(Member).

Assistant Prof. Dr. Abbas Mohamed El-Zafarany.

Assistant Professor of Architecture,
Faculty of Regional Planning – Cairo University.....(Supervisor).

بسم الله الرحمن الرحيم

(و ما أوتيتم من العلم إلا قليلاً)

سورة الإسراء - الآية (85)

EXAMINATION COMMITTEE

Prof. Dr. Magdi Mohamed Moussa.

Professor in the Department of Architecture, Former Dean of Faculty of Fine Arts.
Faculty of Fine Arts – Alexandria University(Member and Chairman).

Prof. Dr. Hoda Abd El-Kader Azzam.

Professor in the Department of Architecture,
Faculty of Fine Arts – Alexandria University(Supervisor).

Prof. Dr. Ahmed Ahmed Fekry.

Professor in the Department of Architecture,
Faculty of Engineering – Cairo University(Member).

Assistant Prof. Dr. Abbas Mohamed El-Zafarany.

Assistant Professor of Architecture,
Faculty of Regional Planning – Cairo University(Supervisor).

ABSTRACT

The research deals with role of using 'building analysis computer software tools' in the building envelope design to reach energy efficiency.

Energy-efficient building envelope systems are discussed. This includes passive heating, passive cooling, and intelligent building envelope systems, in addition to energy generation through the integration of renewable energy systems in the building envelope design.

Building analysis tools are discussed and categorized. These include airflow, natural/artificial lighting and whole building analysis simulation tools. Each tool is discussed showing the inputs, outputs, benefits and the stage where it can be used in design. The relation between analysis tool and CAD tools is also discussed.

In the last part of the research, an application is performed using computer-based measurements and simulations to detect take energy-efficient design decisions for the building envelope in a specified case study,

Finally, a number of conclusions and recommendations are derived.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisors:

Prof. Dr. **Hoda Azzam**

for her valuable advices, guidance and continuous support,
and for her interest throughout the development of this research.

And

Assistant Prof. **Dr. Abbas El -Zafarany**

for his valuable advices since the earliest stages of the study, through which
discussions with him were always helpful and fruitful.

I would like to express my thanks to

Prof. Dr. **Magdi Moussa** and to Prof. Dr. **Ahmed Fekry**
for examining this thesis.

I also, express my thanks to professors in the Department of ITACA
Faculty of Architecture “Ludovico Quaroni”, Uniroma1 University, Rome, Italy

Prof. Dr. **Fabrizio Orlandi** Prof. of Architecture Head of Dept. ITACA.

Prof. Dr. **Eliana Cangelli** Prof. of Architecture, Dept. ITACA.

Dr. **Carlo Brizioli** Lecturer of Architecture, Dept. ITACA.

For the great assistance, guidance and training during my scholarship in Rome.

And to

Asst. Prof. Dr. **Mohamed Faruk El-Abi**. Faculty of Architecture, Kingdom University, Bahrain

Arch. **Mohamed Zaghloul**. Faculty of Fine Arts – Alexandria University

For their assistance in various stages of the research.

At last I would like to express my great thanks to my mother, father, sister and
brother, who always encouraged me and gave me a lot of moral support

Only To You

Dedicated to my

Mother.

Table of Contents

Introduction :	1
<i>Significance of the study:</i>	2
<i>Objectives of the study:</i>	2
<i>Scope of the study:</i>	2
<i>Methodology:</i>	2
<i>Structure of the study:</i>	2
PART I: Climatic Control Systems.....	2
PART II: Computer-Based Building Performance Measurements.....	2
PART III: Using Analysis Tools for Building Envelope Design Decisions. Case Study	3
PART I: Climatic Control Systems.	5
Chapter I : Passive Heating Systems.	7
1.1.0 Introduction:	7
1.1.1 Direct-Gain System:.....	7
1.1.2 Indirect-Gain Systems:.....	7
1.1.3 Isolated Gain System (Sun Spaces) :	10
Chapter II : Passive Cooling Systems	15
1.2.0 Introduction:	15
1.2.1 Excluding heat gains :	15
1.2.2 Inducing Air Movement :	19
1.2.3 Cooling Inlet Air :	20
Chapter III : Energy-Efficient Glazing Systems.	24
1.3.0 Introduction:	24
1.3.1 Thermal Gains for windows :	24
1.3.2 Performance Evaluation of Glazing :	25
1.3.3 Types of Energy Efficient Glazing Systems :	27
Chapter IV : Intelligent Building Envelope Systems.	35
1.4.0 Introduction:	35
1.4.1 The Concept of Intelligence	35
1.4.2 Intelligent Building Envelope Features.....	36
1.4.3 Building-Integrated Photovoltaics (BIPVs):	36
1.4.4 Double Envelope Facades :	37
PART II : Computer-Based Building Performance Measurements	42
Chapter I : Airflow Simulation Tools.	45
2.1.0 Introduction	45
2.1.1 Types of airflow simulation output:.....	45
2.1.2 Software tools used for airflow simulation:.....	45

TABLE OF CONTENTS

Chapter II : Lighting Simulation Tools.	62
2.2.0 Introduction :	62
2.2.1 Types of lighting simulation output:	62
2.2.2 Software tools used for lighting simulation:	62
Chapter III : Whole-Building Analysis Simulation Tools.	70
2.3.0 Introduction:	70
2.3.1 Types of whole-building simulation output:	70
2.3.2 Software tools for whole building analysis	70
2.3.3 Integration of CAD / Analysis tools.	77
2.3.4 Energy Support Tools.	81
2.3.5 Example for using Ecotect, RetScreen and BestClass tools:	84
PART III : Using Analysis Tools For Building Envelope Design Decisions....	88
3.0 Introduction:	88
3.1 Aim of the Case Study:	89
3.2 Description of the Case Study :	90
3.3 Method:	90
Stage A : Selection and calibration of the tool.	91
3.4.1 Selection of the Analysis Tool.	91
3.4.2 Calibrating the Analysis Tool.	93
Stage B : Performing the Simulation.	95
3.5.1 Modeling the Case Study Analysis Room:	95
3.5.2 Shading Analysis.	97
3.5.3 Natural Lighting Simulation.	100
3.5.4 Artificial Lighting Simulation.	102
3.5.5 Energy Consumption Calculation.	105
3.6 Case Study Results.	109
3.7 Analyzing results:	110
CONCLUSIONS	120
SUMMARY	125
APPENDIX : Lighting Simulation Results.	129
REFERENCES	148

Table of Figures:

No.	Content	Source.
Introduction		
1	Role of Computer-based measurements in envelope design.	Researcher.
PART I Chapter I		
2	Direct-gain mechanism.....	S28
3	Trombe wall.....	S16
4	John Smith House	S18
5	Trombe wall mechanism.....	S28
6	Convective loop system.....	S28
7	Convective loop system	S32
8	Barra system	S75
9	Thermal collector roofs and walls	R2, p178.
10	Modified greenhouse sunspace.....	S144.
11	Sunspace thermal characteristics	Researcher.
12	Modified greenhouse	Researcher.
13	Sun porches.....	Researcher.
14	Sunspace connecting wall alternatives.....	Researcher.
Chapter II		
15	Passive cooling systems.....	Researcher.
16	New and Renewable Energy Authority.....	Researcher.
17	Sino-Italiano Ecological and Energy-efficient Building.....	Researcher.
18	Double wall system, EERE building.....	Researcher.
19	Sangath Studio.....	S53.
20	Airtightness door test.....	S58.
21	Halawa Residence.....	S72.
22	Load-bearing straw bales.....	S70.
23	Infill straw bales.....	S71.
24	Prefabricated straw bale panel.....	S69.
25	Inducing air movement systems.....	S27.
26	The effect of vertical louvers on wind-driven ventilation.....	R3, p 96.
27	Building Research Establishment , UK.....	S50.
28	Inland Revenue Centre, UK.....	S134.
29	Exposed pond with water wall.....	S31.
30	Roof ponds.....	S51.
31	Swamp cooler.....	S48.
32	Barajeel (wind catchers), Persia.....	S73.

TABLE OF CONTENTS

33	Acros Fukoka Building, Japan.....	S74.
34	The underground water channel.....	R14, p109.

Chapter III

35	Solar Spectrum.....	S65.
36	Heat flow through windows.....	S62.
37	Glazing Systems according to selectivity	Researcher.
38	Microsoft- Egypt Headquarters	Researcher.
39	Dark fritted glass.....	S51.
40	Layered Glazing.....	S61.
41	Switchable glazing	Researcher.
42	Electrochromic Glazing.....	P4.
43	Angular selective glazing systems.....	Researcher.
44	Fixed concave mirror louvered.....	S51
45	Laser-cut acrylic panels.....	S58
46	LCP applications.....	S55
47	Prismatic panel diagram.....	S57.
48	Prismatic light redirection.....	S63.
49	Prismatic panel visual effect.....	S51.
50	Prismatic panel skylights.....	S59.
51	SUVA Building - Vertical section.....	R4, p137 .
52	SUVA Building.....	R4, p137-142
53	SUVA Building.....	R4, p137-142

Chapter IV

54	Artificial intelligence.....	Researcher.
55	Learning from human body.....	Researcher.
56	PV skylight entry.....	S86.
57	PVs for daylighting.....	S89.
58	Solar Test and Research Centre, Arizona.....	S88.
59	Building Research Establishment.....	S86.
61	Benefits of double skin facades.....	S22.
62	Systems of double-skin.....	Researcher.
63	Buffer system.....	S20.
64	The Occidental Chemical Building.....	S82.
65	The Helicon Building.....	S22.
66	Extract-air system.....	S20.
67	Twin-Face Façade.....	S20.
68	Twin-façade System summer performance.....	S69.
69	The Debis Building, Berlin.....	P2, p24.

PART II

70	Steps of airflow simulation.....	S33.
71	Simulation of airflow streamlines.....	S48.
72	Simulation of airflow temperatures.....	S48.
73	Simulation of airflow in an office space.....	S46.
74	Airflow Simulation of an atrium using FLOVENT.....	L1.
75	Airflow Simulation of an atrium using PHOENICS.....	S42.
76	Building model in PHOENICS.....	S42
77	Three Analysis grids by PHOENICS.....	S42.

Charter I

TABLE OF CONTENTS

78	Airspeed analysis by PHOENICS.....	S42.
79	airspeed analysis on vertical section plane.....	S42.
80	Samples of MicroFlo simulation.....	S37.
81	External CFD simulation around a building using MicroFlo....	S37.
82	Airspeed Vectors using AIRPAK.....	S44.
83	Extension of Pittsburg Project Organisation solar tower.....	A2.
84	Temperature contours using AIRPAK.....	A2.
85	Section view of the proposed extension.....	A2.
86	Velocity vectors around Pittsburg.....	A2.
87	Bioclimatic Residential Building, Italy.....	L2
88	Architectural design concept of cooling system.....	L2.
89	Central atrium airflow simulation using FLUENT.....	L2.
90	Central atrium airflow simulation.....	L2.
91	Airflow simulation Plan of the project.....	L2.

Chapter II

92	Simulation of daylight factor on work plane using FlucsDL....	S49.
93	A combined Ecotect-Daysim simulation.....	S22.
94	Museum and office Building in Seattle simulation.....	R6.
95	Daylight 1-2-3 input and output screen.....	S54.
96	Photorealistic and illuminance simulations using DIALUX.....	S10.
97	Output image using RADIANCE IES.....	S40.
98	ADELINe simple input.....	S49.
99	ADELINe Illuminance Contour and false color images.....	S49.

Chapter III

100	DesignBuilder simulation tool.....	S76.
101	VisualDOE graphic interface.....	L3.
102	VisualDOE output.....	L3.
103	Ecotect shading analysis.....	Researcher.
104	Ecotect-WinAir airflow simulation.....	Researcher.
105	Ecotect-Radiance illuminance levels simulation.....	Researcher.
106	Ecotect-Radiance False color image.....	Researcher.
107	Ecotect thermal analysis.....	Researcher.
108	Ecotect Artificial lighting.....	R12.
109	The concept of Building Information Modeling.....	R10.
110	The Autodesk Revit Architecture software.....	R26.
111	Green Building Studio tool.....	S81.
112	RETScreen Software tool.....	Researcher.
113	BestClass software interface.....	Researcher.
114	Energy-Efficient Residential Compound Design Project.....	Researcher.
115	Material properties for the selected wall composition.....	Researcher.
116	BestClass Results.....	Researcher.

Part III

117	Effect of increasing Window-Wall Ratio.....	Researcher.
118	Case Study Analysis Room Location.....	Researcher.
119	Tested window-wall ratios.....	Researcher.
120	Calibration test room.....	Researcher.
121	Calibration tools for sun patch and shading pattern.....	Researcher.
122	Calibration test room, illumination.....	Researcher.
123	Calibrating tools for artificial lighting.....	Researcher.

TABLE OF CONTENTS

124	Analysis study room properties.....	Researcher.
125	Room Dimensions, orientation.....	Researcher.
126	Indication of artificial lights.....	Researcher.
127	Wall material assignment.....	Researcher.
128	Monthly Shadow range on the building façade.....	Researcher.
129	Direct solar incidence on the building façade.....	Researcher.
130	Annual cloud cover.....	Researcher.
131	Tested cases for window-wall ratio alternatives.....	Researcher.
132	Process of minimizing the number of simulation cases.....	Researcher.
133	Process of detecting the need for artificial lighting.....	Researcher.
134	Level 01 – Natural lighting. Illuminance levels.....	Researcher.
135	Level 01 – Artificial lighting schedules.....	Researcher.
136	Energy simulation output sample.....	Researcher.
137	Annual energy consumption Levels 01-05.....	Researcher.
138	Annual energy consumption Levels 06-09.....	Researcher.
139	Energy-efficient window-wall ratio elevation.....	Researcher.
140	EE WWR 20% Level 01.....	Researcher.
141	Window-wall ratios for level 01.....	Researcher.
142	Window-wall ratios for levels 02, 03, 04.....	Researcher.
143	Window-wall ratios for levels 05, 06, 07.....	Researcher.
144	Window-wall ratios for levels 08, 09.....	Researcher.
145	Maximum annual shadow range from 08:00 to 16:00.....	Researcher.
146	Artificial lighting for WWR 20% in Level 01 , Level 02.....	Researcher.
147	Solar reflections into level 01 in September.....	Researcher.
148	Comparison if illuminance levels on the ceiling of L01, L02...	Researcher.
149	Comparison of energy consumption of the sum of all levels..	Researcher.
150	Alternatives for integration of PV panels in envelope design.	Researcher.

CONCLUSIONS

151	Window-wall ratios for levels 01,02.....	Researcher.
152	Window-wall ratios for levels 03,09.....	Researcher.
153	Alternatives for integration of PV panels in envelope design.	Researcher.

APPENDIX

154	Level 01 – Natural lighting. Illuminance levels.....	Researcher.
155	Level 01 – Artificial lighting schedules.....	Researcher.
156	Level 02 – Natural lighting. Illuminance levels.....	Researcher.
157	Level 02 – Artificial lighting schedules.....	Researcher.
158	Level 03 – Natural lighting. Illuminance levels.....	Researcher.
159	Level 03 – Artificial lighting schedules.....	Researcher.
160	Level 04 – Natural lighting. Illuminance levels.....	Researcher.
161	Level 04 – Artificial lighting schedules.....	Researcher.
162	Level 05 – Natural lighting. Illuminance levels.....	Researcher.
163	Level 05 – Artificial lighting schedules.....	Researcher.
164	Level 06 – Natural lighting. Illuminance levels.....	Researcher.
165	Level 06 – Artificial lighting schedules.....	Researcher.
166	Level 07 – Natural lighting. Illuminance levels.....	Researcher.
167	Level 07 – Artificial lighting schedules.....	Researcher.
168	Level 08 – Natural lighting. Illuminance levels.....	Researcher.
169	Level 08 – Artificial lighting schedules.....	Researcher.
170	Level 09 – Natural lighting. Illuminance levels.....	Researcher.
171	Level 09 – Artificial lighting schedules.....	Researcher.

List of Tables:

No.	Content.	Source.
1	Diff. in heat gain/losses bet. Sunspace/building relationship.	Researcher.
2	Comparable U-values for different glazing types.....	S3.
3	Glazing properties evaluation.....	S3, 66,67,68.
4	Emmisivity values for low-e coatings.....	S3.
5	Glazing types anfd properties.....	S3, 64.
6	VisualDOE Energy-efficiency measures.....	L3.
7	Calibration of Ecotect-Radiance tools.....	Researcher.
8	Calibration of Ecotect-Radiance tools for artificial lighting...	Researcher.
9	Comparison of energy consumption values of tested WWR	Researcher.
10	Energy-efficient window-wall ratio results for each level.....	Researcher.