



Building Integrated Photovoltaics As An Approach for Sustainable Development

BY

NOURHAN AHMED ALI ALI HEIBA

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
Architectural Engineering

Faculty of Engineering, Cairo University

Giza, Egypt

2015



دمج استخدام الخلايا الشمسية فى المباني كمدخل للتنمية المستدامة

اعداد

نورهان احمد على على هيبه

رسالة مقدمة

الى كلية الهندسة ، جامعة القاهرة، كجزء من متطلبات الحصول على
درجة ماجستير العلوم فى الهندسة المعمارية

كلية الهندسة – جامعة القاهرة

الجيزة _ جمهورية مصر العربية

2015

دمج استخدام الخلايا الشمسية فى المباني كمدخل للتنمية المستدامة

اعداد

نورهان احمد على على هيبه

رسالة مقدمة الى كلية الهندسة، جامعة القاهرة

كجزء من متطلبات الحصول على درجة ماجستير العلوم

فى الهندسة المعمارية

يعتمد من لجنة الممتحنين:

(ممتحن خارجى)

الأستاذ الدكتور: ايهاب محمود عقبة

استاذ العمارة - كلية الهندسة - جامعة الفيوم

(ممتحن داخلى)

الأستاذ الدكتور: احمد احمد فكرى

استاذ التصميم البيئى - كلية الهندسة - جامعة القاهرة

(مشرف رئيسى)

الأستاذ الدكتور: ايمن حسان احمد

استاذ تنسيق المواقع - كلية الهندسة - جامعة القاهرة

(مشرف)

الدكتور: هيثم سمير محمود

مدرس - الاكاديمية الحديثة للهندسة والتكنولوجيا

كلية الهندسة، جامعة القاهرة

الجيزة، جمهورية مصر العربية

يناير 2015

Building Integrated Photovoltaics As An Approach for Sustainable Development

BY
Nourhan Ahmed Ali Ali Heiba

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
Architectural Engineering

Approved by the Examining Committee:

Prof. Dr. Ehab Mahmoud Okba (External Examiner)

Professor of Architecture – Faculty of Engineering – Fayoum University

Prof. Dr. Ahmed Ahmed Fikry (Internal Examiner)

Professor of Environmental Design - Faculty of Engineering – Cairo University

Prof. Dr. Ayman Hassan Ahmed (Thesis Main Advisor)

Professor of Landscape Design - Faculty of Engineering – Cairo University

Dr. Haitham Samir Mahmoud (Advisor)

Assistant Professor - Modern Academy for Engineering and Technology

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT

January 2015

دمج استخدام الخلايا الشمسية فى المباني كمدخل للتنمية المستدامة

اعداد

نورهان احمد على على هيبه

رسالة مقدمة الى كلية الهندسة، جامعة القاهرة

كجزء من متطلبات الحصول على درجة ماجستير العلوم

فى الهندسة المعمارية

تحت اشراف

الدكتور: هيثم سمير محمود
مدرس - الاكاديمية الحديثة
للهندسة والتكنولوجيا

الأستاذ الدكتور: ايمن حسان احمد
استاذ تنسيق المواقع - كلية الهندسة -
جامعة القاهرة

كلية الهندسة ,جامعة القاهرة

الجيزة , جمهورية مصر العربية

يناير 2015

Building Integrated Photovoltaics As An Approach for Sustainable Development

BY

Nourhan Ahmed Ali Ali Heiba

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
Architectural Engineering

Under the Supervision of:

Prof. Dr. Ayman Hassan Ahmed
Professor of Landscape Design
Faculty of Engineering
Cairo University

Dr. Haitham Samir Mahmoud
Assistant Professor- Modern
Academy for Engineering
and Technology

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT

January 2015

ACKNOWLEDGMENT

I want to declare my appreciation to Prof. Dr. Ayman Hassan and Dr. Haitham Samir, Both have major contribution through their guidance and support.

I would like to thanks to Dr. Haitham Samir for important directions and great support.

I wish to thank my mother and father and my sister for support and encouragement. I would love to thank them for pushing me forward and standing beside me in hard time.

Contents:

I.	list of figures.....	i
II.	List of tables.....	iv
III.	Abstract.....	viii
IV.	Introduction.....	ix
V.	Research problem.....	x
VI.	Research Question.....	x
VII.	Research Methodology.....	x
VIII.	Research structure.....	xii

Chapter one: Sustainable Development and Non-Renewable Energy

1.1.	Introduction:.....	1
1.2.	Sustainable Development Definition:	1
1.3.	Sustainable Development Dimensions:	2
1.4.	Sustainable environment Aspects:	3
1.4.1	Climate change:.....	3
1.4.2	Ozone Layer Depletion:	4
1.4.3.	Pollution issue:.....	4
1.4.4.	Loss of biodiversity:.....	5
1.4.5.	Health issue:	6
1.4.6.	Energy consumption:	6
1.5.	Energy:	6
1.5.1.	Non renewable energy:.....	7
1.5.1.1.	Chemical:	7
1.5.1.2.	Nuclear :	9
1.5.1.3.	Nonrenewable energy causes greenhouse gas emission:.....	9
1.5.3.	World Statistics of Renewable and NON-Renewable energy:	10
1.6.	conclusion:	10
2.1.1.	Hydropower energy definition:.....	11
2.1.1.1.	River plant:	11
2.1.1.2.	Pumped Storage Power Plants:	12
2.1.1.3.	Oceanic Power Plant:.....	14
2.1.1.4.	Wave power:	14
2.1.2.	Solar energy:	17
2.1.2.1.	Photovoltaic power station:	18
2.1.2.2.	Solar power water pump:	19
2.1.2.3.	Building integration photovoltaics(BIPV):	19
2.1.3.	Wind energy resource:	27
2.1.3.1.	Effect of wind turbine size and height:	27
2.1.3.2.	Types of wind turbine:	27
2.1.3.3.	Building integrated wind turbines or mounted on a building (BIWTs):.....	30
2.1.4.	Biomass:	35

2.1.4.1.Biomass Classification:	35
2.1.4.3.Examples of biomass in architecture:	36
<i>Algae Skin Buildings:Bio Intelligence Quotient Building (BIQ), Hamburg Germany</i>	36
2.1.5.Geothermal energy:	39
2.1.5.1.Utilization process:	39
2.1.5.2.Types Of Geothermal Systems:	40
2.1.5.3.Boston University's Geothermal Building:	40
2.1.6.Conclusion:	41
<i>Algae Skin Buildings: Hamburg Germany which saves 50 % of building consumption.</i>	42
3.1.1. Crude oil in egypt:.....	43
3.1.2. Natural Gas in Egypt:	44
3.2.Renewable energy in Egypt:	44
3.2.1.Wind :	45
3.2.1.1.Zafarana wind Station power with capacity 545 MW:	46
3.2.1.2.Hurghada Wind Farm 5 MW:	48
3.2.2. Hydraulic energy:.....	49
3.2.3.Biomass in Egypt:	50
3.2.4.Solar Energy Resources:	51
3.2.4.1.Solar energy for water pump:Egypt was among the first countries to utilize solar energy. In 1910, A merican engineer F. Shuman built a practical industrial scale solar system engine at Maadi south to Cairo us ing solar thermal parabolic collectors as shown in Figure(3.12). The engine was used to produce steam whic h drove a series of large water pumps for irrigation.	51
3.2.4.2.Concentrating solar power :	52
3.2.4.3. photovoltaics in Egypt:	53
3.3.1.wind furure projects:.....	57
3.3.2.Solar projects:	58
3.4.Conclusion:	58
• Is located in Shobra El Khima	59
• Integrating mono and polycrystalline in the façade and produce 9.63 kwp	59
• is located in Abo Al Ghraddek in Matro.....	59
• pv cost 80,000 L.E	59
• integrate 24 monocrystalline panel which produce 20 kwp.	59
• Located in Bahira	59
• Integrating monocrystalline on roofs which produce 150 kWp	59
• cost 4millions with payback time 5 years	59
4.1. Introduction about photovoltaic:-.....	60
4.2. history of photovoltaic and who invented it first:	61
4.3. Advantages and disadvantages of Photovoltaics	63
4.4. Pv Basics:	63
4. 5. Classification of photovoltaics:	64
4.5.1. First Generation:	64

4.5.1.1. Mono-crystalline silicon cells.....	64
4.5.1.2. Poly or multi-crystalline silicon cells:.....	65
3.5.2. Second generation:	65
3.5.2.1 Amorphous silicon cells:	66
4.5.2.2. Cadmium Telluride (CdTe) and Copper indium gallium selenide (CIGS):	67
4.6. Pv Cost:	68
4.7. Payback period:	69
4.8. Building Integrated Photovoltaics (BIPV) System:	69
4.8.1. Stand alone system :	71
4.8.2. Grid Connected PV system:	72
4.8.3. Building integration photovoltaics system statistics:	73
4.9. Factor that effect photovoltaic efficiency:	74
4.9.1. Module Orientation and Tilt Angles :	74
4.9.2. Temperature effect on photovoltaic:	76
4.9.3. Colour and texture	76
4.9.4. Transparency:	77
4.9.5. Effect of shading on photovoltaic efficiency:	78
4.8.6. Effect of dust on photovoltaics efficiency:	79
4.9. Conclusion:	81
5.1. Building Integration Photovoltaics for Non Residential Buildings:	82
5.2. Façade :	83
5.2.1. Cold façade :	83
5.2.2. Warm Façade :	84
5.2.3. Double Façade :	85
5.3. Pv integrated in roof:	85
5.3.1. Flat Roof:	85
5.3.1.1. The cold roof:	86
5.3.1.2. Warm roof:	89
5.3.2. Sloped roof:	90
5.3.2.1. PV panel into sloped roof:	91
5.3.2.2. PV panel onto sloped roof (ventilated):	92
5.4. Photovoltaic shades:	93
5.4.1. Fixed Pv Shading:	93
6.4.2. Movable PV shading:	93
5.5. Skylight:	93
5.6. BIPV Examples:	94
5.6.1. BP Solar Showcase in BIRMINGHAM, PORT TALBOT:	94
5.6.2. Zero-energy building of Acciona Solar in Spain:	96
5.6.3. Paul-Horn Arena in Germany:	97

5.6.4.Rooftop PV Plant at Politecnico di Milano:.....	98
5.6.5.Wankdorf Stadium, in Bern, Switzerland with pv integration on roof :.....	99
5.6.7.The Smithsonian Tropical Research Institute (STRI):	100
5.6.8.Red tower in eastern Germany:	102
5.6.9.Kowa Elementary School in Tokyo, Japan:	102
5.6.10.THE HYBRID FAÇADE OF FIAT RESEARCH CENTRE:.....	103
5.6.11. Zero Carbon Building in Hong Kong:.....	104
5.7.Conclusion:	105
Facade.....	106
Grid connected	106
Zero- energy building of Acciona Solar, in Spain which integrated pv into façade and roof which produce 89 % (52 KWh) of building energy needed and the rest of needed energy is accomplished by geothermal power for cooling and heating the building.....	106
Paul- Horn Arena in Germany integrated amorphous silicon pv panels into façade which produce annually 30,000 K Wh.....	106
6.1.Case study analysis:	107
A. Building	107
B. Photovoltaics System Type.....	107
C. Building Integration Photovoltaics Type.....	107
6.1.1.Methodology:	107
6.1.2. Criteria of case study selection:	108
6.1.3. Tools:	108
6.1.4. building integration photovoltaics framework.....	109
6.2. Pv softwares	110
PVscout.....	110
6.2.1.Reason for choosing pvsystm program in simulation:	110
6.2.2.pv syst. Software steps:	111
6.2.2.1.choosing a section:	111
6.2.2.3.Input parameters:	112
6.2.2.4.Output:	115
6.3.International and National Analysis	119
6.3.1.St Mary's Church Hall	119
6.3.2.University of Gloucestershire Sports Centre:.....	120
6.3.3.North Devon District Council:	121
6.3.4. Engineering building for Khalada Petrol company	122
6.3.5.EGAS Building.....	123
6.3.6.German School	124
6.4. Comparing National and International Buildings Case of Study:	126
6.4.German school simulation:.....	126

6.4.1.Pv panel at 0°:	127
6.4.2.Pv panels at 5°:	128
6.4.3.Pv panel at 30°:.....	129
6.4.4.Pv panels at 60°:	130
7.1.Conclusion:	131
7.2.Recommendations:.....	132
7.2.1.Future research topics:	132

I. List of figures:

Figure (1. 1) shows Maslow hierarchy of needs.....	2
Figure (1.2) three dimensions of sustainable environment.	2
Figure (1. 3) shows Pollution issues	3
Figure (1.4) shows Carbon dioxide emission from 1960-2010.....	4
Figure (1. 5) shows Proportions of fossil fuel use in developed economies. ⁴	4
Figure (1. 6) shows (A) the major pollutants of the air, and (B): source of pollutants.	5
Figure (1.7) shows energy resource classifications.	7
Figure (1.8) the formation of petroleum and natural gas.	8
Figure (1.9) shows shows the formation of Coal.....	9
Figure (1.10) shows uranium fuel cycle.	9
Figure (1.11) shows the greenhouse emission by renewable and non renewable energy resource by 2010.	10
Figure (1.12) shows World primary energy supply 1973, 2010 and projection 2030.	10
Figure (2 .1) shows the classifications of hydropower plant.	11
Figure (2.2) shows principle of a run of river power plant.	12
Figure (2.3) shows Scheme of diversion canal fed river power plant.	12
Figure (2.4) shows Principle of pumped storage power plant.	13
Figure (2.5) shows three Gorges power plant.	13
Figure (2.6) shows Robert Moses power plant	13
Figure (2.7) Raccoon Mountain Pumped-Storage Plant.	14
Figure (2.8) shows scheme of tidal power.	14
Figure (2.9) shows principle of overtopping systems.	15
Figure (2.10) the main idea of Oscillating water column.	15
Figure (2.11) shows Jiangxia Tidal power	16
Figure (2.12) shows Vessel power plant.....	16
Figure (2.13) shows OE buoy power plant	16
Figure (2.14) shows the core of the sun.....	17
Figure (2.15) shows schematic cross section in a typical solar cell.	17
Figure (2.16) shows the Solarpark Waldpolenz	18
Figure (2.17) shows Photographs of	19
raket (b)stations.....	19
Figure (2.18) shows pv integrated into façade.	20
Figure (2.19) shows Solar Info Center in Germany pv integrated into façade and flat roof.	20
Figure (2.20) shows Plan detail for mounting LEDs and PV modules on the GreenPix Entertainment Complex fa çade.....	21
Figure (2.21) shows GreenPix Elevation and cladding structure detail of Media Wall.	21
Figure (2.22) shows photovoltaics integrated on roof either pitched roof or flat roof.	21
Figure (2.23) shows photovoltaics on Sydney's pitched roof Wharf Theatre.	22
Figure (2.24) shows pv integrated on the edges of the roof of the building	22
Figure (2.25) shows Mauna Lani resort top view and Photovoltaic panel integratated on roof.	23
Figure (2.26) shows Pv sunshades integrated on the building façade.	23
Figure (2.27) shows cross section and elevation in pv fixed shade.	24
Figure (2.28) shows standard solar water heating system.	24
Figure (2.29) shows layers of flat plate	24
f Figure (2.30) shows evacuated tube collectors.	25
Figure (2.31) shows parabolic trough concentrators.	25
Figure (2.32) shows power tower design.	25
Figure (2.33) shows Gemasolar solar power plant.	26
Figure (2.34) shows parabolic dish reflector.	26
Figure (2.35) shows solar furnace building.	27
Figure (2.36) shows Evolution of wind turbine size.	27

Figure (2.37) shows features of horizontal wind turbine.	28
Figure (2.38) shows various concepts for Horizontal-axis wind turbine.	28
Figure (2.39) shows vertical wind turbine.	29
Figure (2.40) shows different concepts of vertical wind turbine.	29
Figure (2.41) shows vertical-axis wind turbines.	31
Figure (2. 42) shows Council House 2 building which land marked with Savonius turbines.	31
Figure (2.43) shows cross section of Council House 2 building.	32
Figure (2.44) shows wind turbines integrated ontop of the castle house and the wind velocity around it.	33
Figure (2.45) shows Wind portal at mechanical floor.	33
Figure (2.46) shows the Pearl River Tower and the wind movement.	34
Figure (2.47) shows Bahrain world trade center and simulation for optimum wind between two towers which is t hrough wind direction 45°.	34
Figure (2.48) shows wind turbine integrated between two towers.	34
Figure (2.49) shows Technological pathway to transform biomass into biofuel.	36
Figure (2.50) shows Intelligence Quotient Building	37
Figure (2.51) shows how bioreactor algae works.	37
Figure (2.52) shows the plan of BEI-Teesside and elevation inaddition to interior shot.	38
Figure (2.53) shows the types of geothermal environments in the Earth's upper crust.	39
Figure (2.54) shows geothermal utilization process	39
Figure (2.55) shows Schematic of Geothermal Systems.	40
Figure (2. 56) shows the Boston university building.	41
Figure (2.57) shows the geothermal process in building underground	41
Figure (3.1) shows <i>Egypt production and consumption of oil from 1965-2010</i>	43
Figure (3.2) shows <i>the Areas of crude oil production</i>	44
Figure (3.3) shows <i>Egypt natural gas production and consumption</i>	44
Figure (3.4) shows <i>Egypt's energy consumption by source</i>	45
Figure (3.5) shows <i>Electricity consumption in 2010</i>	45
Figure (3.6) shows <i>Wind atlas map of Egypt</i>	46
Figure (3.7) shows <i>Zafarana location</i>	47
Figure (3.8) shows <i>Zafarana wind turbine</i>	47
Figure (3.9) shows <i>evolution of installed capacity of zafarana</i>	47
Figure (3.10) shows <i>location of Hurghada</i>	48
Figure (3.11) shows <i>Hurghada wind farm</i>	48
Figure (3.12) shows <i>high dam electricity production(MWh)in 2000 and 2007</i>	49
Figure (3.13) shows <i>cross section in Aswan high dam</i>	49
Figure (3.14) shows <i>an overview of the prototype of biomass</i>	50
Figure (3.15) shows <i>Egypt solar radiation</i>	51
Figure (3.16) shows <i>Frank Shuman parabolic solar collectors</i>	52
Figure (3.17) shows <i>Parabolic mirror collect sunrays during the day</i>	52
Figure (3.18) shows <i>Technical concept of Integrated Solar Combined Cycle of Kuraymat</i>	53
Figure (3.19) shows <i>ministry of electricity location</i>	54
Figure (3.20) shows <i>ministry of electricity with pv panels integrated on top of the building</i>	54
Figure (3.21) shows <i>Om Al Sager Village in siwah with pv integration ontop of houses</i>	55
Figure (3.22) shows <i>diwan building with pv integration in Bahira</i>	55
Figure (3.23) shows <i>pv panels integrated on top of the Diwan building and battries for storage</i>	55
Figure (3.24) shows <i>building location in Abo Al Ghraddek in Matroh</i>	56
Figure (3.25) shows <i>Engineering building with pv panels integrated infront of the building and 80 batteries for st orage</i>	56
Figure (3.26) shows <i>wind future projects in Gulf of Suez</i>	57
Figure (3.27) shows <i>solar project loction in Kom Ombo</i>	58
Figure (4.1) shows the photovoltaic cell, module and array.	60

Figure (4.2) shows Diagram of apparatus described by Becquerel.....	61
Figure (4.3) shows Sample geometry used by Adams and Day for the investigation of the photoelectric effects in selenium.....	61
Figure (4.4) shows Thin-film selenium demonstrated by Fritts in 1883.....	62
Figure (4.5) shows Early Grondahl-Geiger copper-cuprous oxide photovoltaic cell.	62
Figure (4.6) shows Monocrystalline solar panel manufacturing process and module.	64
Figure (4.7) shows diagram of production from silica stone to polycrystalline silicon and finished product	65
Figure (4.8) shows cross section in amorphous silicon cell.	66
Figure (4.9) shows amorphous cell flexibility.	66
Figure (4.10) shows process flow of amorphous silicon cell.....	66
Figure (4.11) shows Diagram show Types of PV systems.	70
Figure (4.12) shows remote and independent stand alone system for a farm house.	71
Figure (4.13) shows grid connected building.	72
Figure (4. 14) shows Cumulative installed PV power by application area for international countries between 1992 -2003.....	73
Figure (4.15) shows tilt and azimuth of solar cell.....	74
Figure (4.16) shows Change in the obtained electrical energy during the day, depend on the position of the solar module in relation to vertical plane (angle α) for the West.	75
(Figure 4.17) shows Change in the obtained electrical energy during the day, depend on the position of the solar module in relation to vertical plane (angle α) for the East.	75
Figure (4.18) shows Change in the obtained electrical energy during the day, depend on the position of the solar module in relation to vertical plane (angle α) for the South.	75
Figure (4.19) shows Effect of cell temperature on module performance.....	76
Figure (4.20) shows efficiency of the cell according to its colour.	77
Figure (4.21) shows Examples of the coloured effects on polycrystalline Silicon cells created by varying the thickness Of the anti-reflection coating.	77
Figure (4.22) Source of shading generated by building itself can drastically reduce annual energy output. The negative effect of shading can be reduced by careful PV module positioning.....	78
Figure (4.23) shows the effect of shading on cells.	79
Figure (4.24) shows The PV output power as a function of various directions and tilt angles.	80
Figure (5.1) shows inside view of transparent PV façade. ³	82
Figure (5.2) shows detail of cold façade.	83
Figure (5.3) shows cold façade and movement of air in the air gap and non transparent glass to decrease the warm of interior wall.	83
Figure (5.4) shows detailed section of exterior PV insulation unit in typical framing	84
Figure (5.5) shows interior view of warm facade	84
Figure (5.6) shows Ventilation scheme of the double-skin.	85
Figure (5.7) shows Interior view of the PV facade, showing how the semi-transparent PV contrasts with the clear glazing of the entrance doors.	85
Figure (5.8) shows fixed ventilated tilt.	86
Figure (5.9) shows the minimum distance between rows of panels ¹	87
Figure (5.10) shows freestanding photovoltaic panel on flat roof.	87
Figure (5.11) shows one axis tracker.	88
Figure (5.12) shows two axis tracker	89
Figure (5.13) shows pv non ventilated roof	90
Figure (5.14) shows In flat roof	90
Figure (5.15) shows detail for photovoltaic panels.	90
Figure (5.16) shows sloped roof and PV panels on it.....	91
Figure (5.17) shows pv panel integrated in sloped roof	91
Figure (5.18) shows PV panels integrated into slope roof.	92
Figure (5.19) shows PV panels integrated onto slope roof.....	92
Figure (5.20) shows cross section in building with sloped roof and PV panel on it.	92
Figure (5.21) shows movable shade	93