The Impact of Building Orientation, Opening to Wall Ratio, Aspect Ratio and Envelope Materials on Buildings Energy Consumption in the Tropics

تأثير توجيه المبنى، نسبة مساحة النافذة الى الجدار، نسبة عرض الفراغ الى طوله و مواد البناء المستعملة في الغلاف الخارجي على استهلاك المباني للطاقة في المناطق المدارية

By:

Tareq Maher Ayyad

Dissertation Submitted in partial fulfillment of

MSc in Sustainable Design of the Built Environment

Dissertation Supervisor

Dr. Moshood Olawale Fadeyi

October-2011

Abstract:

As the coming years will witness a noticeable depletion of many resources, significant increase in the planet's temperature and unprecedented increase in the Green house gases (GSG) emissions, the importance of curbing energy consumption is now more obvious that ever. Office Buildings sector is considered as one of the major emitters of the GHGs gasses due to the enormous amount of energy it consumes through the buildings life cycles. In hot and humid climates such as the UAE's providing cooling for the internal spaces all over the year is a major challenge. And as new regulations and laws regarding buildings energy consumption will be set in the coming few years, finding architectural passive solutions that would lessen the consumption to comply with the new regulations is essential. This research is using a survey followed by a computer modeling method to achieve an aim of providing architects with techniques that reduce energy consumption in office buildings.

In order to get reliable results that would be helpful for the construction industry in the country, the researcher has ensured that the virtual environment created in the modeling process imitates a typical UAE office buildings environment. A long survey that included office buildings located on Sheikh Zayed Road-the main business spine of the city- was performed. Architectural and mechanical drawings for the surveyed buildings were obtained and the architectural and materials characteristics of each office space - such as floor area, wall to floor ratio, glass opening sizes and external walls area- were measured and registered. The survey results have shown that offices of Dubai can be classified according to their architectural shape into two major categories: One external wall rectangular offices and corner offices. Built on the average values obtained from the survey results, simulation models were developed and modeled in IES<VE>. By changing the architectural parameters and materials data in the simulated models, simulating the new scenarios and compare the results, an overview of the impact of each factor on the thermal performance of office buildings in Dubai was obtained.

The research has found that passive design techniques have a great influence on buildings energy consumption. Significant reduction of the consumption was noticed when the orientation and the opening to wall percentages were modified. To understand the

previous results, the survey has analyzed the sources of heat and found out that solar radiation penetrating the spaces through the glass opening is responsible of around 55% of its energy consumption, followed by the conduction through the envelopes materials and radiation of the internal sources.

In conclusion, this research has found that adopting inexpensive and simple passive design techniques has a major impact of office spaces energy consumption. If these ideas were taken in consideration by architects during the design process, buildings will more environmentally responsible and consequently carbon dioxide emissions will be reduces.

الخلاصة:

سوف تشهد الأعوام القادمة زيادة ملحوظة في درجة حرارة الأرض نتيجة لزيادة انبعاثات غازات الاحتباس الحراري الناتجة من عمليات توليد الطاقة.من هنا تتضح أهمية التقليل من استخدام الطاقة الغير متجددة أكثر من أي وقت مضى. و حيث أن قطاع المباني المكتبية يعتبر واحدا من أكثر القطاعات المستهلكة للطاقة و بالتالي المنتجة لغازات الاحتباس الحراري، فان هذة الدراسة تهدف الى تخفيض الاستهلاك في هذا القطاع المؤثر و خاصة في المناطق الحارة و الرطبة كالامارات العربية المتحدة حيث يتطلب تبرييد الفراغات الداخلية لفترات طويلة. للتخفيض من هذه الانبعاثات سوف تشهد الأعوام القادمة اصدار لوائح و قوانين صارمة بشأن تخفيض استهلاك الطاقة،و لذلك يعتبر ايجاد حلول معمارية خلال مرحلة التصميم هو الطريق الأبسط و الأسهل لتخفيض الستهلاك و الانبعاثات للالتزام بهذه القوانين الجدبدة. هذا البحث الذي بني عن طريق مسح ميداني متبوع ببناء بيئة افتراضية باستخدام برنامج IES<VE> يقوم بتزويد المهندسين المصممين ببعض الطرق المساعدة في تخفيض استهلاك الطاقة في المباني المكتبية في المناطق الحارة و الرطبة.

بغرض الحصول على نتائج موثوقة و مفيدة، قام الباحث ببناء بيئة افتراضية تحاكي واقع البناء في الامارات العربية المتحدة مستندا على عملية مسح ميداني طويلة تتضمنت عدد من المباني المكتبية الواقعة في شارع الشيخ زايد بمدينة دبي. عملية المسح بدأت بالحصول على الرسومات المعمارية والميكانيكية للمباني التي شملها المسح و من ثم تحليلها حيث تم حساب عدد المكاتب، متوسط مساحتها، متوسط مساحة النوافذ ، عمق الفراغات المكتبية و أخيرا المواد المستعملة في البناء. نتائج المسح أظهرت أن الفراغات المكتبية في المباني المدروسة يمكن تقسيمها الى قسمين رئيسيين: مكاتب ذات واجهة زجاجية واحد و و مكاتب ذات واجهتين زجاجيتين (المكاتب الواقعة في زوايا المبنى). بناء على الملاحظة السابقة و جميع المعلومات و البيانات التي تم جمعها، قام الباحث ببناء نماذج مكتبية تحاكي الواقع باستخدام برنامج الكمبيوتر و حساب استهلاكها السنوي للطاقة و من ثم قام بتغيير البيانات المعمارية و مواد البناء و حساب الاستهلاك السنوي لكل حالة. عن طريق المقارنة بين جميع النتائج قدم هذا البحث بتوضيح كيفية تأثير حميع العناصر المعمارية و مواد البناء المستعملة على الاستهلاك السنوي للطاقة في المكاتب الواقعة في مدينة دبي.

هذا البحث يظهر أن للقرارات التصميمية تأثير كبير على استهلاك الطاقة في المباني المكتبية، حيث أبانت النتائج انخفاض ملحوظ في الطاقة المستهلكة ينتج عند تغيير توجه المبنى، مساحة النوافذ و أخيرا عمق الفراغ بالنسبة الى طوله. كما أوضحت النتائج أن اختراق أشعة الشمس المباشرة للفراغات المكتبية هو المصدر الرئيسي للحرارة و المسئول الأول عن ارتفاع استهلاك الطاقة في هذا الفطاع من المباني .البحث أظهر أن هذا المصدر مسئول عن 55% من استهلاك الطاقة متبوعا بعملية التوصيل الحراري من خلال المواد و أخيرا الاشعاع الحراري للمصادر الداخلية).

في النهاية، هذا البحث يؤكد أن تبني تصاميم و حلول معمارية بسيطة تراعي البيئة قد يساهم في انخفاض ملحوظ في استهلاك الطاقة في المباني المكتبية. فاذا ما تم اتخاذ هذه القرارات خلال مراحل التصميم الأولى، تحقق الهدف في تصميم مباني بيئية تساهم في خفض انتاجات غازات الاحتباس الحراري و بالتالي تحمي البيئة للأجيال القادمة.

ACKNOWLEDGEMENT:

Though this work appears to be an individual research, a great many people contributed in the production of this dissertation. I owe my gratitude to all of the people who have made this dissertation possible.

My deepest and sincere gratitude is to my supervisor, Dr. Moshood Olawale Fadeyi for his guidance, understanding and patience and most importantly his friendship during my studies in BUiD.

I also like to extend my gratitude to all the members of the British University in Dubai family for supporting and encouraging me in the past 2 years.

To my friends, thank you all of caring and supporting. You made the journey so enjoyable.

Most importantly, none of this would have been possible without the support of my family. Because they have been a source of love, support and strength, I dedicate this work to them.

Table Of Contents:

Abstract (English) i
Abstract (Arabic) iii
Acknowledgement iv
Table of Contents v
List of Figures.......... viii
List of Tables.......... xii

CHAPTER 1: INTRODUCTION.......... 1
1.1 Architects and global energy consumption.......... 2
1.2 Effects of buildings energy consumption on the environment.......... 2
1.3 Thermal energy consumption in buildings.......... 2
1.4 Factors affecting thermal energy consumption in buildings.......... 3
1.5 Buildings design 3
1.6 Materials data (Façade Materials); Aesthetical, structural and environmental functions.......... 4
1.7 Energy saving motivation.......... 5
1.8 A problem that needs to be solved.......... 6
1.9 The necessity for a radical solution.......... 7
1.10 A proposed method to find solutions.......... 7
1.11 Significance of this study.......... 7
1.12 Research Outline.......... 9

CHAPTER 2: LITERATURE RIVEW.......... 10
2.1 Introduction 11
2.2 Method 11
2.3 Buildings energy consumption.......... 13
2.3.1 Different sectors with different energy consumption.......... 13
2.3.2 Energy consumption in buildings: Noticeable changes in architecture and lifestyle leading to worrying numbers and facts.......... 14
2.3.3 Buildings sub-sectors.......... 15
2.4 More Focus on Office Buildings and Their Energy Consumption.......... 15
2.5 Energy use in Buildings.......... 16
2.6 Operational energy in buildings.......... 17
2.7 Major factors affecting operational energy consumption in buildings.......... 17
2.8 Architectural Design of Envelopes (their Energy Consumption).......... 18
2.9 Energy Required to Achieve Thermal Comfort.......... 19
2.10 Heat exchange mechanisms.......... 20
2.11 Factors affecting indoor thermal comfort.......... 20
2.12 Optimum envelopes to achieve users comfort.......... 21
2.12.1 Required thermal comfort conditions in offices.......... 21
2.12.2 Analyzing the Microclimate of the Buildings Location.......... 22
2.12.3 Specifying the Space's Usage and the Activity Level.......... 22
2.12.4 Design and materials parameters.......... 23
2.12.5 Different methodologies used in evaluating Buildings energy Consumption.......... 25
2.12.6 Controlling the applicability.......... 26

2.13 Green Buildings…………………………………………………………………………………… 26
2.14 Efforts to Implement the Concepts of Green Architecture Worldwide……. 27
2.15 Development of the research aim and hypothesis built on all the knowledge gained……………………………………………………………………….. 27
2.16 Research's aim and Objectives………………………………………………………………. 29

CHAPTER 3: THE CASE OF THE UAE………………………………………………………………………………. 30
3.1 UAE General Information (Facts and Statistics)……………………………………… 31
3.1.1 Location, Current Climate and Predicted Climate…………………………….. 31
3.2.2 Demography and Economy………………………………………………………….. 31
3.2 Energy Profile, Energy Consumption and GHG Emissions……………………….. 32
3.3 Impact of the Global Climatic Change on Energy Consumption in the UAE. 33
3.4 Sectoral energy consumption and GHG emissions in the UAE…………………. 34
3.5 Buildings Sector Energy Consumption in the UAE…………………………………….. 34
3.6 Causes of Building's Energy Consumption Increase in the UAE (Architectural, Social and technological factors)…………………………………….. 34
3.7 Glass Facades Trend in Dubai………………………………………………………………… 35
3.8 The UAE Strategies and Initiatives toward a Sustainable Built Environment……………………………………………………………………………………… 36

CHAPTER 4: METHODOLOGY…………………………………………………………………………………………… 39
4.1 Method Selection………………………………………………………………………………… 40
4.1.1 The research's parameters…………………………………………………………… 40
4.1.2 Advantages and disadvantages of the different methodologies used.. 42
4.1.3 A quick comparison between the different methods………………………… 44
4.1.4 The method selected…………………………………………………………………… 45
4.1.5 Computer Modeling: The Best Method to predict Energy Performance in the design stage………………………………………………………… 45
4.2 The Selection of the Computer Simulation Program………………………………… 46
4.3 Integrated Environmental Solutions – Virtual Environment……………………… 48
4.4 A survey performed to build an office spaces that represents offices in Dubai…………………………………………………………………………………………….. 48
4.5 Modeling and simulation process…………………………………………………………… 50

CHAPTER 5: BUILDING THE SIMULATION MODEL……………………………………………………………. 53
5.1 Parameters of the base cases IES<VE> files……………………………………………. 54
5.1.1 Assigning Weather Data………………………………………………………………… 54
5.1.2 Usage Data…………………………………………………………………………………… 55
5.1.3 Design Data…………………………………………………………………………………... 56
5.1.4 Materials Data……………………………………………………………………………… 59
5.2 Parameters studied……………………………………………………………………………….. 63
5.2.1 Architectural Design Data……………………………………………………………… 63
5.2.2 Materials Data……………………………………………………………………………… 64
5.3 Research's Matrix and Models………………………………………………………………… 66

CHAPTER 6: RESULTS AND DISCUSION ………………………………………………………………………… 71
6.1 Results of Prototype 1…………………………………………………………………………… 72
6.1.1 Design Data…………………………………………………………………………………... 72
6.1.1.1 Orientation……………………………………………………………………………… 72

6.1.1.2 Opening-to-wall-ratio……………………………………………………………… 74
6.1.1.3 Aspect Ratio……………………………………………………………………….. 77
6.1.2 Materials Data……………………………………………………………………………… 80
6.1.2.1 Opaque Construction Systems………………………………………………… 80
6.1.2.2 Transparent Construction Systems……………………………………….. 84
6.2 Results of Prototype 2…………………………………………………………………………. 89
6.2.1 Design Data……………………………………………………………………………………. 89
6.2.1.1 Orientation………………………………………………………………………………. 89
6.2.1.2 Opening-to-wall-ratio……………………………………………………………… 91
6.2.1.3 Aspect Ratio……………………………………………………………………….. 93
6.2.2 Materials Data……………………………………………………………………………… 95
6.2.2.1 Opaque Construction Systems………………………………………………… 95
6.2.2.2 Transparent Construction Systems……………………………………… 98
6.3 Summary and Discussion…………………………………………………………………….. 101
6.3.1 Architectural Parameters…………………………………………………………… 101
6.3.2 Materials Parameters………………………………………………………………… 106
6.4 Heat flow mechanism in the studied cases……………………………………………….. 108
6.5 Heat Sources…………………………………………………………………………………………….. 108
6.6 The impact of the sources of heat on thermal energy performance…………… 109
6.7 Solar Radiation and energy consumption……………………………………………….. 111

CHAPTER 7: Conclusions and Future Work………………………………………………… 113
7.1 Summary and Conclusions…………………………………………………………………. 114
7.2 Further Work ………………………………………………………………………………………… 116
7.3 A need for a new computer program………………………………………………….. 117

References………………………………………………………………………………………………… 120
Appendices……………………………………………………………………………………………… 126
Appendix 1: survey results ………………………………………………………………………. 127
Appendix 2: Dubai Weather Data…………………………………………………………………. 130
Appendix 3: Operation Profiles…………………………………………………………………… 132
Appendix 4: Variables Abbreviations…………………………………………………………. 133
Appendix 5: Research's Matrix…………………………………………………………………. 134
Appendix 6: Simulation Results…………………………………………………………………. 141

List of Figures:

Figures		Page
Figure 4.1	Area surveyed to develop simulation models	49
Figure 4.2	A summary of the research's methodology process	52
Figure 5.1	Module (prototype 1). (A) A perspective view. (B) Plan and Elevation	57
Figure 5.2	Office module (prototype 2). (A) A perspective view. (B) Plan and Elevation	58
Figure 5.3	Detail of external wall (DM Construction System 5). Source: (DM,2010)	60
Figure 5.4	Detail of internal partitions. Source: (DM,2010)	61
Figure 5.5	Detail of internal ceilings/floors. Source: (DM,2010)	61
Figure 5.6	Detail of external windows	63
Figure 5.7	(A) Orientations tested for prototype 1. (B) Orientations tested for prototype 2	64
Figure 5.8	(A) External Wall Layers (DM Construction System 3). (B) External Wall Layers (DM Construction System 4) (DM,2010)	65
Figure 5.9	The models simulated with different orientations and materials.	70
Figure 6.1	The impact of changing the orientation on cooling energy consumption in 1.8:1 aspect ratio offices with different opening-to-wall percentages	72
Figure 6.2	The impact of changing the orientation on cooling energy consumption in 1:1 aspect ratio offices with different opening-to-wall percentages	73
Figure 6.3	The impact of changing the orientation on cooling energy consumption in 1:1.8 aspect ratio offices with different opening-to-wall percentages.	73
Figure 6.4 (A&B)	The impact of changing the opening-to-wall Percentage on cooling energy consumption in south-oriented offices with different aspect ratios.	74
Figure 6.5 (A&B)	The impact of changing the opening-to-wall percentage on cooling energy consumption in East-oriented offices with different aspect ratios	75
Figure 6.6 (A&B)	The impact of changing the opening-to-wall percentages on cooling energy consumption in North-oriented offices with different aspect ratios	76

Figure 6.7 (A&B)	The impact of changing the aspect ratio on cooling energy consumption in south-oriented offices with different opening-to-wall ratios	77
Figure 6.8 (A&B)	The impact of changing the aspect ratio on cooling energy consumption in east-oriented offices with different opening-to-wall ratios.	78
Figure 6.9 (A&B)	The impact of changing the aspect ratio on cooling energy consumption in North-oriented offices with different opening-to-wall ratios.	79
Figure 6.10 (A&B)	The impact of changing the opaque construction materials on cooling energy consumption in South-oriented offices with different aspect ratios and Opening-to-wall percentages.	81
Figure 6.11 (A&B)	The impact of changing the opaque construction materials on cooling energy consumption in East-oriented offices with different aspect ratios and Opening-to-wall percentages.	82
Figure 6.12 (A&B)	The impact of changing the opaque construction materials on cooling energy consumption in North-oriented offices with different aspect ratios and Opening-to-wall percentages.	84
Figure 6.13 (A&B)	The impact of changing the transparent construction materials on cooling energy consumption in South-oriented offices with different aspect ratios and Opening-to-wall percentages.	85
Figure 6.14 (A&B)	The impact of changing the transparent construction materials on cooling energy consumption in East-oriented offices with different aspect ratios and Opening-to-wall percentages.	87
Figure 6.15 (A&B)	The impact of changing the transparent construction materials on cooling energy consumption in North-oriented offices with different aspect ratios and Opening-to-wall percentages.	88
Figure 6.16	The impact of changing the orientation on cooling energy consumption in 2.55:1 aspect ratio offices with different opening-to-wall percentages.	89
Figure 6.17	The impact of changing the orientation on cooling energy consumption in 1.88:1 aspect ratio offices with different opening-to-wall percentages.	90
Figure 6.18	The impact of changing the orientation on cooling energy	90

	consumption in 1:1 aspect ratio offices with different opening-to-wall percentages.	
Figure 6.19 (A&B)	The impact of changing the opening-to-wall Percentage on cooling energy consumption in East-South oriented offices with different aspect ratios.	91
Figure 6.20 (A&B)	The impact of changing the opening-to-wall percentage on cooling energy consumption in North-East oriented offices with different aspect ratios.	92
Figure 6.21 (A&B)	The impact of changing the aspect ratio on cooling energy consumption in East-South oriented offices with different opening-to-wall ratios.	93
Figure 6.22 (A&B)	The impact of changing the aspect ratio on cooling energy consumption in North-East oriented offices with different opening-to-wall ratios.	94
Figure 6.23 (A&B)	The impact of changing the opaque construction materials on cooling energy consumption in East-South oriented offices with different aspect ratios and Opening-to-wall percentages.	96
Figure 6.24 (A&B)	The impact of changing the opaque construction materials on cooling energy consumption in North-East oriented offices with different aspect ratios and Opening-to-wall percentages.	97
Figure 6.25 (A&B)	The impact of changing the transparent construction materials on cooling energy consumption in East-South oriented offices with different aspect ratios and Opening-to-wall percentages.	99
Figure 6.26 (A&B)	The impact of changing the transparent construction materials on cooling energy consumption in North-East oriented offices with different aspect ratios and Opening-to-wall percentages.	100
Figure 6.27	A comparison between two offices with similar area but different architectural parameters.	101
Figure 6.28	Classifications of offices towers studied according to their floor plan shape.	102
Figure 6.29	A comparison between corner offices and one-external wall offices.	103
Figure 6.30	Orientation and energy consumption.	103
Figure 6.31	Opening-to-wall percentage and energy consumption.	104
Figure 6.32	Aspect Ratio and energy consumption.	105
Figure 6.33	A comparison between two offices with similar	106

	architectural design but different materials.	
Figure 6.34	Heat flow mechanisms and sources of heat.	109
Figure 6.35	Heat sources influence on the internal space thermal performance in prototype 2 base case.	101
Figure 6.36	Solar altitude and energy consumption in south-oriented offices	111

List of tables:

Table 4.1	Survey final results	50
Table 5.1	Internal gains of heat	56
Table 5.2	External gains of heat	56
Table 5.3	Properties of materials used for the base case external walls	60
Table 5.4	Properties of materials used for the base case internal walls	61
Table 5.5	Properties of materials used for the base case internal ceilings	62
Table 5.6	Properties of materials used for the base case doors	62
Table 5.7	Properties of materials used for the base case external windows	62
Table 5.8	Properties of External wall layers of DM construction system 3	65
Table 5.9	Properties of External wall layers of DM construction system 4	65
Table 5.10	Properties of glass construction system 2	66
Table 5.11	Properties of glass construction system 3	66
Table 5.11	Research Matrix	67

CHAPTER 1: INTRODUCTION

1.1 Architects and global energy consumption:

The last decades have witnessed an unprecedented increase in buildings energy consumption and carbon dioxide emissions. Understanding the fact that buildings themselves don’t need energy but people inside them do, adapting pure architectural solutions to provide users with a thermally, visually and acoustically comfortable space that don't consume much energy is essential to achieve the required carbon reduction and hence meet the international commitments. To fully address the task ahead, architects should take their moral and environmental responsibility and develop their professional expertise to improve users comfort inside buildings and seek ways of reducing energy consumption. Moreover, it would be wise for architects to claim leadership role in this area before another group of buildings scientists does. This research is trying to remind architects of their significant role and provide them with simple techniques that if taken in consideration in the design process, architects can participate in saving the planet for the coming generations.

1,2 Effects of buildings energy consumption on the environment:

Buildings have a significant influence on the environments and ecosystems that surround them; they require huge amounts of energy, water and many other resources during their designing, construction, operation and finally demolition stages. Due to their enormous energy consumption rates, buildings are responsible of emitting huge amounts of Green house gases into the atmosphere. Nowadays, buildings sector is considered as one of the major sectors that are threatening our environment. If we can make the buildings in which we live, work and study more energy-efficient, we can go a long way towards protecting our environment for the coming generations.

1.3 Thermal Energy Consumption in Buildings:

The proliferation of energy consumption and CO2 emissions in the built environment has made energy efficiency and savings strategies a priority objective for energy policies in most countries. Especially important has been the intensification of energy consumption in HVAC systems, which has now become almost essential in parallel to the spread in the demand for thermal comfort, considered a luxury not long ago. According to Lombard et. al. (2007), it is the largest energy end use both in the residential and non-residential sector, comprising heating, ventilation and air conditioning (when compared with other end uses HVAC systems were responsible of around 50% of energy consumption in the USA and Europe). Moreover, predictions indicate a massive growth in HVAC energy consumption and conditioned area around the world as world's temperature and population are increasing rapidly.

1.4 Factors affecting thermal energy consumption in Buildings:

Thermal energy consumption in buildings is caused by a combination of internal and external factors. The studies -presented in the literature review chapter- have showed that four major factors participate in determining the amount of energy required for cooling or heating a specific space and these factors are: climatic data, usage data, design data and finally materials data. In order to find solutions that would radically reduce thermal energy consumption, these factors should be studied and understood properly. Climatic data "the climate of the environment in which the building is sited" and usage data "the usage of spaces" have a major effect on the buildings energy consumption. Moreover users should understand that their behaviors have an impact on the environment and must take responsibility and change their behaviors accordingly. Since these two factors are uncontrolled by the designers, finding solutions that adapt to the climatic data and the usage data in both the Design and materials factors is the major role of architects and decision makers and can achieve the required energy reduction.

1.5 Buildings Design:

Buildings come in a wide variety of shapes, sizes, and purposes and they have been built at different times according to different standards. Consequently, addressing energy use in any given building requires a holistic approach to ensure the best results. This holistic approach requires a full team of architects, engineers and buildings scientists that can determine the amount of energy a building will require and take decisions that improve the overall building design and reduce energy consumption. These design decisions can be divided into two major categories: architectural decisions and mechanical decisions. The first category includes all the decisions architects take during the architectural design stage. These decisions include buildings orientation, the area of glass and the depth of the spaces. On the other hand the mechanical decisions tries to find out mechanical alternatives such as new HVAC equipments that are more energy-efficient and would participate in the desired energy reduction. As this study is being performed by an architect, architectural design decision will be studied in this paper. However, mechanical studies decisions should be always considered as important as architectural decisions.

<u>1.6 Materials Data (Façade Materials); Aesthetical, structural and environmental functions:</u>

A building's façade can be defined as the outer boundary or the external envelope of a building. It has always been considered as a major element of the building architecture that performs many *aesthetical*, *structural* and *environmental* functions. Aesthetically, façades can metaphorically resemble a dress that covers the building's skeleton. The word (façade) is driven from the Italian word (facciata) which literally means appearance, visage or aspect and hence the external appearance of a building. Structurally, façade systems fulfill the functions of load bearing; they have a main role in supporting the edges of the suspended floors and ceilings. Finally, they play a great environmental role in separating the internal and external environments of a building and therefore enhancing comfortable indoor spaces for buildings' users.

Throughout history, many materials have been used for the buildings' outer envelope. The use of glass as the main material for façade systems became a trend in the era that followed World War II. Based on a theoretical relation between democracy and transparency, designing buildings with large glass façades has been considered as a symbol of a healthy and open society. The quick spread of glass blocks in the world's major cities had led to many aesthetical and structural debates in the early years of its use. According to many observations and studies, a lot of architects claimed that whenever glass is involved in architecture, it behaves as a dark and shiny material that reflects the surrounding rather than a transparent skin that shows what's inside the building. This huge contradiction between the main aim of using such materials and the actual use of them had always represented a conflict between contemporary and classical architects. Another contradiction of the material properties, being easily broken and fragile on one hand but solid and durable on the other, had flamed another structural debate that has always been as fierce as the aesthetical one.

As a result of the global environmental revolution sparked by the 1970's energy crisis and the discovery of the greenhouse gases' effect in increasing the globe temperature, a debate about the environmental functions of the glass façades started to come into sight. Many observers and researchers started to understand and clarify the significance of energy, and many of their observations and statistics showed that building sector is one of the biggest consumers of energy. As most of the energy was discovered to be used for cooling, heating and lighting purposes, researchers had agreed that improving façade systems and adopting new design techniques that achieves a balance between the buildings transparent and opaque materials should be the first steps in achieving the ethical and environmental goal of energy reduction. Since then, architects and engineers have devoted most of their work and effort to find smart design and materials solutions that would help in reducing the bad effect of glass.

1.7 Energy saving motivation:

Dubai is a modern city that brings together the eastern traditions with the western lifestyle in a remarkable combination. Catalyzed by a significant financial boom and a clear vision of the city's rulers, Dubai has achieved an outstanding development in all aspects of life. Architecturally, the city has been fascinating the world with huge pioneer and innovative projects since the last decade of the 20^{th} century. Such projects include Burj Khalifa, the tallest man-made structure ever built. The Burj, which was opened in October 2009, has followed many revolutionary developments that undoubtedly demonstrate the notion of what is impossible can only be possible in Dubai.

However, the rapid growth in the city had prompted developers, architects and engineers to give more attention for buildings' architectural and structural aspects and neglect the vital environmental aspect. Moreover, the absence of clear environmental policies and the neglecting of the role of environmental engineers in the design process had allowed many designers to implement ideas and concepts that are not suitable for the UAE climate. All of the previous factors had participated in a growing energy consumption of an average rate of 15 percent compared to the global range of 4 percent in the year 2007 (Gulf news, 2007).

Responding to these shocking numbers, In October 2007 Dubai government launched The Sustainable Vision of Dubai initiative. The initiative calls for issuing and implementing the international standards regarding the green buildings in order to reduce the excessive increase of energy consumption in the city. In 2007 the government laid down a goal to reduce cooling loads by 30% and artificial lighting energy by 9% before 2015 (CTBUH, 2007). To comply with the new regulations and to act in accordance with these initiatives, research regarding the buildings' energy consumption is a vital issue that needs to be done and encouraged.

1.8 A problem that needs to be solved:

When visiting Dubai for the first time, tourists are usually captivated by the impressive view of the huge high rise buildings located on both sides of Sheikh Zayed Road. Despite their impressive architecture and inventive construction techniques, these buildings are representing a huge environmental burden due to the enormous amount of energy they consume. This problem has been caused by many un-environmental and irresponsible decisions at the first stages of the design process (i.e. Buildings orientation and spaces sizes and shapes). Another important factor that participate in this massive increase in energy consumption is that many designers in the city are still depending on full glass facades to perform many architectural and aesthetical roles such as brightening rooms, improving visibility and providing design versatility regardless of the fact that these systems are not suitable for a hot and humid climate such as the UAE's.

Over the years, many façade materials have been used in the city. A quick look at these facades shows clearly that architects have always been using materials that are designed according to American or European standards. Though most of these materials are being claimed to save energy by their manufacturers, their function depends mainly on the location and the climatic conditions of the place they will be used in. If clients and architects recognize this important fact during the material's specification stage of the design process, a noticeable reduction in a building's energy consumption will be achieved.

To sum up, many factors are contributing in increasing energy consumption in buildings in the city. The absence of responsible design decisions –buildings orientation and openings sizes as an example- combined with wrong materials specifications, are major problems that needs to be tackled.

1.9 The necessity for a radical solution:

Apart from the ethical and moral responsibility, saving energy in buildings represents a huge dilemma that needs to be addressed by all the organizations and individuals involved in the construction industry. Responding to the international initiatives and agreements, both developed and developing countries will be forced to change their buildings regulations and codes in the coming few years. Architects and designers will be asked to design buildings that comply with these new regulations. Therefore, finding smart and inexpensive solutions for energy saving in buildings is a certain requirement. Moreover, saving cooling and lighting energy will contribute in reducing carbon dioxide emissions from buildings and hence play a great role in the global fight against the current man-made phenomena of increasing temperatures.

1.10 A proposed method to find solutions:

The aim of this research is to help architects in understanding how simple and inexpensive passive decisions taken in the design process of offices buildings can achieve the required energy consumption. The research started by a survey that included all of the offices towers located on Sheikh Zayed Road. The results of the survey have provided the researcher with ideas and data about the current architectural trends and constructional systems being implemented in the country. The data obtained from the survey was used to build simulation models using the computer modeling software: Integrated Environmental Solutions <Virtual Environment> "IES<VE>". In order to understand how each architectural factor and materials parameters affect energy consumption, many different scenarios were modeled and simulated. By comparing the results obtained from all the different scenarios the researcher was able to approximately define how each factor participates in buildings thermal performance.

1.11 Significance of this study:

This research is aimed to increase the environmental awareness among developers, architects, engineers and all the experts that are involved in the construction industry. The findings of this research will help developers to understand the effect of adopting environmental solutions and choosing the best material on long term energy and hence money savings. Architects will be able to take the best decisions regarding building's orientation, openings sizes and aspect ratios. Glass manufacturer and suppliers will have a clear vision of what materials are really needed in such climatic conditions. This research will also help engineering students in understanding the influence of materials on energy consumption and architectural students in adopting environmental solutions in the design process. Most importantly, the finding of this research might help the municipalities in regulating specific laws regarding the opening sizes, buildings orientation aspect ratios and materials properties used in buildings located in hot and humid climates.

Finally, this study will have some benefits for the scientific society and the findings will hopefully add to what is known and already proven. A quick review at most of the researches that have been done regarding this subject shows that most of them have either been done to locations with different climatic conditions or have been done by materials manufacturer companies. This research will provide non-subjective results that would work in hot and humid climates. Other researchers will be able to use these results and improve them to find better environmental solutions. Eventually, the following papers would represent a non-profitable scientific and environmental study that would confidently participate in the global effort of reducing non-renewable energy consumption and greenhouse emissions and therefore save the planet for the next generations.

1.12 Research Outline:

The dissertation is divided into 7 chapters as follows:

- In the first chapter the problem this research is tackling, the motivation of the research and the significance of its results are presented.

- In the literature review chapter, the researcher tries to provide the reader with boarder knowledge about the major sectors that control the global energy consumption. More focus is given to offices buildings categorized under buildings sector. The factors that affect their thermal performance and the comfort inside them are addressed. Moreover papers that discuss the same parameters o have already found some solutions are reviewed.

- In the third chapter, the current energy situation of the UAE is elaborated. Moreover, a section that talks about the current initiatives and futuristic regulation, laws and projects is presented.

- In the fourth chapter, the method used to achieve the research's aim is described in details. Moreover, it compares the different methodologies that are being used by other researchers and elaborates the different parameters used in the modeling process.

- In the fifth chapter, the details of the simulation models and the configuration of the base cases and the different scenarios are elaborated.

- In the sixth chapter, results from the simulation are presented and compared to know the exact impact of each parameter on the energy consumption. Moreover discussion about the results and their implementations are discussed.

- In the seventh and last chapter, conclusions are presented and further work is identified.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction and method:

As office buildings consumes much more energy than all other buildings subsectors and subsequently produces a huge amount of greenhouse gases, a lot of research and effort should be devoted to finding solutions that would mitigate the problem. Most of the studies reviewed claim that energy consumption in office buildings is mainly affected by three major interacted factors: envelope and architectural design, services design and finally users' behaviors. This paper is mainly concerned with the first factor as the two others are controlled by mechanical and psychological aspects which are beyond the scope of this study and the researcher's specialty. Therefore, concentration in the literature review presented in the coming pages is on the significant effect of architecture and the built environment on the current environmental situation. However and as the previously mentioned three factors are connected to each others, studies about the other two factors by other researchers is a certain need in order to find radical and holistic solutions that would manage to reduce energy consumption in office buildings and therefore participate in the global effort of saving the environment for the coming generations.

As this chapter is addressing a wide variety of specialists, scientists, architects and engineers and who ever interested in the built environment, ideas in the literature review were presented in a simple an interesting flow. In addition to providing information for the researcher to carry on with this research, the coming pages main goal is to increase the reader's knowledge about the effect of the built environment on the global environmental situation.

2.2 Method:

A literature search using the key terms energy consumption, building's energy consumption, buildings envelopes, glass facades, buildings orientation, buildings aspect ratio, office buildings energy needs and finally UAE energy situation was performed limiting the search to title or abstract of papers and articles that were published in the last two decades. The ideas were then presented according to the flow shown in (Fig. 1).

Literature Review

Introduction

Method

Results

Global Energy Consumption

- How Global Energy Is Being Consumed
- Global Sectoral Consumption of Energy (Industry, Transportation and **Buildings**)

Buildings Energy Consumption

- Architectural, Demographical and Social Changes Leading to Shocking Numbers

Buildings Sub-sectors:

- Office Buildings and Their Energy Consumption

- Energy Use in Buildings (Construction, **Operation** and Demolition Phases)
- Operational Energy (HVAC, Lighting, Appliances)
- Factors Affecting Operational Energy (**Envelope Design**, Systems Design, Users Behaviors)

- **Architectural Design** of Envelopes (their Energy Consumption)

- Energy required to achieve thermal comfort

- Factors affecting indoor thermal comfort

- Optimum envelopes to achieve comfort
  - Required thermal conditions required.
  - Understanding the outside environment.
  - Specifying the Usage and activity levels.
  - Design and Materials properties
  - Choosing the proper Method
  - Checking Applicability

Green Buildings (Defining Sustainability in Buildings)

Efforts to Implement the Concepts of Green Architecture Worldwide

UAE Energy Consumption:

- UAE General Information
  - Location, Climate, Predicted Climate Change
  - Demography and Economy
- Energy Profile
  - Factors Affecting Energy Consumption in the UAE and Leading to Shocking Rates
  - Impact of the Global Climatic Change on Energy Consumption in the UAE
  - Sectoral Energy Consumption and GHG Emissions in the UAE
    - Buildings Sector Energy Consumption in the UAE
      - Increase of Buildings Energy Consumption in the UAE causes
      - Glass Façades Trend in Dubai
- The UAE Strategies and Initiatives toward a Sustainable Built Environment

Results:

2.3 Buildings energy consumption:

2.3.1 Different sectors with different energy consumption (How is the global energy being consumed?):

Following the technological revolution, human's life has changed dramatically. People are excessively depending on non-renewable energy resources to perform major tasks that ease life and guarantee a certain degree of comfort. Waking up on the sound of an alarm that was manufactured in a far factory and transported to the store it was bought from is a simple example that elaborates how energy is consumed to manufacture, transport and use this essential device. For energy reduction, locally-manufactured electricity-efficient multi-functional device that comprises an alarm can be considered as an effective solution. The previous simple example clearly shows that understanding how and where energy is being consumed is the first step in the attempt of finding environmental alternatives.

Generally, most of the studies and researches reviewed consider that the final energy consumption is split into three major sectors: transportation, industry and buildings (domestic and non-domestic) sectors (Lombard et al. 2008) (EIA, 2010). It is very complicated to determine how much energy each sector is consuming due to many synaptic activities. For example, as people move from one building to another, the energy consumed is being calculated under the transportation sector. However, many researchers and urban planners claim that it should be calculated under the buildings' sector. According to them, energy consumption can be reduced if these buildings were designed according to a well-organized mixed-used urban plan that helps people to walk to their destinations instead of relying on non-environmental transportation means. Regardless of this complexity, many studies have come up with approximate numbers regarding energy consumption and its splitting up into the different sectors:

- 474 Exajoules of energy was consumed worldwide in 2008 (Bp, 2009).
- The global average annual growth rate of energy consumption between 1980 and 2006 was about 2% (Bp, 2006).

- World energy consumption is predicted to grow by 49% from 2007 to 2035 (EIA, 2010).
- Developing countries energy consumption is growing rapidly with an annual rate of 2.9% compared to an annual rate of 1.4% in the developed countries (IAC,2007).
- Industry is considered as the major energy consumer with around 50% of the world's total delivered energy (EIA, 2010).
- Transportation is considered as the second energy consumer sector with a percentage of 30% (EIA, 2010).
- Buildings sector is consuming the remaining 20% (EIA, 2010).

2.3.2 Energy consumption in buildings: Noticeable changes in architecture and lifestyle leading to worrying numbers and facts:

In order to provide comfortable and healthy internal spaces that would help him to perform his daily activities, man has traditionally developed buildings designs and techniques that adapt with the surrounding environment (Bouden, 2007). Unfortunately, the current trend of growing human population, increasing demand on buildings services and comfort levels, together with the rise in time spent inside buildings have negatively affected the environmental designs of buildings and increased their energy consumption resulting in uncontrolled and unprecedented increase in green house gases emissions (Lombard et al. 2008). Moreover -and as demographical projections shows- the coming quarter century will witness a huge population growth in urban areas where enormous amount of energy will be required to light, heat and cool the millions newly-constructed houses, apartments and services buildings (IAC,2007).

Nowadays, the buildings sector is consuming around 38% of the US total energy (EIA, 2006), 41% of Europe total energy (Janssen, 2004) and 30% of China's total energy (Fridley et.al. , 2007). Studies also show that buildings are responsible for almost 70% of sulfur oxides and 50% of CO_2 global emissions (Ghaius and Inard, 2004). As these percentages are predicted to grow substantially due to the factors mentioned in the previous paragraph, significant increase of the buildings environmental burden is predicted to occur in the coming decades. Attempts to reduce buildings' energy consumption and greenhouse emissions by adapting new techniques that takes in consideration the environmental factors without compromising the users comfort, is a prime objective for most of the parties that are concerned with the environment and the construction industry (Lombard et al. 2008). These attempts should start by understanding how buildings consume energy. By recognizing this, researchers with different specialties can work on different aspects of energy use in different types of buildings and find separate solutions. When exchanging the results among researchers and sharing them with architects, consultants and engineers, holistic solutions that would definitely mitigate the problem would be available.

2.3.3 Buildings sub-sectors:

The building sector is separated into two major divisions: Domestic and non-domestic sub-sectors. The latter covers all commercial and public buildings -such as educational, cultural and health buildings- with a wide variety of uses and energy services; heating, cooling, lighting and food preparation are some simple examples (Lombard et al. 2008). According to Ramesh et. al. (2010), the consumption of energy in residential buildings over their life cycle falls in the range of 150-400 kWh/m^2 per year, while for office (commercial) buildings it falls in the range of 250-500 kWh/m^2 per year. Moreover, Released by the InterAcademy Council in 2007 with an aim of identifying a scientific consensus framework for directing global energy development, the "Lighting the way: Toward a Sustainable Energy Future" report has clearly showed the energy consumption in commercial and services buildings grew about 50% faster than residential buildings in the period between 1971 and 2002. This number is predicted to increase as growing population will demand more services (IAC, 2007). Therefore, reducing energy in this subsector should be a priority for researchers as fast solutions are needed in the coming desired century of neutral carbon emissions buildings.

2.4 More Focus on Office Buildings and Their Energy Consumption:

As the world witnessed a rapid economical growth in the previous two decades, there have been obvious increases in large office buildings development projects (Esken and Turkmen, 2008). Due to many environmental concerns, and when compared with the other subsectors of the buildings' main sector, many researchers and scientists called for concentrating on this type of buildings as they consume the hugest amount of energy and therefore have the greatest impact on the environment and the atmosphere. In the US -

and according to EIA (2001)- in 1995 office buildings were the hugest consumer of energy compared to all other buildings sectors; they consumed around 19% of all commercial energy consumption. Moreover and as another example, office buildings consume around 2% and 2.7% of the total energy being consumed in the UK and Spain respectively (Lombard et al. 2008).

2.5 Energy use in Buildings:

Buildings consume huge amounts of energy through construction, operation, maintenance, refurbishment and demolition phases (Fay et. al., 2000). In order to understand the total consumption of buildings and accurately calculate how much energy each building uses, taking in consideration all the building's lifecycle phases is essential. According to Ramesh et. al. (2010), the life cycle energy of any building can be calculated according to the following equation: $LCE = EE_i + EE_r + OE + DE$ where:

LCE: Life cycle energy.

EE_i: Embodied energy, which is all the energy contained in the building's materials. In other words it is the energy needed to manufacture, construct, install and renovate these materials.

EE_r: The embodied energy in all the materials that are replacing the old ones through the life span of the building.

OE: The energy needed to operate the building (HVAC, lighting and appliances).

DE: The energy needed to demolish the building.

Ramesh et. al. (2010) has calculated the life cycle energy for more than 73 buildings around 13 countries using the previous equation. The results clearly shows that operation of buildings require almost (80-90) % of its energy consumption. According to the study, adapting passive and active technologies that would reduce the operation energy would achieve a huge reduction in any building's energy consumption. Though adapting these techniques may lead to an increase in the embodied energy, the total energy consumption over the life cycle would be reduced. Because embodied energy is beyond the scope of this paper, this research will focus on the operational energy due to its significant impact on any building energy consumption.

2.6 Operational energy in buildings:

In order to provide thermal comfort and a healthy environment for users, huge amounts of energy is demanded for buildings operation. Generally in all buildings most of the energy is being required to perform the following tasks:

1 Heating and cooling: In all buildings, providing heat, ventilation and air-conditioning systems (HVAC systems) is an essential requirement to maintain thermal comfort and indoor air quality. The amount of energy required for cooling or heating a specific space depends mainly on the location and size of that space.

2 Lighting: Daylight and sunlight has a significant influence on people living inside buildings. Naturally-lit spaces provide a comfortable and enjoyable environment for users and embrace happiness, relaxation and productivity.

3 Appliances: All of the buildings are currently equipped with many electrical appliances that consume energy. Moreover, some of them produce heat and therefore increase the cooling loads.

2.7 Major factors affecting operational energy consumption in buildings:

The amount of energy needed for operating all buildings is mainly influenced by the interaction of interior factors with the outside conditions. Therefore and as the latter factor -which depends mainly on building's location micro-climate- can't be controlled by humans, architects understanding of how their designed interior spaces will interact with the outside conditions is the first step in achieving a climatic design that reduces buildings energy consumption. According to Radhi (2009), three major factors have a significant impact on the interior spaces energy performance and they are: envelope design, systems design and finally occupants' behaviors. Though the impact of each factor cannot be determined accurately due to their connectivity, the influence of the first two factors on the energy performance of any building can be achieved by taking suitable decisions at the first stages of the design process. Built on this fact, designing an envelope that takes in consideration the micro-climate of the location, reduces HVAC loads and allows daylight to come inside the building accompanied with an optimum services design and appropriate equipments sizes are the first steps in achieving the desired aim of reducing any building energy reduction. However, to achieve the maximum benefits of the design, the users should understand that their behaviors affect the whole system; efficient use of the systems results in a huge reduction of energy use. As mentioned previously, this paper is mainly concerned about the architectural factors that affect the buildings energy consumption. Therefore, more concern about the role of buildings design in achieving the energy reduction goals is presented in the coming paragraphs.

2.8 Architectural Design of Envelopes (their Energy Consumption):

The building envelope is a major architectural feature. It can be defined as an external shell that separates the interior spaces of a building from the exterior environment. Its main role is creating proper and healthy internal spaces that guarantee the user's comfort. Buildings envelope design -which is a specialized area of architectural and engineering practice-, is a very complicated task that needs a lot of awareness among all the people involved in the process. Moreover a strong cooperation between all the parties involved in the design process would ensure that the designed envelope will achieve the major tasks it is designed to perform. Bouchlaghem claims that all the architectural and engineering design decisions should be according to five major systems –as he called them- and they are: Environment, cost analysis, structure, activity and finally aesthetic. Each one of these inter-related systems consists of many sub-systems. As an example, the environmental system which is the main concern of this paper is consisting of three major sub-systems: thermal, visual and aural subsystems. Therefore, the building envelope is considered successful in performing its major environmental role only if it guaranteed human comfort in the three previous subsystems. In other words, the envelope should ensure that the internal space is achieving the users' thermal comfort, allowing proper amounts of daylight and finally insulate the building from the outside noise. However it should always be taken in consideration that the level of comfort in each sub-system should always be in accordance with the main function of the space behind the envelope.

Analyzing any envelope environmental role in particular should always start with understanding its major components. In general, any envelope consists of five major physical and architectural elements; foundation, walls, roof, doors and windows. These elements can be classified according to their transparency into two major parts: opaque and transparent parts. The transparent part of the building is very important as it connects the interior spaces with the outside world and allows natural daylight to penetrate the space. Although these two main functions are major needs in what can be called a healthy space, the transparent elements usually cause many undesirable thermal and acoustical conditions. Therefore, a suitable balance between the opaque and transparent features according to the space location, size and use should always be considered.

However –no matter how well-designed the envelope is- and in order to eliminate all of its inappropriate properties, artificial lighting and HVAC systems are always needed to achieve the required visual and thermal comfort. This indoor artificially-controlled environment requires huge amounts of energy and as we are living in an unprecedented era of an Earth that is rapidly witnessing a huge depletion of most of its energy resources, using the natural and artificial energy efficiently is a vital moral aspect that should always be taken in consideration by the designers. Moreover, and as these resources become rarer, the costs of energy worldwide will increase in considerable trends. Therefore the cost factor would also force the designers to adopt more sustainable techniques that will save the energy required to achieve both the thermal and visual comfort.

For acoustical comfort, Unver et. al. (2004) claims that this factor should always been taken in consideration in the first stages of the design as solutions for any acoustical problem during the operation stages is not possible or too difficult and expensive. To sum up, Unver et. al. urged architects and designers to adopt the "optimum building envelope" theory in their designs, which is designing an envelope that has all the required performances and designed considering light, heat and sound as a whole.

2.9 Energy Required to Achieve Thermal Comfort:

One of the major factors that caused this unprecedented increase in buildings energy consumption and their GHG emissions is the intensification of energy consumption in HVAC systems. Nowadays -and though it was considered as luxury not long time ago- providing thermal comfort for users is becoming an essential need in almost every single building. Based on information cited from EIA, IDAE and BRE, Lombard et. al (2008) states that the energy used to run the HVAC systems is the largest energy end use in both residential and commercial sectors. According to the statistics cited, space conditioning consumes around 42%, 68%, 53% and 62% of the final residential buildings energy use in Spain, European Union, USA and UK respectively. Regarding office buildings, the HVAC systems consume more than 50% of the energy consumption energy use in a lot of southern European countries such as Italy and Spain while it consumes around 48% in the states. Though it was difficult to get any statistics about the percentage of end use energy in buildings located in hot climates such as the UAE's climate, the numbers are predicted to be much higher than the previous percentages due to the hot weather almost every day of the year. Unfortunately, most of these numbers are predicting to increase as the global climate is changing rapidly. More HVAC systems will be required to overcome these significant changes and hence more energy will be consumed.

2.10 Heat exchange mechanisms (between the building and the external environment through the envelope):

Usually heat is being transferred between any two objects through 3 major processes: Conduction, Convection, and Radiation. The situation is similar in buildings were the major heat flows occurs by conduction through the building elements (i.e. walls, roof, ceiling), by convection through air movements, by radiation of heat from the different internal and external surfaces and finally by the solar radiation transmitted through the transparent parts of the building's envelope.

2.11 Factors affecting indoor thermal comfort:

Bouchlaghem (1999) defines two factors affecting thermal performance of any space; unsteady climatic excitation that the building is subject to, and the design variables controlled by the building designers. In another paper, Ünver et. al. (2004) has classified the physical and environmental elements that affect thermal indoor comfort conditions into four major parameters:

1- Indoor environment comfort parameters: The internal parameters that affect humans comfort inside the space (i.e. air temperature, relative humidity and mean radiant temperature.

2- Outdoor design parameters: The outside parameters that interact with and affect the internal parameters (i.e. obstruction properties, outside air temperature and outside relative humidity)

3- Indoor design parameters: The architectural properties of the space and the kind of activity performed in it (i.e. room dimension, windows sizes and user activity level)

4- Buildings envelope properties: The thermal properties of the transparent and opaque materials used in the design.

2.12 Optimum envelopes to achieve users comfort:

In order to design buildings that not only reduce thermal consumption in buildings but provides all the thermal, visual and acoustical requirements, architects should develop their skills in order to be able to design optimum envelopes that achieve the previous goals. Based on the two previous papers reviewed in the previous paragraph, the procedure that should be followed by architects to design such envelopes can be summarized in the following steps:

- Determining the values that control thermal, visual and acoustical comfort. Such values can be obtained from international standards or local regulations.
- Understanding the micro-climate of the location of the building. Values and numbers of all the external environmental parameters can be provided from governmental and non-governmental validated statistics.
- Specifying the type of the activity being performed in the space and getting usage values from international standards.
- Determining the architectural parameters of the room according to researchers' findings, international standards or local regulations.
- Selecting materials according to their environmental performance, availability in the local market and harmony with the conceptual design.
- Checking the energy and comfort performance using different methodologies.
- Controlling the applicability.

Each one of these specific steps is addressed in the following paragraphs:

2.12.1 Required thermal comfort conditions in offices:

Improper thermal conditions from high temperatures and high relative humidity reduce indoor thermal comfort and air quality. The uncomfortable spaces not only affect the productivity of the users but also cause some health problems; thermal discomfort has been known to lead to sick building syndromes. The internal spaces thermal comfort levels are usually controlled by two major factors: Outside environment and personal factors. Being controlled by gender, age, health psychology, situational factors and clothing levels, the personal factor complicates the process of achieving a thermal comfort level that satisfies all of the buildings users. However, according to the United States Department of Labor, Occupational Safety and Health Administration (OSHA) (2003), architects should try to create an internal thermal environment that satisfies the majority of the spaces users, or in other words: an environment in which an employee wearing a normal amount of clothing feels neither too cold nor too warm.

Despite the complexity of determining specific numbers for all the parameters that affect thermal comfort, international standards built on many accurate researches and validated statistics make the job easier. ASHRAE (2010) standard 55-2010- Thermal environmental Conditions for Human Occupancy- set required values for offices indoor air temperature, humidity level and air velocity. According to the general recommendation of the published standards, indoor air temperature should always be in the range of 21-23°C, relative humidity should be kept at 50% and finally air velocity should be maintained under 0.25 meters/second.

2.12.2 Analyzing the Microclimate of the Buildings Location:

As mentioned above, in order to achieve thermal comfort the interaction between the internal and external environments should always be considered. This research is analyzing buildings located in hot and humid climates. The case of the UAE was chosen to represent such climates. More information about the external environment in the UAE and the current energy situation in the country are presented in chapter 3.

2.12.3 Specifying the Space's Usage and the Activity Level:

The users of any internal space are responsible of increasing the internal temperature and relative humidity depending on the kind and level of activities they perform. Activity level is measured in the terms of metabolic rates or 'met'. By metabolism, human bodies convert the energy existing in the food into the energy needed to perform the different activities. According to the laws of thermodynamics, this process of energy conversion through chemical reactions results in the emission of specific amount of heat depending on the intensity of the activity performed. In order to specify the metabolic rates for offices spaces, Charles (2003) has reviewed some of the researches that experimented or monitored human activities in different spaces. The researcher has found that these laboratory studies -in which heat or oxygen production were measured for participants in the research- are time consuming and not practical. Instead, the researcher has found that measurements and estimations developed by international bodies such as ASHRAE and built on laboratory experiments and tables of met rates are more accurate. For offices spaces the researcher urges architects to depend on ASHRAE standards: 1.2 met.

2.12.4 Design and materials parameters:

According to Bouchlaghem (1999) the design parameters that affect the thermal comfort in the buildings internal spaces are:

- General layout and setting (Orientation and aspect ratio of the spaces).
- Location and sizes of windows and the use of shading devices.
- The thermo physical properties of the building materials (Materials of the building envelope and the internal partitions).
- Insulation of the building from its surrounding environment.

These factors don't have the same impact on the thermal performance. As an example changing the windows area would have a greater impact on the internal thermal comfort than increasing the thickness of the external walls. Moreover, some of these variables are independent - parameters available at the start of the process and don't change when other parameters change- (i.e. orientation and space size) and independent parameters -parameters dependant on independent parameters- (i.e. room height and its volume).

In the study done by Morrissey et.al., (2011), the aim of the researchers was to investigate the impact of changing buildings orientation on their thermal performance. The study which was performed in Australia "Southern hemisphere" started with analyzing around 100 different building plans. Characteristics of each plan such as floor area, wall to floor ratio, glass opening sizes and external walls area were measured and registered. The following step was modeling and simulating all of the 100 cases using AccuRate computer modeling program. The results have shown that significant energy reduction can be achieved by just changing the building orientation.

Florides et.al. (2002), studies the effect natural ventilation, solar shading, various types of glazing, thermal mass and various orientations on energy performance in buildings in the UK. The research used TRNSYS simulation computer program to model and simulate different scenarios. The results have shown that energy can be reduced by 24% by using double glazed windows and 8.2% to 26.7% when the spaces proportions or (Aspect ratio) change. The research concluded that gains through windows are an important factor and significant savings can result when extra measures are taken.

Haung and Shu, (2010) claimed that solar radiation penetrating the glass façade is the major factor that affects users' thermal and visual comfort. In a study aimed to minimize the bad influence of solar radiation, the researchers performed a study on an existing building located in Taiwan. Computer simulation modeling program ENVLOAD was used to model and examine different windows to wall ratios (0.25, 0.5 and 0.75) and different glass materials. The results obtained from the research shows how can architects by simply change the architectural or materials parameters reduce energy consumption in buildings.

In the study of Ünver (2004), the basic design process which can be used at the stage of architectural design in order to determine the optimum building envelope providing indoor visual, thermal and acoustical comfort is introduced. Three different offices modules that are usually used in architectural applications were tested with different envelope scenarios: different architectural parameters and different construction details. The results of the 12 cases developed and tested and show that unobstructed south oriented offices achieve the required optimum envelopes only if sunlight was controlled.

Bouden (2005) investigated the proper glass facades strategies and glass materials appropriate for the Tunisian climate. Using TRNSYS software, the researcher has modeled and simulated a real existing administrative building. The following step was splitting the building into 5 major thermal zones with different glass materials, glass sizing and façade systems for each zone. The results have shown that glass curtain wall implementation in the Tunisian context would be interesting only if proper orientation and type of glass was used by the designers.

2.12.5 Different methodologies used in evaluating Buildings energy consumption:

Based on the literature review done by the researcher; in order to predict thermal performance of buildings, different researchers worldwide are currently depending on three major methodologies: Monitoring and observation methodology, experimental methodology and finally computer programming methodology. In order to understand the advantages and disadvantages of each methodology, three papers with similar aim but different methods were reviewed and presented in the coming paragraphs. In the three papers, the researchers aim was to understand how using new design strategies such as double skin facades affect the internal space energy consumption and hence the comfort of the users:

Perino and Serra (2002) has monitored an office building located in Torino, Italy for one full year. 32 sensors with different functions were installed in different parts of the internal spaces. Their major task was taking regular measurements of internal air temperature, temperatures on the surfaces of the glass, internal relative humidity and internal wind speed. The results of the study showed that using this kind of facades systems in Italy climate can achieve reduction in heating energy loads in winter, however it can cause excessive heating in the interior spaces in hot summer days.

In another research with the same aim, Marszal and Thomas (2008) has used a full scale experiment methodology. The experiment facility, which was located in a university campus in Denmark, was not surrounded by any buildings that would block solar radiation from penetrating the facility's internal space or natural air ventilation from flowing around it. As many different techniques and measurements were taken for a long period, the researchers managed to come up with results that show the performance of the facility at different timings of the year.

Finally, computer modeling method was used by Høseggen et.al. (2008) to compare buildings envelopes with different glass constructions in Norway. The researchers have used the computer simulation software (ESP-r) to model, predict and calculate energy performance of different offices buildings with different envelopes techniques. The results have shown the in Norway Double skin facades thermal performance is much better than other envelopes techniques.

2.12.6 Controlling the applicability:

After defining the thermal parameters of the internal and external environments, the users' activity, the design and materials parameters and the proper methodology, the final step in understanding and designing optimum buildings envelopes is checking the applicability of implementing such systems on the designed project. In many situation design or environmental obstacles could prevent implementing the optimum designs.

2.13 Green Buildings:

As it was obvious from the previous reviews, the main aim for most of the researchers, scientists, architects, engineers and whoever involved in the buildings sector is to create a sustainable built environment that depends totally on renewable resources of energy and therefore doesn't pollute the environment. In other words, all the researches reviewed are seeking "sustainable or green buildings". As defined by the World Commission of Environment and Development in their report "Toward a Sustainable Future" released in 1987, sustainable development can be defined as meeting the needs of the present without compromising the ability of future generation to meet their own needs (UN, 1987). Since the previous definition is very general and covering a wide variety of levels such as economy, development, agriculture, and building practices, a more specific definition is needed. According to the U.S. Environmental Protection Agency (EPA)(2011) green buildings can be defined as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from sitting to design, construction, operation, maintenance, renovation and deconstruction. In order to be able to design green buildings and according to the LEED Green buildings certification system, 8 major points should be addressed: Location and planning, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and design process and finally regional priority (USGBC, 2011). If the environment was taken in consideration in each of the previous major points, achieving green buildings become easily possible.

2.14 Efforts to Implement the Concepts of Green Architecture Worldwide:

During the Rio Earth Summit in 1992, many issues were discussed regarding the sustainable development and green buildings. Based on information sited in "The Earth summit strategy to save our planet" book edited by Sitarz D., Aboulnaja and Elsheshtawy (2001) summarized the discussed issues in the following points:

- The importance of choosing locally manufactured materials in buildings.
- The value of vernacular and traditional architecture which used to respect the environment. Incentive to promote these techniques has to be encouraged.
- Regulating principles regarding energy-efficient buildings.
- Encouraging a global exchange of information regarding green buildings between researchers and scientists on one hand and architects and engineers on the other hand.
- Finding new techniques and methods that make recycling and reusing of some of the buildings materials possible.

Nowadays, and after many years of trials and errors and much effort done by individuals and international organizations, green buildings dream became a reality. Many exceptional projects worldwide are currently running on renewable energy and don't emit any pollutant into the atmosphere. However, to reach the required reduction in buildings energy consumption, such designs should be a trend not just a phenomena. This wouldn't be achieved unless architects and designers realize the moral and ethical role they play to save the environment. Moreover, governments worldwide should regulate policies that would direct the designers to the right environmental track.

2.15 Development of the research aim and hypothesis built on all the knowledge gained:

The data presented above has directed the researcher to build his hypothesis, aim and objectives. Moreover it has provided the researcher with all the data and knowledge needed to carry on with this research. In the beginning of the review, offices buildings was considered as the most growing energy consuming sector; more focus was given to this sector in this study. By knowing that 90% of the energy is being used in operating the offices buildings, this research is trying to find solutions that reduce operational loads and as most of the operational energy is being used to create adequate thermal environments for users, reducing thermal loads in the offices buildings became the research's main aim.

By reviewing articles that has discussed thermal comfort and energy consumption, well-designed buildings envelopes were found to be the major controller of the internal spaces energy consumption and thermal comfort. The well-designed envelopes were defined as the envelopes that achieve users' thermal, visual and acoustical comfort. Many researches worldwide has tried to improve the performance of building envelopes and researchers have found that passive techniques adopted in the design stage (i.e. orientation, opening sizes and envelope materials) have the greatest impact on reducing the internal energy consumption. Built on this fact, the researcher has decided to know if these strategies and techniques can work in a hot and humid environment such as the UAE's.

2.16 Research's aim and Objectives:

This research is aiming to support the global efforts of reducing energy consumption and carbon dioxide emissions in buildings by providing the design-stage architects with a clear analysis of the factors and variables that affect thermal energy consumption and therefore CO2 emissions. This analysis would also be accompanied with some solutions that if implemented would achieve a radical reduction in energy consumption. In order to make the study more focused, office buildings are taken as the only building typology under consideration, as they are considered to be the largest energy consumers in the buildings sector (McCarthy and Mihlmester, 1997).

Mainly –and as it has been clarified in the literature review chapter- the four major factors that have a great impact on the users thermal comfort and therefore the space's energy consumption are: the climatic data, the building's usage, the design data and finally the materials data. Since both the climatic data and usage data are determined by the research's aim, all of the variables categorized under these two major factors will be stabilized. On the other hand, analyzing and understanding all the variables categorized under the design data factor and examining materials with different U-values are considered as this research's main objectives.

NOTE: It should be clearly notified that this research is concerned about the thermal energy consumption; other consumptions caused by lighting, appliances or occupants are important too but are beyond the scope of this study and the researcher's specialty).

All objectives can be summarized in the following points:

1- Study and analyze the current architectural trends in office buildings.

2- Study and compare the thermal energy consumption in buildings with different orientations.

3- Determine the effect of both the opening to wall ratio and the aspect ratio on the thermal energy consumption of buildings.

4- Understand the effect of the U-value of the materials used in the external facades of office buildings on the thermal energy consumption.

5- Clarify some architectural and materials combinations that would participate in a radical reduction in thermal energy consumptions by trying different scenarios.

6- Determine the exact impact of every heat source on the thermal energy consumption.

CHAPTER 3: THE CASE OF THE UAE

3.1 UAE General Information (Facts and Statistics):

3.1.1 Location, Current Climate and Predicted Climate:

The 83,600 sq km Middle Eastern country lies between 22.0° and 26.5° N and between 51° and 56.5° E (UNFCCC, 2006). Being located in the Arabian Peninsula; the general characteristics of the UAE's climate resemble those of arid and semi-arid zones (Radhi, 2009). In the hot and humid summer -which stretches from April through September- temperatures in coastal cities such as Dubai can raise to about 48 °C with accompanying humidity levels reaching as high as 90%. On the other hand, winter -which stretches from November through March- witnesses a moderate climate with an average annual rainfall of about 120 mm per year over the period 1970-2001 (UNFCCC, 2006).

As a consequence of the current trend of increasing Greenhouse Gases emissions, atmospheric pollutions and urban heat islands, the coming years will witness many climatic changes worldwide. A study done by the Environment Agency of Abu Dhabi, the Ministry of Energy and other concerned parties in the UAE clearly shows that the country will witness a noticeable increase in temperature and a significant decline in precipitation levels by the end of the current century. The study ,which aims to predict the effect of the climatic change on the UAE ecosystems, shows that by 2050 the temperature in the UAE will be between 1.6°C and 2.9°C warmer than they were over the period 1961-1990 and between 2.3°C and 5.9°C by 2100 (UNFCCC, 2006). As these changes would negatively affect the natural environment by putting additional stresses on a variety of systems, the built environment will be affected too; buildings would consume more energy and emit more Carbon Dioxide into the atmosphere.

3.2.2 Demography and Economy:

The United Arab Emirates is one of the leading fast-developing countries in the Middle East that has achieved solid steps in sustainable economic growth and urban development. Since the union of the 7 Emirates in 1971, the country has undergone a profound transformation from undeveloped small desert principalities into a developed state with high standards of living (CIA, 2011). The country's economical and demographical growth -that followed the discovery of oil in the 60s of the previous century- has converted it into a center hub for regional trade and finance (Kazim, 2007).

The quality of life and the high GDP per capita have made the country a center of attraction for expatriates; experts and labors. This has led to a huge increase in the population and economical growth rate. Nowadays, and according to the CIA World Factbook, the country's population in 2011 is almost around 4,975,000 with 40,200$ average GDP per capita (CIA, 2011).

3.2 Energy Profile, Energy Consumption and GHG Emissions:

The UAE has access to almost 10% of the world's proven oil reserves and ranks fifth in the world in terms of natural gas resources (UNFCCC, 2006). Nowadays the UAE is a key player in the organization of petroleum exporting countries (OPEC) and is considered as a leading exporter of oil and natural gas worldwide (Kazim, 2007). Following the increase of oil and natural gas prices in the last decade of the 20^{th} century and first years of the 21^{st} century, the country has witnessed a remarkable economical and demographical boom. Despite of its several advantages, this boom has caused many environmental problems; depending heavily on the available cheap fossil fuel resource of energy together with rapid and increasing economic expenditure, huge architectural projects and high population growth rates, electricity generation has grown substantially and consequently fossil fuel consumption and CO2 emissions have increased tremendously (Radhi, 2010).

Beside the previously mentioned man made causes of the current uncontrolled increase of energy consumption and Greenhouse emissions in the country, some uncontrolled natural factors are participating in the dilemma and limiting the ability of finding fast solutions. As the UAE is located in an arid and semi arid climatic region, continuous cooling for all public and private facilities is a certain requirement. Keeping in mind that air-conditioning and refrigerating appliances require a large quantity of electrical power, the amount of energy needed to overcome this natural obstacle is enormous (Kazim, 2007). Another major natural factor that makes matters worse is the scarcity of water resources. To face this issue, the country is obliged to desalinate water for drinking and irrigation purposes (Kazim, 2007). As the daily water consumption per capita in the UAE is considered as one of the world's highest rates with around 300 liter/capita, the country is currently producing around 12.5% of the world desalinated water (Kazim, 2007). Water desalination consumes huge energy; a study shows that Fuel requirements for desalination are expected to raise from 9 million tonnes of oil equivalent (Mtoe) in 2003 to 16 Mtoe or nearly one-fifth of total primary energy demand in 2030.

The combination of the natural and man-made factors has made the UAE as one of the world largest energy consumer per capita. According to the US Energy Information Administration (EIA)(2011), the UAE total energy consumption in 2008 was around 3.25 quadrillion Btus and the total per capita energy consumption is around 703.3 million Btus. Compared with other countries, the UAE's energy consumption is four and two times more than EU countries and the US respectively, and the consumption per capita is about 6-and 9-folds greater than energy consumption per capita in the Middle East and the world (Kazim, 2007). Moreover, and as almost all of this energy is produced by the combustion of fossil fuels, the UAE is considered as one of the world's largest carbon dioxide emitters (Kazim, 2007). According to the United Nations Statistics Division, in 2007 CO_2 emissions in the UAE was about 135,540 thousand metric tons with around 31 metric tons per capita (UNSD, 2010).

3.3 Impact of the Global Climatic Change on Energy Consumption in the UAE:

While the country is devoting a lot of effort on finding solutions and alternatives that would mitigate the environmental problem of increasing energy consumption and GHG emissions rates, global warming and its impact on all aspects of life is a major obstacle that is confronting all the environmental attempts. As the coming years would witness a significant and unprecedented increase in air temperatures, all the energy sectors in the UAE will be vulnerable to huge environmental stresses that would increase their energy consumption. For instance: the projected previously mentioned 2.3°C or 5.9°C increase in air temperature by 2100 will certainly have a tremendous increase on cooling loads in the buildings sector. In Al-ain city, Radhi's study (2009) has clearly shown that the 5.9°C increase in temperature will be accompanied with around 23.5% increase in cooling loads. Moreover, the increase in sea and air temperatures will increase the energy consumed and GHG emitted from the country's power plants and desalination infrastructure. This would happen due to efficiency losses and forced reductions in outputs of the facilities which are designed for specific climatic conditions (UNFCCC, 2006).

3.4 Sectoral energy consumption and GHG emissions in the UAE:

In the UAE -and as all the other developed countries- the industrial sector is the largest consumer of energy and CO_2 emitter followed by transportation and buildings sectors respectively. Based on the United Nations Economic and Social Commission for Western Asia (UN/ESCWA) statistics, in 2004 the industrial sector has consumed around 44.90% of the total primary energy consumed that year followed by the transportation sector by 32.20% and the others sectors (buildings sector) by 22.90% (UN/ESCWA, 2008). Radhi (2009) addressed the CO_2 emissions by the different sectors in the UAE in 1999 based on statistics cited from world's resources institute. The results show that buildings directly emit around 4% of the total UAE CO_2 emissions. Moreover, 43% of the emitted CO_2 is produced by electricity generation plants and 45% by industry and construction. Though the previous numbers show that buildings are the least CO_2 emitter, the buildings' sector influence on all the other sectors should always be recognized and understood. On one hand most of the electricity generated is consumed by buildings and on the other hand most of the industries in the country are manufacturing buildings materials.

3.5 Buildings Sector Energy Consumption in the UAE:

In general, any economical boom is usually followed by a substantial increase in construction rates. As the UAE is considered as one of the world's fastest developing countries in the last decade, the construction boom was totally mind boggling. Realizing two important facts: first is that buildings consume a lot of energy -not only during the period of use but also during construction and demolition-, and second the effect of buildings sector on all the other sectors, the increasing ratio of energy consumption in the country can be effortlessly understood and hence Radhi (2009) results about CO_2 emissions are totally logical. Regarding the buildings subsectors, Dubai Statistics Center (DSC) (2009) shows that commercial buildings in the country consumed 145,845 energy units compared to 8,791 unites consumed by the residential subsector in 2009.

3.6 Causes of Building's Energy Consumption Increase in the UAE (Architectural, Social and technological factors):

The UAE's economical boom has affected all aspects of its residents' life. The rapid development has forced the people in the city to change their buildings and lifestyle in order to adapt to the new requirements of modern life. Architecture in the city has been affected negatively. New high rise towers have replaced the old vernacular small buildings that were designed with huge thermal mass, small openings, local materials and many other architectural features that take in consideration all the environmental aspects. As a result and according to AbulNaja and Elsheshtawy (2001), contemporary buildings in the country consumed almost six times more energy that traditional buildings in 2001. Moreover, many changes in the lifestyle and daily routines have occurred. A major change that is causing a significant increase in buildings energy consumption is the extension of daily working hours till 5 or 6 pm. Office buildings now need to be cooled for longer periods and during the hottest hours of the day. As a result and according to Dubai Electricity and Water Authority (DEWA)(2011) the high electrical peak hours in Dubai are between 12 noon and 5 p.m. during summer season. Finally, technological aspects increase the problem. Most of the buildings are being equipped with instruments and electrical machines that produces huge amount of heat raising the internal temperatures and therefore more cooling energy is required.

<u>3.7 Glass Facades Trend in Dubai:</u>

In the last few years, fully glass buildings became an icon in the UAE in general and in Dubai in particular. Architects and consultants in the city have always defended their excessive and irresponsible use of this trend by reminding of its many architectural and psychological benefits such as providing daylight, view, solar gain and last but not least regulating the biological clock in the body. As most of these benefits are essential in architectural designs, architects in the city should understand that many long term environmental problems will accompany this excessive use affecting the public health and economy. Therefore a balanced use of the material and a responsible choice of its properties should always be considered. Unfortunately, that isn't the case in Dubai. In a study that aims to investigate the use and misuse of glass as a building element in the Gulf region with more emphasis on Dubai, Aboulnaja (2006) examined 15 fully-glazed office buildings in the UAE. The study started by analyzing the properties of the glass used in these buildings (i.e. thickness, reflection, and relative heat gain) and ended up with assessing the daylight factor (DF) and daylight level by using Ecotect software. The results showed that the material is being misused in most of the buildings selected resulting in a tremendous DF and DL that are far beyond the recommended international levels.

3.8 The UAE Strategies and Initiatives toward a Sustainable Built Environment:

Fortunately, the UAE is one of the first countries in the region that realized the environmental, social and economical benefits gained by the reduction of energy consumption and GHG emissions, and hence many strategies and initiatives were issued and implemented. In general, any attempt to tackle the environmental problems of increasing energy consumption and GHG emissions should concentrate on two major patterns: First, regulations to replace fossil fuels with renewable and sustainable sources of energy and second, actions to protect the natural resources from depletion (Radhi, 2010). As the country is suffering from a severe scarcity of natural resources, most of the government efforts are devoted to adopt effective policies and strategies that aim to substitute the current fossils fuel electricity power plants with new innovative methods that depend on clean energy resources. As a result, the previous years have witnessed huge investments in sustainable and renewable energy projects. For instant, three major projects are planned to be completed in the coming few years: a $2 billion hydrogen-fueled power plant (Radhi, 2010), a $350 million solar power plant (UNFCCC, 2010) and finally a $20 billion nuclear power plant (ENEC, 2010). Despite the intense moral and environmental debate about the latter project due to its difficult-to-get-red-of radioactive wastes, these promising projects -when completed- would manage to achieve a significant reduction in the UAE Greenhouse Gases emissions and therefore alleviate many environmental dilemmas.

Beside the attempts of providing clean sources of energy, the country has also dedicated a huge amount of its budget on supporting environmental organizations, researches and projects. Such effort has given the country a good international environmental reputation that was crowned with the choice of the capital Abu Dhabi to host the International Renewable Energy Agency (IRENA) (2011) headquarters. This important success was built upon many tremendous and remarkable achievements accomplished by Masdar organization -wholly owned subsidiary of the Abu Dhabi Government-owned Mubadala Development Company-. Masdar which is aiming to become an international leader in renewable energy has planned and developed many outstanding projects. The most noticeable one is Masdar city which is planned to be the world's first carbon-neutral, zero-waste city (Radhi, 2010). Despite the many obstacles that are facing the designers and contractors, the city is considered as an exceptional exemplar of sustainable built environment development due to the many innovative environmental techniques its design comprises.

Realizing the fact that was discussed in the UAE energy profile section about building's sector energy consumption and its participation in raising consumption ratios in other sectors, the government has recently adopted many buildings' codes and regulations aimed to reduce energy consumption in all buildings' sub-sectors. Unfortunately, these essential steps -which started by Dubai Municipality enforcing Decree 66 code regarding energy saving requirements in 2003 and Abu Dhabi establishing the Urban Planning Council (UPC) to enforce buildings regulations in 2007- were late (Hammad and Abu-Hijleh, 2010). As the majority of the buildings stock in the UAE were built and designed prior to the setting of these environmental controlling regulations, a high electricity usage per capita is noticed in the country; the poor environmental design of the buildings combined with the harsh weather have always forced buildings owners to depend on HVAC equipments and artificial lighting instead of natural ventilation and lighting in order to achieve the desired comfort. However, a closer look at the released codes and initiatives clearly shows that the country has already accomplished many profound steps toward achieving sustainable policies. If implemented by all the parties involved in the buildings and construction industry, these steps would result in a huge reduction in the UAE building's sector energy consumption.

To recognize how these steps can achieve the country's environmental goals, understanding and implementing these initiatives and codes is an essential need. Built on many international standards, the UAE regulating parties have developed many buildings codes -such as the efficiency, thermal insulation, energy and the green buildings codes- (Radhi, 2010). Moreover, both Dubai and Abu Dhabi have launched many sustainable initiatives regarding green buildings. On October 24th 2007, a resolution regarding implementing international green buildings standards was released by the ruler of Dubai. The impact of this resolution –also known as the sustainable vision of Dubai- is expected to achieve a noticeable saving in Dubai buildings' energy consumption as the following numbers: 30% for cooling and air-conditioning, 9% for artificial lighting and finally 6% for heating water (Gulf news,2007). In Abu Dhabi, Estidama -the first initiative of its kind in the middle east- was launched 2 years ago by UPC with many sustainable goals. The initiative which focuses on the built environment is aimed to improve the quality of life for the Emirate's residents while preserving the capital physical and cultural identity. Moreover, one of the initiatives essential tools is the Pearl Rating System which is considered as the world's first framework for sustainable design in hot and arid climatic regions.

CHAPTER 4: METHODOLOGY

4.1 Method Selection:

For selecting a proper methodology that would achieve the main research's aim, the researcher started with determining all the parameters that would be studied in the research together with analyzing and comparing the different methodologies that have been used by other researchers to achieve similar aims.

4.1.1 The research's parameters:

The following parameters will define the final results and would either be stabilized or examined to know their actual effect:

A- Constant parameters:

1- Climatic Data: The outside environment has a major impact on the users' thermal comfort inside the built environment as it is impossible to achieve full thermal insulation, not to mention the aesthetical and wellbeing factors associated with openings and glass. This research is studying building in hot and humid climates where the harsh environment of high temperatures, high relative humidity and high sun radiation is a major obstacle for architects and researchers. Since achieving a balance in the design between the environmental, aesthetical and wellbeing factors in such environments isn't an easy task, this research would help designers in the complicated process of achieving the desired balance. For this study, Dubai –a city with hot and humid climate almost every day in the year- has been selected to be the city in which the research was carried out. Climatic data of Dubai was to be used.

2- Building Usage Data: The usage of any space determines how intense the human activity is, the kind of appliances used and the lighting level required. All of these "internal heat gain factors" affect the thermal performance of any space. For this research, office spaces -which have been found to be the hugest energy consumer in the non-domestic buildings subsectors- were chosen to be studied.

B- Variables:

3- Design Data: The decisions taken in the design process have the greatest impact on buildings' energy performance. Both architectural and mechanical designers have to ensure that achieving an environmental design that guarantees users comfort is a priority. As mechanical design is out of the researcher's specialty, the mechanical design in the study would be stabilized. For architectural design the following variables were to be studied:

1- Orientation: The orientation of a building is the first decision architects make in the design process. Therefore it has been decided to be the first variable to be studied. Office spaces with different orientations were to be examined.

2- Window-to-wall Ratio: Designing office buildings with big glass facades has been an international trend that represents modern architecture. However, depending on this technique in hot and humid environments can be considered as an "environmental crime" due to the significant increase in cooling energy they cause. In this research, different window (glass)-to-wall-ratios were to be examined to understand their exact impact on energy performance and help architects in understanding their ethical environmental responsibility.

3- Aspect Ratio: While designing the internal spaces, designers should understand that the length of the external façade which faces the external environment compared to the depth of the space designed plays a great role in determining the energy consumption. To examine how this important factor affects the amount spaces consume energy, different aspect ratios were to be examined.

4- Materials Data: The selection of the materials used in the building's facade is a major step in the design process. Based on personal experience, studies and observations, selection of the materials is usually done according to aesthetical and economical criteria. Such unstudied and irresponsible criteria of selecting materials cause an increase in energy consumption. Decision makers should understand that besides the moral values, selecting environmental materials can achieve economical benefits on the long term as they reduce the amount of energy consumed and therefore results in lower electricity bills. Construction materials can be divided into the following:

1- Opaque constructions: The opaque constructions which include all the materials used in the external walls, internal partitions, internal ceilings, roofs, ground contact and doors should achieve the maximum thermal insulation. In circular no.197, Dubai Municipality has specified five construction systems that should be used in all buildings. However these construction systems don’t have similar U-Values (U-Value is a measure of air-to-heat transmission (loss or gain) due to the thermal conductance and the difference in indoor and outdoor temperatures). Three of these systems were to be examined. This examination results are to show and clarify the effect of opaque materials U-Values on the energy consumption.

2- Transparent Constructions: Though this part of the building's envelope has a negative impact on its environmental performance, its existence is a nonnegotiable necessity due to its various aesthetical and wellbeing advantages. Worldwide, different glass techniques and facades has been developed and used. In this research three different glass systems and materials with different U-values were to be examined. The results obtained are to help architects to understand the importance of the materials used in the transparent constructions.

4.1.2 Advantages and disadvantages of the different methodologies used:

As it was clearly shown in the previous chapter, the major three methodologies used in achieving similar aims were observation and monitoring methodology, experimental methodology and finally computer simulation methodology. Understanding the advantages and disadvantages of each one of these methodologies would justify the method used in this study:

1- The Monitoring and Observing Methodology: This methodology studies and analyzes a real building that has already been constructed in a real environment. All the climatic, usage, design and materials factors that affect the buildings energy performance have been determined by the architects and the decision makers involved in the design process; researchers influence on these variables is minimal. Therefore, all the results that are obtained from this methodology are reliable. Furthermore, as the results are directly obtained from the monitoring instruments where no equations or softwares are involved, the accuracy is high; unintentional errors and researchers' objectivity are limited. On the other hand, this method has many disadvantages. Monitoring a building consumes a lot of time and money; for accurate results expensive sensors and instruments should be used for the monitoring process that extends for at least one year. And as this method studies a limited number of buildings, the results are usually very specific and can't be generalized in many cases. Moreover, technical problems with the devices used can cause miscalculations. Furthermore, the users of the space monitored might not feel comfortable with all the instruments positioned in their working spaces and might not cooperate with the researchers. Finally, any changes of the buildings parameters or surrounding environment – i.e. a new high rise building erected close to the studied case- would cancel all the data obtained from the long expensive monitoring and observing process.

2- Experimental Methodology: In this kind of researches a small mockup that represents the building is constructed and tested under a real environment, as a result the outcome is reliable and accurate. The mockup flexibility gives the researcher the opportunity to try several inputs and observe their effect in the output therefore it is considered as the best method to try a new hypothesis; any innovative design idea or pioneering material that would reduce buildings' energy consumption can be examined under real circumstances to judge their performance. On the other hand –and as the previous method- this methodology consumes a lot of time and money; a lot of funds should be available in order to construct the experiment's model and monitor it for a long period. Moreover in some cases, it's very difficult to build a model that mimics exactly a real building therefore some factors are neglected or provided by the researcher; as an example, all the usage data would be inserted by the researcher since it's impossible to provide users inside the experimental model. Accordingly it's very important that a well-experienced researcher runs the facility and accurately registers all the data and information obtained from it. A final disadvantage, mistakes in calibrating the facility and researcher's bias can lead to mischief calculations.

3- Computer modeling Methodology: This methodology is the fastest method that can predict any building (simple or complicated structures) energy consumption and carbon dioxide emissions. The tools being used in this methodology - computer softwares- are learnable and available in cheap prices compared to the other methods. Though it has always been claimed to be inaccurate and unreliable, the companies that creates the softwares always work on improving the accuracy of the results seeking more clients and financial profits. Another advantage, using this kind of cheap and easy method gives the researchers the opportunity to examine different data inputs and different locations and climates which would help them in understanding the exact impact of each variable on the final result. However, in order to get accurate results, all of these data should exactly mimic the real environment variables. Neglecting or manipulating these variables -which are very complicated to mimic in some cases (i.e. human activities) - can lead to wrong estimations and calculations and therefore wrong energy consumption predictions. Moreover, all the climatic data should be updated regularly for more accuracy. Since the results are obtained from formulas and equations created using other methodologies such as monitoring or experimental methodologies, results can still be considered as not always reliable. Eventually, computer modeling is still a virtual world. People can't feel it with their senses and there is no evidence that the predicted performances will be happening.

4.1.3 A quick comparison between the different methods:

After understanding the advantages and disadvantages of each method, a quick comparison between them would help in justifying the method used in this research. The comparison was done according to the following criteria:

1) Economically: the amount of funds needed in the computer modeling method is neglected compared to the huge amounts of money needed for getting the instruments in the observation method and building the mockup model in the experimental method.

2) Time Consuming: Observation and experimental methods consume a lot of time compared to the time used in the computer modeling method.

3) Accuracy: The results obtained from the observation method are the most accurate among all the other methods. Computer modeling is considered as the least accurate method. However and as mentioned above, programming companies are developing the softwares and the results are becoming more and more reliable.

4) Flexibility: In the computer modeling method, changing the variables and the data that need to be examined is easy. Changing variables in the experimental method can be done but not as easy as in the simulation method. Changing the variables in the observation method is very complicated and quite impossible in some cases.

5) Objectivity: The researchers' influence in the observation method can be neglected compared to the other methods where the researchers determine which factors should be stabilized or examined.

6) Knowledge provided: The output of the experiments and computer modeling methods provide the researcher with a lot of information about the different variables studied. Observation method output is specific to the buildings studied and can't be generalized.

7) Experience needed: The observation and experimental methods requires experienced researchers to observe and monitor the equipments. In computer modeling, the

researchers only need to know how to use the computer software which is usually easy and learnable.

4.1.4 The method selected:

Based on the previous comparison, the different parameters to be studied and the nature of this research, computer simulation method was deemed most appropriate for this study. It's easier to control and examine all the different research parameters in the computer modeling method. Moreover the researcher doesn't have the time, funds or experience required for the other methods. This approach is complimented with literature review that has been covered in the previous chapter. The review provided the researcher with a broader knowledge about buildings energy consumption and the different factors that affect them.

4.1.5 Computer Modeling: The Best Method to predict Energy Performance in the design stage:

As it is well known among all the people involved in buildings science, reduction of energy consumption can be achieved by increasing thermal insulation, decreasing air leakage, decreasing lighting levels, designing shading devices and finally installing efficient HVAC systems and appliances and maintaining them. Applying all of these environmental techniques in a design that takes in consideration the aesthetic and economical values, achieves the desired sustainable design. However in order to achieve this, architects require a method to predict the energy performance during the design process. These predictions can be either done manually or by using computer programs. Usually most of the calculations that are done manually are based upon peak summer hour and peak winter hour or on predictions based upon data obtained from an experimental or observation method. Thus, they are usually not accurate and lead to over-sizing of the equipment which consequently leads to over heating or over cooling. On the other hand, calculations done using modeling softwares provide the engineers with almost accurate estimations. Therefore, modeling is considered as the most efficient tool to predict the thermal performance of buildings in the design process -only if the modeling and the input of the data was done precisely-.

4.2 The Selection of the Computer Simulation Program:

Over the past 50 years, many buildings energy programs have been released and used by the building energy community. The last decade has witnessed an unprecedented improvement in the quality and depth of analysis capability of the different tools. At present, there are many reliable programs that vary in cost, accessibility to the users, program's structure and the assumptions and data used for the predictions. According to Crawley et. al. (2008), the major building energy simulation programs are BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREAL, Tas, TRACE, and TRNSYS. Choosing one of these computer programs to do the required modeling and simulation was done according to the following criteria:

- Hourly basis simulation: As the buildings thermal loads vary hour-by-hour, simulation tools that are able to model energy flows on hourly basis are preferable.
- Thermal mass effect: The type of construction and properties of materials have a major effect on any building ability of absorbing and reflecting heat. The program that would be used should be able to give the user the flexibility of choosing the construction systems and the materials used and their thermal characteristics.
- Part load performance: Most of the mechanical systems rarely experience full load operation conditions. Selecting a computer program that gives its user the opportunity to determine the days and hours in which the mechanical system would be used is essential.
- Updated weather data: The weather data used in the simulation should be updated regularly. Moreover it should be obtained from long term and reliable weather statistics.
- Reliability and accuracy: The software used should be reliable with validation certificates. Moreover it should be already used by other scholars in similar research.
- Price of the software: The software should be available in cheap prices due to the researcher limited funds. Softwares companies that offer cheap versions for students are preferable.
- Ease of use: The software should be easy to use for a person with an architectural background. User guide and tutorials should be downloadable and easy to follow and implement.

- Growth potential of the software: The software must be used by the major companies in the market. Moreover it should be growing and developing to be one of the five most used energy simulation tools worldwide.
- Level of support provided by local firms: It is preferred if the software is being used by some of the major local firms. Any help or support can be requested if needed. Moreover the fact that the biggest local firms currently depend on that software proves that it's adequate for the city's climate and the results would be more reliable.

Based on the previous criteria together with consultations with professionals in the field, Integrated Environmental Solution – Virtual Environment IES-VE© was chosen. The software fulfills all the previous criteria: Simulations using this software can be performed on hourly basis and it gives its users the opportunity to input the construction systems, buildings materials and operation timing. Moreover the user has the opportunity to define the usage and the location. What's important is that the software interface is very easy and learnable and is currently used by many firms in the region such as Atkins. Last but not least, thought the full license version of the software is expensive (between 3000 and 3500£), a student license version can be purchased by only 50£.

In addition to all the previous factors, the decision was made built on reviewing some of the papers that compare the different simulation tools. In a study called "Contrasting the capabilities of building energy performance simulation program", Crawley et. al. (2008) compared the previously listed 20 major simulation tools according to specific criteria. The study which was supported by the United States Department of Energy, University of Strathclyde and University of Wisconsin (Non-biased parties) has nominated IES-VE to be one of the easiest and most accurate simulation tools currently available. In another study, Attiea et. al (2009) reviewed the current simulation tools. The researchers adopted a survey method that included engineers and architects. According to the research's result, both DP and IES-VE plug in received the highest percentage of agreement from both groups –architects and engineers-. That clearly shows that the software generates reliable results and can be easily used by researchers from architectural backgrounds.

4.3 Integrated Environmental Solutions – Virtual Environment (VE):

The software -which has been provided by Glasgow-based Integrated Environmental Solutions (IES) Ltd since 1994- is a very strong tool for energy professionals as it provides them with a range of design oriented building analysis. The easily used software allows the designers to create or import models that represent real or under-design buildings. The users can easily modify the design, determine the location, specify the usage of the spaces, specify the materials and last but not least determine the HVAC systems. All of these abilities help the design team to integrate sustainable and environmental solutions early in the design process where it belongs.

The software incorporates the following utilities: Model builder, Energy, Solar, Lighting, Cost and Value, Egress, Mechanical and CFD. Each utility is specialized to perform a specific task. In this study, the researcher had to depend mainly on both the Model Builder and Energy utilities. In the model builder utility, all of the studied spaces had to be modeled -no models were to be imported from other softwares such as Google SketchUp© or Autodesk AutoCad©-. On the other hand, all of the model thermal parameters and construction data were to be inserted in the energy utility.

<u>The Software Validity:</u> Based on information cited in Katanbafnasab (2010), the software has been validated by the following bodies:

- CIBSE TM33
- IEA Task 12:
    - Envelope BESTEST.
    - Empirical.

4.4 A survey performed to build an office spaces that represents offices in Dubai:

In order to build simulation models that represent office spaces located in high-rise glass-façade buildings, a survey of office spaces in Dubai was performed. The survey studied all the area located between World Trade Center roundabout and Burj Khalifa as shown in Fig. 4.1. The 85 towers existing in the surveyed area were separated according to their main usages. 24 of them were found to be either offices or mixed-used towers. The drawings (Architectural and Mechanical) were requested from Dubai Municipality-Buildings department and around 19 of them were obtained. As 7 of the 19 cases were even missing some essential drawings, still under construction or were designed as open spaces plans and were not divided into separate units yet, 12 of the 19 cases were included in the survey. Each case was analyzed in order to get the following data:

- The number of office's units in the building. (Obtained from architectural drawings)
- Shapes of the offices (i.e. some offices are located on a corner and others only have one external wall) (Obtained from architectural drawings).
- The area of the offices' units (Obtained from architectural drawings).
- The external wall length of every unit (Obtained from architectural drawings).
- The area of the external façade (Obtained from mechanical drawings and was calculated from architectural drawings in some cases).
- Glass opening Area (Obtained from mechanical drawings and was calculated from architectural drawings in some cases).
- Opening to external wall percentage and Aspect ratio. (Calculated based on the data obtained from the previous points).
- The materials that have been used in some of the cases "new buildings" (Obtained from mechanical drawings).

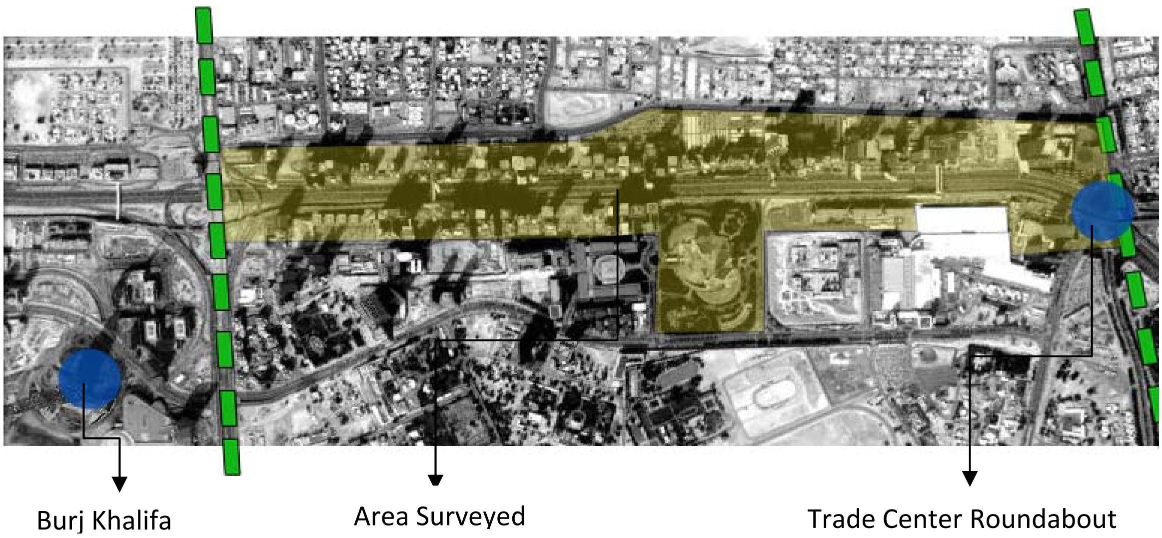


Figure 4.1: *Area surveyed*

All the data obtained from the previous survey was inserted into an Excel sheet. The offices units were separated into two major categories: 1-offices that have one external wall and 2: Offices that have 2 external walls or "corner offices". In both cases the number of office spaces, the average area, average aspect ratio and average opening-to-wall ratio was calculated. As these numbers were obtained from the survey, it was easy to build the simulation models that represent the majority of the office spaces located in the surveyed area. The final results of the survey are presented in the following schedule (Table 4.1). For all the results and data collected refer to (Appendix 1).

Table 4.1: Survey final results

	The Number of Offices	Total Area (sq. m.)	Average Area (sq. m.)	Average External wall Length (m)	Average Rough Opening (sq.m.)	Average Window Opening (sq.m.)
1 External Wall Offices	182	27420	150.7	16.4	43.9	**29.8**
2 External Walls Offices	567	93371	164.7	32.3	86.8	54.9

Note that in all the cases the drawings were obtained in PDF format. They were inserted into Autocad and scaled in order to get all the areas and measurements. That means that the results might not be 100% accurate. However each case was measured around 2 or 3 times in order to get precise results. Moreover it should be taken in consideration that the opening ratio includes all the mullions and framing as it was very difficult to obtain their total area in each case. A last note, these statistics were done according to the original architectural plans; any changes in the spaces done by the users were not considered.

4.5 Modeling and simulation process:

After getting data for the base cases which represent office spaces in Dubai, research matrix was to be set and the different scenarios were to be modeled and simulated to get the results. Finally, the modeling and simulation process were done according to the following steps:

1- Building the offices modules based on the survey results.

2- Creating thermal and construction templates that specifies the following (Templates are explained in the next chapter):

- Thermal weekly and daily profiles which describe the time variation of thermal input parameters.
- The time of HVAC equipments operation in addition to cooling and heating setpoints.
- HVAC system data (i.e. cooling mechanism, system's efficiency, generators' fuel and HVAC air supply condition).
- Internal gains (i.e. lighting, users and appliances).
- Air exchange mechanisms.

- Properties of the opaque and transparent materials.

3- Assigning thermal templates created to the modeled spaces.

4- Choosing a location and importing its weather data.

5- Running the simulation.

6- Viewing results.

7- Modeling the different scenarios determined by the research matrix (elaborated more in the next chapter).

8- Repeating all the previous steps for each scenario and recording the results.

9- Comparing and analyzing all the results obtained from the different scenarios.

Summary:

After defining the research's main aim and determining the objectives, the researcher chose computer simulation method to achieve the aim. The choice was built on the parameters of the research and the review of previous papers. Moreover, the simulation tool was chosen according to a criteria set by the researcher. The office modules were built based on a survey performed in Dubai. The simulation was done and the results from the base case were obtained. Finally changes to the model and the materials were done according to the research matrix and simulation was performed again for each case. Results were analyzed and compared. Fig 4.2 simplifies the process. Models data and simulation matrix are viewed in the following chapter.

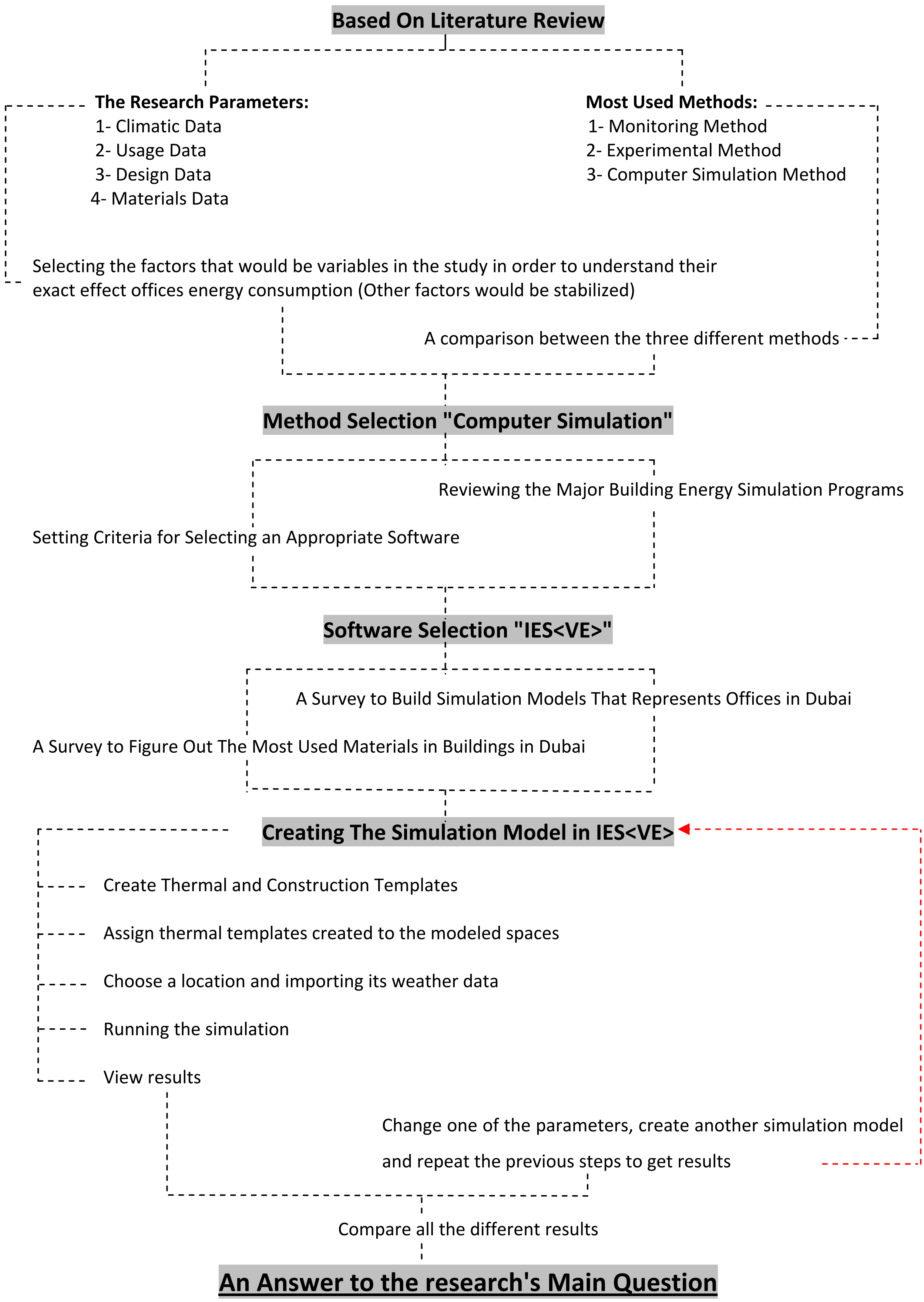


Figure 4.2: *A summary of the research's process*

CHAPTER 5: BUILDING THE SIMULATOIN MODELS

Introduction:

After determining the aim and objectives, the previous chapter described the steps followed by the researcher to get evidence and results that inform and support the research answer. As it was described in details, these results and evidence were to be obtained from a long process of modeling office spaces based on a survey performed in a city with hot and humid climate, creating a virtual environment that mimics the real one and finally running the simulation in a validated computer program specialized in calculating energy performance of buildings. Before writing down all the results obtained from the research process, it is essential to present all the data and numbers that were set for the different research's parameters due to their major impact on the final results. Knowing that these numbers were obtained from standards databases, a validated computer program and an accurate long survey ensures for other researchers and readers that the results obtained are reliable. Besides presenting the data used, this chapter sets the research's matrix and specifies the different scenarios that were modeled and simulated. (It is always important to remember that this research is only studying the thermal energy consumed by HVAC systems. Other consumers of energy such as lighting energy were not studied in this paper as it is out of this research scope of work. Further studies that include lighting energy consumption will support this paper).

Parameters of the offices modeled based on the survey will be presented first, followed by all the data that were used in the other different scenarios:

5.1 Parameters of the base cases IES<VE> files:

5.1.1 Assigning Weather Data:

The weather data in IES<VE> are obtained from ASHRAE weather Database©, 2005. The weather data file of Dubai international airport was chosen. From the weather file: The longitude and latitude of the chosen location are 55.33° E and 25.25° N respectively, the altitude is 5 meters above sea level and the ground reflectance is 0.2. From the terrain type category, city terrain type was selected. (You may refer to Appendix: 2 for graphs that illustrate Dubai's sun bath, dry-bulb and wet bulb temperature, solar altitude, solar azimuth, direct radiation, relative humidity, wind speed and finally cloud cover.)

5.1.2 Usage Data:

Based on the research's aim, the modeled and simulated spaces are offices. In the computer program IES<VE>, the usage of any space can be determined by two major tabs built inside the ApacheSim in the software: 1- Profiles utility 2- Heat gains utility.

<u>- Operation profiles:</u>

As explained in the software's tutorials downloaded from its "help menu", The APpro (Apache Profiles Database) utility inside the ApacheSim enables the users of the software to describe the time variation of thermal input parameters. To elaborate more; by using this important utility, the user of the software can specify the timing plant equipments are operated, modulate internal and external heat gains and define time-varying set-points and supply temperatures. There are two types of profiles; modulating profiles and absolute profiles. In the first type -which take the form of a time series of value in the range 0-1-, users modulate inputs such as gains and the time equipments are operated. On the other hand, the second type is used to specify time variation of variables such as set-points and it takes the form of a time series of a physical variable (i.e. temperature). For this study, the following profiles were created or imported from a database of profiles built inside the software:

- Modulating Profiles:
    - [Mod] Always on (100%)
    - [Mod] 7am to 7pm weekday working no lunch (7TO7NL)
    - [Mod] 8am to 6pm weekday working- with lunch break (8TO6)
    - [Mod] 9am to 5pm weekday working- no lunch (9TO5NL)
    - [Mod] 9am am to 5pm weekend working- with lunch break (9TO5)
- Absolute Profiles:
    - [Abs] - [15]

Note that the usage of these created profiles will be elaborated later on in this chapter. (You may refer to Appendix:3 for graphs that represent the different created profiles.)

<u>Internal and external sources of heat:</u>

In the second utility, the users of the software can determine all the internal and external sources of heat. Moreover the software gives its user the ability to determine the parameters of each source. In this study, three sources of internal heat were determined:

Lighting, people and finally computers. For lighting, the researcher chose fluorescent lights to be used in the spaces created. The following values and data were entered: a maximum sensible gain of 15 W/m^2, a power consumption of 17 W/m^2, a radiant fraction of 0.45, electricity as the source of energy and finally a "7-7 no lunch" weekly profile. For the second source of internal heat –People- the following values and data were entered: a maximum sensible gain of 90 W/person, a maximum latent gain of 60 W/person, an occupancy density of 10m^2/person and finally a "9-5 with lunch" weekly profile. For the third and final internal source of heat –computers-, the following data and values were entered: a maximum sensible gain of 10 W/m^2, a power consumption of 10 W/m^2, a radiant fraction of 0.22, electricity as the source of energy and finally a "9-5 no lunch" weekly profile - People tend to leave their computers on during their lunch breaks-. For external sources, Infiltration was assigned to be the only external source of heat. A maximum air change rate of 0.25 ach was assigned and a "on continuously" profile was chosen. Note that all of these values were obtained from the IES<VE> help menu which is built on ASHRAE standards.

Internal heat gain values are presented in Table 5.1, while Table 5.2 presents the values entered for the external sources.

Table 5.1: Internal gains of heat

Type	Max. Sensible Gain	Max.Latent Gain	Occupancy	Max. Power	Radiant Fraction	Fuel	Variation Profile
Fluorescent lighting	12 W/m^2	-	-	17 W/m^2	0.45	Electricity	(7TO7NL)
People	90 W/m^2	60 W/per.	10m^2/per.	-	-	-	(9TO5)
Computers	10 W/m^2	-	-	10 W/m^2	0.22	Electricity	(9TO5NL)

Table 5.2: External gains of heat

Type	Max. Flow	Unit	Variation Profile
Infiltration	0.25	Ach	On continuously

5.1.3 Design Data:

- Architectural Design Data:

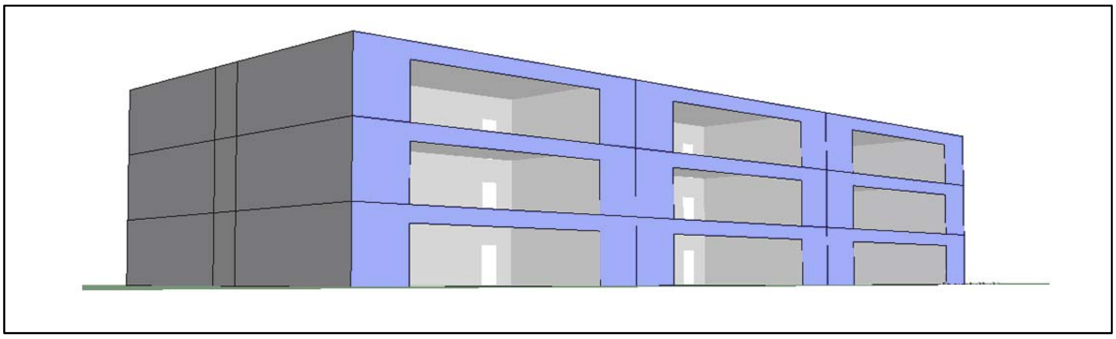
Based on the data obtained from the survey mentioned in the previous chapter, two models that represent offices in Dubai were created and simulated. The architectural design data of these two models is presented below:

1: Office Module Prototype 1 (1 external wall offices) (P1):

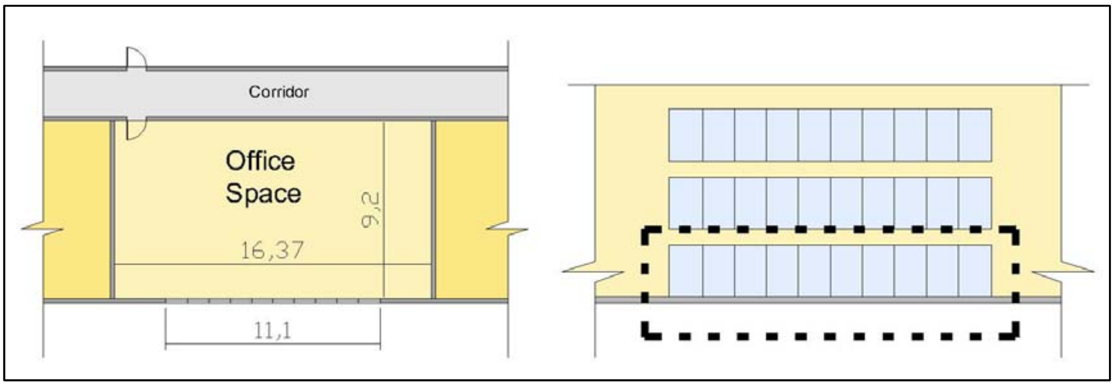
This kind of offices represents around 25% of the total offices spaces studied. As table 4.1 showed, the average area of a single office space (prototype 1) is around 150.7m^2 where 16.4m is the length of that external façade. The area of the external façade that faces the outside environment is 43.9m^2 with 29.8m^2 opening. Based on this information, simulation model 1, shown in Fig. 5.15 was developed.

Summary:

Dimensions: (L: 16.37m x W: 9.2m x H: 3.5m). Opening's Height: 2.7m. Opening length: 11.1m.



(A)



(B)

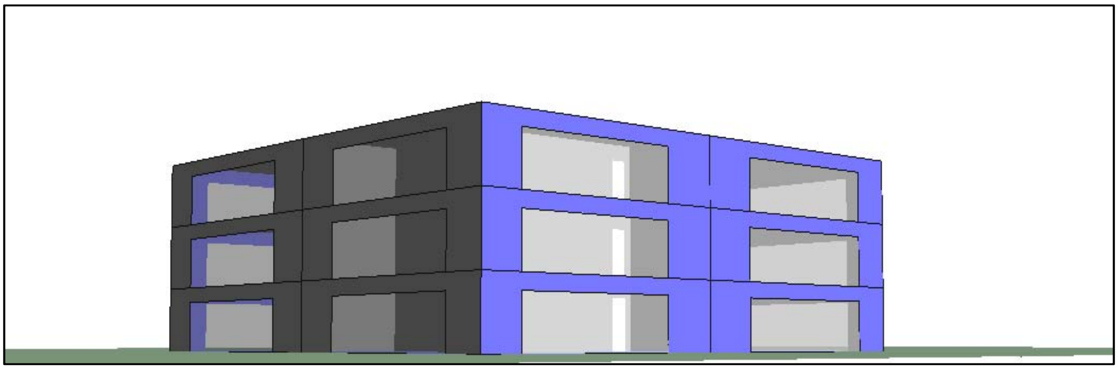
Figure 5.1: *Office module (prototype 1). (A) A perspective view. (B) Plan and Elevation.*

2: Office Module Prototype 2 (2 external wall offices or corner offices) (P2):

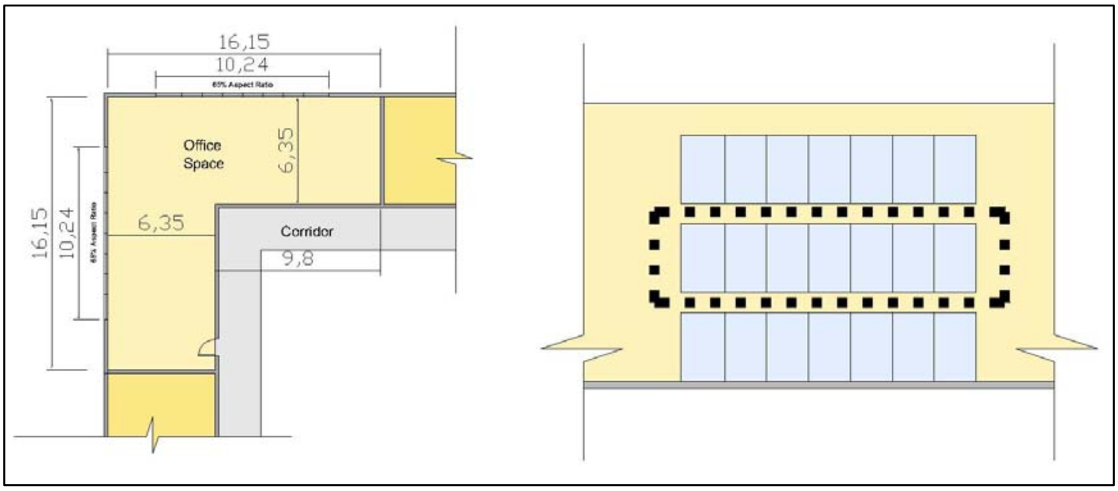
This kind of offices represents around 75% of the total offices spaces studied. The average area of a single office space (prototype 2) is around 164.7m^2. 32.3m is the length of the external façade. The area of the external façade that faces the outside environment is around 86.8m^2 where 54.9m^2 of it is an opening. Based on all of that, Simulation model 2, shown in Fig. 5.16 was developed.

Summary:

Dimensions: Corner Office (L: (2x16.15m) x W: 6.35m x H: 3.5m). Opening's Height: 2.7m. Opening length: (2x10.24m).



(A)



(B)

Figure 5.2: *Office module (prototype 2). (A) A perspective view. (B) Plan and Elevation.*

Mechanical Design Data:

As HVAC equipments consume the biggest portion of energy supplied for office spaces in Dubai, defining the systems used in the spaces modeled and manipulating their operational profiles is a critical step. Luckily, the IES<VE> software enables its users to create and control HVAC systems easily. In this study, the first step of creating a HVAC system was defining the time the system is operated and the heating and cooling set-points: "8 to 6 weekday working profiles" (8TO6) cooling and heating profiles were chosen and a constant simulation heating set-point of 19.0°C and a constant simulation cooling point of 23°C were assigned. The Second step was setting up a database of HVAC systems for the entire project: In the cooling systems tab built in the Apache Systems Window, "air conditioning system" was selected from the "Cooling Mechanism" list, "electricity" was selected from "Generator (or chiller) Fuel" list, chillers energy efficiency ratio was set to 5.0, cooling delivery efficiency was set to 0.64 and finally heat rejection pump and fan power was assigned as 10%. In the "Outside Air Supply" tab, "temperature from profile" was selected from the "supply condition menu" and "constant 15 absolute weekly profile" was assigned (HVAC supply air is supplied at 15°C). Knowing that software's default settings were used for the other tabs such as "Heating, Hot Water and Aux energy System tabs", the database for the HVAC system was ready. Finally, the following input was filled and assigned in the "Systems" tab: heating and cooling plant radiant fraction were set to 0.3 and 0.0 respectively, humidity minimum and maximum saturation percentages were set to 30% and 70% respectively and the minimum flow rate of the system's outside air supply was set to 3 ach (air change per hour) on a "8am to 6pm weekday working profile". After creating the HVAC system, it was assigned to the created spaces in the virtual environment. "Note that all of the numbers used were obtained either from ASHRAE standards or from consulting some professionals in the field".

5.1.4 Materials Data:

The final step before running the simulation was creating construction templates for the project. These templates define all the construction materials that are being used in the modeled spaces. In IES<VE> the construction templates are split up into two major categories: opaque and glazed constructions. Each category comprises multiple categories such as internal ceiling/floors, doors, internal partitions and external walls for opaque construction and external windows, internal windows and rooflights for the glazed construction. In this research some construction materials were obtained from the software's pre-built database while others were created by the researcher as the following:

<u>- Opaque Constructions:</u>

The researcher has ensured that the details and materials used in the spaces modeled represent the common construction practice in Dubai. In the construction circular no.179, Dubai Municipality has regulated and published five construction systems (DM,2010). Each system comprises a number of details for external walls, internal partitions, ground floors, etc. Dubai Municipality construction system type-5 was used in the base cases modeled (It has the lowest U-Value among all the other systems). The system comprises the following details:

1- External Wall:

In Construction system type-5 and as fig. 5.17 shows, the external wall consists of 5 layers. Arranged from the outside to the inside these layers are: plaster, 10cm aerated concrete block wall, thermal insulation layer, 10cm aerated concrete block wall and plaster. The materials used for each layer and their properties are illustrated in Table 5.3.

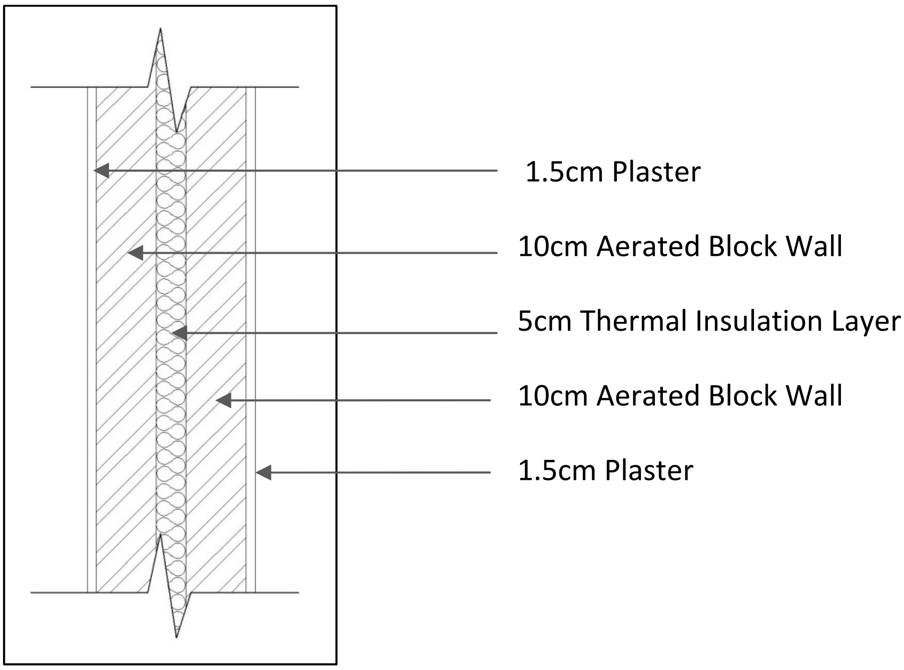


Figure 5.3: *Detail of external wall (DM Construction System 5).* **Source**: *(DM,2010).*

Table 5.3: Properties of materials used for the base case external walls

Material	Thickness. (m)	Conductivity W/(m.K)	Density Kg/m^3	Specific Heat Capacity J/(Kg.K)	U-Value $W/m^2.K$ (ASHRAE)
Plaster (Lightweight)	0.015	0.1600	600.0	1000.0	
Aerated Concrete Block	0.100	0.2400	750.0	1000.0	
Polyurethane Board	0.050	0.0250	30.0	1400.0	**0.3134**
Aerated Concrete Block	0.100	0.2400	750.0	1000.0	
Plaster (Lightweight)	0.0.15	0.1600	600.0	1000.0	

2- Internal Partitions: Internal partitions in construction system-5 and -all the other 4 systems- consist of 3 layers: plaster, 20cm block wall and another layer of plaster. Fig. 5.18 illustrates the detail while Table 5.4 presents the properties of the details materials.

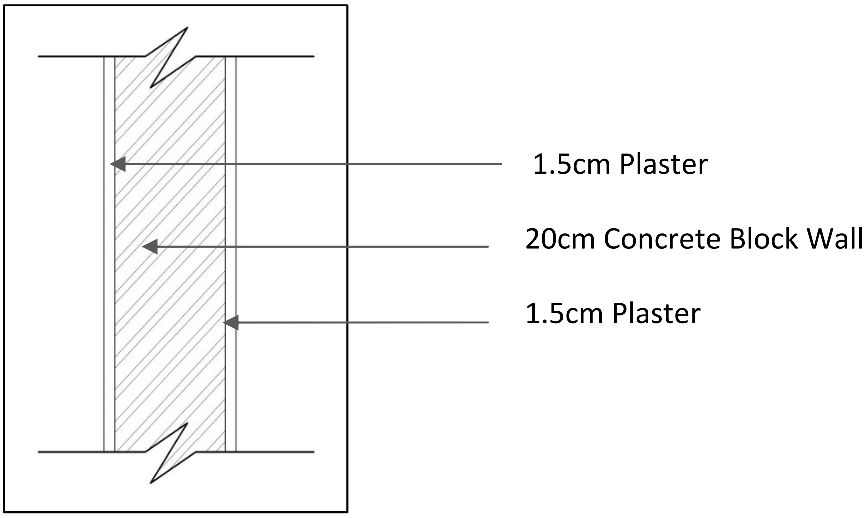


Figure 5.4: *Detail of internal partitions.* **Source**: *(DM,2010).*

Table 5.4: Properties of materials used for the base case internal walls

Material	Thickness. (m)	Conductivity W/(m.K)	Density Kg/m^3	Specific Heat Capacity J/(Kg.K)	U-Value W/m^2.K (ASHRAE)
Plaster (Lightweight)	0.015	0.1600	600.0	1000.0	**1.4243**
Common Brick HC-F4	0.200	0.7270	1922.0	837.0	
Plaster (Lightweight)	0.015	0.1600	600.0	1000.0	

<u>3- Internal Ceiling/Floors:</u>

The detail of internal ceilings in construction system-5 and all the other systems consists of 4 layers: plaster, R.C.C slab, cement sand mortar and tiles (arranged from bottom to top). In this study, the researcher has added one more layer of ceiling tiles "false ceiling" located 80cm under the concrete slab. Fig. 5.19 and Table 5.5 illustrate and present the layers and their properties.

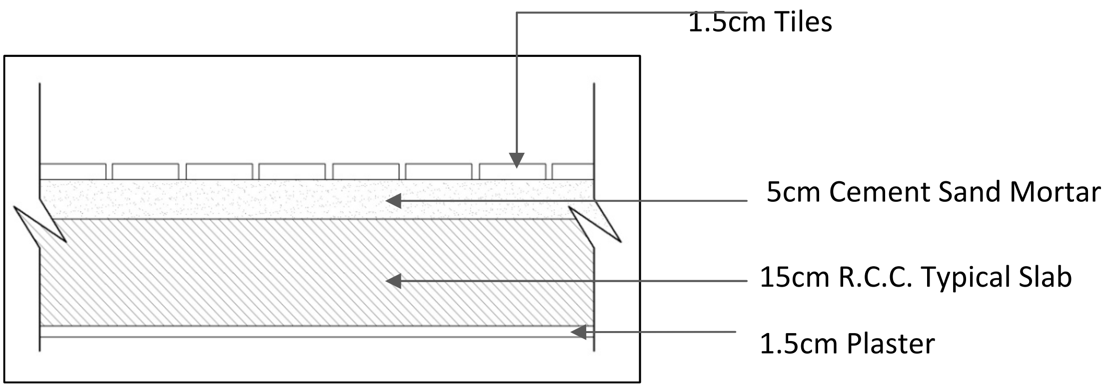


Figure 5.5: *Detail of internal ceilings/floors.* **Source**: *(DM,2010).*

Table 5.5: Properties of materials used for the base case internal ceilings

Material	Thickness. (m)	Conductivity W/(m.K)	Density Kg/m^3	Specific Heat Capacity J/(Kg.K)	U-Value W/m^2.K (ASHRAE)
Clay Tile (Ceramic Cover)	0.015	0.8400	1900.0	800.0	**1.2723**
Tile Bedding (Cement Sand Mortar)	0.050	1.4000	2100.0	650.0	
Reinforced Concrete	0.150	2.3000	2300.0	1000.0	
Plaster (Lightweight)	0.015	0.1600	600.0	1000.0	
Cavity	0.800				
Ceiling Tiles	0.010	0.0560	380.0	1000.0	

4- Doors:

The doors detail for all the construction systems is shown in fig. 5.20 and Table 5.6.

Table 5.6: Properties of materials used for the base case doors

Material	Thickness. (m)	Conductivity W/(m.K)	Density Kg/m^3	Specific Heat Capacity J/(Kg.K)	U-Value W/m^2.K (ASHRAE)
Pine (20%MOIST)	0.04	0.1400	419.0	2720.0	**2.2967**

Glazed Constructions:

In the base cases modeled, a double glazed façade was used. The detail of the glazed construction is shown in fig. 5.20 and consists of three layers; coated glass, air cavity and clear float glass. The properties of the materials comprised in this construction detail are shown in table 5.7. Note that aluminum framing counts for around 20% of the detail. Therefore the U-Value calculated and shown in the table is the Net U-value where framing was taken in consideration.

Table 5.7: Properties of materials used for the base case external windows

Material	Thickness (m)	Conductivity W/(m.K)	Transmittance	Refractive Index	Reflectance		U-Value (ASHRAE) Frame Included
					In	Out	
Coated Glass	0.006	1.0600	0.630	1.526	0.02	0.02	**2.167 W/m^2.K**
Air Cavity	0.016						
Clear Float Glass	0.006	1.0600	0.780	1.526	0.07	0.07	

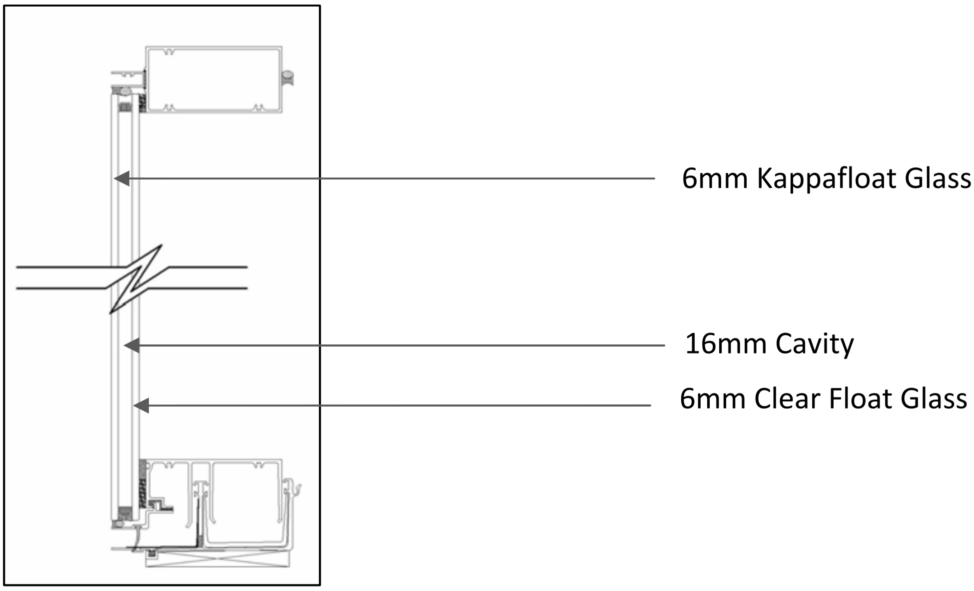


Figure 5.6: *Detail of external windows.*

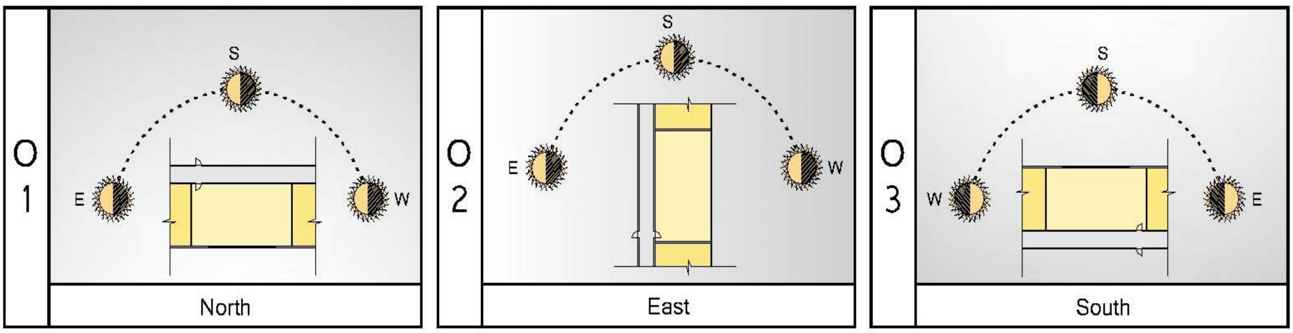
5.2 Parameters studied:

As mentioned before, the climatic data and usage data was stabilized and all the other factors (except mechanical design data as it's out of the researcher's specialty) were manipulated and studied. The following paragraphs present the parameters studied:

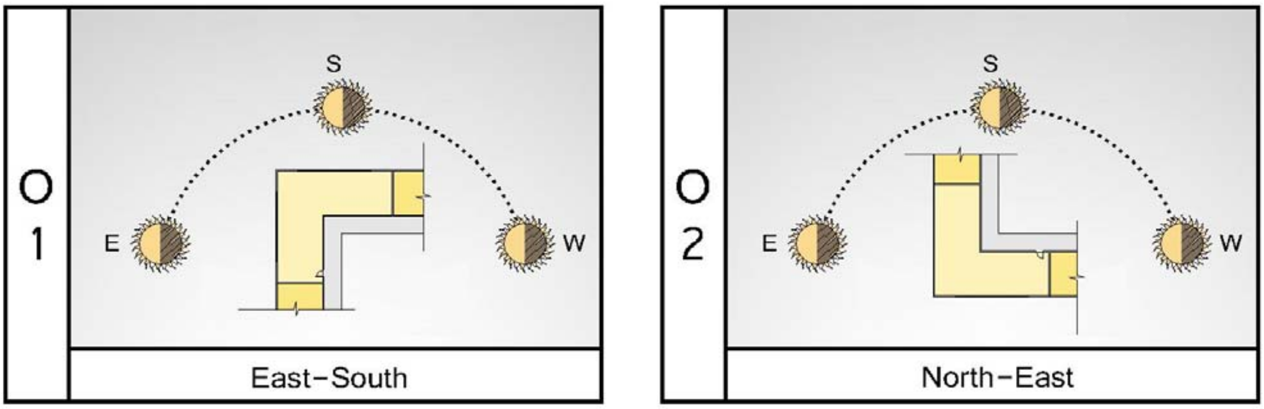
5.2.1 Architectural Design Data:

1- Orientation:

The simulation was done with the following different orientations: South (P1:O1), East (P1:O2) and North orientations (P1:O3) for prototype 1 and North-East (P2:O1) and East-South (P2:O2) orientations for prototype 2 (Note that west orientation in prototype 1 and North-West and South-West orientations in prototype 2 were not studied as their results would match the results obtained from the East orientation in prototype 1 and North-East and East-South orientations in prototype 2 respectively). Fig. 5.21 shows the orientation studied for both prototypes.



(A)



(B)

Figure 5.7: *(A) Orientations tested for prototype 1. (B) Orientations tested for prototype 2.*

<u>2- Opening to Wall Percentage:</u>

As the opening to wall percentages were 67.9% (P1:OtoW:p-1) and 63.4% (P2:OtoW:p-1) for prototype 1 and prototype 2 respectively, two different percentages for each prototype were modeled and simulated. These percentages are: 100% (P1:OtoW:p-2) and 35.8% (P1:OtoW:p-3) for offices prototype 1 and 100% (P2:OtoW:p-2) and 26.8% (P2:OtoW:p-3) for offices prototype 2. It should be always considered that these values don't include the framing and mullions (Their area is already calculated in the software and it's always estimated to be 20% of the total area of glass). Moreover, these numbers represent the percentages of "the opening" of the "wall under the false ceiling".

<u>3- Aspect Ratio:</u>

Different aspect ratios for each prototype was modeled and tested. For prototype 1, where the length to width ratio was 16.37(L):9.2m(W) or 1.8:1 (P1: A-R:1), the two other aspect ratios modeled and tested were 1:1 (P1: A-R:2)and 1:1.8 (P1: A-R:3). On the other hand, prototype two -which has an aspect ratio of (2x16.15)(L):(2x6.35)(W) "or 2.55:1" (P2: A-R:1) was also tested with 2 other different window to wall ratios: (2x14.49)(L):(2x7.70)(W) "or 1.88:1" (P2: A-R:2) and (2x12.83)(L):(2x12.83)(W) "or 1:1" (P2: A-R:3). Note that the areas of the modeled offices were stabilized as 150.7m^2 and 164.7m^2 for both prototype 1 and prototype 2 respectively.

5.2.2 Materials Data:

<u>1: Opaque Construction Systems:</u> While DM construction system 5 with an external wall U-Value of 0.3134 was used in the base cases, construction system 3 with an external wall

U-Value of 0.4184 and construction system 4 with an external wall U-Value of 0.7252 were also tested. Fig 5.22 shows the layers of both external walls, while tables 5.7 and 5.8 show the properties of the materials used in each detail.

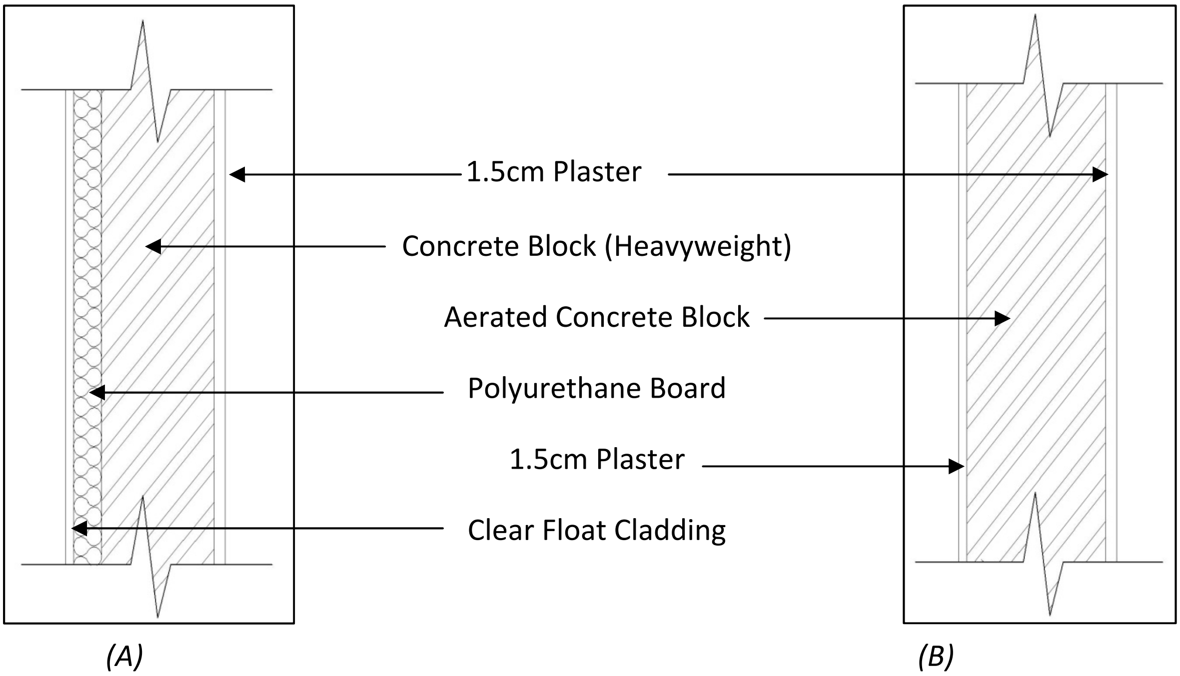


Figure 5.8: *(A) External Wall Layers (DM Construction System 3). (B) External Wall Layers (DM Construction System 4) (DM,2010).*

Table 5.8: Properties of External wall layers of DM construction system 3

Material	Thickness. (m)	Conductivity W/(m.K)	Density Kg/m^3	Specific Heat Capacity J/(Kg.K)	U-Value W/m^2.K (ASHRAE)
Plaster (Lightweight)	0.015	0.1600	600.0	1000.0	**0.4184**
Concrete Block (Heavyweight)	0.200	1.6300	2300.0	1000.0	
Polyurethane Board	0.050	0.0250	30.0	1400.0	
Clear Float Cladding	0.025	1.0500	2500.0	750.0	

Table 5.9: Properties of External wall layers of DM construction system 4

Material	Thickness. (m)	Conductivity W/(m.K)	Density Kg/m^3	Specific Heat Capacity J/(Kg.K)	U-Value W/m^2.K (ASHRAE)
Plaster (Lightweight)	0.015	0.1600	600.0	1000.0	**0.7252**
Aerated Concrete Block	0.250	0.2400	750.0	1000.0	
Plaster (Lightweight)	0.0.15	0.1600	600.0	1000.0	

2: Glazed Construction Systems: Besides the window detail used in the base cases, two other details with 3.2985 and 5.8652 U-Values were examined. Tables 5.9 and 5.10 show the components of each detail and the properties of the materials used in them.

Table 5.10: Properties of glass construction system 2

Material	Thickness (m)	Conductivity W/(m.K)	Transmittance	Refractive Index	Reflectance		U-Value (ASHRAE) Frame Included
					In	Out	
Clear Float Glass	0.006	1.0600	0.780	1.526	0.07	0.07	**3.2985 W/m^2.K**
Air Cavity	0.016						
Clear Float Glass	0.006	1.0600	0.780	1.526	0.07	0.07	

Table 5.11: Properties of glass construction system 3

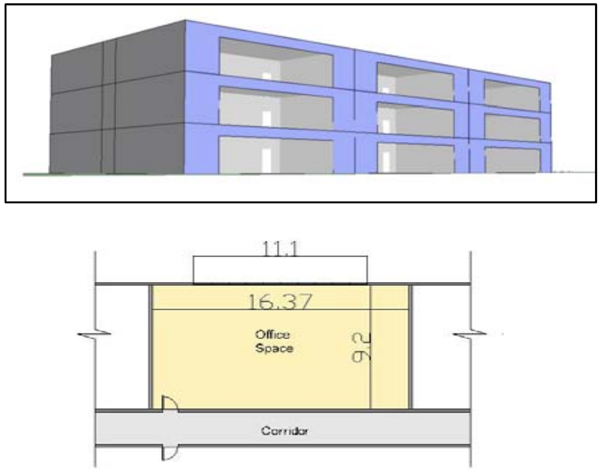
Material	Thickness (m)	Conductivity W/(m.K)	Transmittance	Refractive Index	Reflectance		U-Value (ASHRAE) Frame Included
					In	Out	
Clear Float Glass	0.006	1.0600	0.780	1.526	0.07	0.07	**5.8652 W/m^2.K**

5.3 Research's Matrix and Models:

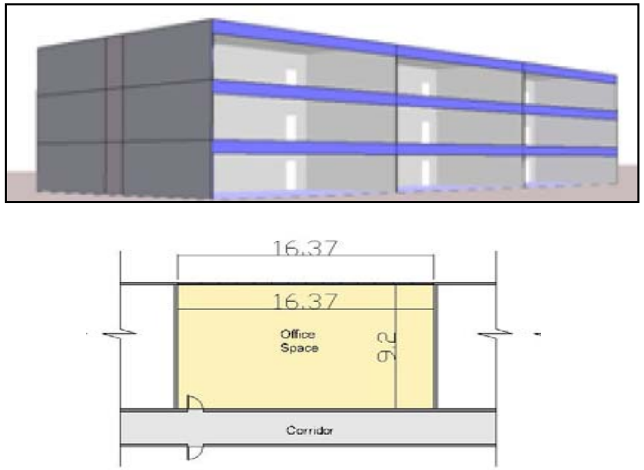
After defining the entire research constant and varying parameters, research matrix was set and the different models were built (Table 5.11). The difference between the cases was made possible by changing the following parameters in both prototype 1 and prototype 2: 1- Orientation. 2- Aspect Ratio. 3- Opening to Wall Percentages. 4- Opaque external wall materials and 5- Glazed constructions materials. Because both aspect ratio and opening to wall percentages determine the architectural shape of the spaces, 9 offices models were created for each prototype (Fig. 5.23). Each one of these models was simulated with different orientations and different opaque and transparent materials. As a result, 135 different cases were simulated for prototype 1, while 90 different cases were simulated for prototype 2 (the difference is because prototype 2 has two orientations only) (You may refer to appendix 4 and appendix 5 for the research parameters and the different cases modeled and studied). The annual energy consumption of each case was measured and recorded in the tables in appendix 6. The final step was comparing all the results of each case to know the exact affect of each parameter studied on the offices energy consumption.

Table 5.12: Research Matrix

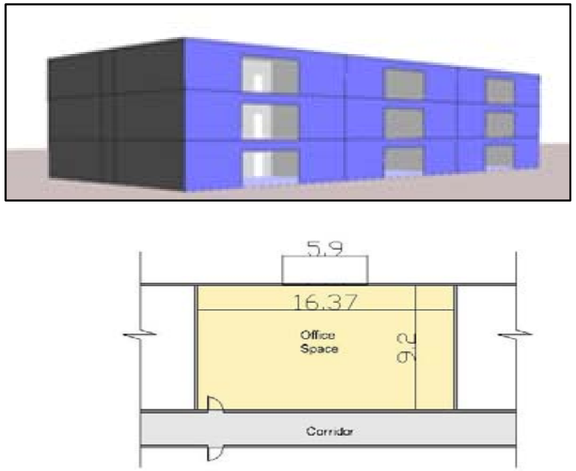
Climatic Data	Usage Data	Design Data				Materials Data	
		Shape & Area	**Orientation**	**Opening-to-Wall-Percentage**	**Aspect Ratio**	**Opaque Materials**	**Transparent Materials**
Dubai, UAE	**Offices Spaces**	Offices Prototype 1 (P1) 150.7m^2	South Orientation (O1)	67.9% (OtoW-r:1)	1.8:1 (A-R:1)	0.3134 U-Value (OC-S1)	2.1670 U-Value (GC-S1)
			East Orientation (O2)	100% (OtoW-r:2)	1:1 (A-R:2)	0.4184 U-Value (OC-S2)	3.2985 U-Value (GC-S2)
			North Orientation (O3)	35.8% (OtoW-r:3)	1:1.8 (A-R:3)	0.7252U-Value (OC-S3)	5.8652 U-Value (GC-S3)
		Offices Prototype 2 (P2) 164.7m^2	East-South Orientation (O1)	63.4% (OtoW-r:1)	2.55:1 (A-R:1)	0.3134 U-Value (OC-S1)	2.1670 U-Value (GC-S1)
			North-East Orientation (O2)	100% (OtoW-r:2)	1.88:1 (A-R:2)	0.4184 U-Value (OC-S2)	3.2985 U-Value (GC-S2)
				26.8% (OtoW-r:3)	1:1 (A-R:3)	0.7252U-Value (OC-S3)	5.8652 U-Value (GC-S3)



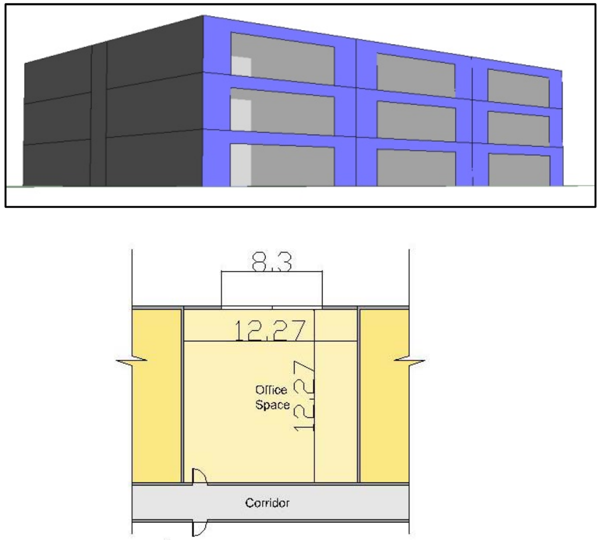
P1, A-R:1, OtoW-P:1



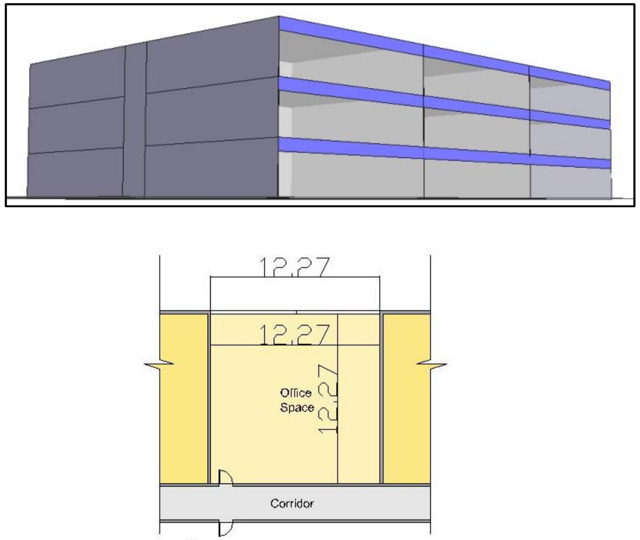
P1, A-R:1, OtoW-P:2



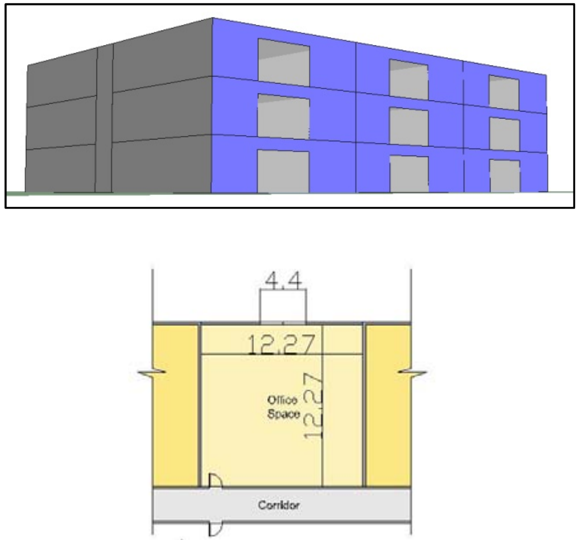
P1, A-R:1, OtoW-P:3



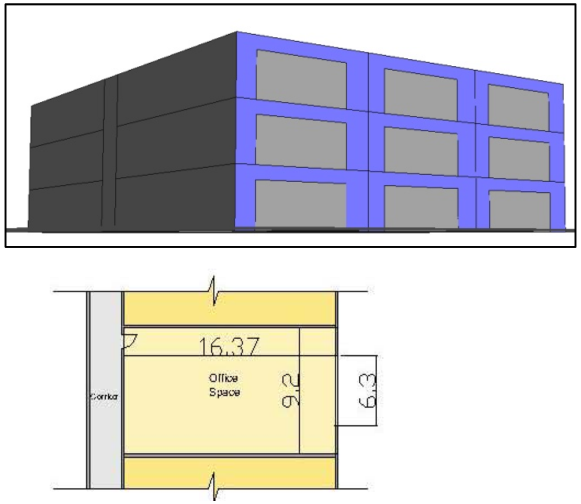
P1, A-R:2, OtoW-P:1



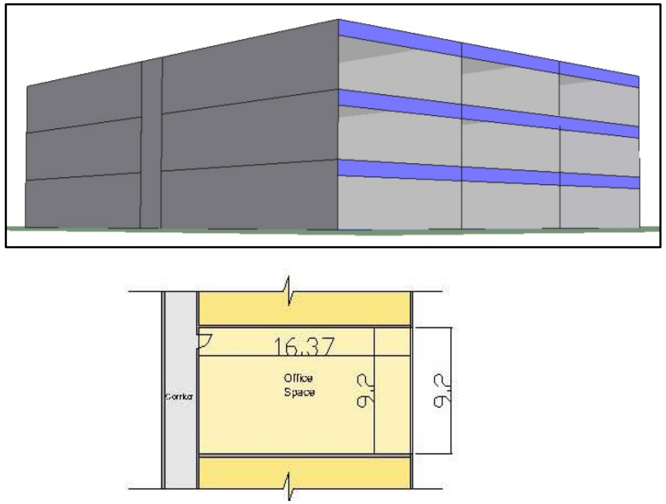
P1, A-R:2, OtoW-P:2



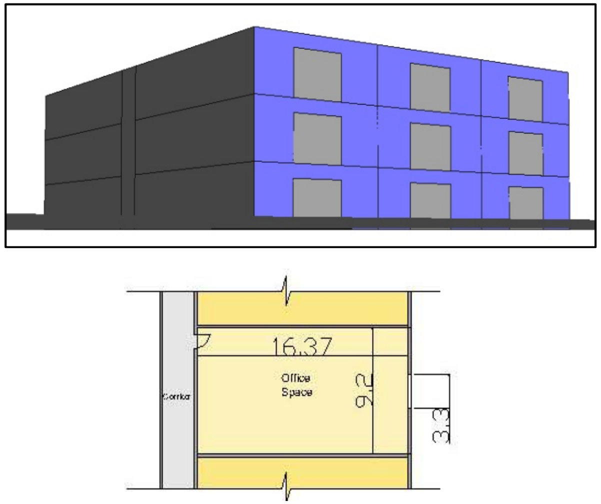
P1, A-R:2, OtoW-P:3



P1, A-R:3, OtoW-P:1

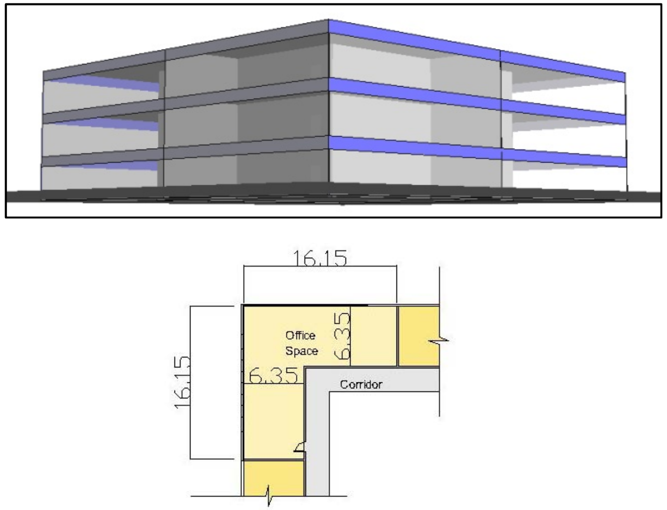


P1, A-R:3, OtoW-P:2

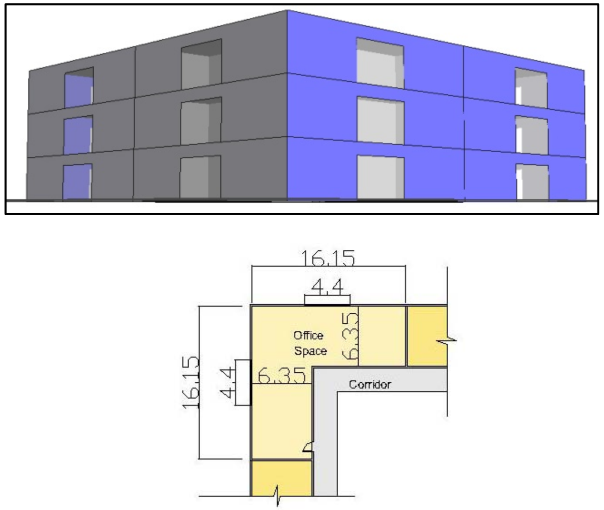


P1, A-R:3, OtoW-P:3

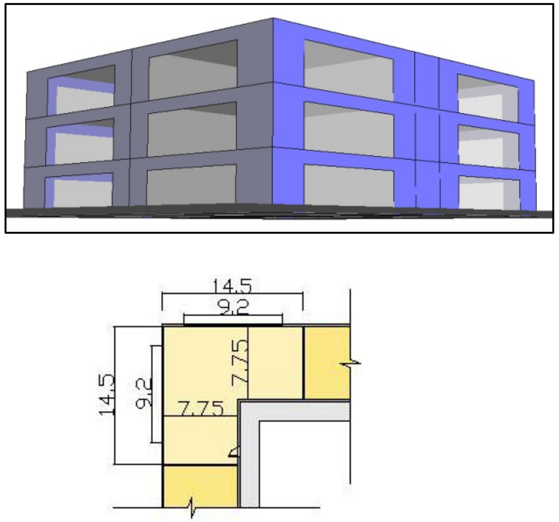
P2, A-R:1, OtoW-P:1



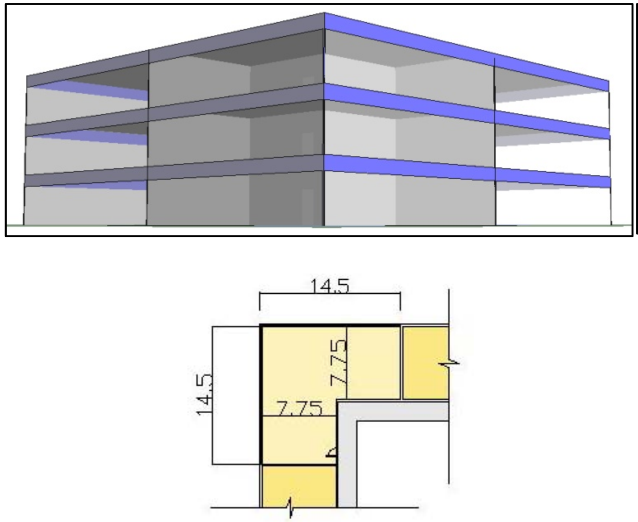
P2, A-R:1, OtoW-P:2



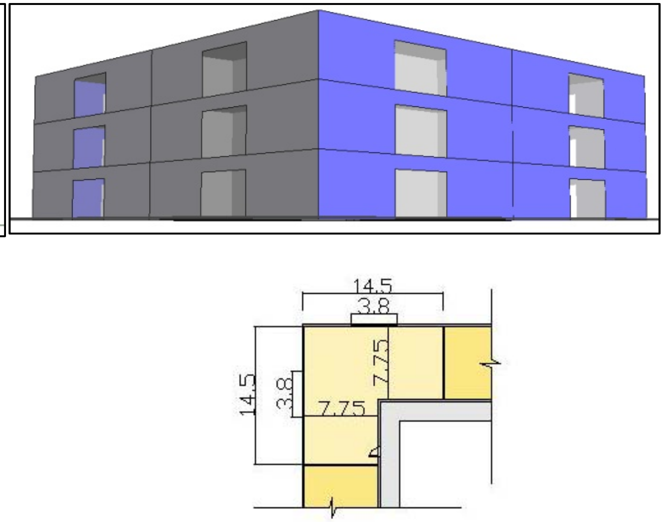
P2, A-R:1, OtoW-P:3



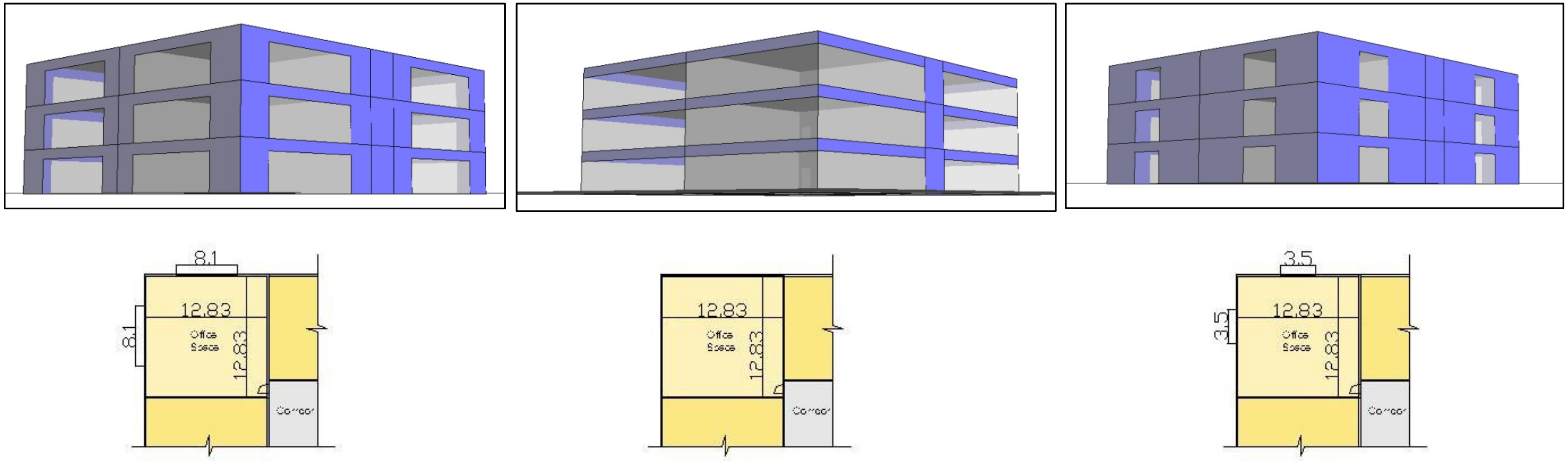
P2, A-R:2, OtoW-P:1



P2, A-R:2, OtoW-P:2



P2, A-R:2, OtoW-P:3



P2, A-R:3, OtoW-P:1 P2, A-R:3, OtoW-P:2 P2, A-R:3, OtoW-P:3

Figure 5.9: *The models simulated with different orientations and materials.*

CHAPTER 6: RESULTS AND DISCUSSION

6.1 Results of Prototype 1:

6.1.1 Design Data:

6.1.1.1 Orientation:

- Offices with 1.8:1 aspect ratio (A-R:1) (OC-S:1 & GC-S:1): When compared to the South-oriented offices (O:1), both East-oriented (O2) and North-oriented offices (O3) reduce cooling energy consumption depending on the opening-to-wall percentage as the following:

100% opening-to-wall percentage: 4.5% and 40.1% respectively.

68% opening-to-wall percentage: 3.8% and 36.5% respectively.

36% opening-to-wall percentage: 3% and 29% respectively.

Fig. 6.1 illustrates the results.

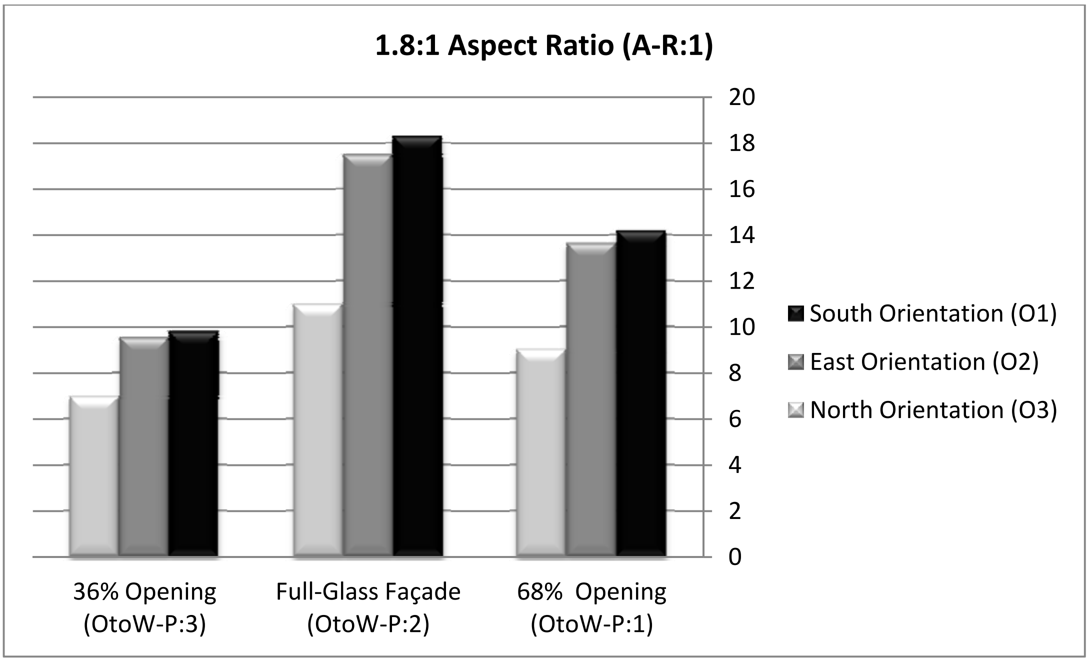


Figure 6.1: *The impact of changing the orientation on cooling energy consumption in 1.8:1 aspect ratio offices with different opening-to-wall percentages.*

- Offices with 1:1 aspect ratio (A-R:2) (OC-S:1 & GC-S:1): When compared to the South-oriented offices (O:1), both East-oriented (O2) and North-oriented (O3) offices reduce cooling energy consumption depending on the opening-to-wall percentage as the following:

100% opening-to-wall percentage: 4.5% and 38% respectively.

68% opening-to-wall percentage: 3.8% and 33.8% respectively.

36% opening-to-wall percentage: 2.9% and 25.9% respectively.

Fig. 6.2 illustrates the results.

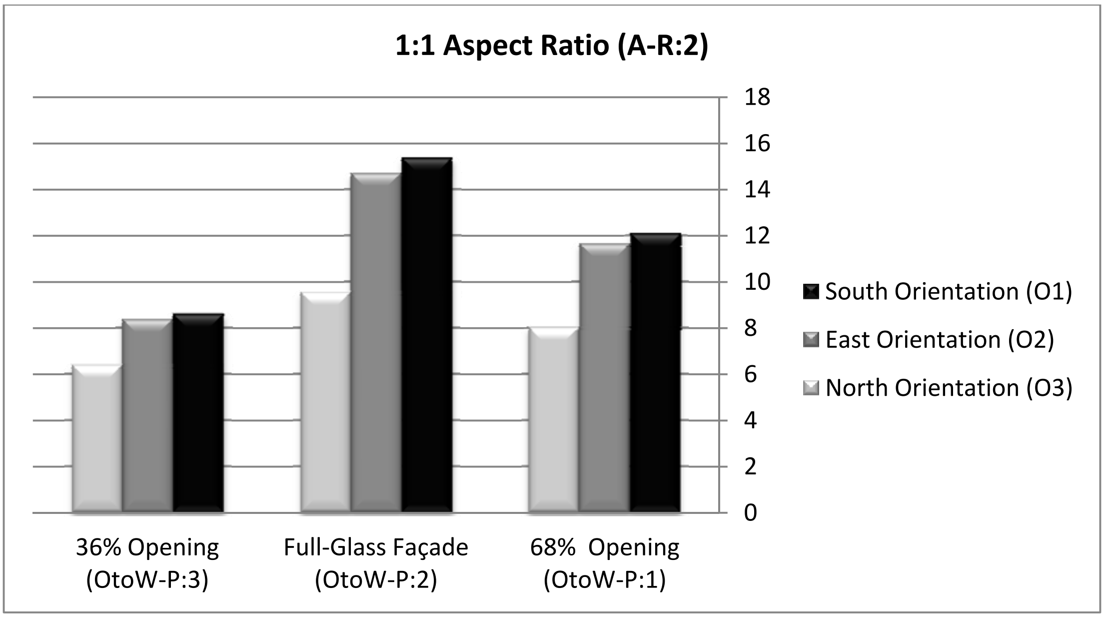


Figure 6.2: *The impact of changing the orientation on cooling energy consumption in 1:1 aspect ratio offices with different opening-to-wall percentages.*

<u>- Offices with 1:1.8 aspect ratio (A-R:3) (OC-S:1 & GC-S:1):</u> When compared to the South-oriented offices (O:1), both East-oriented (O2) and North-oriented (O3) offices reduce cooling energy consumption depending on the opening-to-wall percentage as the following:

100% opening-to-wall percentage: 4.0% and 35.4% respectively.

68% opening-to-wall percentage: 3.7% and 30.7% respectively.

36% opening-to-wall percentage: 2.9% and 23.6% respectively.

Fig. 6.3 illustrates the results.

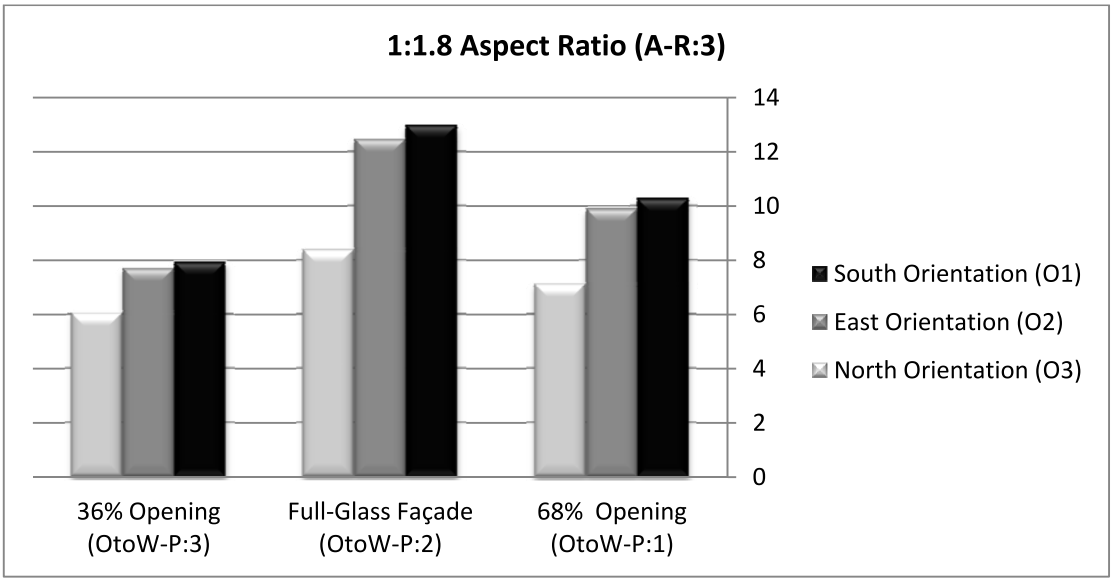


Figure 6.3: *The impact of changing the orientation on cooling energy consumption in 1:1.8 aspect ratio offices with different opening-to-wall percentages.*

6.1.1.2 Opening-to-wall-ratio:

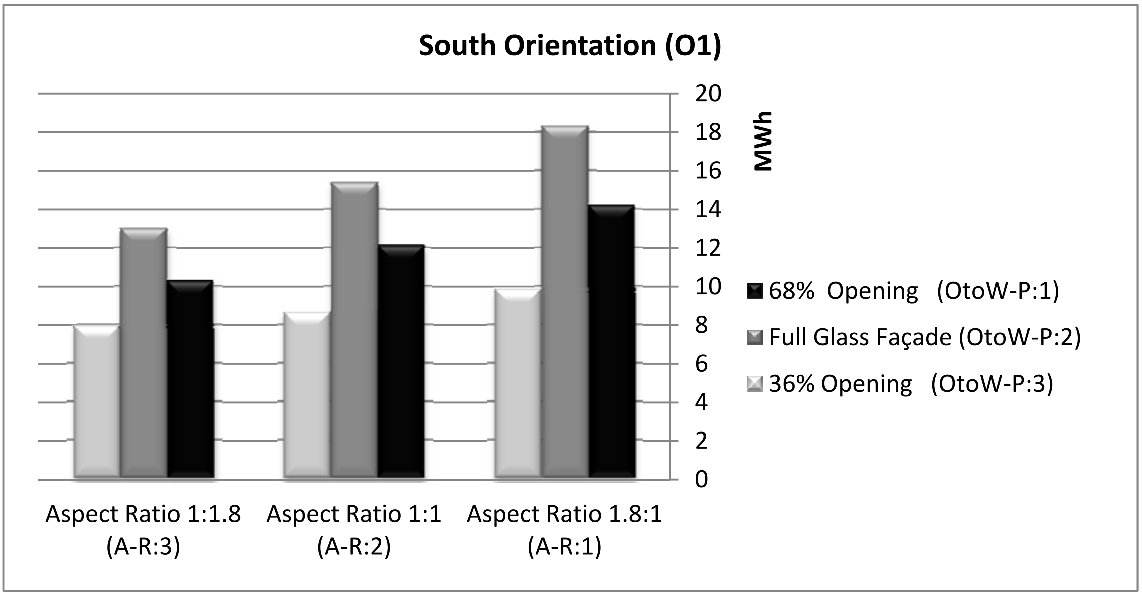
- South-oriented offices (O1) (OC-S:1 & GC-S:1): When compared to the South-oriented full-glazed facades offices (OtoW-P:2), both offices with 68% (OtoW-P:1) and 36% (OtoW-P:3) opening-to-wall percentages reduce cooling energy consumption depending on the aspect ratio as the following:

1.8:1 Aspect Ratio Offices (AR1): 22.5% and 46.4% respectively.

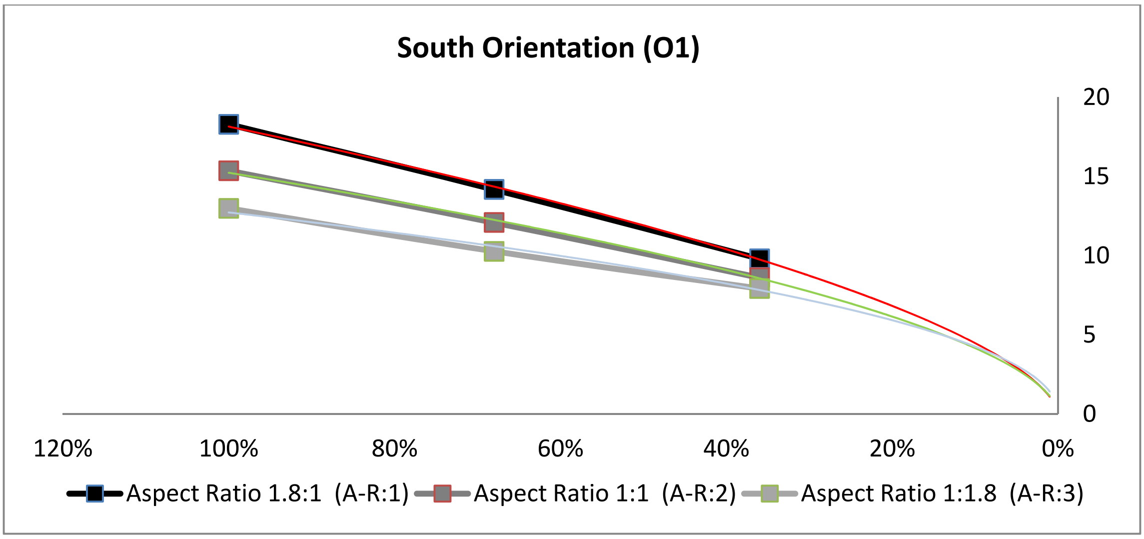
1:1 Aspect Ratio Offices (AR2): 21.2% and 43.9% respectively.

1:1.8 Aspect Ratio Offices (AR3): 20.8% and 38.9% respectively.

Fig. 6.4 illustrates the results.



(A)



(B)

Figure 6.4 (A&B): *The impact of changing the opening-to-wall Percentage on cooling energy consumption in south-oriented offices with different aspect ratios.*

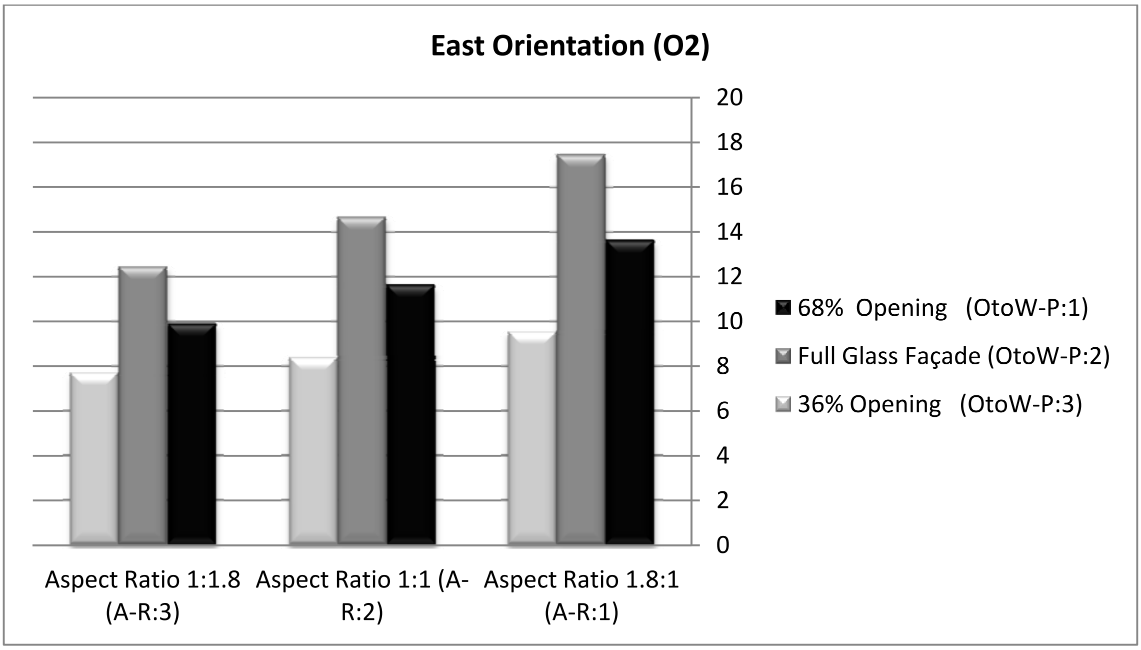
- <u>East-oriented offices (O2) (OC-S:1 & GC-S:1):</u> When compared to the East-oriented full-glazed facades offices (OtoW-P:2), both offices with 68% (OtoW-P:1) and 36% (OtoW-P:3) opening-to-wall percentages reduce cooling energy consumption depending on the aspect ratio as the following:

1.8:1 Aspect Ratio Offices (AR1): 22% and 45.5% respectively.

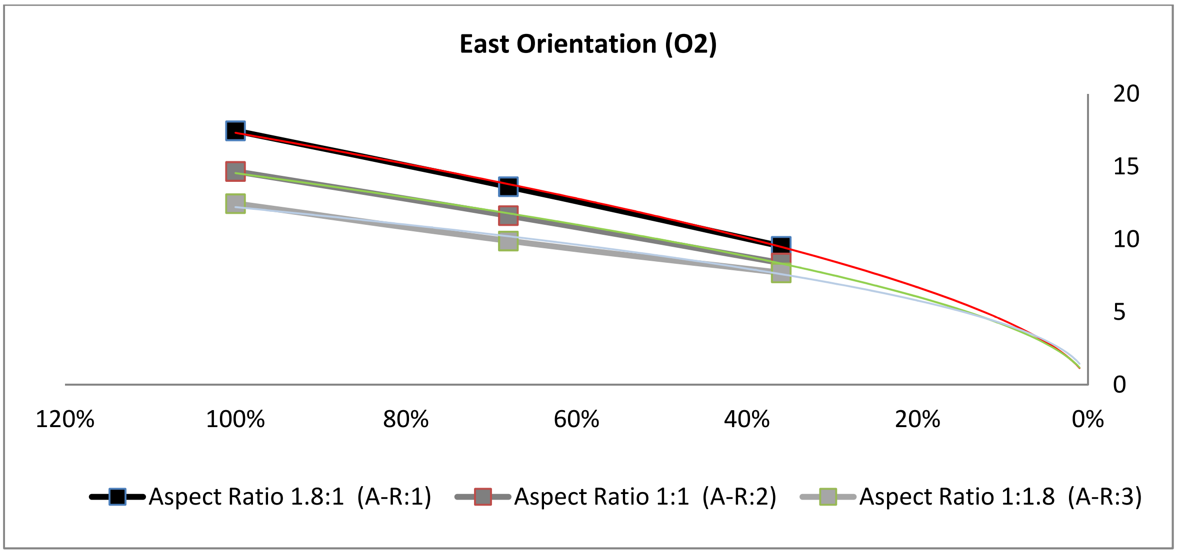
1:1 Aspect Ratio Offices (AR2): 20.7% and 42.9% respectively.

1:1.8 Aspect Ratio Offices (AR3): 20.5% and 38.2% respectively.

Fig. 6.5 illustrates the results.



(A)



(B)

Figure 6.5 (A&B): *The impact of changing the opening-to-wall percentage on cooling energy consumption in East-oriented offices with different aspect ratios.*

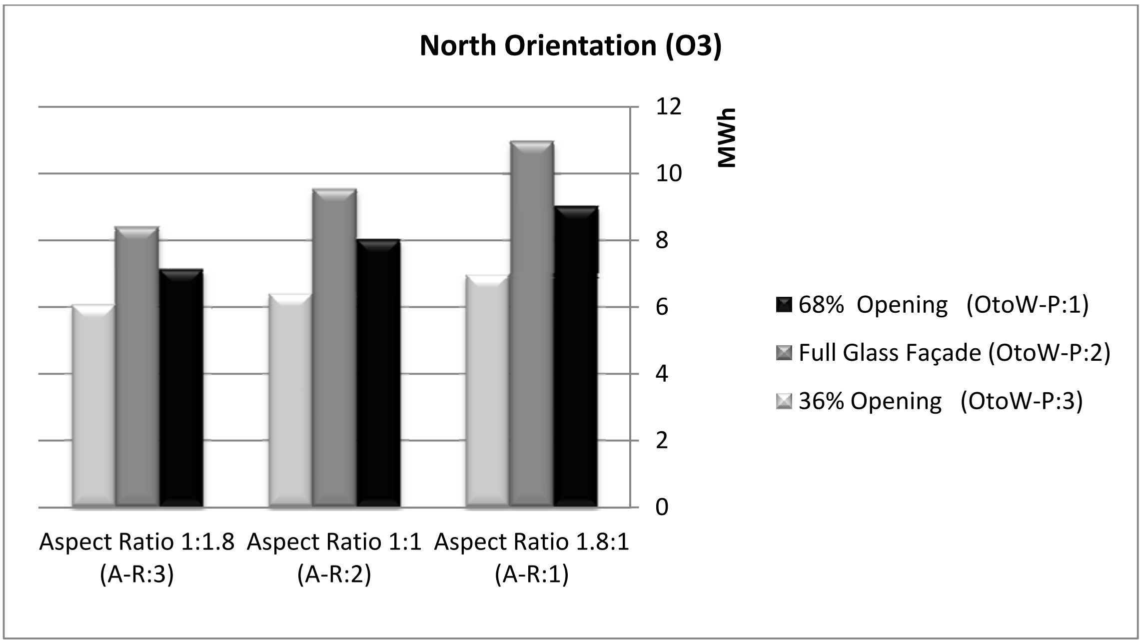
<u>- North-oriented offices (O3) (OC-S:1 & GC-S:1):</u> When compared to the North-oriented full-glazed facades offices (OtoW-P:2), both offices with 68% (OtoW-P:1) and 36% (OtoW-P:3) opening-to-wall percentages reduce cooling energy consumption depending on the aspect ratio as the following:

1.8:1 Aspect Ratio Offices (AR1): 17.8% and 36.5% respectively.

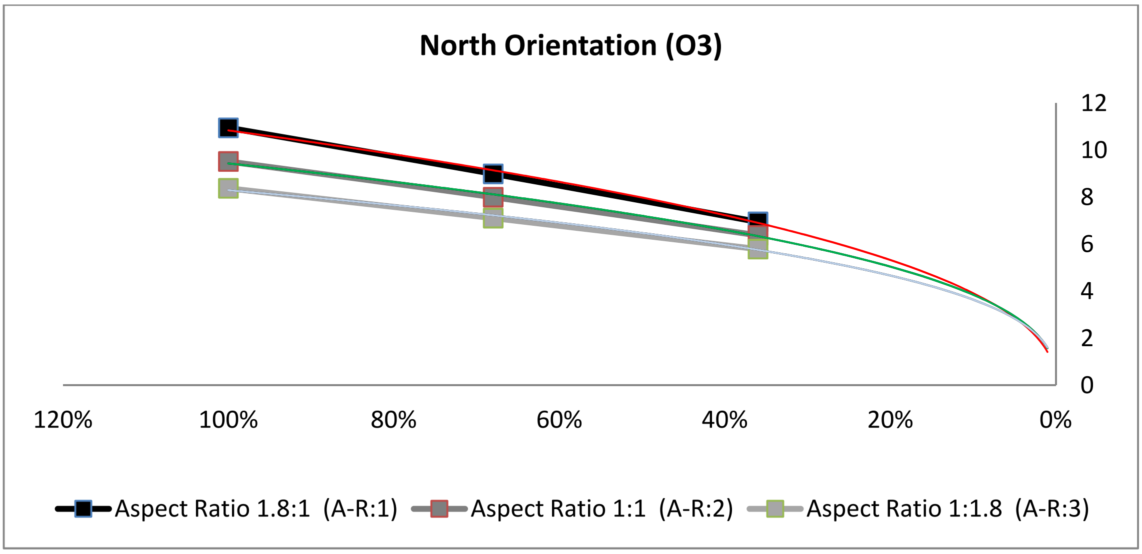
1:1 Aspect Ratio Offices (AR2): 15.9% and 33% respectively.

1:1.8 Aspect Ratio Offices (AR3): 15.1% and 27.8% respectively.

Fig. 6.6 illustrates the results.



(A)



(B)

Figure 6.6 (A&B): *The impact of changing the opening-to-wall percentages on cooling energy consumption in North-oriented offices with different aspect ratios.*

6.1.1.3 Aspect Ratio:

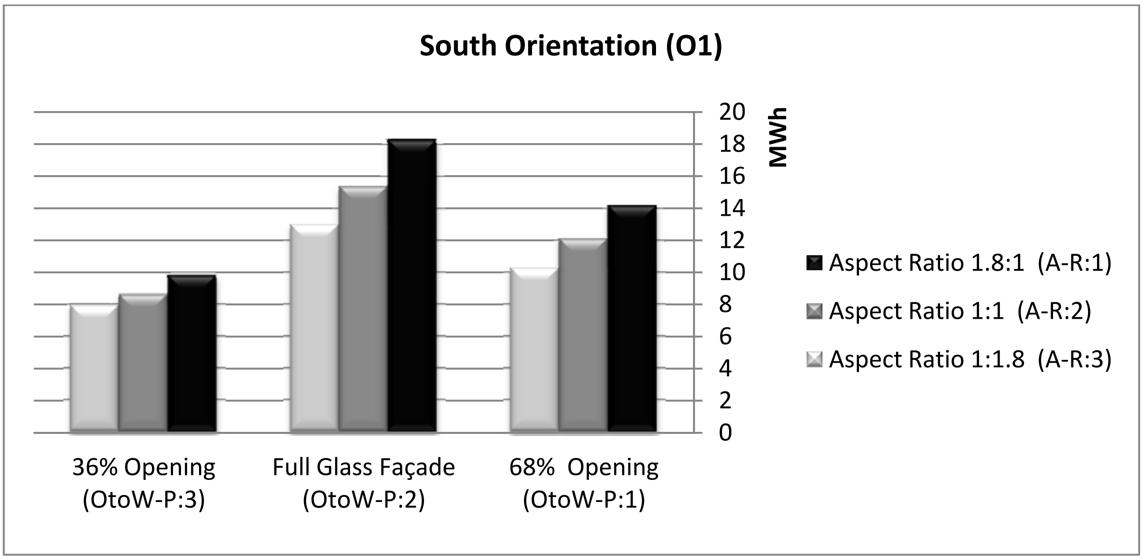
- South-oriented offices (O1) (OC-S:1 & GC-S:1): When compared to the South-oriented offices with 1.8:1 aspect ratio (A-R:1), both offices with 1:1 (A-R:2) and 1:1.8 (A-R:3) aspect ratios reduce cooling energy consumption depending on the opening-to-wall percentages as the following:

100% opening-to-wall percentage: 16% and 29% respectively.

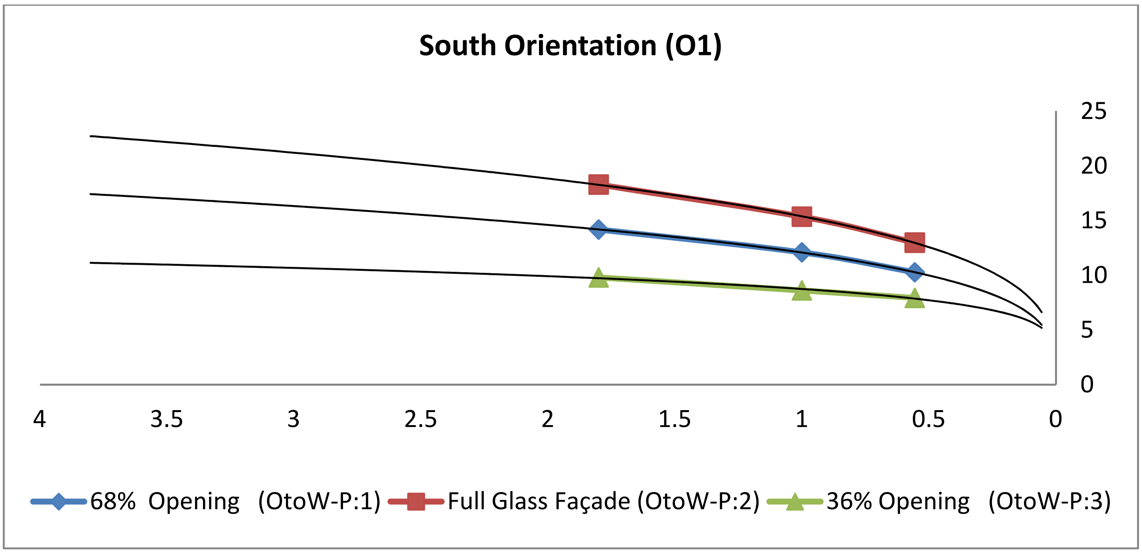
68% opening-to-wall percentage: 14.7% and 27.5% respectively.

36% opening-to-wall percentage: 12.1% and 19.1% respectively.

Fig. 6.7 illustrates the results.



(A)



(B)

Figure 6.7 (A&B): *The impact of changing the aspect ratio on cooling energy consumption in south-oriented offices with different opening-to-wall ratios.*

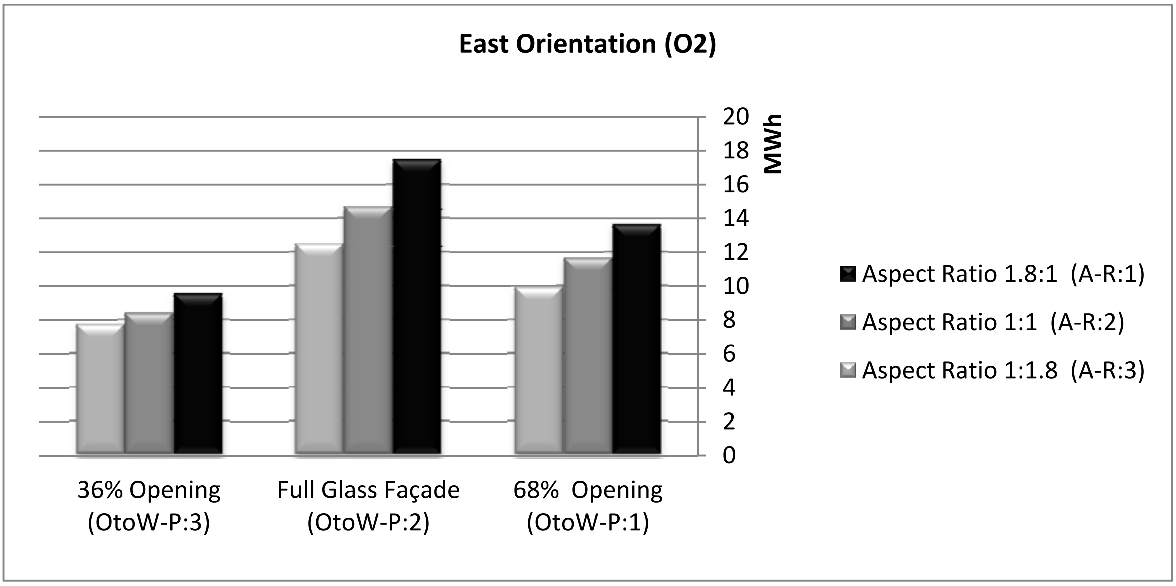
<u>- East-oriented offices (O1) (OC-S:1 & GC-S:1):</u> When compared to the East-oriented offices with 1.8:1 aspect ratio (A-R:1), both offices with 1:1 (A-R:2) and 1:1.8 (A-R:3) aspect ratios reduce cooling energy consumption depending on the opening-to-wall percentages as the following:

100% opening-to-wall percentage: 16% and 28.6% respectively.

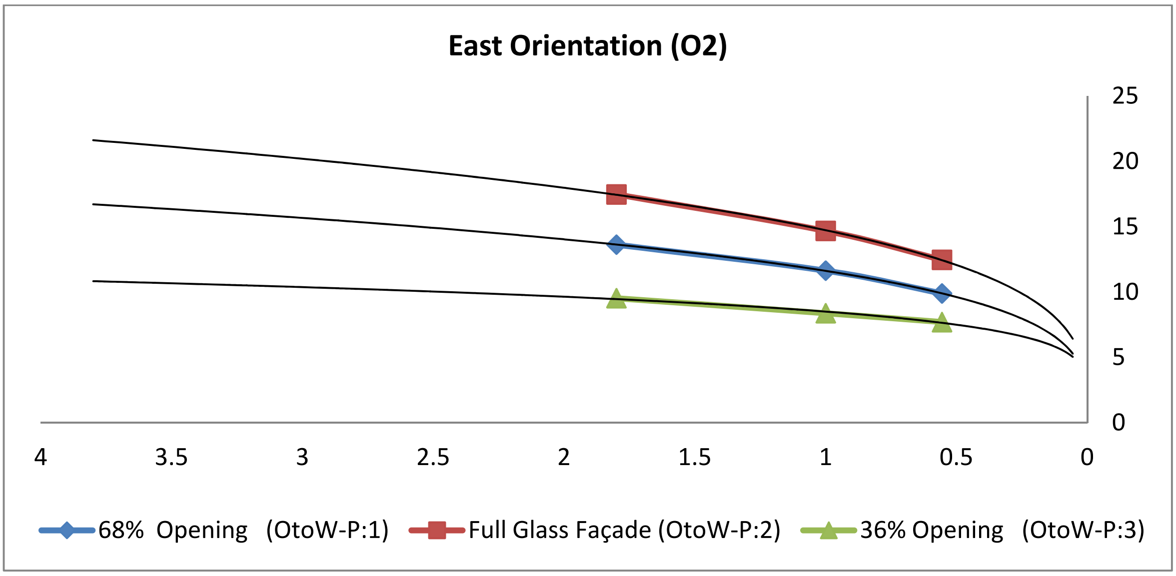
68% opening-to-wall percentage: 14.6% and 27.4% respectively.

36% opening-to-wall percentage: 12.1% and 19.1% respectively.

Fig. 6.8 illustrates the results.



(A)



(B)

Figure 6.8 (A&B): *The impact of changing the aspect ratio on cooling energy consumption in east-oriented offices with different opening-to-wall ratios.*

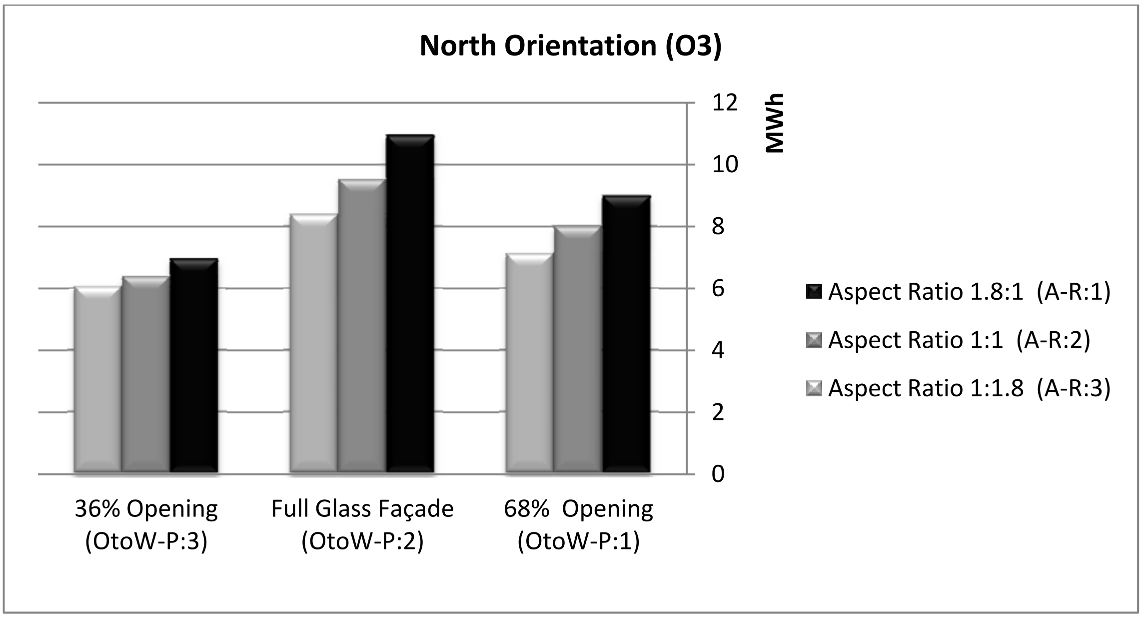
<u>- North-oriented offices (O3) (OC-S:1 & GC-S:1):</u> When compared to the North-oriented offices with 1.8:1 aspect ratio (A-R:1), both offices with 1:1 (A-R:2) and 1:1.8 (A-R:3) aspect ratios reduce cooling energy consumption depending on the opening-to-wall percentages as the following:

100% opening-to-wall percentage: 13% and 23.5% respectively.

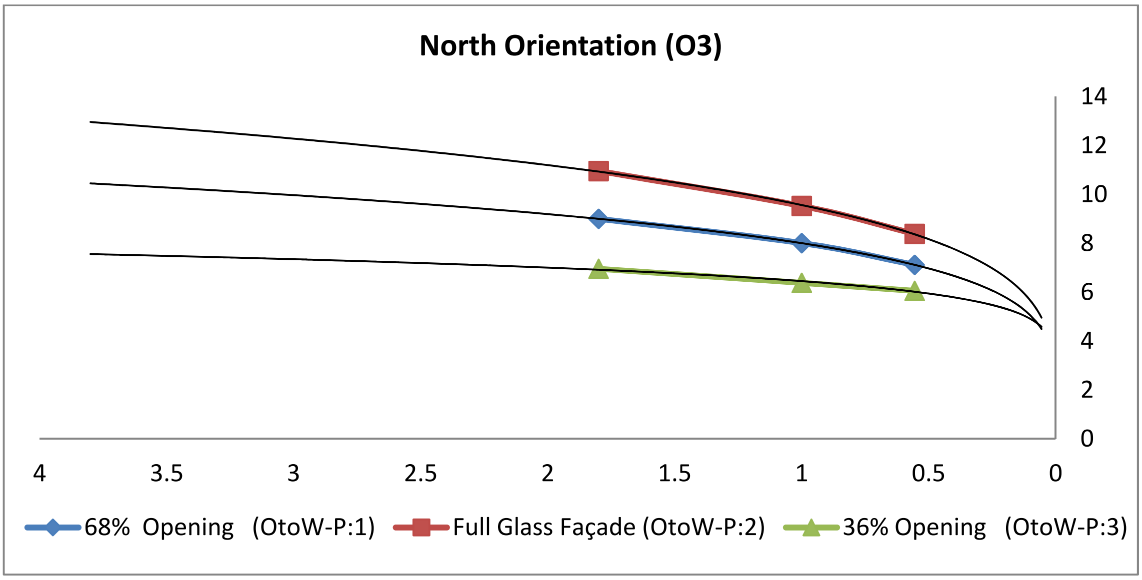
68% opening-to-wall percentage: 11% and 20.9% respectively.

36% opening-to-wall percentage: 8.2% and 13% respectively.

Fig. 6.9 illustrates the results.



(A)



(B)

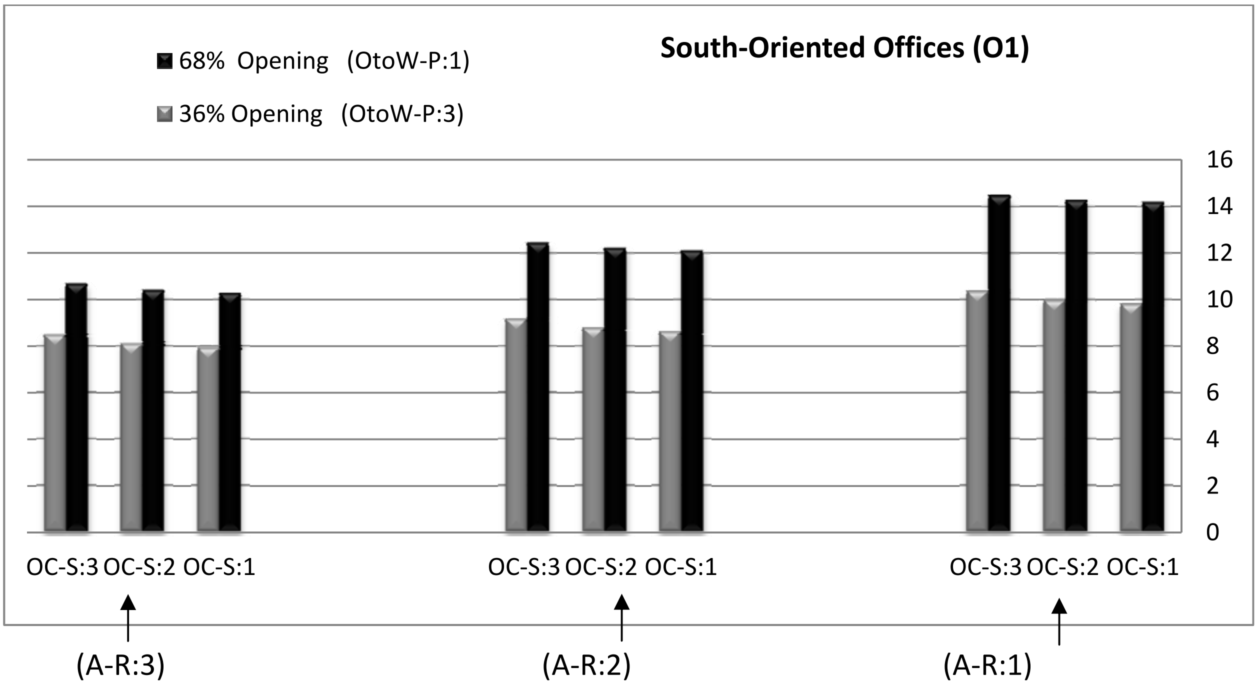
Figure 6.9 (A&B): *The impact of changing the aspect ratio on cooling energy consumption in North-oriented offices with different opening-to-wall ratios.*

6.1.2 Materials Data:

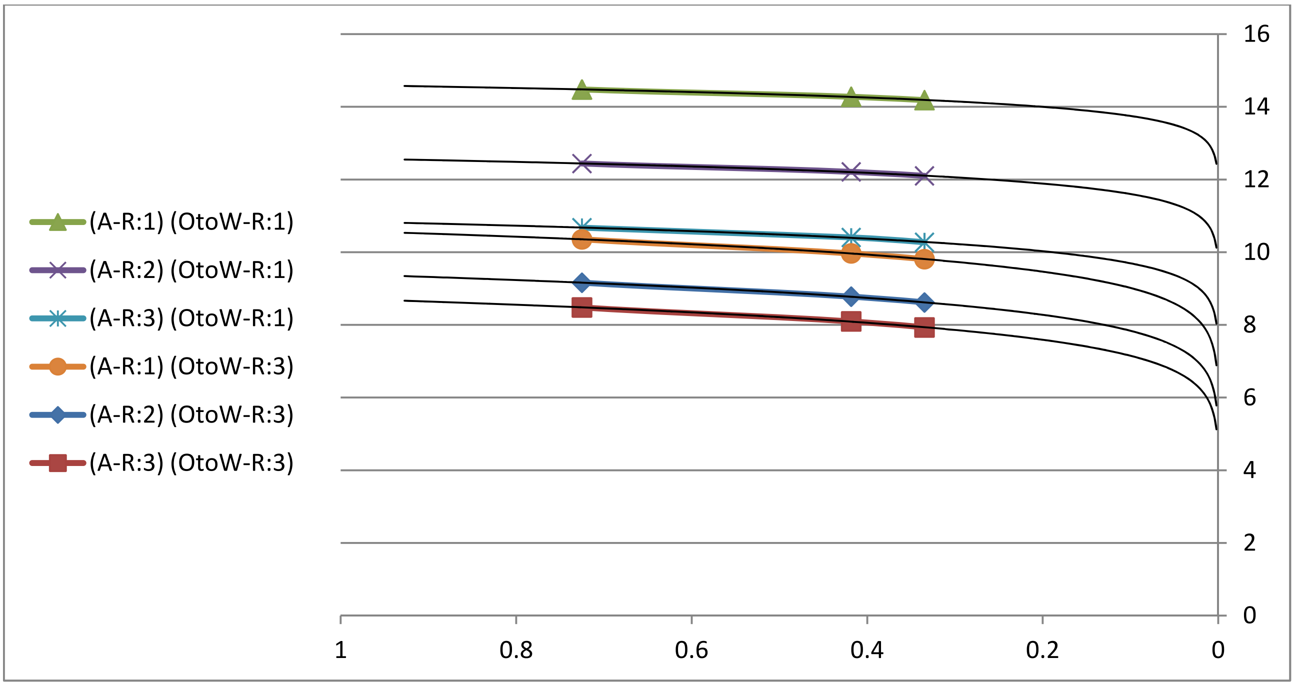
6.1.2.1 Opaque Construction Systems:

- South-Oriented Offices (O1): When compared to the South-oriented offices using opaque construction system 3 (OC-S:3) with 0.7252 U-value and Glazed construction system (GC-S:1) with 2.06 U-value, both offices using opaque construction system 2 (OC-S:2) with 0.4184 U-value and opaque construction system 1 (OC-S:1) with 0.3349 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Note that full glass facades were not taken in consideration; the area of opaque construction systems in this scenario is neglected) (Fig. 6.10 illustrates the results):

- 1.8:1 Aspect Ratio (A-R:1):
    - 68% Opening-to-Wall percentage (OtoW-P1): 1.3% and 2% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 3.7% and 5% respectively.
- 1:1 Aspect Ratio (A-R:2)
    - 68% Opening-to-Wall percentage (OtoW-P1): 1.8% and 2.7% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 4.2% and 5.9% respectively.
- 1:1.8 Aspect Ratio (A-R:3)
    - 68% Opening-to-Wall percentage (OtoW-P1): 2.5% and 3.7% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 4.5% and 6.4% respectively.



(A)

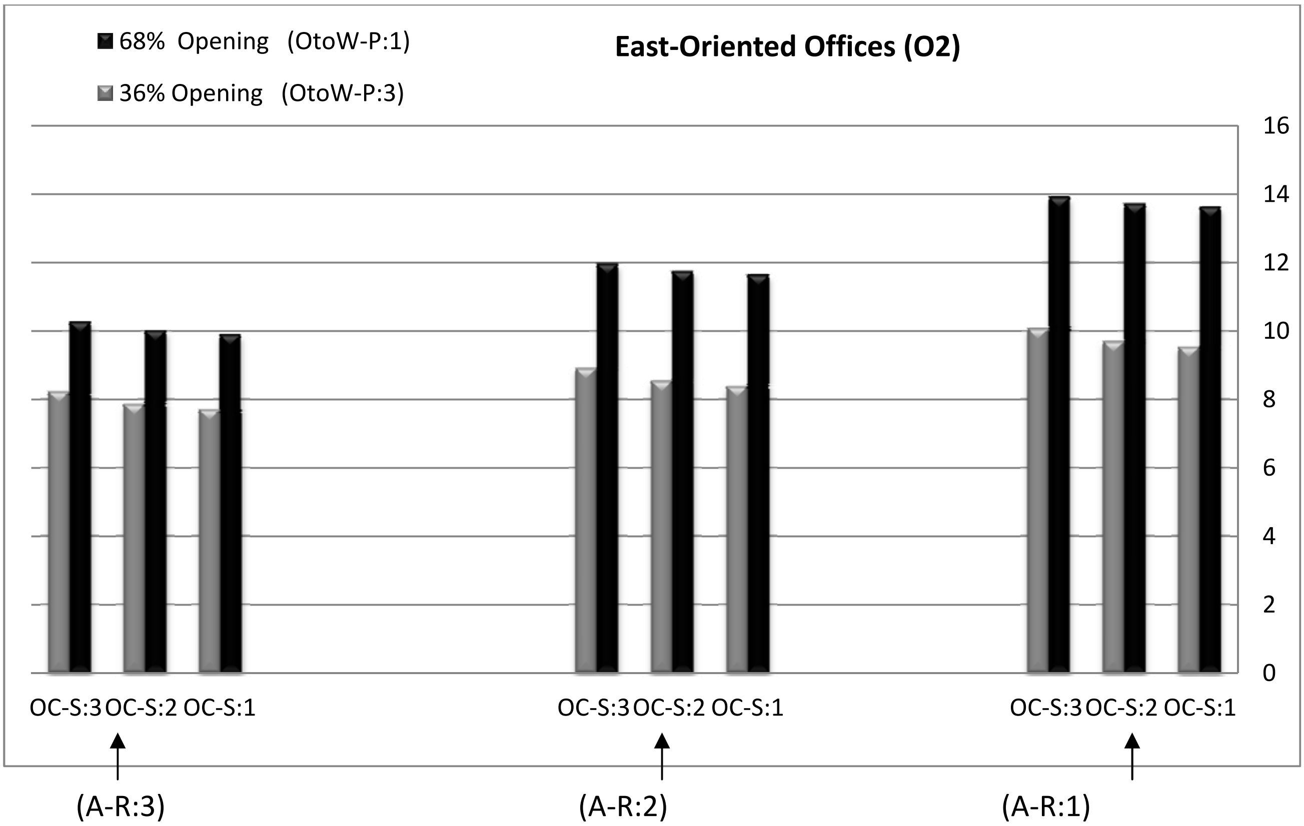


(B)

Figure 6.10 (A&B): *The impact of changing the opaque construction materials on cooling energy consumption in South-oriented offices with different aspect ratios and Opening-to-wall percentages.*

<u>- East-Oriented Offices (O2):</u> When compared to the East-oriented offices using opaque construction system 3 (OC-S:3) with 0.7252 U-value and Glazed construction system (GC-S:1) with 2.06 U-value, both offices using opaque construction system 2 (OC-S:2) with 0.4184 U-value and opaque construction system 1 (OC-S:1) with 0.3349 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Note that full glass facades were not taken in consideration; the area of opaque construction systems in this scenario is neglected) (Fig. 6.11 illustrates the results):

- 1.8:1 Aspect Ratio (A-R:1):
    - 68% Opening-to-Wall percentage (OtoW-P1): 1.4% and 2.1% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 3.8% and 5.3% respectively.
- 1:1 Aspect Ratio (A-R:2)
    - 68% Opening-to-Wall percentage (OtoW-P1): 1.8% and 2.7% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 4.2% and 5.9% respectively.
- 1:1.8 Aspect Ratio (A-R:3)
    - 68% Opening-to-Wall percentage (OtoW-P1): 2.5% and 3.7% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 4.5% and 6.4% respectively.



(A)

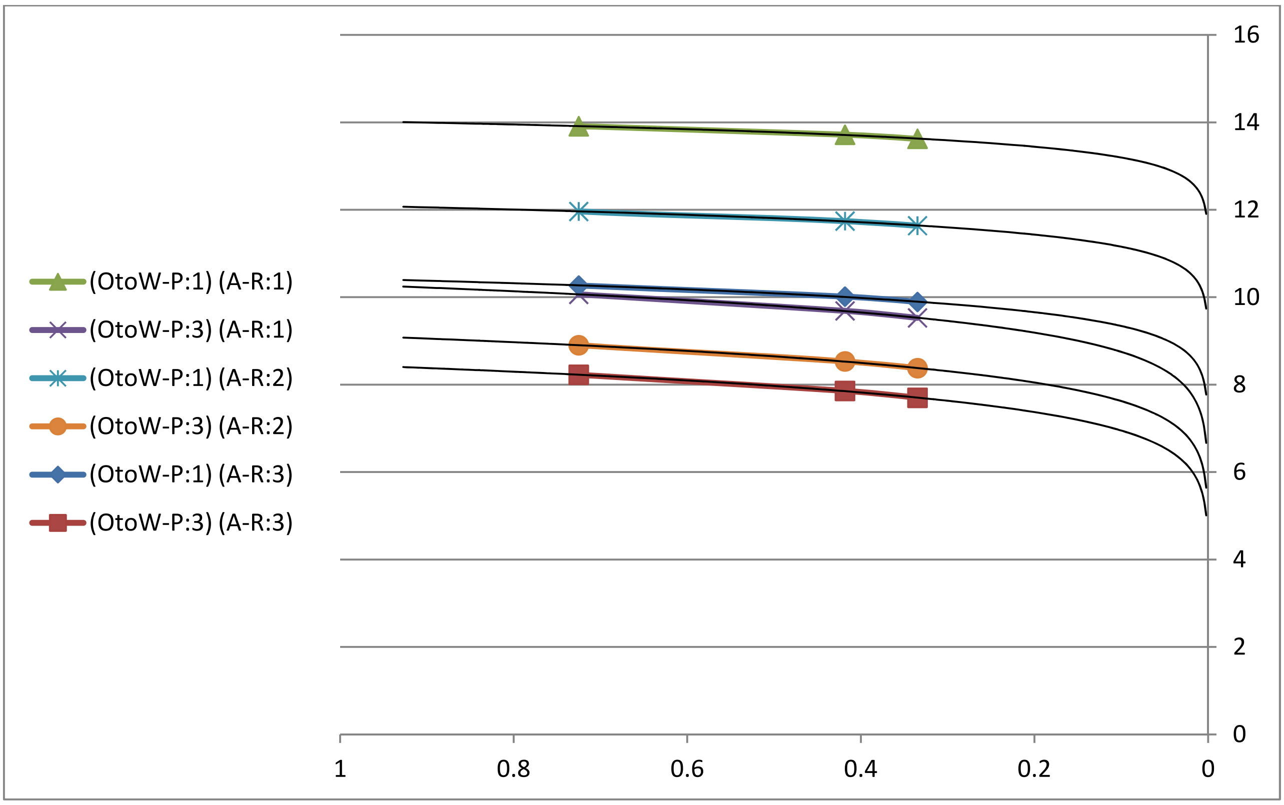
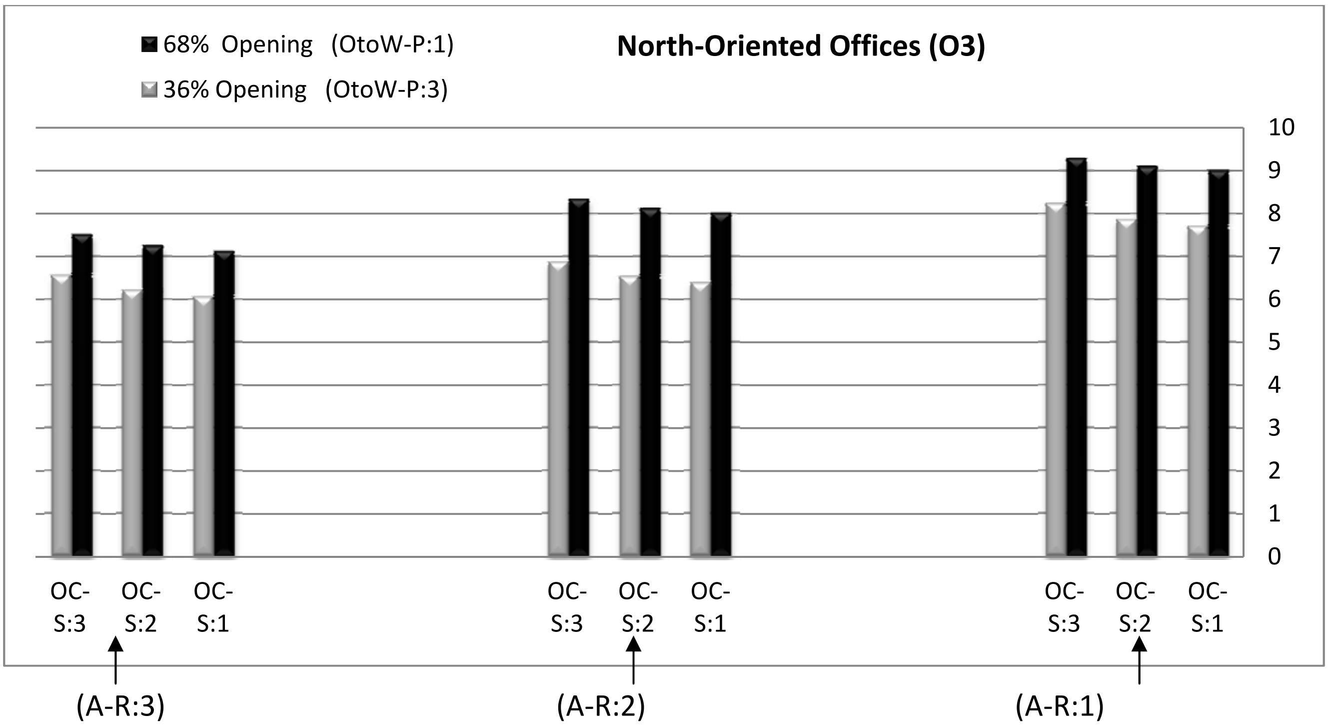


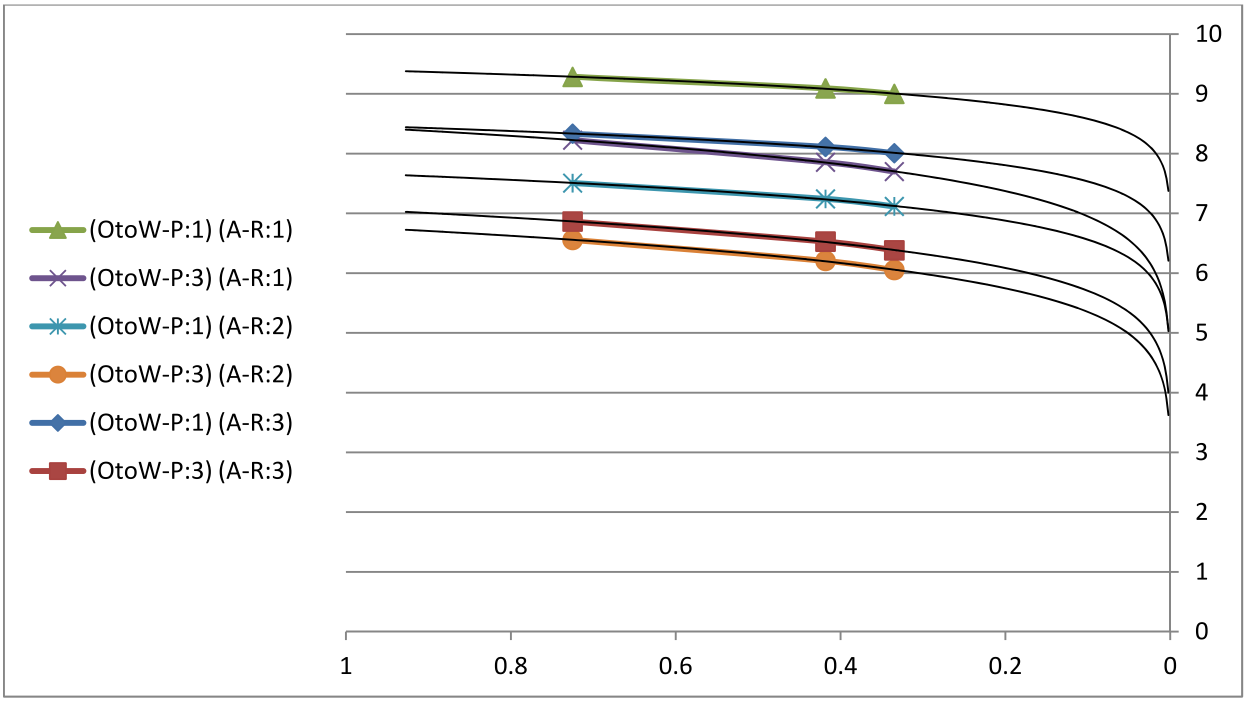
Figure 6.11 (A&B): *The impact of changing the opaque construction materials on cooling energy consumption in East-oriented offices with different aspect ratios and Opening-to-wall percentages.*

-<u>North-Oriented Offices (O3):</u> When compared to the North-oriented offices using opaque construction system 3 (OC-S:3) with 0.7252 U-value and Glazed construction system (GC-S:1) with 2.06 U-value, both offices using opaque construction system 2 (OC-S:2) with 0.4184 U-value and opaque construction system 1 (OC-S:1) with 0.3349 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Note that full glass facades were not taken in consideration; the area of opaque construction systems in this scenario is neglected) (Fig. 6.12 illustrates the results):

- 1.8:1 Aspect Ratio (A-R:1):
    - 68% Opening-to-Wall percentage (OtoW-P1): 2.0% and 3.1% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 4.5% and 6.4% respectively.
- 1:1 Aspect Ratio (A-R:2)
    - 68% Opening-to-Wall percentage (OtoW-P1): 2.6% and 3.9% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 4.9% and 7% respectively.
- 1:1.8 Aspect Ratio (A-R:3)
    - 68% Opening-to-Wall percentage (OtoW-P1): 3.5% and 5.2% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 5.4% and 7.7% respectively.



(A)



(B)

Figure 6.12 (A&B): *The impact of changing the opaque construction materials on cooling energy consumption in North-oriented offices with different aspect ratios and Opening-to-wall percentages.*

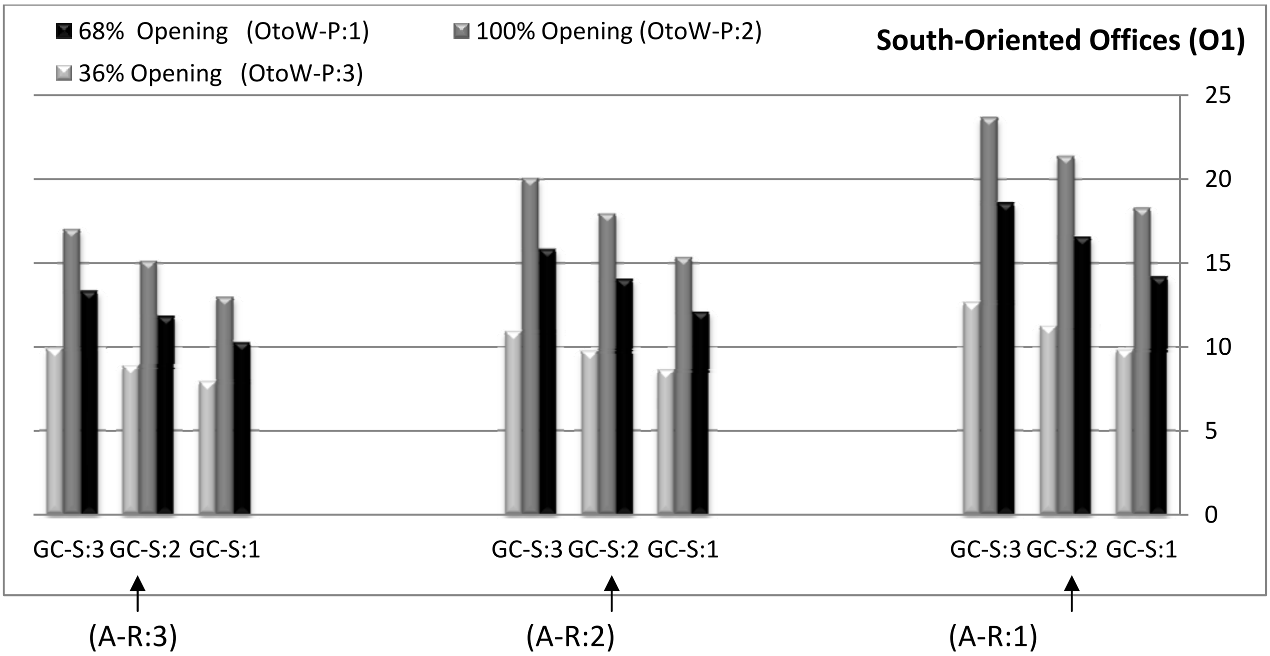
<u>6.1.2.2 Transparent Construction Systems:</u>

<u>- South-Oriented Offices (O1):</u> When compared to the South-oriented offices using opaque construction system 1 (OC-S:1) with 0.3349 U-value and Glazed construction system (GC-S:3) with 5.8652 U-value, both offices using transparent construction system 2 (GC-S:2) with 3.3917 U-value and transparent construction system 1 (GC-S:1) with 2.06 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Fig. 6.13 illustrates the results):

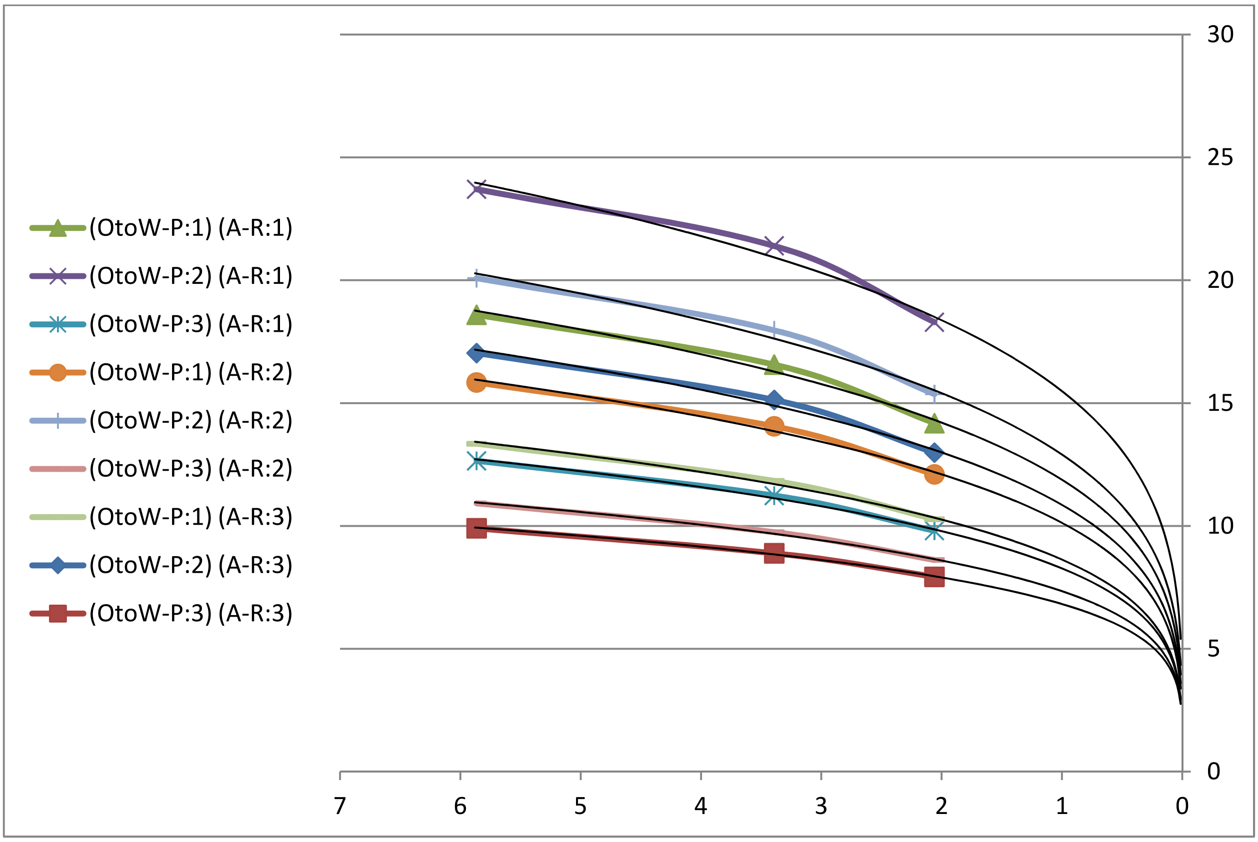
- 1.8:1 Aspect Ratio (A-R:1):
  - 100% Opening-to-Wall percentage (OtoW-P2): 9.7% and 23% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 11% and 23.7% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 11.1% and 22.5% respectively.
- 1:1 Aspect Ratio (A-R:2)
  - 100% Opening-to-Wall percentage (OtoW-P2): 10.5% and 23.5% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 11.2% and 23.6% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 10.7% and 21% respectively.
- 1:1.8 Aspect Ratio (A-R:3)
  - 100% Opening-to-Wall percentage (OtoW-P2): 11.2% and 23.8% respectively.

- 68% Opening-to-Wall percentage (OtoW-P1): 11.3% and 23% respectively.

- 36% Opening-to-Wall percentage (OtoW-P3): 10.2% and 20% respectively.



(A)

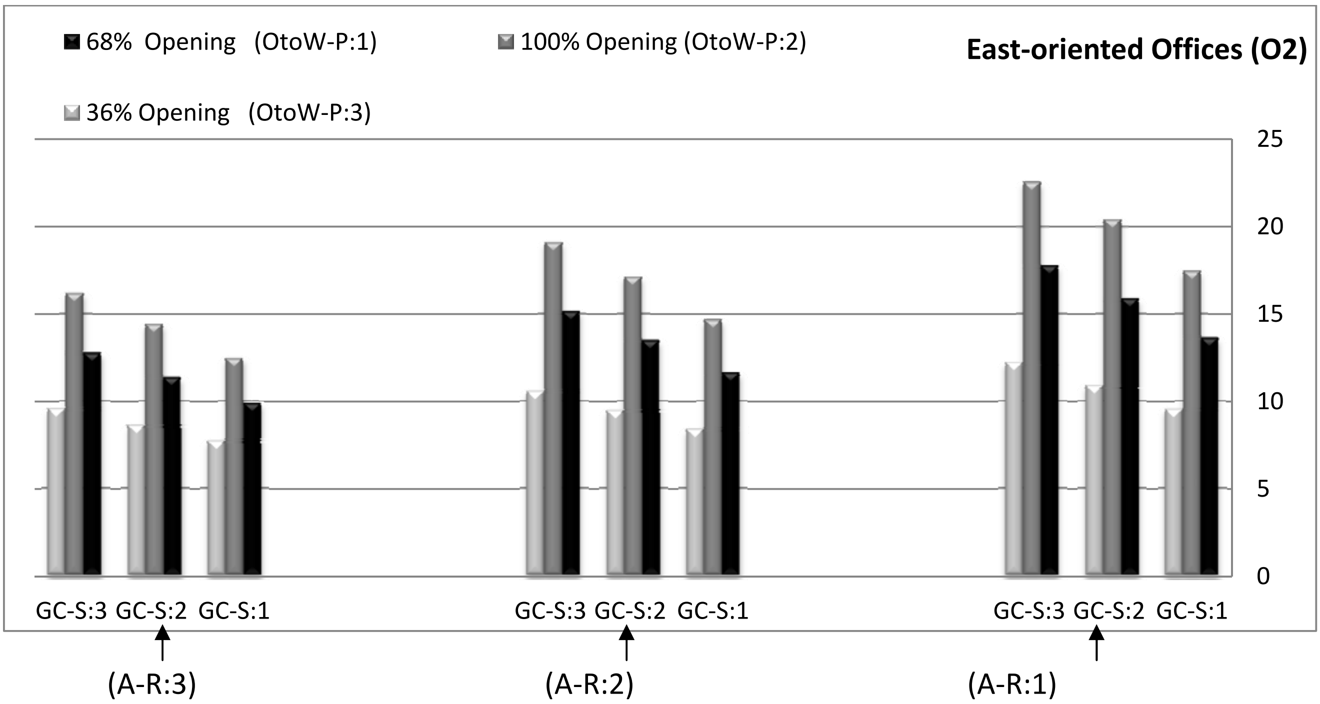


(B)

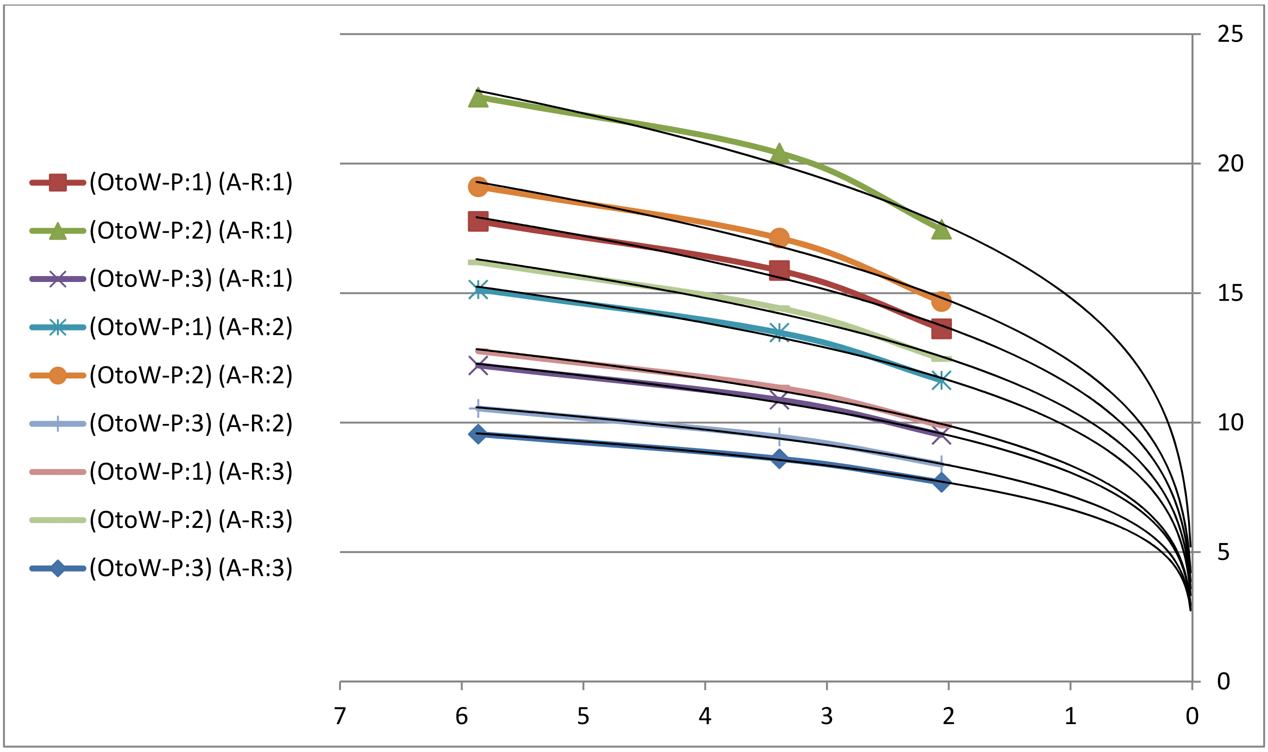
Figure 6.13 (A&B): *The impact of changing the transparent construction materials on cooling energy consumption in South-oriented offices with different aspect ratios and Opening-to-wall percentages.*

- <u>East-Oriented Offices (O2):</u> When compared to the East-oriented offices using opaque construction system 1 (OC-S:1) with 0.3349 U-value and Glazed construction system (GC-S:3) with 5.8652 U-value, both offices using transparent construction system 2 (GC-S:2) with 3.3917 U-value and transparent construction system 1 (GC-S:1) with 2.06 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Fig. 6.14 illustrates the results):

- 1.8:1 Aspect Ratio (A-R:1):
    - 100% Opening-to-Wall percentage (OtoW-P2): 9.5% and 22.6% respectively.
    - 68% Opening-to-Wall percentage (OtoW-P1): 10.7% and 23.3% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 10.8% and 22% respectively.
- 1:1 Aspect Ratio (A-R:2)
    - 100% Opening-to-Wall percentage (OtoW-P2): 10.3% and 23.2% respectively.
    - 68% Opening-to-Wall percentage (OtoW-P1): 10.9% and 23.1% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 10.4% and 20.1% respectively.
- 1:1.8 Aspect Ratio (A-R:3)
    - 100% Opening-to-Wall percentage (OtoW-P2): 10.9% and 23% respectively.
    - 68% Opening-to-Wall percentage (OtoW-P1): 11% and 22.5% respectively.
    - 36% Opening-to-Wall percentage (OtoW-P3): 9.9% and 19.4% respectively.



(A)



(B)

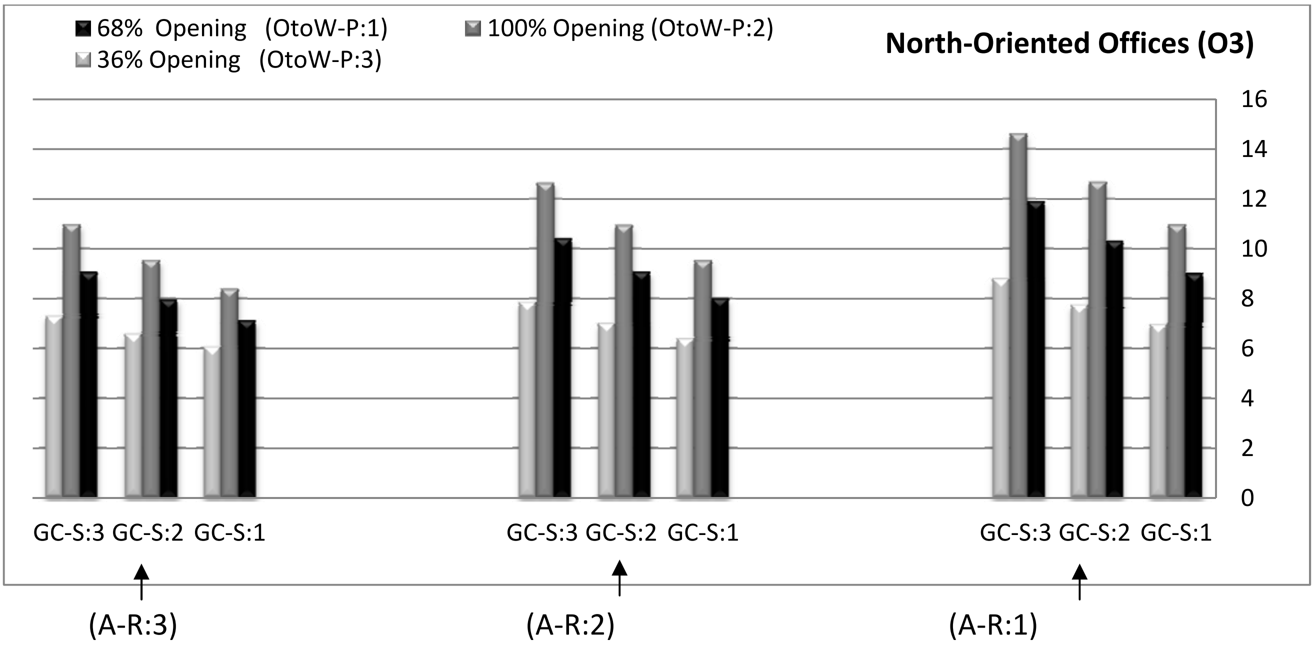
Figure 6.14 (A&B): *The impact of changing the transparent construction materials on cooling energy consumption in East-oriented offices with different aspect ratios and Opening-to-wall percentages.*

<u>- North-Oriented Offices (O2):</u> When compared to the North-oriented offices using opaque construction system 1 (OC-S:1) with 0.3349 U-value and Glazed construction system (GC-S:3) with 5.8652 U-value, both offices using transparent construction system 2 (GC-S:2) with 3.3917 U-value and transparent construction system 1 (GC-S:1) with 2.06 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Fig. 6.15 illustrates the results):

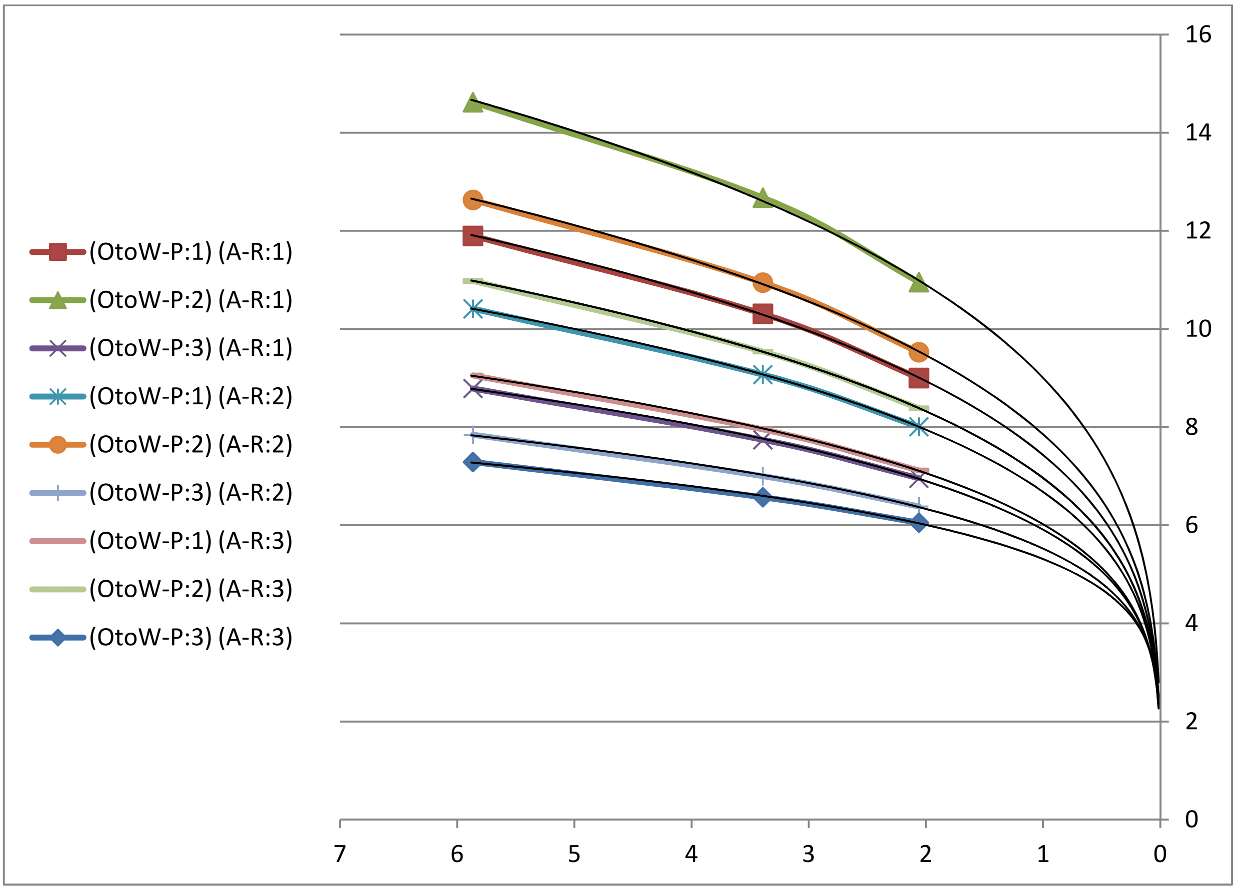
- 1.8:1 Aspect Ratio (A-R:1):
  - 100% Opening-to-Wall percentage (OtoW-P2): 13.3% and 25.1% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 13.3% and 24.3% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 11.8% and 20.8% respectively.
- 1:1 Aspect Ratio (A-R:2)
  - 100% Opening-to-Wall percentage (OtoW-P2): 13.3% and 24.6% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 12.9% and 23.1% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 10.7% and 18.6% respectively.
- 1:1.8 Aspect Ratio (A-R:3)
  - 100% Opening-to-Wall percentage (OtoW-P2): 10.9% and 23% respectively.

- 68% Opening-to-Wall percentage (OtoW-P1): 11% and 22.5% respectively.

- 36% Opening-to-Wall percentage (OtoW-P3): 9.9% and 17% respectively.



(A)



(B)

Figure 6.15 (A&B): *The impact of changing the transparent construction materials on cooling energy consumption in North-oriented offices with different aspect ratios and Opening-to-wall percentages.*

6.2 Results of Prototype 2:

6.2.1 Design Data:

6.2.1.1 Orientation:

- Offices with 2.55:1 aspect ratio (A-R:1) (OC-S:1 & GC-S:1): When compared to the East-South oriented offices (O:1), North-East oriented offices reduce cooling energy consumption depending on the opening-to-wall percentage as the following:

100% opening-to-wall percentage: 21.5%.

63.4% opening-to-wall percentage: 19.7%.

26.8% opening-to-wall percentage: 15.6%.

Fig. 6.16 illustrates the results.

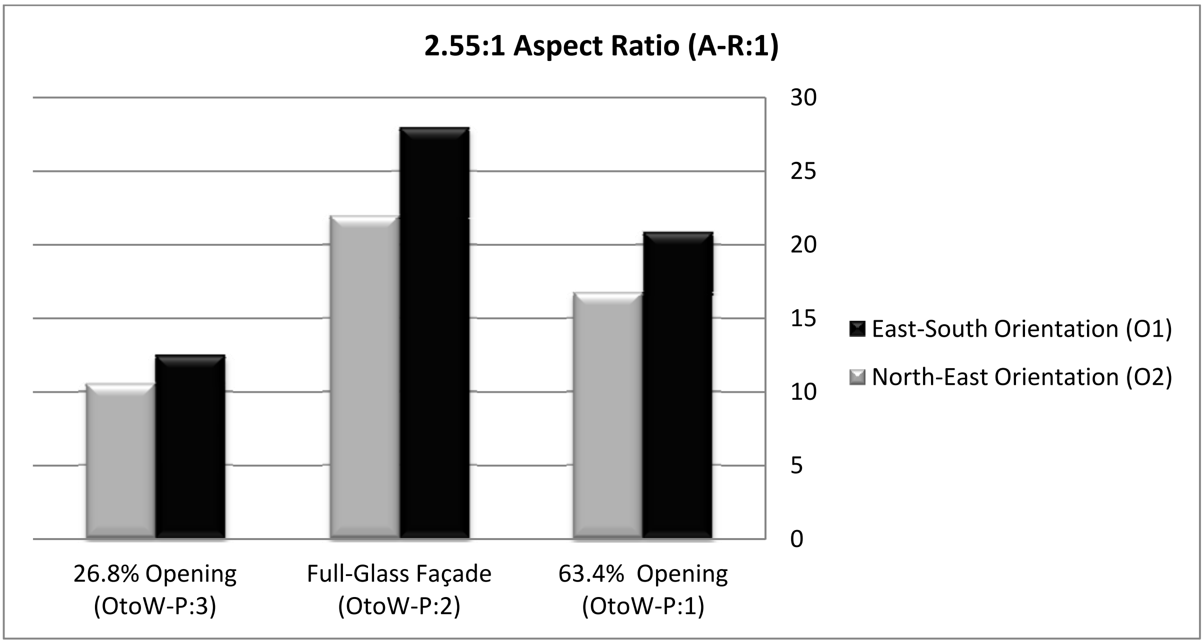


Figure 6.16: *The impact of changing the orientation on cooling energy consumption in 2.55:1 aspect ratio offices with different opening-to-wall percentages.*

- Offices with 1.88:1 aspect ratio (A-R:2) (OC-S:1 & GC-S:1): When compared to the East-South oriented offices (O:1), North-East oriented offices (O3) reduce cooling energy consumption depending on the opening-to-wall percentage as the following:

100% opening-to-wall percentage: 21.1%.

63.4% opening-to-wall percentage: 19.4%

26.8% opening-to-wall percentage: 15%.

Fig. 6.17 illustrates the results.

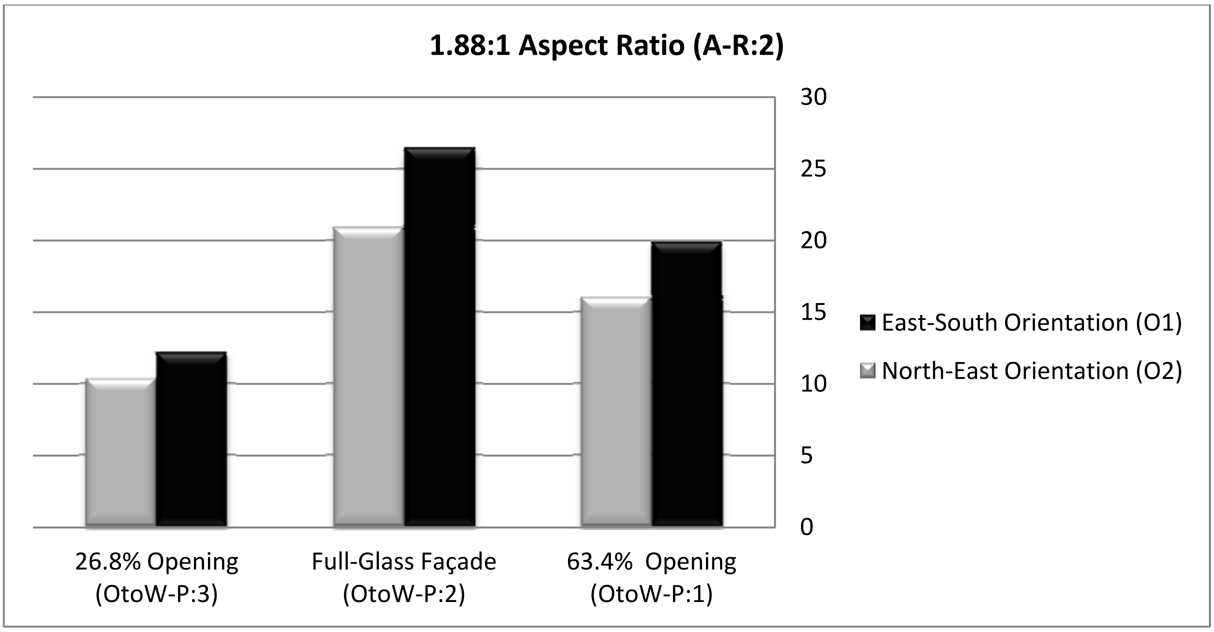


Figure 6.17: *The impact of changing the orientation on cooling energy consumption in 1.88:1 aspect ratio offices with different opening-to-wall percentages.*

<u>- Offices with 1:1 aspect ratio (A-R:3) (OC-S:1 & GC-S:1):</u> When compared to the East-South offices (O:1), North-East oriented offices (O2) reduce cooling energy consumption depending on the opening-to-wall percentage as the following:

100% opening-to-wall percentage: 19.9%.

63.4% opening-to-wall percentage: 17.9%.

26.8% opening-to-wall percentage: 13.3%

Fig. 6.18 illustrates the results.

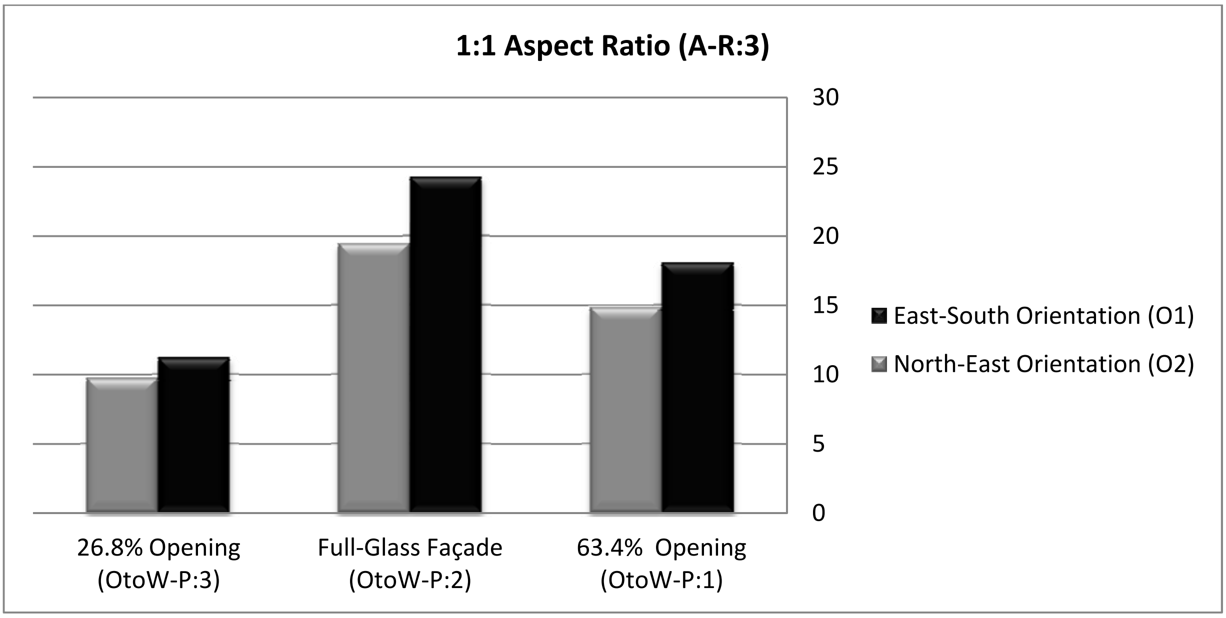


Figure 6.18: *The impact of changing the orientation on cooling energy consumption in 1:1 aspect ratio offices with different opening-to-wall percentages.*

6.2.1.2 Opening-to-wall-ratio:

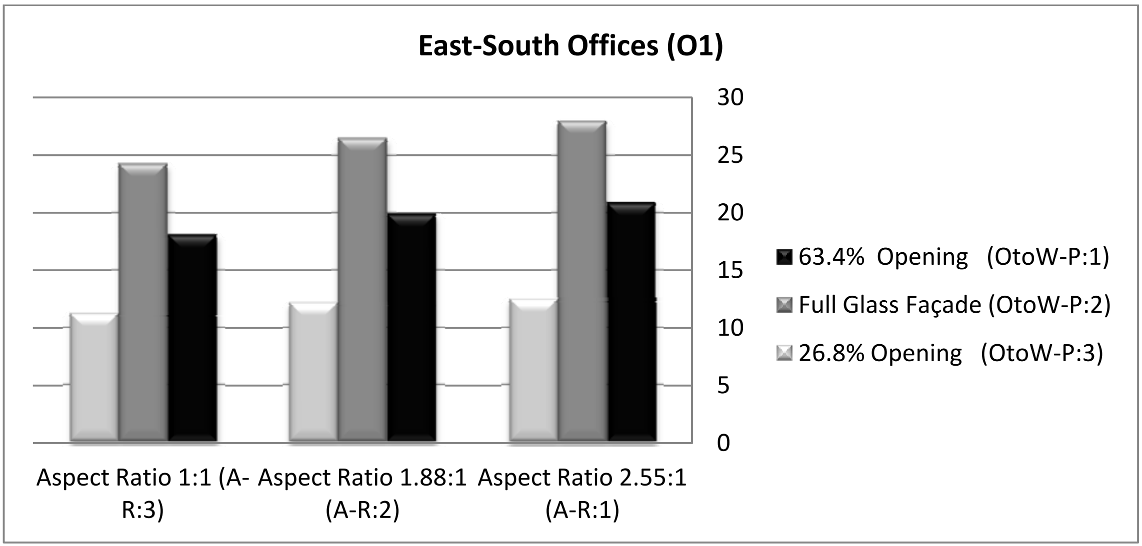
- East-South oriented offices (O1) (OC-S:1 & GC-S:1): When compared to the East-South oriented full-glazed facades offices (OtoW-P:2), offices with 63.4% (OtoW-P:1) and 26.8% (OtoW-P:3) opening-to-wall percentages reduce cooling energy consumption depending on the aspect ratio as the following:

2.55:1 Aspect Ratio Offices (AR1): 25.4% and 55.4% respectively.

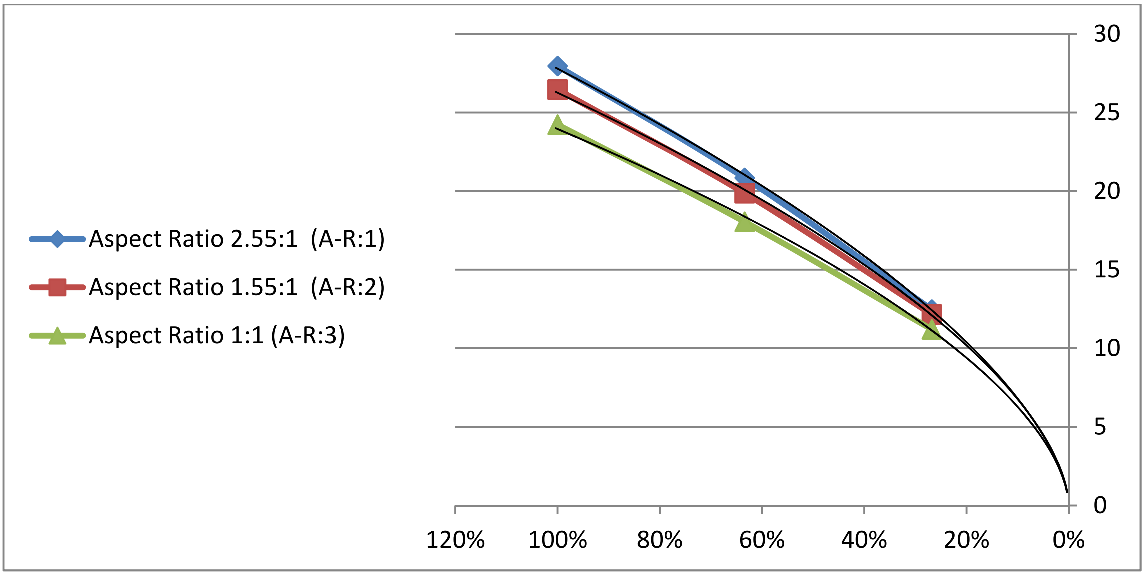
1.88:1 Aspect Ratio Offices (AR2): 24.9% and 54.1% respectively.

1:1Aspect Ratio Offices (AR3): 24.5% and 53.1% respectively.

Fig. 6.19 illustrates the results.



(A)



(B)

Figure 6.19 (A&B): *The impact of changing the opening-to-wall Percentage on cooling energy consumption in East-South oriented offices with different aspect ratios.*

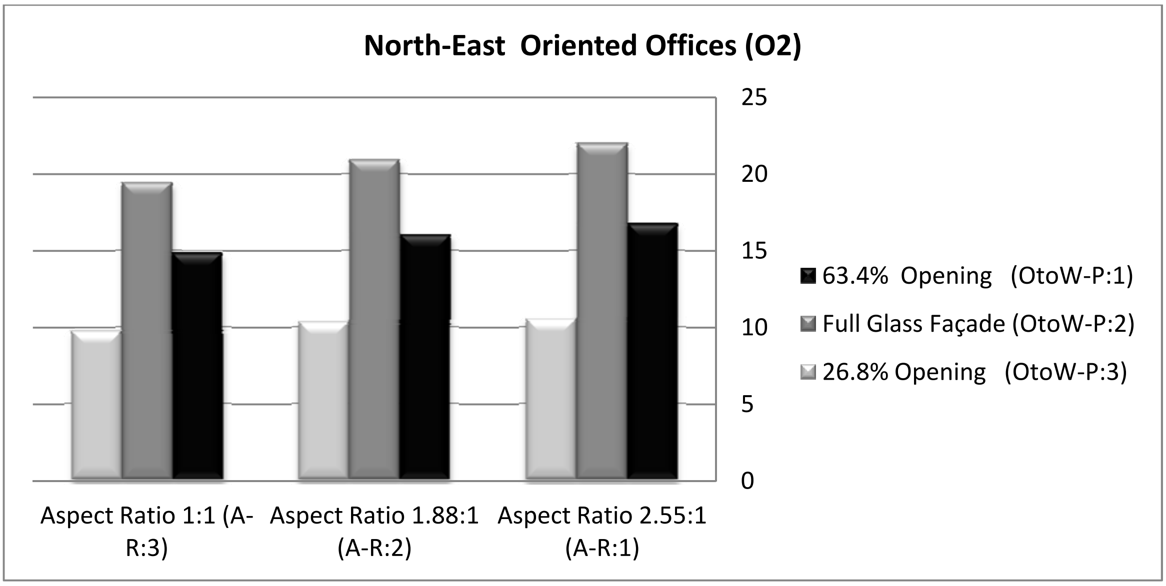
- <u>North-East oriented offices (O2) (OC-S:1 & GC-S:1):</u> When compared to the North-East oriented full-glazed facades offices (OtoW-P:2), both offices with 63.4% (OtoW-P:1) and 26.8% (OtoW-P:3) opening-to-wall percentages reduce cooling energy consumption depending on the aspect ratio as the following:

2.55:1 Aspect Ratio Offices (AR1): 23.8% and 52.1% respectively.

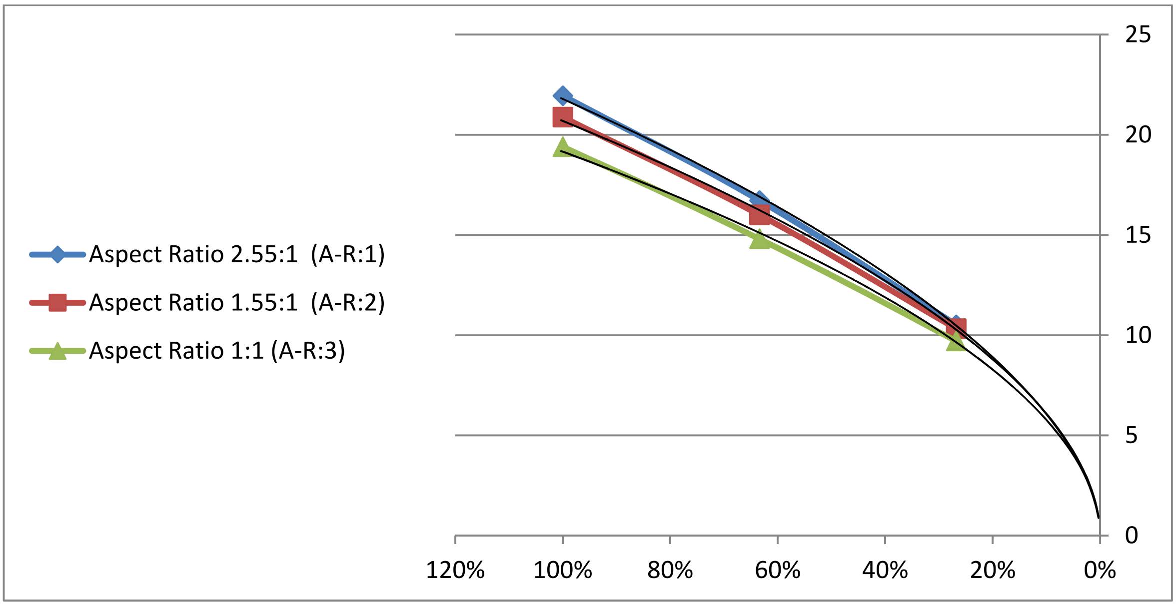
1.88:1 Aspect Ratio Offices (AR2): 23.3% and 50.5% respectively.

1:1 Aspect Ratio Offices (AR3): 22.9% and 49.9% respectively.

Fig. 6.20 illustrates the results.



(A)



(B)

Figure 6.20 (A&B): *The impact of changing the opening-to-wall percentage on cooling energy consumption in North-East oriented offices with different aspect ratios.*

6.2.1.3 Aspect Ratio:

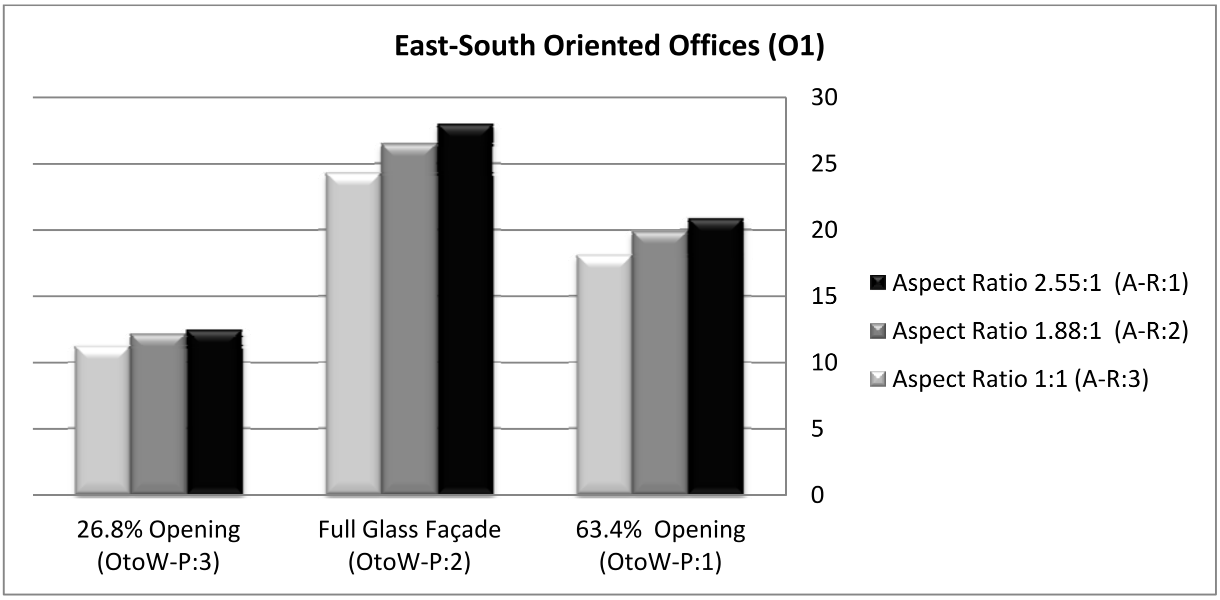
- East-South oriented offices (O1) (OC-S:1 & GC-S:1): When compared to the East-South oriented offices with 2.55:1 aspect ratio (A-R:1), both offices with 1.88:1 (A-R:2) and 1:1 (A-R:3) aspect ratios reduce cooling energy consumption depending on the opening-to-wall percentages as the following:

100% opening-to-wall percentage: 5.4% and 13.3% respectively.

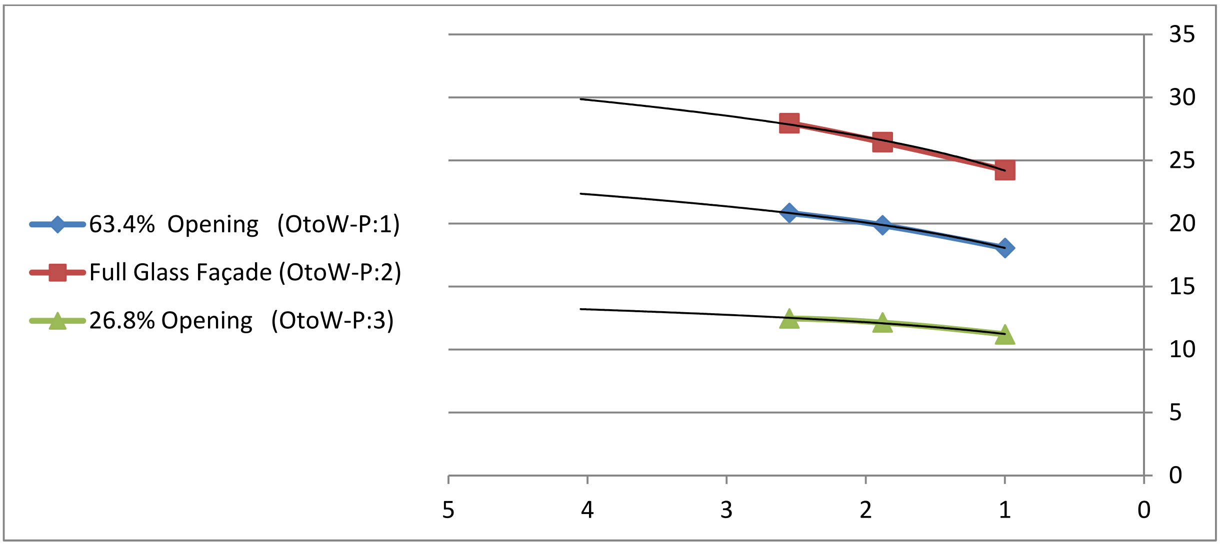
63.4% opening-to-wall percentage: 4.6% and 13.3% respectively.

26.8% opening-to-wall percentage: 2.6% and 10.1% respectively.

Fig. 6.21 illustrates the results.



(A)



(B)

Figure 6.21 (A&B): *The impact of changing the aspect ratio on cooling energy consumption in East-South oriented offices with different opening-to-wall ratios.*

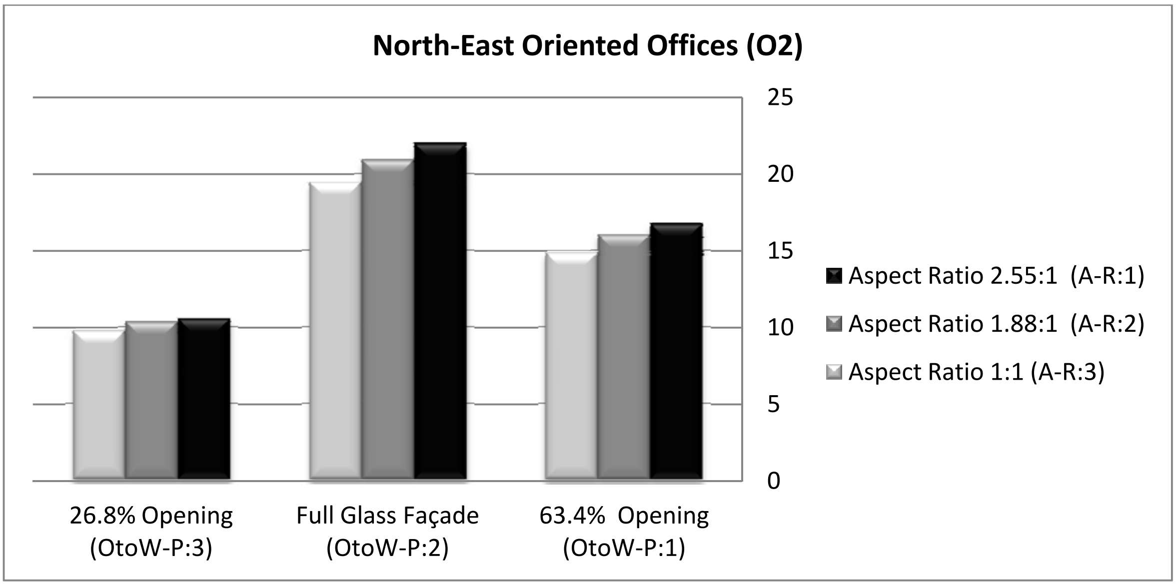
<u>- North-East oriented offices (O1) (OC-S:1 & GC-S:1):</u> When compared to the North-East oriented offices with 2.55:1 aspect ratio (A-R:1), both offices with 1.88:1 (A-R:2) and 1:1 (A-R:3) aspect ratios reduce cooling energy consumption depending on the opening-to-wall percentages as the following:

100% opening-to-wall percentage: 4.8% and 11.6% respectively.

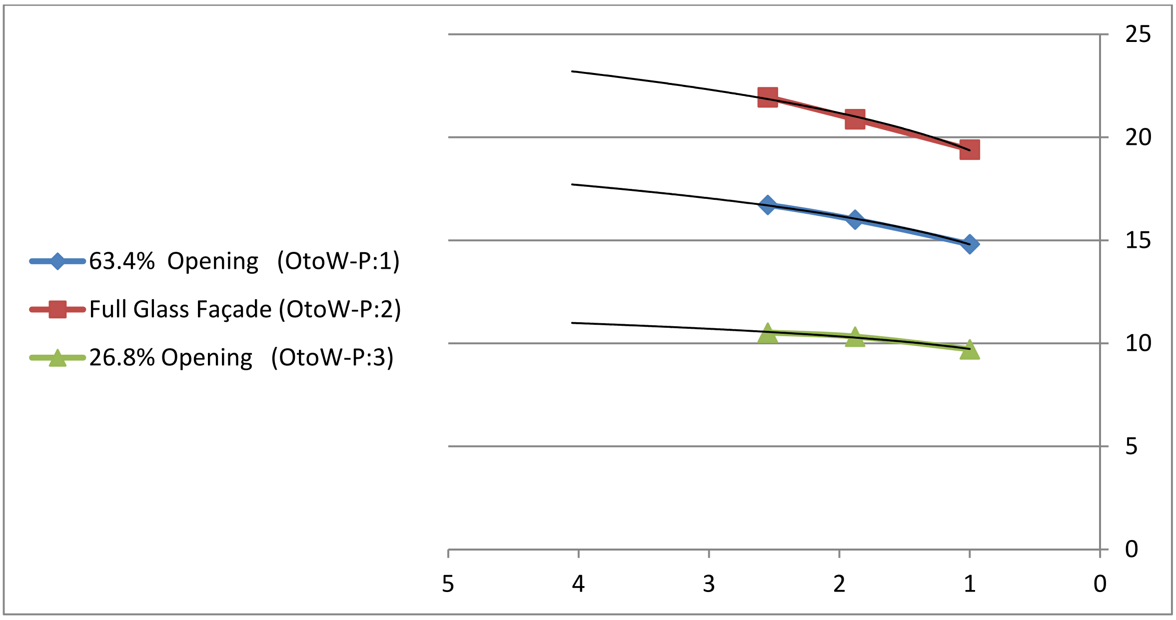
63.4% opening-to-wall percentage: 4.3% and 11.4% respectively.

26.8% opening-to-wall percentage: 1.9% and 7.7% respectively.

Fig. 6.22 illustrates the results.



(A)



(B)

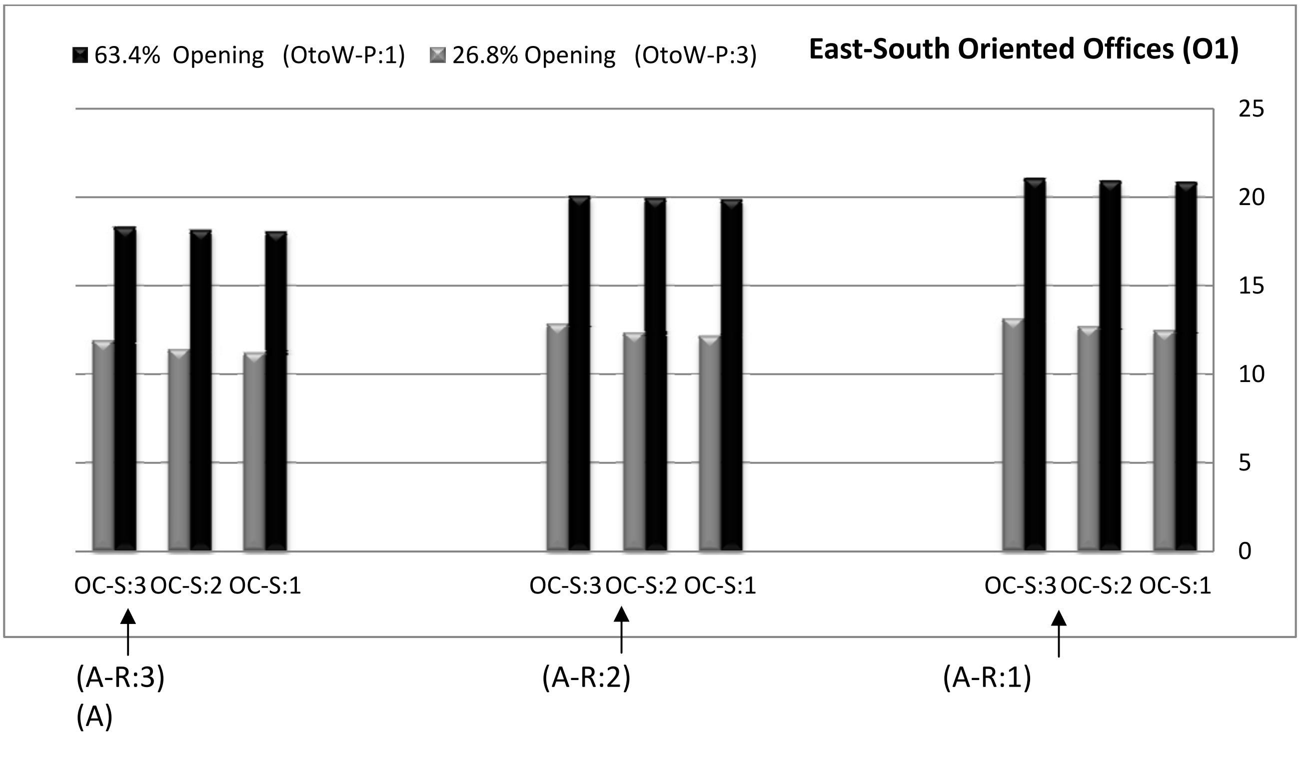
Figure 6.22 (A&B): *The impact of changing the aspect ratio on cooling energy consumption in North-East oriented offices with different opening-to-wall ratios.*

6.2.2 Materials Data:

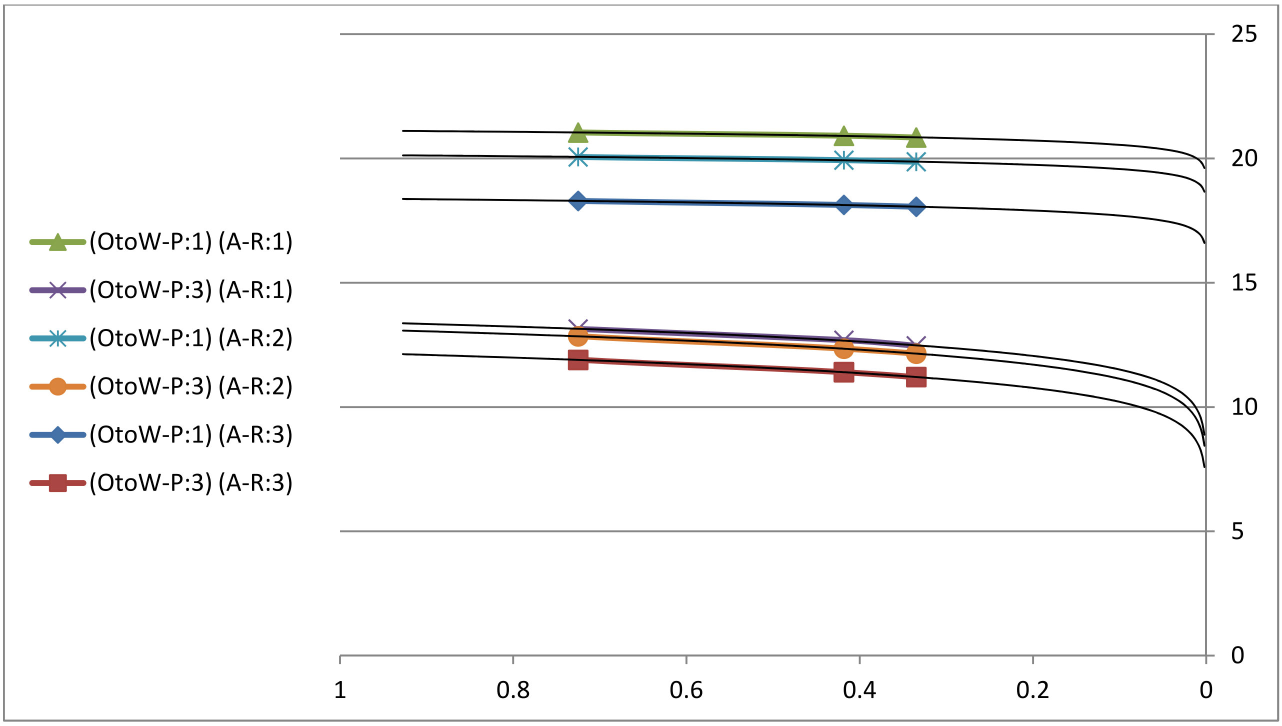
6.2.2.1 Opaque Construction Systems:

- East-South Oriented Offices (O1): When compared to the East-South oriented offices using opaque construction system 3 (OC-S:3) with 0.7252 U-value and Glazed construction system (GC-S:1) with 2.06 U-value, both offices using opaque construction system 2 (OC-S:2) with 0.4184 U-value and opaque construction system 1 (OC-S:1) with 0.3349 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Note that full glass facades were not taken in consideration; the area of opaque construction systems in this scenario is neglected) (Fig. 6.23 illustrates the results):

- 2.55:1 Aspect Ratio (A-R:1):
    - 63.4% Opening-to-Wall percentage (OtoW-P1): 0.6% and 1% respectively.
    - 26.8% Opening-to-Wall percentage (OtoW-P3): 3.4% and 5.1% respectively.
- 1.88:1 Aspect Ratio (A-R:2)
    - 63.4% Opening-to-Wall percentage (OtoW-P1): 0.6% and 1% respectively.
    - 26.8% Opening-to-Wall percentage (OtoW-P3): 3.8% and 5.4% respectively.
- 1:1 Aspect Ratio (A-R:3)
    - 63.4% Opening-to-Wall percentage (OtoW-P1): 0.8% and 1.3% respectively.
    - 26.8% Opening-to-Wall percentage (OtoW-P3): 4.1% and 5.8% respectively.



(A)

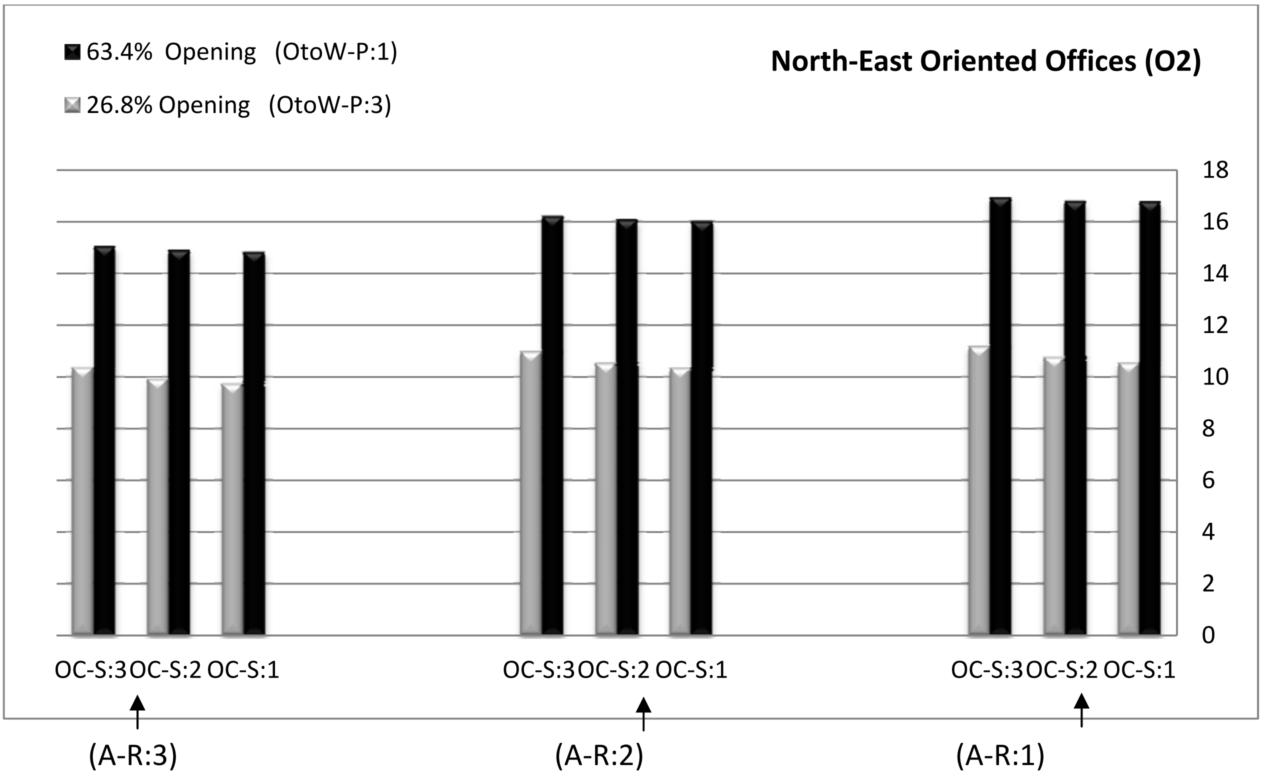


(B)

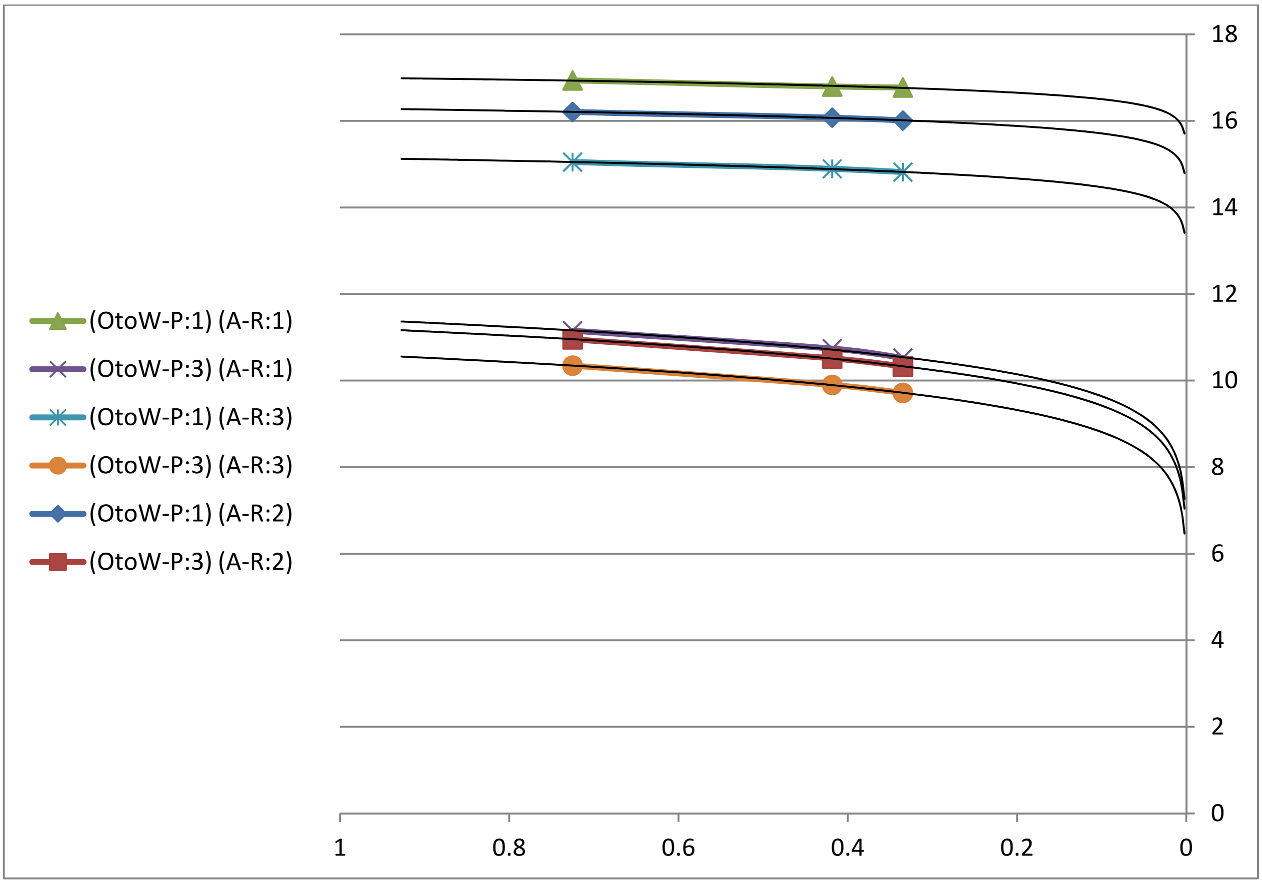
Figure 6.23 (A&B): *The impact of changing the opaque construction materials on cooling energy consumption in East-South oriented offices with different aspect ratios and Opening-to-wall percentages.*

<u>- North-East Oriented Offices (O2):</u> When compared to the North-East-South oriented offices using opaque construction system 3 (OC-S:3) with 0.7252 U-value and Glazed construction system (GC-S:1) with 2.06 U-value, both offices using opaque construction system 2 (OC-S:2) with 0.4184 U-value and opaque construction system 1 (OC-S:1) with 0.3349 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Note that full glass facades were not taken in consideration; the area of opaque construction systems in this scenario is neglected) (Fig. 6.24 illustrates the results):

- 2.55:1 Aspect Ratio (A-R:1):
    - 63.4% Opening-to-Wall percentage (OtoW-P1): 0.8% and 1% respectively.
    - 26.8% Opening-to-Wall percentage (OtoW-P3): 3.7% and 5.6% respectively.
- 1.88:1 Aspect Ratio (A-R:2)
    - 63.4% Opening-to-Wall percentage (OtoW-P1): 0.8% and 1.2% respectively.
    - 26.8% Opening-to-Wall percentage (OtoW-P3): 4% and 5.7% respectively.
- 1:1 Aspect Ratio (A-R:3)
    - 63.4% Opening-to-Wall percentage (OtoW-P1): 1% and 1.5% respectively.
    - 26.8% Opening-to-Wall percentage (OtoW-P3): 4.3% and 6.1% respectively.



(A)



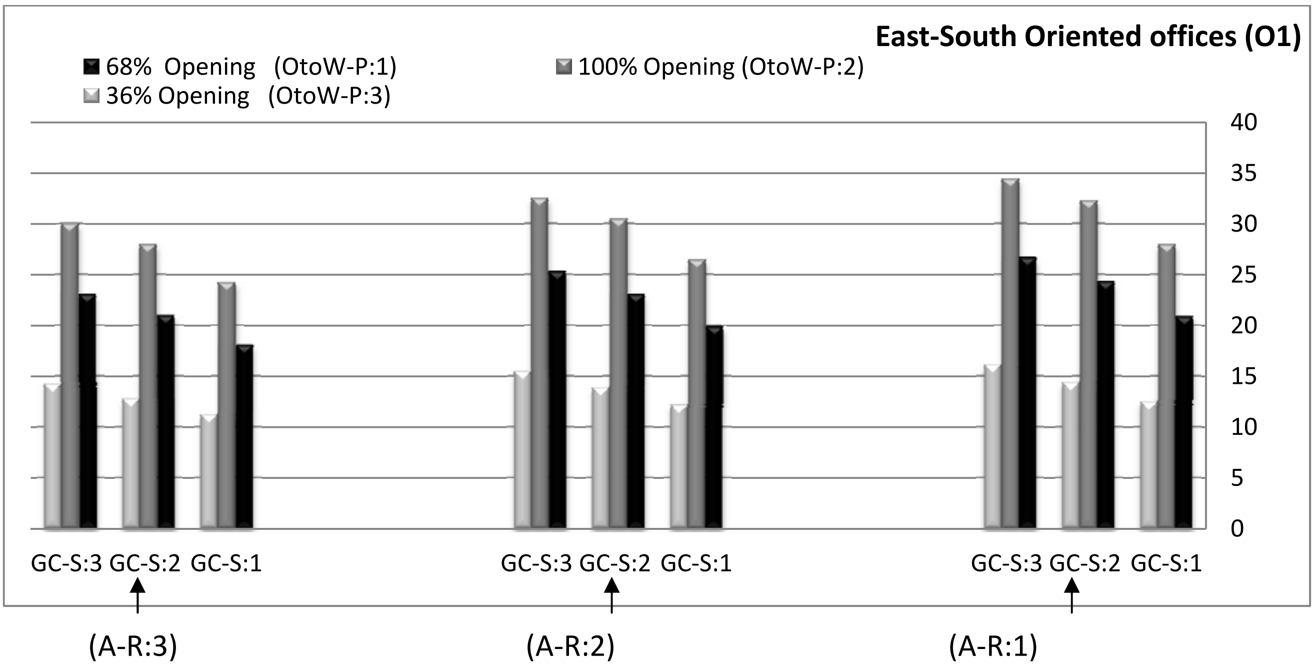
(B)

Figure 6.24 (A&B): *The impact of changing the opaque construction materials on cooling energy consumption in North-East oriented offices with different aspect ratios and Opening-to-wall percentages.*

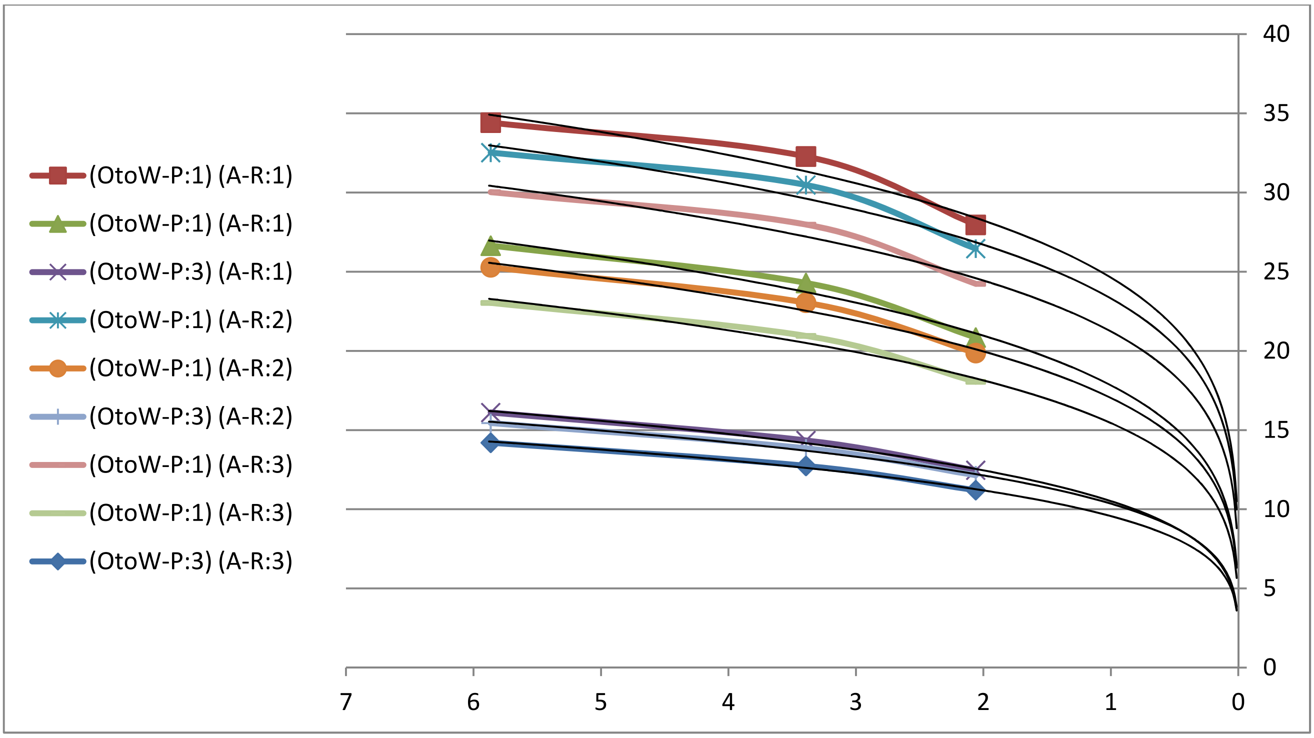
6.2.2.2 Transparent Construction Systems:

- East-South Oriented Offices (O1): When compared to the East-South oriented offices using opaque construction system 1 (OC-S:1) with 0.3349 U-value and Glazed construction system (GC-S:3) with 5.8652 U-value, both offices using transparent construction system 2 (GC-S:2) with 3.3917 U-value and transparent construction system 1 (GC-S:1) with 2.06 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Fig. 6.25 illustrates the results):

- 2.55:1 Aspect Ratio (A-R:1):
  - 100% Opening-to-Wall percentage (OtoW-P2): 6.2% and 18.7% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 8.8% and 21.8% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 10.9% and 22.6% respectively.
- 1.88:1 Aspect Ratio (A-R:2)
  - 100% Opening-to-Wall percentage (OtoW-P2): 6.3% and 18.6% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 8.8% and 21.4% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 10.3% and 21.8% respectively.
- 1:1 Aspect Ratio (A-R:3)
  - 100% Opening-to-Wall percentage (OtoW-P2): 6.8% and 19.3% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 9% and 21.6% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 10.3% and 21.9% respectively.



(A)



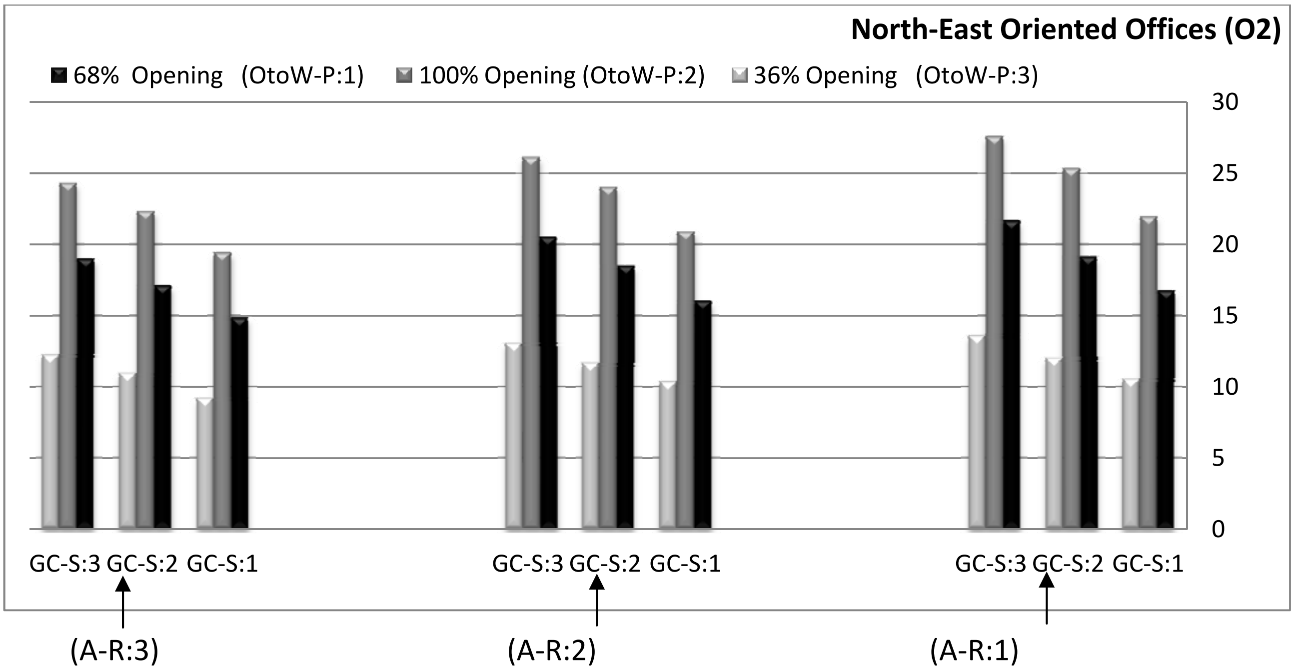
(B)

Figure 6.25 (A&B): *The impact of changing the transparent construction materials on cooling energy consumption in East-South oriented offices with different aspect ratios and Opening-to-wall percentages.*

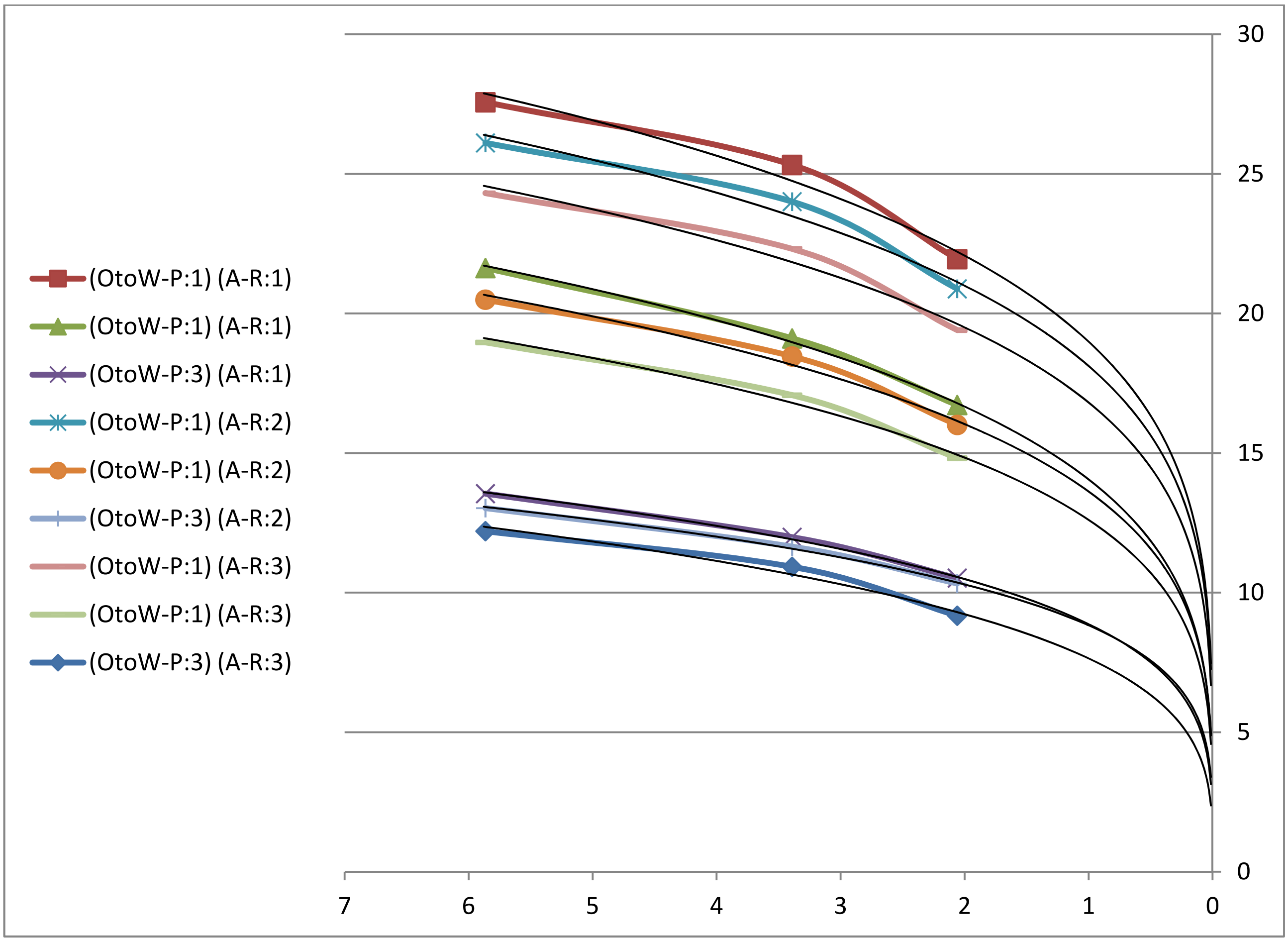
<u>- North-East Oriented Offices (O1):</u> When compared to the North-East oriented offices using opaque construction system 1 (OC-S:1) with 0.3349 U-value and Glazed construction system (GC-S:3) with 5.8652 U-value, both offices using transparent construction system 2 (GC-S:2) with 3.3917 U-value and transparent construction system 1 (GC-S:1) with 2.06 U-value reduce cooling energy consumption depending on the opening-to-wall percentages and the aspect ratios as the following (Fig. 6.26 illustrates the results):

- 2.55:1 Aspect Ratio (A-R:1):
  - 100% Opening-to-Wall percentage (OtoW-P2): 8% and 20% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 11.7% and 22.7% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 11.8% and 22.9% respectively.
- 1.88:1 Aspect Ratio (A-R:2)
  - 100% Opening-to-Wall percentage (OtoW-P2): 8% and 20% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 9.9% and 21.9% respectively.
  - 36% Opening-to-Wall percentage (OtoW-P3): 14% and 23.7% respectively.
- 1:1 Aspect Ratio (A-R:3)
  - 100% Opening-to-Wall percentage (OtoW-P2): 8% and 20.1% respectively.
  - 68% Opening-to-Wall percentage (OtoW-P1): 10% and 21.9% respectively.

- 36% Opening-to-Wall percentage (OtoW-P3): 10.5% and 22.1% respectively.



(A)



(B)

Figure 6.26 (A&B): *The impact of changing the transparent construction materials on cooling energy consumption in North-East oriented offices with different aspect ratios and Opening-to-wall percentages.*

6.3 Summary and Discussion:

6.3.1 Architectural Parameters:

- As the results show; Architectural decisions have a great impact on any space energy consumption. As an example; a quick comparison between prototype1 case#27 and case#112 (two offices with similar area but with different architectural parameters) show that the basic architectural decisions taken in the design stage can reduce thermal energy consumption by about 67% (Fig. 6.26). This research has studied and analyzed three main architectural parameters which are: Orientation, Opening to Wall Percentage and finally Aspect Ratio. These three parameters were selected due to their major effect on energy consumption in buildings. Despite their importance, other architectural parameters such as the impact of adjacent buildings and the use of overhangs and louvers were not studied in this research. Moreover, the effect of the architectural design on the visual and acoustical comfort was not studied. To sum up the results clarify the impact of the previously mentioned three basic architectural factors on thermal energy consumption and thermal comfort only.

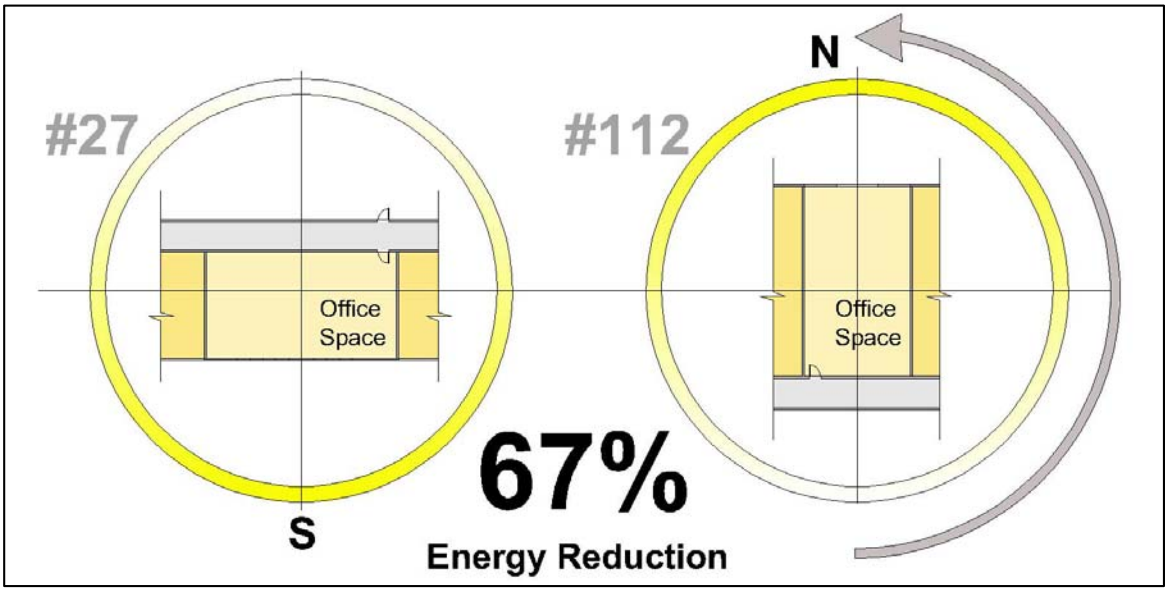


Figure 6.27: *A comparison between two offices with similar area but different architectural parameters.*

- Based on the survey performed on 12 offices towers located on Sheikh Zayed Road -the main business spine in the city-, offices towers in Dubai can be classified according to their floor plan shapes into two major types: square shaped and rectangular shaped towers. In the first type, offices spaces were found to be located at each corner surrounding the main services core. Offices in this type are facing the four directions. In the second type, most of the spaces were found to be rectangular with only one external wall that faces the main road. Fig. 6.27 illustrates the two types.

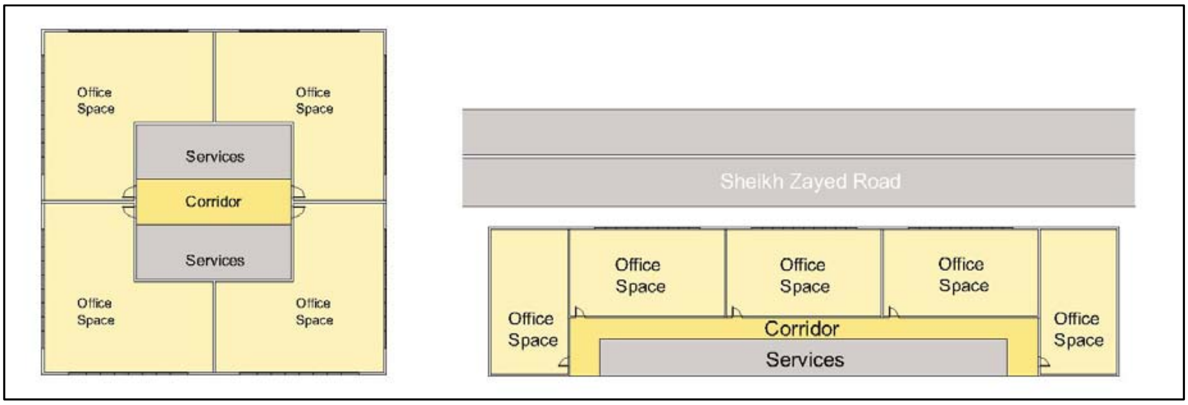


Figure 6.28: *Classifications of offices towers studied according to their floor plan shape.*

- Despite having many architectural advantages, designing corner offices was found to be environmentally irresponsible when compared to offices with one external wall. The results of the simulation have shown that designing offices with one external wall instead of two can achieve a reduction in energy consumption in the range of 25% to 41% (Fig. 6.27). Unfortunately, the survey performed has shown that around 75% of the offices were corner offices. This important fact clearly shows that most of the designers in the city lack environmental awareness and responsibility and tend to give visual architectural factors the priority in the design process.

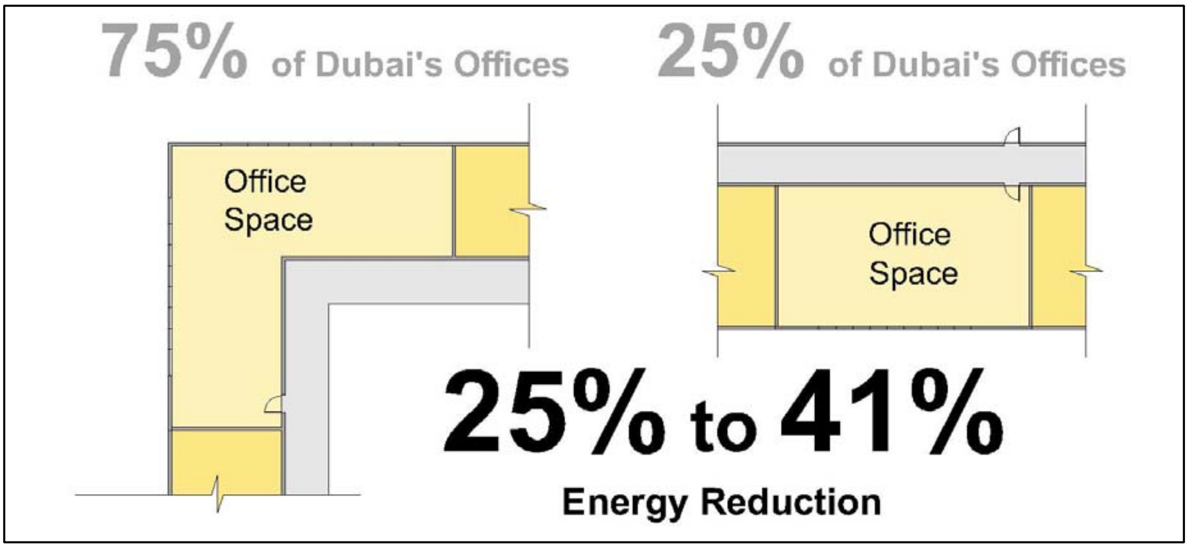


Figure 6.29: *A comparison between corner offices and one-external wall offices.*

- Though the survey results have clarified that architects tend to select buildings orientations according to architectural aspects (i.e. most of the offices were designed to face the main road), the simulation results prove that selecting the proper orientation can achieve remarkable reduction in energy consumption. The results of the scenarios studied have shown that in offices with one external wall, East and North oriented offices reduce energy consumption in the range of 3-4.5% and 23-40% respectively when compared to south oriented offices while in corner offices, North-East oriented offices reduce energy consumption in the range of 13-22% compared to East-South oriented offices (Fig. 6.28).

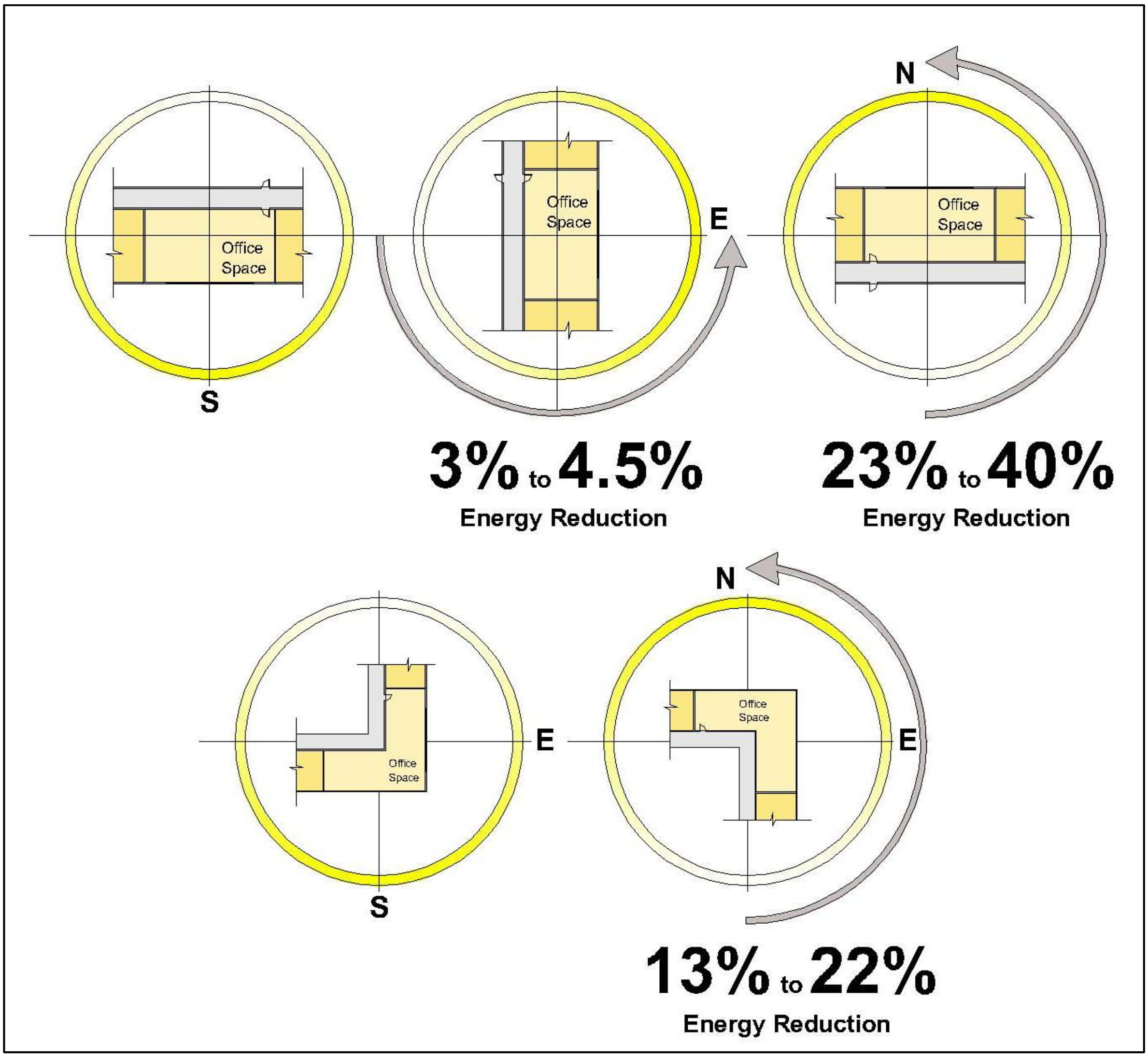


Figure 6.30: *Orientation and energy consumption.*

- Based on the literature review, opening-to-wall percentage is considered as a major architectural parameter that affects energy consumption. In the surveyed area, the results have shown that buildings in the city vary in their opening sizes; some of them have full glass facades while many others have normal medium sized windows. The average opening-to-wall percentage was found to be 67.9% in the normal rectangular one-external wall offices and 63.4% in the corner offices. Trying to figure out how does this parameter affect energy consumption, offices with different opening to wall ratios were modeled and simulated. The results of the scenarios studied have shown that when compared to the full-glass-façade, one-external-wall offices with 67.9% and 35.8% opening-to-wall ratios reduce energy consumption in the range of 15.1-20.8% and 27.8-46.4% respectively while corner offices with 63.4% and 26.8% reduce energy consumption in the range of 22.9-25.4% and 50-55.5% respectively (Fig. 6.29). Fortunately, the government of Dubai has realized this important fact and has set a limit of 60% glazing for building which will go into effect in 2014. However and though it has almost exactly the same climate, Abu Dhabi which is the country's capital has more stringent limit of 30% only.

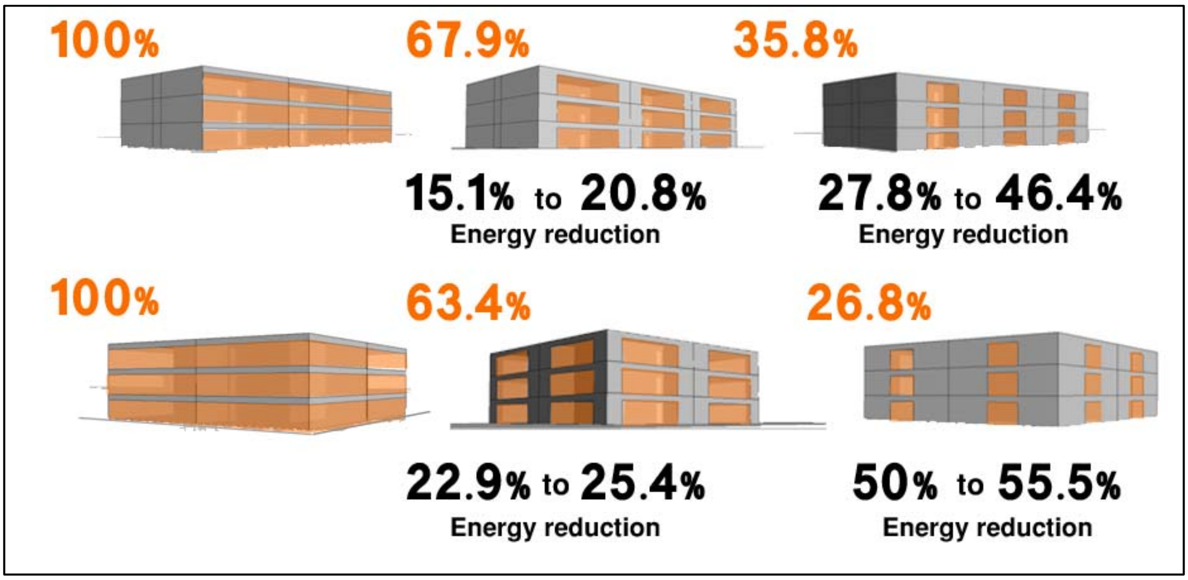


Figure 6.31: *Opening-to-wall percentage and energy consumption.*

- The final architectural parameter studied and analyzed was aspect ratio. Regardless of the advantages architects can get from locating office desks close to windows, designing narrow offices spaces can really cause a significant increase in energy consumption especially in hot and humid climates. Therefore, aspect ratio is an important architectural factor that needs to be studied and analyzed in the design stage as achieving a balance between the environmental and other architectural factors is a must. In Dubai, the survey has shown that the average aspect ratio of one-external-wall offices is around 1.8:1, while it is 2.55:1 for corner offices. Two different scenarios for each offices type were tested and the results were as the following: in the one external wall offices, when compared to the 1.8:1 aspect ratio both 1:1 and 1:1.8 aspect ratio offices reduce energy consumption in the ranges of 8.2-16% and 13-29% respectively. In corner offices, when compared to the 2.55:1 aspect ratio, offices with 1.88:1 and 1:1 aspect ratios reduce energy consumption in the ranges of 1.9-5.4% and 7.7-13.3% respectively (Fig. 6.30).

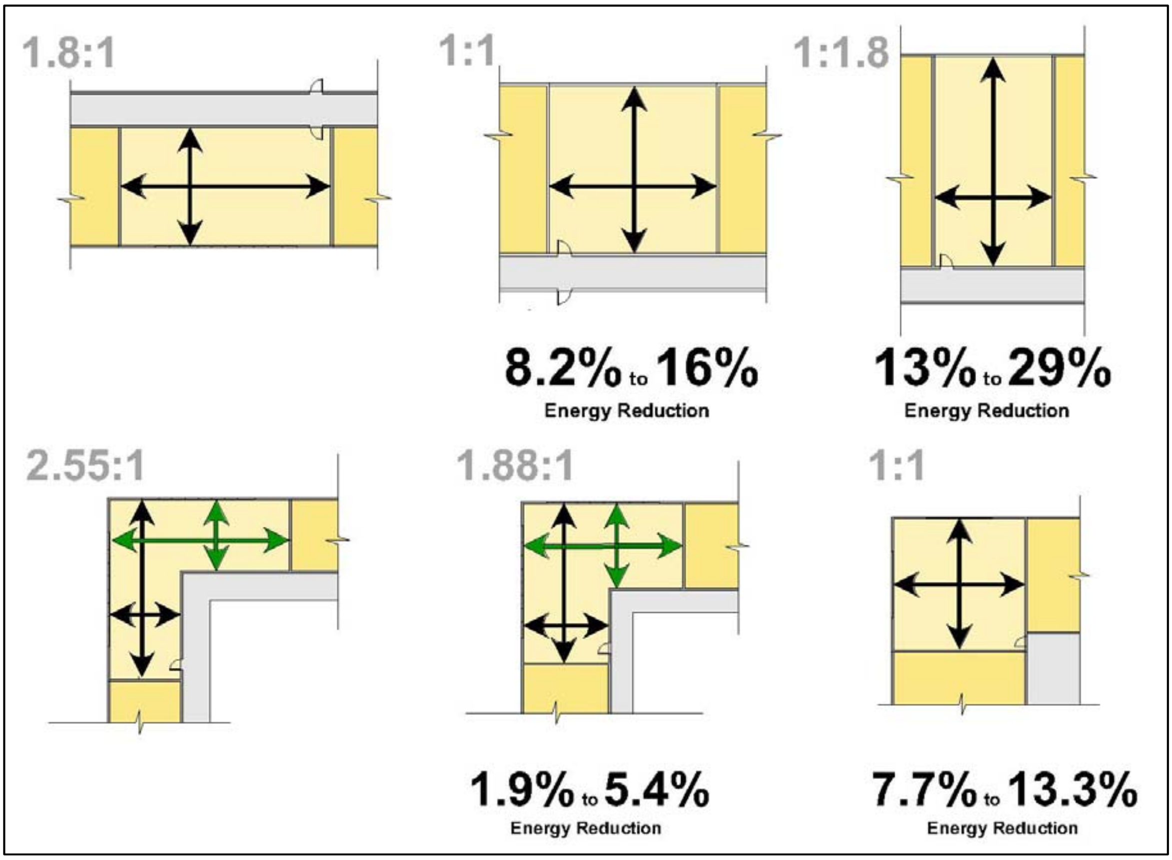


Figure 6.32: *Aspect Ratio and energy consumption.*

To sum up: Architectural decisions have a great impact on any space energy consumption. The results obtained from examining offices spaces with different architectural data obviously clarify that architects have a great responsibility of saving energy in buildings through the decisions they take in the design process. When environmental decisions in the design stage are adopted, buildings consume less energy and would comply with the current and futuristic energy regulations. Moreover, proper environmental design avoids radical interference of other buildings specialists that impose techniques and devices such as sensors and building management systems in the spaces created. Using such devices contradicts with a major architectural concept: Buildings were designed by humans and should be controlled by humans.

6.3.2 Materials Parameters: As solar radiation and outside heat penetrates and flows into the internal spaces through the outside materials used in the building envelope, selecting proper materials that thermally insulate the inside spaces from the outside environment without compromising the importance of the visual and acoustical factors is vital for reducing energy consumption. As an example; when prototype 1 case#1 was modeled with different construction systems (OC-S3 and GC-S3 instead of OC-S1 and GC-S3) energy consumption has increased from 14.1850MWh to 18.7499MWh (32% increase in energy consumption) (Fig. 6.31).

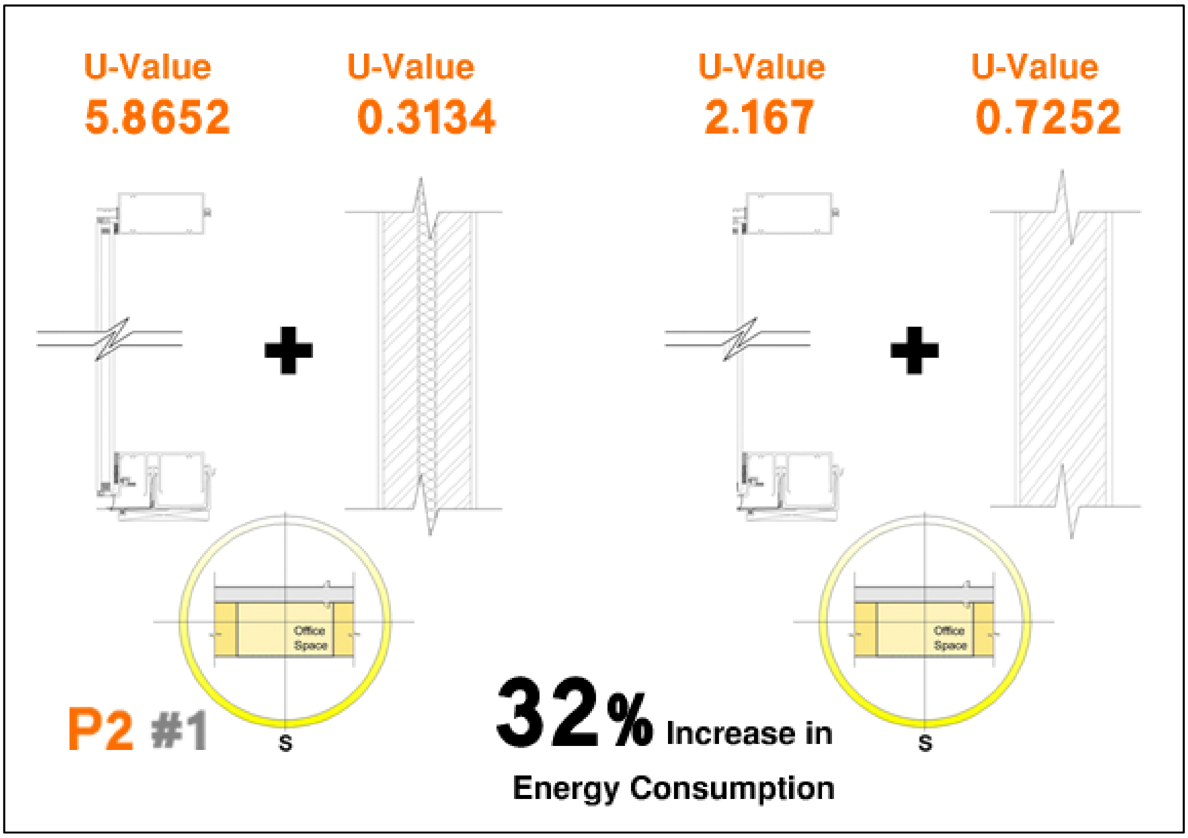


Figure 6.33: *A comparison between two offices with similar architectural design but different materials.*

- Opaque Construction: In Dubai, the municipality determines five different construction systems that should be used in all the buildings in the city. A quick look at the different systems shows that they all use similar details for the internal partitions and ceilings. However, the details of the external walls vary in the layers that consist them and hence their U-Values. In this study, the U-values of the 5 construction systems were studied and the results have shown that they all fall in the range of 0.3134 W/m^2.K to 0.7252 W/m^2.K. In this cases modeled and studied, construction system#5 with 0.3134 W/m^2.K, construction system#3 with 0.4184 W/m^2.K and construction system#4 with 0.7252

$W/m^2.K$ were tested. The results have shown that despite the slight difference in their U-Values, their impact on the internal spaces energy consumption is noticeable. In prototype 1, choosing construction system#3 instead of construction system#4 achieves a reduction in the energy consumption in the range of 1.3-3.5% and 3.7-5.4% when the opening to wall percentages are 68% and 36% respectively, while choosing construction system#5 instead of construction system#4 achieves a reduction in energy consumption in the range of 2-5.2% and 5-7.7% when the opening to wall percentages are 68% and 36% respectively. In prototype 2, when compared to system#4, system#3 reduces energy consumption in the range of 0.6-1% and 3.4-4.3% when the openings to wall percentages are 63.4% and 25.8% respectively, while system#5 reduces energy consumption in the range of 1-1.5% and 5.1-6.1% when the openings to wall percentages are 63.4% and 25.8% respectively.

- Transparent Construction: In Dubai, there are many companies that are providing different kinds of glass with different U-Values, prices, quality, reflectance, colors.. etc. As it was so difficult for the researcher to choose three glass materials that exactly represent and mimic what is being used in the market, three regular façade systems were modeled and simulated. The first glass system modeled (GC-S:1) was double-glazed with a coated external glass panel (2.167 $W/m^2.K$ U-Value). The second system modeled (GC-S2) was double-glazed too but with 2 clear float glass panels (3.2985 $W/m^2.K$ U-Value). Finally glass construction system#3 was modeled with one glass panel only (5.8652 $W/m^2.K$ U-Value). The results have shown that In prototype 1, choosing glass construction system#2 instead of construction system#3 achieves a reduction in the energy consumption in the range of 9.5-13.3%, 10.7-13.3% and 9.9-11.8% when the opening to wall percentages are 100%, 68% and 36% respectively, while choosing construction system#1 instead of construction system#3 achieves a reduction in energy consumption in the range of 22.6-25.1%, 22.5-24.3% and 17-22.5% when the opening to wall percentages are 100%, 68% and 36% respectively. In prototype 2, when compared to system#3, system#2 reduces energy consumption in the range of 6.2-8%, 8.8-11.7% and 10.3-14% when the openings to wall percentages are 100%, 63.4% and 25.8% respectively, while system#1 reduces energy consumption in the range of 18.6-20.1%, 21.4-22.7% and 21.8-23.7% when the openings to wall percentages are 100%, 63.4% and 25.8% respectively.

6.4 Heat flow mechanism in the studied cases:

In order to analyze the previous results and understand how the changes in the architectural design and materials data has significantly affected the thermal energy consumption in the spaces studied, it is essential to first understand all the heat sources and identify the mechanisms of how they were transferred into the studied spaces. As has been clarified in the literature review, heat can be transferred through the following physical mechanisms:

- Conduction: Due to temperature difference, heat can flow from the outside to the inside or vice versa through the buildings elements such as walls, roofs, ceiling… etc.
- Convection: Heat can be transferred from one space to another by the movement of air.
- Solar radiation: Direct and indirect solar radiation penetrates the spaces through the transparent buildings elements and raises the internal temperatures as it is absorbed by the internal surfaces.

6.5 Heat Sources:

1- External Sources: Because the buildings internal spaces temperatures are always different from the outside temperature, heat always flows from one side of the building's envelope to the other through conduction. In Dubai, the outside temperature is much higher than the temperatures required for achieving comfort in the internal spaces almost every day in the year. The direct and indirect intense solar radiations hitting the external layers of the building envelope cause an increase in their temperatures. By conduction, heat flows to the envelope internal layers and consequently to whatever close to it including air. By convection, hot air moves around the room and increases all the others surfaces temperatures. On the other hand, some of the solar radiation penetrates the space through the transparent parts of the external facades and raises the surfaces they contact. Consequently the previous process of heat flow in the internal space through conduction and convection occurs again resulting in an increase in the space's mean radiant temperature. Finally, air infiltration – unintentional or accidental introduction of outside air into the building- is considered as the last source of external heat, full insulation of the internal spaces from the outside environment is almost impossible as construction cracks, structural inaccurate details or irresponsible human behaviors can't be avoided.

2- Internal sources: The existence of humans, HVAC equipments, lighting devices and other appliances participate in raising the internal spaces temperatures. All of these factors produce heat due to metabolic actions as in human bodies or energy conversion as in the other sources. All of these factors emit heat in the space and raises its mean radiant temperature.

To sum up: Internal and external sources of heat are responsible for increasing the internal spaces temperatures. Fig 6.32 illustrates the heat sources and their flow mechanisms.

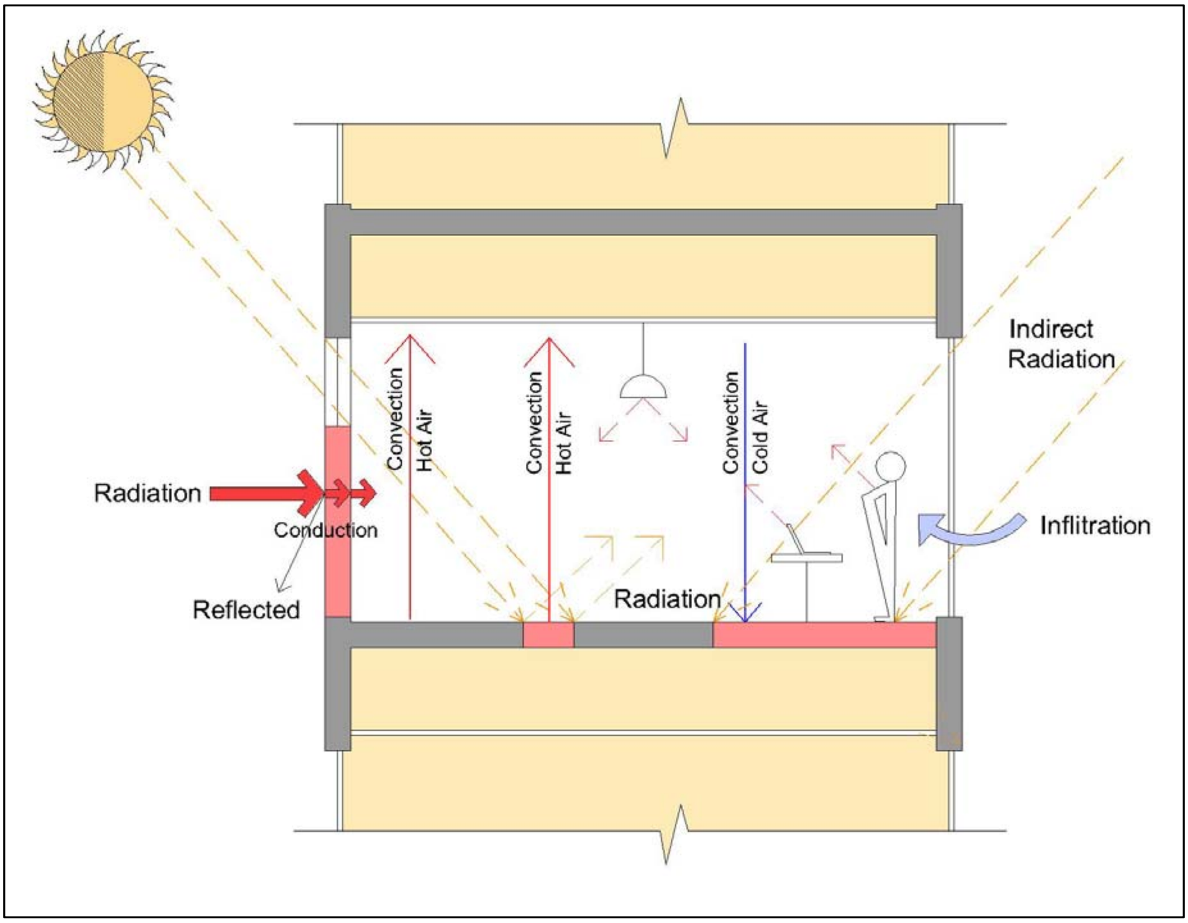


Figure 6.34: *Heat flow mechanisms and sources of heat.*

6.6 The impact of the sources of heat on thermal energy performance:

In order to understand how each source of heat affect the thermal performance of the internal spaces, some of the parameters of prototype 2 base case (75% of Dubai offices) were changed, modeled and simulated. The researcher started by changing the parameters of air infiltration; 0.001 max flow was assigned instead of 0.25 max flow used in the base case. The results showed that thermal energy consumption has dropped from

20.8438MWh to 20.2746MWh and from 16.7223MWh to 15.968MWh in both East-South and North-East orientation respectively.

In the following step, the glass was changed with a similar U-value non-transparent material that doesn't allow solar radiation to penetrate the space. By doing this, it was ensured that heat flows from the outside only through the external layers of the envelope via conduction. The results showed that energy consumption has dropped to 8.0167MWh and 7.3494MWh in both East-South and North-East orientation respectively.

To know the influence of the conduction through the glass on the internal thermal performance, external walls in the previous modified model were changed with 0.01 U-Value imaginary very thick walls. This ensures that conduction through the glass is the only source of external heat. The results have shown that energy consumption dropped to 7.3813MWh and 6.7666MWh in both East-South and North-East orientation respectively.

In the final step, heavy thick walls with only 0.01 U-Values were tested and windows were deleted. The purpose of this was to measure how internal factors affect the energy consumption. When simulated, results have dropped to 2.2664 in both orientations. Fig. 6.33 illustrates the results.

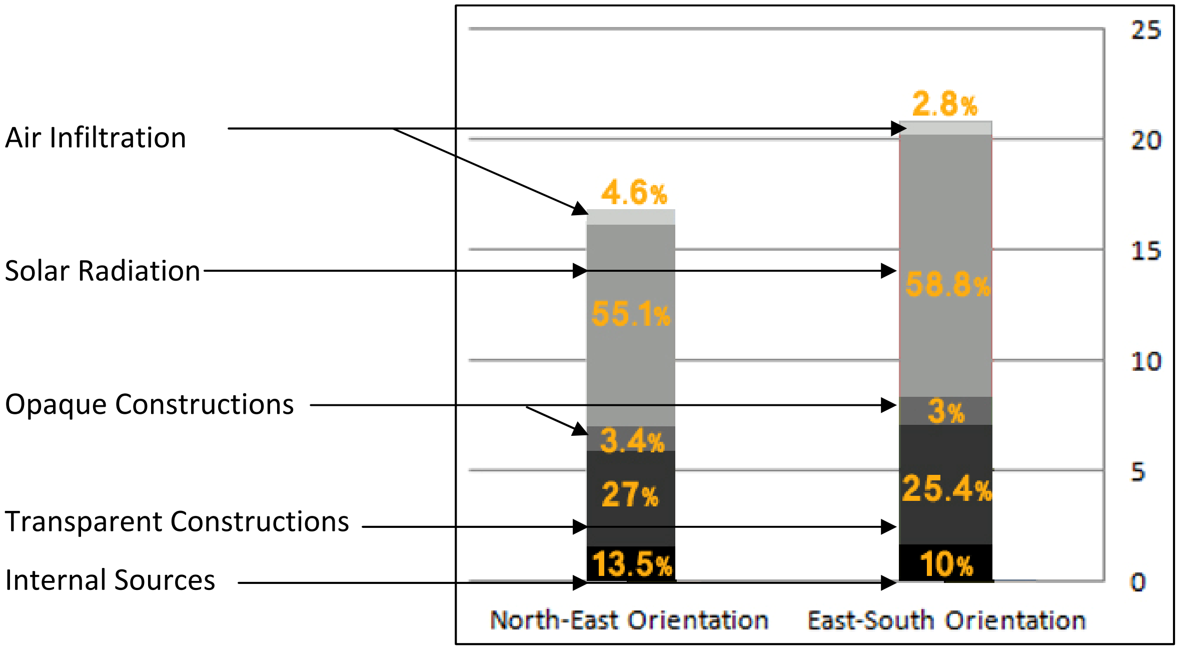


Figure 6.35: *Heat sources influence on the internal space thermal performance in prototype 2 base case.*

The previous results show that both solar radiation through transparent construction and heat flow through the buildings envelope are responsible of around 82% and 87% of Dubai's offices spaces energy consumption. Therefore it's clear that adopting the proper design strategies that achieves thermal comfort through preventing solar radiation from penetrating the interior spaces together with selecting the proper materials that doesn't conduct heat easily can achieve a significant reduction in the spaces energy consumption. However and in order to find a holistic solution, other sources should also be taken in consideration. Architects and engineers should ensure that the proper construction details are implemented to prevent air infiltration and efficient equipments are installed to reduce the amount of heat emitted. Finally, users of the spaces designed should be considered as a part of the process as their behaviors has a significant influence on energy consumption.

6.7 Solar Radiation and energy consumption:

- The climatic data of Dubai shows that the 23rd of July is the hottest day of the year with an average dry bulb temperature of 47°C. However, simulation results show that in prototype1 base case (which is the one-external-wall offices), the peak date the space simulated consumes energy was on the 11th of October in south-oriented offices and 26th of July in east-oriented offices and north oriented offices. This contradiction in south oriented offices can be interpreted by different solar altitudes; the climatic data shows that on the 23rd of July solar altitude in Dubai is around 82.3° while its around 58.7° on the 11th of October. Hence the sun is lower on the 11th of October; solar radiation on that day deeply penetrates the space and increases its cooling energy consumption (Fig. 6.31). Note that same observation was noticed in corner offices.

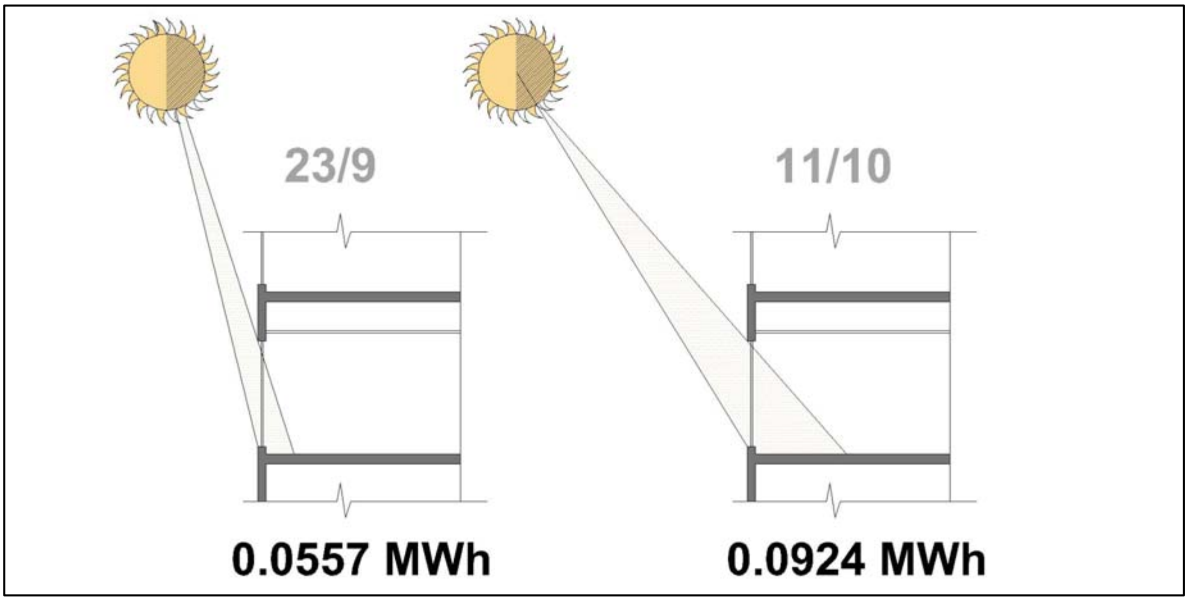


Figure 6.36: *Solar altitude and energy consumption in south-oriented offices.*

Solar radiation is responsible of around 55% of the energy consumption in the base cases. This important fact explains how energy consumption can be reduced by changing the architectural design parameters:

- Both East and South orientations are not exposed to direct solar radiation as the South facades and therefore the intensity of solar radiation penetrating their internal spaces are lower than the south facades.

- Solar radiation penetrates the spaces through glass openings. The bigger the opening is the more solar radiation penetrates the space and hence high mean radiant temperature causing an increase in thermal energy performance.

- Finally solar radiation doesn't reach the internal spaces in the deep plans and therefore, temperatures in such offices are less when compared to deep plans.

To sum up: Both architectural and materials parameters have a great impact on energy consumption. If taken in consideration in the design process, architects can really achieve the required reduction even without depending on any systematic or active solution that reduces humans control over buildings.

CHAPTER 7: CONCLUSION AND FURTHER WORK

7.1 Summary and Conclusions:

This research studied the impact of the major decisions architects and engineers take during the design process on the buildings energy consumption and users thermal comfort. The starting point of the study was identifying the problem; In Dubai, accompanied with a rapid, huge and unstudied growth, the lack of awareness among architects and the absence of environmental regulations has prompted architects and developers to give aesthetical, economical and functional aspects the priority in the design. Due to the neglecting of the environmental aspects, the amount of energy required for operating the building stock in the city has grown substantially. As the increase of the buildings energy consumption lead to an increase in the carbon dioxide emissions, the city has a new environmental vision that would control consumption and emission of GHGs.

In the literature review chapter, which lays the back bone of this study, the researcher tried to understand the current global energy situation and environmental problems. From the review, it was clearly shown that offices buildings are a major contributor to the unprecedented increase of carbon dioxide emissions. After analyzing how office buildings use energy, 90% of this energy is being used to operate the buildings; in addition to running all the electrical equipments, the power supplied to offices is used to heat, light and cool the spaces. Therefore finding solutions that reduce operation energy consumption is a must especially in hot and humid climates as the outside harsh environments forces the users to operate air conditioning systems for long periods. According to the literature reviewed, energy can be reduced in buildings by either passive or active design techniques. The first solution is controlled by the decisions designers through the long process of the design stage and is usually very simple and inexpensive only if the basic knowledge about the interaction between the outside environment, the internal spaces and the users was understood.

Reviewing some papers that tried to study the impact of passive solutions on buildings energy consumption has clearly showed that by adopting the proper environmental design decisions, significant amount of energy can be reduced. After recognizing this important finding, the researcher has connected the results of the review with the problem of the research and the aims and objectives were set. The main aim was to try to figure out how do these solutions found by many other researchers can help in reducing the energy consumption in Dubai taking in consideration the climatic differences.

Based on a survey performed in the city to figure out the common construction practices, different scenarios of offices were tested and modeled using IES<VE> computer program. The method was chosen as it was found to be most adequate due to the nature of this research. The ability of calculating and predicting the energy consumption of spaces designed is critical as it helps architects and mechanical engineers in approximately calculating the duration of uncomfortable periods in non-conditioned buildings and determining the type and size of the HVAC equipments in conditioned buildings. Moreover, these calculations and estimations are essential as they enable architects to design energy efficient buildings that provide healthy and comfortable internal spaces.

The results of the method have proven the research hypothesis -using passive techniques would significantly participate in mitigating the current environmental problem in the city-. The results were as the following:

- By comparing 2 offices with the same are but different architectural data, one of the designs consumed 67% less energy than the other.

- Corner offices were found to be 25% to 41% more energy consuming than normal one-external-wall offices.

- For one-external-wall offices: When compared to South oriented offices both, East oriented and North oriented reduce energy consumption by around 3-4.5% and 23-40% respectively. The 68% and 36% opening to wall percentage reduce full glazed-facades energy consumption by 15.1-20-8% and 27.8-46.4% respectively. Finally aspect ratios 1:1 and 1:1.8 were found to be reducing energy consumption by 8.2-16% and 7,7-13% when compared to offices with 1.8:1 aspect ratios.

- For corner offices: North-East orientation saves energy consumption by 13-22% when compared to South-East orientation. 63.4% and 26.8% opening to wall ratios reduce energy consumption by 22.9-25.4% and 50-55% respectively. And finally when changing the aspect ratio from 2.55:1 to 1.88:1 and 1:1, energy dropped by 1.9-5.4% and 7.7-13.3% respectively.

- Choosing the proper materials can participate in a huge reduction of energy consumption. When comparing the best and worst materials being used in this research on a typical office module, 32% energy reduction was registered.

As heat can flow into the internal spaces through solar radiation, conduction and convection, this research tried to know how each heat mechanism affects energy consumption in offices in Dubai. The results have shown that if solar radiation is responsible of around 55% of the studied cases energy consumption compared to 25% caused by the conduction through the envelope's materials. Based on this, architects should try their best to reduce the amount of direct solar radiation penetrating the internal spaces without compromising the visual and well-being factors. Moreover they should really consider the insulation values of the selected construction materials as they have a great portion of the spaces consumed energy. On the other hand around 10% of the energy consumption was found to be caused by the users of the spaces. This indicated that users should also take their responsibilities and start acting more environmentally in order to achieve a holistic approach to reduce energy consumption in office buildings located in Dubai.

7.2 Further Work:

In the UAE, the environmental burden of buildings represents a problem that need to be alleviated. In order to fulfill with international agreements and commitments, the government of Dubai and other governments in the region will be forced to set new rules regarding building energy consumption. As a first step, the coming few years will witness the implementation of new regulations that will decrease the amount of energy and power supplied to new buildings. Futuristic visions show that the regulations will be stricter in the coming decades and laws for neutral carbon emission buildings will be regulated.

In order to comply with the new regulations, architects should develop their design techniques, adopt more environmental strategies and finally increase their knowledge about the environment and buildings. As each building will be provided with limited amount of energy, architects will be forced to change many design decisions, concepts, elements and materials. On the other hand, mechanical and environmental engineers will have a major role in the design process as they will be studying how each decision architects take affects the building total energy consumption. By estimating the energy performance, the mechanical and environmental engineers will check if the architectural design works in accordance with the supplied power. If it wasn't, architects would be forced to do some changes in the design and send it back to the engineers to evaluate the thermal performance again and the full process will be repeated.

After reading the results, architects would know how some of the major decision they take in the design process can affect the building energy consumption. However not all of the factors and parameters that affect the consumption of energy were studied in this research -only the major factors were examined due to time limitations-. Other passive factors such as the impact of the surrounding buildings on the spaces studied and the thermal mass of the inner spaces were neglected. Moreover, the researcher was not able to find and model glass materials that represent what is available in the market due to the wide variety of glass systems available and the limited knowledge of the computer program used.

Therefore, in order to provide the architects with a holistic approach of reducing thermal energy consumption in office buildings located in hot and humid climates, this research matrix should extend to include the influence of all the other passive strategies on the energy thermal consumption. Other researchers can study the effect of the other environmental techniques on the models built and the scenarios studied. Finally, more research should be done on achieving a balance between reducing energy by the passive techniques and the user's visual and acoustical comfort. If done, all of these researches would help architects and designers in taking the proper environmental design decisions that achieve users comfort in the built environment.

7.3 A need for a new computer program:

As this new procedure of involving mechanical and environmental engineers in the design process will consume a lot of time, a new easy-to-use tool that helps architects in approximately estimate the energy consumption of the buildings they design will be so useful. The available energy performance softwares are usually designed for mechanical and environmental engineers. Filling data tables and dialogue boxes about HVAC systems, air infiltration, internal heat sources and thermal properties of materials used in the construction are major obstacles for architects as they are not familiar with numbers and calculations. To conclude, a new computer program that let architects only input easy data about their design such as the area of the office space, the orientation, opening size, etc. together with selecting the materials of the construction from a menu that includes most of the construction systems applied in the market would be so useful.

In order to design this software, the researcher will work on expanding this research matrix to include most of the other passive design techniques. Moreover, a survey about most of the materials and construction systems used in the city will be performed. The researcher will then try to analyze the results and come up with equations and coefficient factors that will help in designing an excel sheet which can be developed into a small software. This software will be only specialized in predicting energy consumption in office buildings that are located only in Dubai. If succeeded, other sectors of buildings and other location will be studied.

REFERENCES

AboulNaga, M. M. and Elsheshtawy, Y. H., (2001). Environmental sustainability assessment of buildings in hot climates: the case of the UAE. *Renewable Energy*, 24(3-4), pp. 553-563.

ASHRAE, American Society of Heating, Refrigeration and Air Conditioning, (2010). *ANSI/ASHRAE 44-2010*, Thermal Environmental Conditions for Human Occupancy.

Attia, S., Beltran, L., De Herde, A. and Hensen, J., (2009). Architect friendly: A comparison of ten different building performance simulation tools. *Building Simulation 2009,* Pp. 204-211.

Bouchlaghem N. (1999). Optimising the design of building envelopes for thermal performance. *Automation and Construction*, (10), p.101–121.

[Accessed 5 October 2011]

Bp p.l.c., (2008). *Energy- Consumption' A1 "Consumption by fuel, 1965-2008: Statistical Review of World Energy 2008*. [XLS] Available at: http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2009_downloads/statistical_review_of_world_energy_full_report_2009.xls#'Primary [Accessed 2 October 2011]

Central Intelligence Agence (CIA), (2008). *The World Fact Book: The United Arab Emirates.* [Online] CIA. Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/ae.html [Accessed 2 July 2011]

Charles, K. E., (2003). *Fanger's Thermal Comfort and Draught Models*. [PDF]Institute for research in construction, Canada. Available at: www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/rr/rr162/rr162.pdf [Accessed 7 October 2011]

Chiheb, B., (2007). Influence of glass curtain walls on the building thermal energy consumption under Tunisian climatic conditions: The case of administrative buildings. *Renewable Energy*, 32(1), pp. 141-156.

Council on Tall Buildings and Urban Habitat (CTBUH), (2007). *The sustainable vision of Dubai,* [Online]. Available at: http://www.ctbuh.org/Portals/0/Repository/P1_SheikhMakteum.3d3c0499-b670-4a4d-a73c-2ea73283f3ce.pdf [Accessed 12 March 2012]

Crawley, D. B., Hand, J. W., Kummert, M.Griffith, B. T., (2008). Contrasting the capabilities of building energy performance simulation programs. *Building and Environment,* 43(4), pp. 661-673.

Dubai Electricity and Water Authority DEWA, (2011). *Your Decision Campaign: Load Campaign.* [Online] Available at: http://www.dewa.gov.ae/community/conservation/ydc/savepower.aspx [Accessed 27 June 2011]

Dubai Municipality DM, (2010). *Circular no. 197 regarding design self assessment forms.* (812/02/02/1/1007559). Dubai: Dubai Municipality.

Dubai Statistics Center (DSC), (2009). *Generated electricity and consumed by type of construction- Emirate of Dubai (2007-2009).* [pdf]DSC. Available at: http://dsc.gov.ae/Reports/DSC_SYB_2009_09_07.pdf [Accessed 8 October 2011]

EIA, U.S. Energy Information Administration, (2007). *Office buildings: How do they use energy and how much does it cost?*. [Online]. Available at: http://eia.gov/emeu/consumptionbriefs/cbecs/pbawebsite/office/office_howuseenergy.htm [Accessed 8 October 2011]

EIA, U.S. Energy Information Administration, (2010). *Building Energy Data Book*. [Online]USA: D&R International, Ltd. Available at: http://buildingdatabook.eren.doe.gov/ [Accessed 8 October 2011]

Emirates Nuclear Energy Corporation (ENEC), (2010). *Emirates Nuclear Energy Corporation Submits Construction License Application for Braka Units 1 and 2.* [Online]ENEC. Available at: http://enec.gov.ae/media-centre/news/content/emirates-nuclear-energy-corporation-submits-construction-license-applicatio [Accessed 7 October 2011]

Eskin, N. and Türkmen, H. (2008). Analysis of annual heating and cooling energy requirements for office buildings in different climates in Turkey. *Energy and Buildings*, 40(5), pp. 763-773.

Fay, R. , G. Treloar , P.E.D. Love, U. Iyer-Raniga, (2000). Analysing the life-cycle energy of an Australian residential building and its householders, *Building Research & Information,* 28 (3), pp.184–195.

Florides, G. A., Tassou, S. A., Kalogirou, S. A., Wrobel, L. C., (2002) Measures used to lower building energy consumption and their cost effectiveness. *Applied Energy*, 73(3-4), pp. 299-328.

Fridley, D., Nathaniel, T. A., and Nan. Z., (2007). China's Building Energy Use. [Online]California: Lawrence Brekeley National Laboratory. Available at: http://china.lbl.gov.publications/chinas-building-energy-use [Accessed 4 October 2011]

Ghiaus C., C. Inard, (2004). A Handbook for Intelligent Building. Smart Buildings, pp. 26–51. [Online] Available at: http://www.ibuilding.gr/handbook/ [Accessed 26 May 2011]

Gulf News, (2007). Dubai Executive Council Outline Green Building Rules. Gulf News, [Internet] 21 November. Available at: http://www.dsc.gov.ae/en/newsmedia/newsreleases/pages/detail.aspx?newsid=19 [Accessed 10 October 2011]

Hammad, F. and Abu-Hijleh, B., (2010). The energy savings potential of using dynamic external louvers in an office building. *Energy and Buildings*, 42(10), pp. 1888-1895.

Høseggen, R.,Wachenfeldt, B. J., Hanseen, S.O., (2008). Building simulation as an assisting tool in decision making: Case study: With or without a double-skin façade? *Energy and Buildings,* 40(5), pp. 821-827.

Hwang, R.-L. and Shu, S.-Y. ,(2011). Building envelope regulations on thermal comfort in glass facade buildings and energy-saving potential for PMV-based comfort control. *Building and Environment***,** 46(4), pp. 824-834.

IAC, Interacademy council, (2007). *Lighting the way: Toward a sustainable energy future*. [Online]
Available at: http://www.interacademycouncil.net/CMS/reports/11840/11842.aspx [Accessed 12 September 2011]

International Renewable Energy Agency (IRENA), (2011). IRENA prepares for important milestones. [PDF]IRENA. Available at: http://www.irena.org/DocumentDownloads/newsletter/IRENA_newsletter_4.pdf [Accessed 7 October 2011]

Katanbafnasab, M., (2010). *Alternative facades: Assessment of buildings integrated photovoltaic and electrochromic glazing energy – Energy benefits and future potentials in office building in UAE*. MSc. The British University in Dubai.

Janssen R., (2004). Towards energy efficient buildings in Europe. [Online] EuroACE, Available at: http://www.euroace.org [Accessed 12 June 2011]

Kazim, A. M. , (2007). Assessments of primary energy consumption and its environmental consequences in the United Arab Emirates. *Renewable and Sustainable Energy Reviews*, 11(3), pp. 426-446.

Lombard, L. P., Ortiz J., Pout, C., (2008). A review on buildings energy consumption information. *Energy and Buildings*, 40(3), pp. 394-398.

Marszał, A.J. and Thomas S.J., (2008). *Modeling and design of Double Skin façade.* MSc. Alborg University.

McCarthy, P., and Mihlmester, P., (1997). HVAC Audits. *Journal of property management*, January 1, pp. 60-63.

Morrissey, J., Moore, T., and Horne, R. E., (2011). Affordable passive solar design in a temperate climate: An experiment in residential building orientation. *Renewable Energy***,** 36(2), pp. 568-577.

Occupational Safety and Health Administration (OSHA), (2003). OSHA Policy on Indoor Air Quality: Office Temperature/Humidity and Environmental Tobacco Smoke. [Online] United States Department of Labour. Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=INTERPRETATIONS&p_id=24602

Perino, M., Serra. V, and Corgnati, S. P.,(2007). Experimental assessment of the performance of an active transparent façade during actual operating conditions. *Solar Energy,* 81(8), pp:993-1013.

Radhi, H. , (2009). Evaluating the potential impact of global warming on the UAE residential buildings – A contribution to reduce the CO2 emissions. *Building and Environment*, 44(12), pp. 2451-2462.

Radhi, H. ,(2010). Energy analysis of façade-integrated photovoltaic systems applied to UAE commercial buildings. *Solar Energy*, 84(12), pp. 2009-2021.

Radhi, H. ,(2010). On the optimal selection of wall cladding system to reduce direct and indirect CO2 emissions. *Energy*, 35(3), pp. 1412-1424.

Ramesh, T., Prakash, R., Shukla, K. K., (2010). Life cycle energy analysis of buildings: An overview. *Energy and Buildings* ,42(10), pp. 1592-1600.

United Nations, Economic and Social Commission for Western Asia (UN/ESCWA), (2008). *Promoting sustainable energy production and consumption in the Arab region.* [pdf]UN/ESCWA. Available at: http://esa.un.org/marrakechprocess/pdf/ESCWA_SEPC_paper_15march2008.pdf [Accessed 17 August 2011]

United Nations Framework Convention on Climatic Change (UNFCCC), (2006). The United Arab Emirates. [pdf]UNCFF. Available at: http://unfccc.int/resource/docs/natc/arenc1.pdf [Accessed 7 October 2011]

United Nations General Assemply (UN), (1987). *Our Common Future, Chapter 2: Towards Sustainable Development*. [Online]Oxford: Oxford University Press. Available at: http://www.un-documents.net/ocf-02.htm [Accessed 10 October 2011]

United Nations Statistics Division (UNSD), (2007). *Environmental Indicators: Greenhouse Gas Emissions*. [Online] (July, 2010) Available at: http://unstats.un.org/unsd/environment/air_co2_emissions.htm [Accessed 8 October 2011]

U.S. Energy Information Administration – EIA, (2011). United Arab Emirates. [Online] (January, 2011) Available at: http://205.254.135.24/emeu/cabs/UAE/Full.html [Accessed 9 October 2011]

U.S. Green Building Council (USGBC), (2011). LEED Green Building Certification System. [Online]USGBC. Available at: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1989 [Accessed 7 October 2011]

Ünver, R., Akdağ N. Y.,Gedik G. Z., Öztürk, L. D., Karabiber Z., (2004). Prediction of building envelope performance in the design stage: an application for office buildings. *Building and Environment*, 39(2), pp: 143-152.

Appendices

Appendix 1: Survey Results

Appendix 2: Dubai's Weather Data

Appendix 3: Operation Profiles

Appendix 4: Variables' Abbreviations

Appendix 5: Research's Matrix

Appendix 6: Simulation Results

Appendix 1

Survey Results

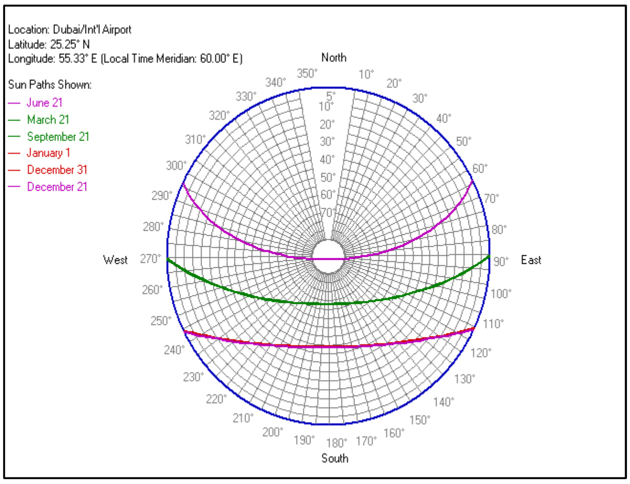
	No. of Offices Units	Space Area (Sq. m)	External wall Length (m)	Total Area (Sq. m)	Area Percentage	Length of external facade (Sq. m)	Windows Opening (Sq. m)	Total windows opening area (Sq.m)	Opening to Wall Percentage	Office prototype
Nassima Tower (Acico Office Tower)										
Office 1	48	138	38.6	6624	57.77%	104.22	97.47	4678.56	93.50%	
Office 2	24	160	27.3	3840	33.49%	73.71	63.45	1522.8	86%	One Orientation Office
Office 3	2	193	45.5	386	3.37%	122.85	112.86	225.72	91.80%	Corner Office
Office 4	1	408	64	408	3.56%	194.21	181.19	181.19	93.20%	Corner Office
Office 5	1	208	64	208	1.81%	171.18	159.84	159.84	93.30%	Corner Office (open voids)
	76			11466	100.00%					
Al-Moosa Tower 1										
Office 1	76	165	27.5	12540	100.00%	74.25	36.89	2803.64	49.70%	Corner Office
	76	165		12540	100.00%					
Al-Moosa Tower 2										
Office 1	120	170	30	20400	100.00%	81	48.42	5810.4	59.80%	Corner Office
	120			20400	100.00%					
Latifa Tower										
Office 1	2	331	22.3	662	3.96%	60.21	39.15	78.3	65%	One Orientation Office
Office 2	2	198	32.8	396	2.37%	88.56	66.42	132.84	75.00%	Corner Office
Office 3	2	300	44	600	3.59%	118.8	84.51	169.02	71.10%	Corner Office
Office 4	2	117	19.4	234	1.40%	52.38	47.79	95.58	91%	One Orientation Office
Office 5	24	360	19.1	8640	51.66%	51.57	29.97	719.28	56.70%	One Orientation Office
Office 6	24	147	26.1	3528	21.10%	70.47	51.57	1237.68	73.20%	Corner Office
Office 7	24	111	14.2	2664	15.93%	38.34	31.86	764.64	83.10%	One Orientation Office
	80			16724	100.00%					

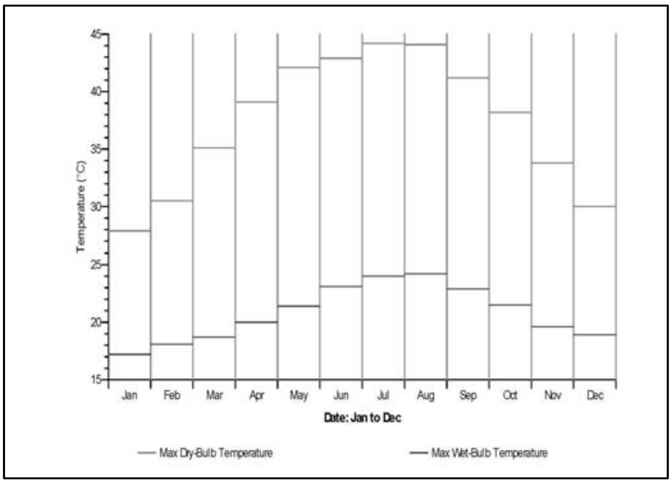
HHHR Tower										
Office 1	4	53.3	15.5	213.2	5.13%	41.85	19.2	76.8	45.90%	Corner Office
Office 2	4	93.8	10.5	375.2	9.02%	28.35	12.96	51.84	45.70%	One Orientation Office
Office 3	4	93.4	9	373.6	8.98%	24.3	10.88	43.52	44.80%	One Orientation Office
Office 4	4	87.3	15	349.2	8.40%	40.5	13.76	55.04	34%	Corner Office
Office 5	2	59.9	8	119.8	2.88%	21.6	8.32	16.64	38.50%	One Orientation Office
Office 6	8	80.1	9	640.8	15.41%	24.3	7.04	56.32	29%	One Orientation Office
Office 7	8	97	17	776	18.66%	45.9	20.16	161.28	44%	Corner Office
Office 8	4	88.7	23	354.8	8.53%	62.1	27.84	111.36	44.80%	Corner Office
Office 9	4	72.9	11	291.6	7.01%	29.7	11.36	45.44	38.20%	One Orientation Office
Office 10	2	110.3	17	220.6	5.30%	45.9	17.6	35.2	38.30%	Corner Office
Office 11	2	59.9	8	119.8	2.88%	21.6	8.32	16.64	38.50%	One Orientation Office
Office 12	2	68.1	17	136.2	3.28%	45.9	17.92	35.84	39%	Corner Office
Office 13	4	46.9	7.5	187.6	4.51%	20.25	8.16	32.64	40.30%	One Orientation Office
	52			4158.4	100.00%					
Union Tower										
Office 1	20	145.5	31.4	2910	100.00%	81.64	57.2	1144	70.10%	Corner Office
	20			2910	100.00%					
API World Tower										
Office 1	29	160	32.5	4640	100.00%	82.875	59.52	1726.08	72.90%	Corner Office
	29			4640	100.00%					
Saeed Tower 2										
Office 1	36	145	29.5	5220	100.00%	79.65	50.49	1817.64	63.40%	Corner Office
	36			5220	100.00%					
Park Palace Tower										
Office 1	17	220	40	3740	36.14%	108	56.32	957.44	52.10%	Corner Office
Office 2	15	158	39	2370	22.90%	105.3	31.02	465.3	29.50%	Corner Office
Office 3	15	264	35	3960	38.26%	94.5	49.28	739.2	52.10%	One Orientation Office
Office 4	1	110	28	110	1.06%	75.6	39.82	39.82	52.70%	Corner Office
Office 5	1	170	35	170	1.64%	94.5	49.28	49.28	52.10%	One Orientation Office
	49			10350	100.00%					
Al-Attar Business Tower										
Office 1	6	93	20.5	558	2.87%	55.35	52.275	313.65	94.44%	Corner Office

Office 2	1	58	6.7	58	0.30%	18.09	17.085	17.085	94.44%	One Orientation Office
Office 3	6	120	22.5	720	3.70%	60.75	57.375	344.25	94.44%	Corner Office
Office 4	5	90	6.7	450	2.31%	18.09	17.085	85.425	94.44%	One Orientation Office
Office 5	2	123	27	246	1.26%	72.9	36.975	73.95	50.70%	Corner Office
Office 6	4	190	32	760	3.91%	86.4	49.98	199.92	57.80%	Corner Office
Office 7	4	105	24	420	2.16%	64.8	33.66	134.64	51.90%	Corner Office
Office 8	10	305	50	3050	15.68%	135	126.735	1267.35	93.90%	Corner Office
Office 9	10	295	59	2950	15.16%	159.3	84.405	844.05	53%	Corner Office
Office 10	15	683	109	10245	52.65%	294.3	211.14	3167.1	71.70%	Corner Office
	63			19457	100.00%					
Crown Plaza Tower										
Office 1	36	102	29	3672	36.62%	78.3	28.89	1040.04	36.70%	Corner Office
Office 2	36	94	11	3384	33.75%	29.7	17.82	641.52	60%	One Orientation Office
Office 3	18	78	18	1404	14.00%	48.6	32.4	583.2	66.70%	Corner Office
Office 4	18	87	23.5	1566	15.62%	63.45	29.97	539.46	47.20%	Corner Office
	108			10026	100.00%					
Khalid Al Attar Tower										
Office 1	10	80	19	800	27.59%	46.55	30.87	308.7	66.30%	Corner Office
Office 2	10	85	19.7	850	29.31%	48.265	33.565	335.65	69.50%	Corner Office
Office 3	10	67	10	670	23.10%	24.5	22.54	225.4	92%	One Orientation Office
Office 4	10	58	9	580	20.00%	22.05	22.05	220.5	100%	One Orientation Office
	40			2900	100.00%					

Appendix 2

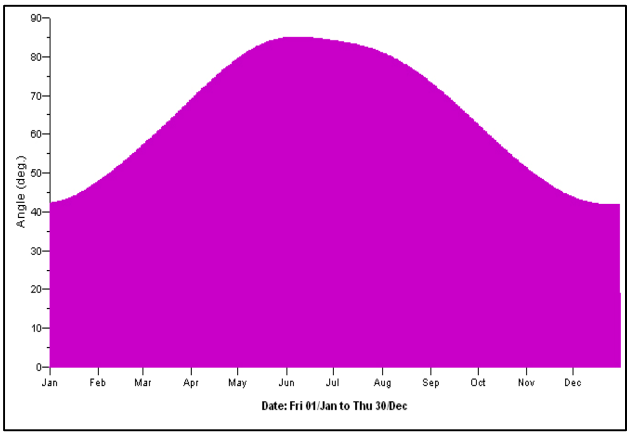
Dubai Weather Data

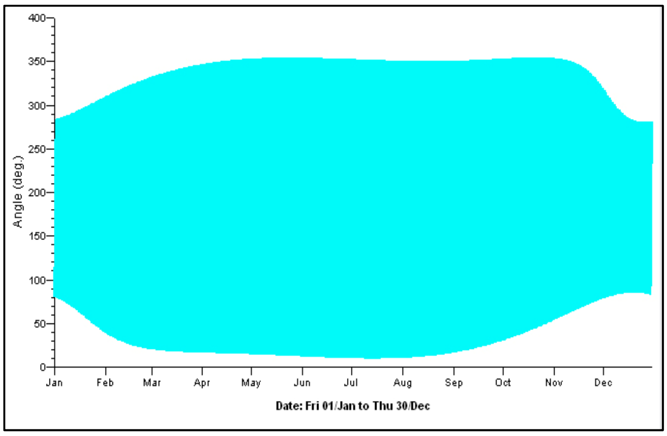




(A) *(B)*

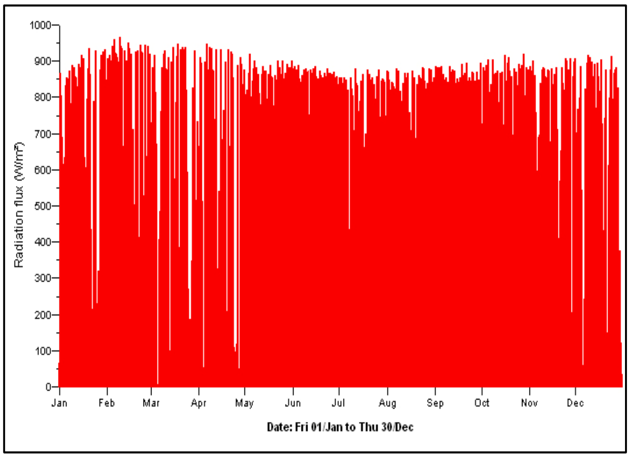
(A) Sun path diagram at Dubai International Airport obtained from IES Database.
(B) Maximum dry-bulb and wet-bulb temperature (IES Database).

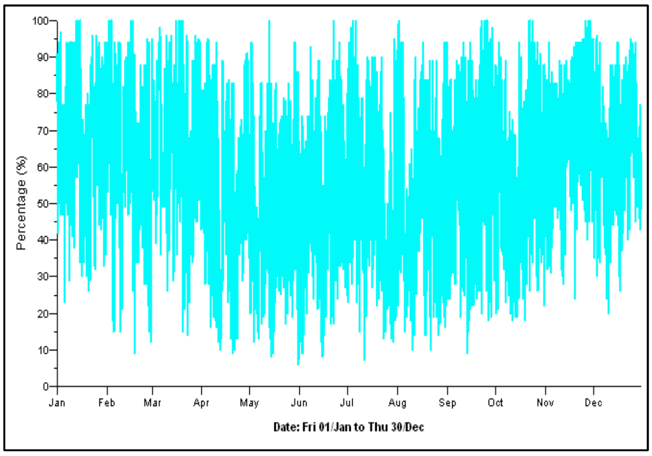




(A) *(B)*

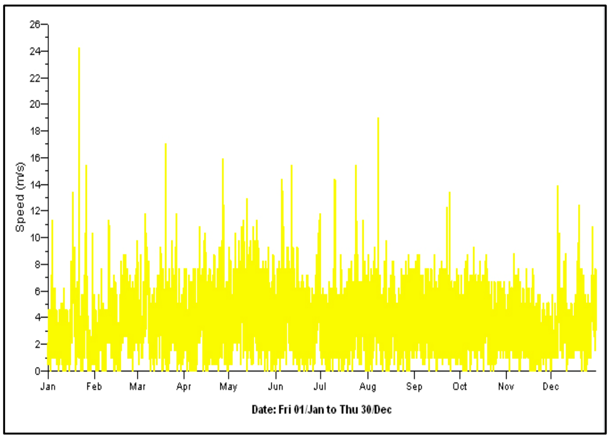
(A) Solar altitude (IES Database).
(B) Solar azimuth (IES Database).

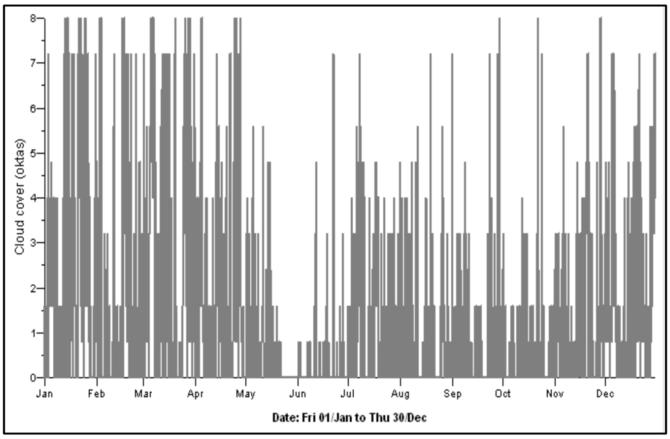




(A) *(B)*

(A) Direct radiation (IES Database).
(B) Relative humidity (IES Database).





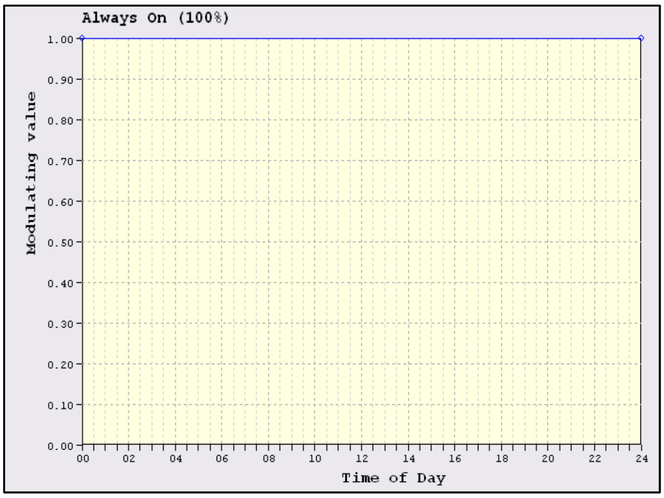
(A) *(B)*

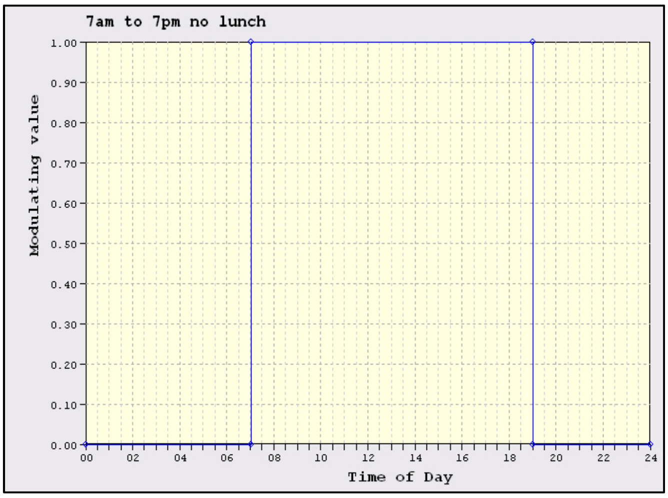
(A) Wind speed (IES Database).

(B) Cloud cover (IES Database).

Appendix 3

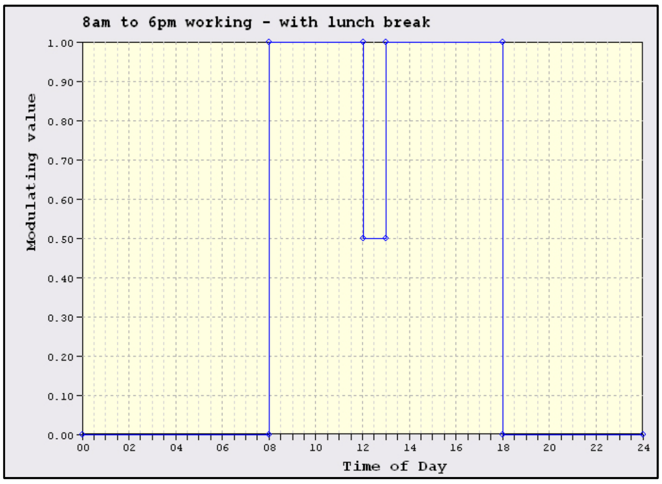
Operation Profiles

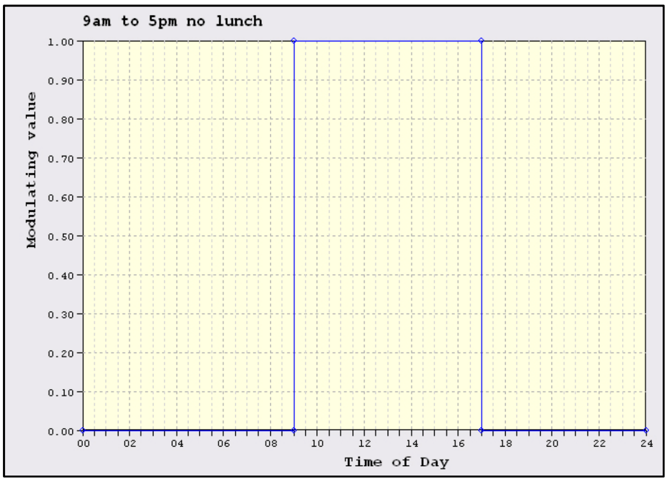




(A) (B)

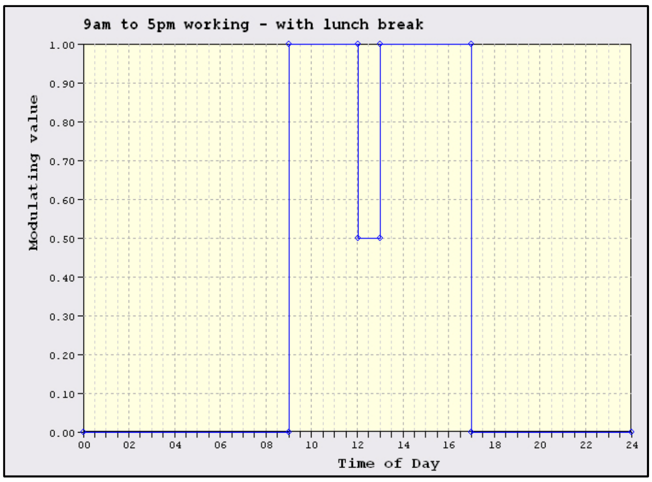
(A) [Mod] Always on (100%). (B) [Mod] 7am to 7pm weekday working- no lunch (7TO7NL)

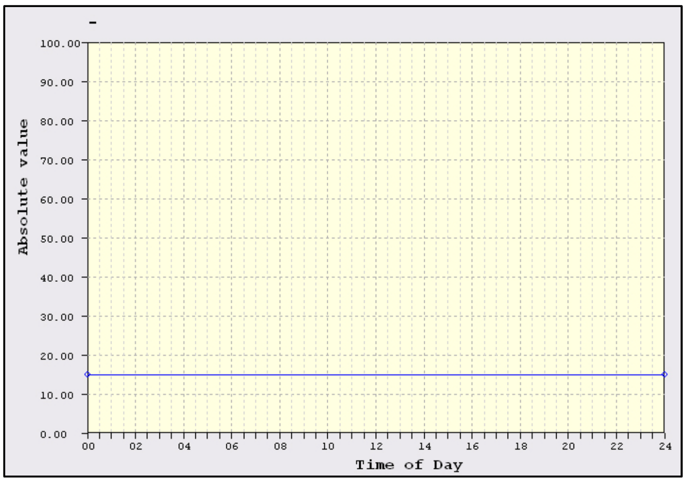




(A) (B)

(A) [Mod] 8am to 6pm weekday working- with lunch break (8TO6). (B) [Mod] 9am to 5pm weekday working no lunch break (9TO5NL)





(A) (B)

(A) [Mod] 9am to 5pm weekend working- with lunch break (9TO5). (B) [Abs] - [15].

Appendix 4

Variables' Abbreviations

Prototype 1 (P1) **150.7m²**		Prototype 2 (P2) **164.7m²**	
O:1	South Orientation	O:1	East-South Orientation
O:2	East Orientation	O:2	North-East Orientation
O:3	North Orientation		
OtoW-P:1	67.9% Opening-to-Wall Percentage	OtoW-P:1	63.4% Opening-to-Wall Percentage
OtoW-P:2	100% Opening-to-Wall Percentage	OtoW-P:2	100% Opening-to-Wall Percentage
OtoW-P:3	35.8% Opening-to-Wall Percentage	OtoW-P:3	26.8% Opening-to-Wall Percentage
A-R:1	1.8:1 Aspect Ratio	A-R:1	(2x16.15):(2x6.35) Aspect Ratio (2.55:1)
A-R:2	1:1 Aspect Ratio	A-R:2	(2x14.49):(2x7.70) Aspect Ratio (1.88:1)
A-R:3	1:1.8 Aspect Ratio	A-R:3	(2x12.83):(2x12.83) Aspect Ratio (1:1)
OC-S1	Opaque Construction System 1 (U-Value: 0.3349)	OC-S1	Opaque Construction System 1 (U-Value: 0.3349)
OC-S2	Opaque Construction System 2 (U-Value: 0.4184)	OC-S2	Opaque Construction System 2 (U-Value: 0.4184)
OC-S3	Opaque Construction System 3 (U-Value: 0.7252)	OC-S3	Opaque Construction System 3 (U-Value: 0.7252)
GC-S1	Glazed Construction System 1 (U-Value: 2.0600)	GC-S1	Glazed Construction System 1 (U-Value: 2.1670)
GC-S2	Glazed Construction System 2 (U-Value: 3.3917)	GC-S2	Glazed Construction System 2 (U-Value: 3.2985)
GC-S3	Glazed Construction System 3 (U-Value: 5.8652)	GC-S3	Glazed Construction System 3 (U-Value: 5.8652)

Appendix 5

Research Matrix

Simulation Case	Prototype	Orientation	Opening to Wall Percentage	Aspect Ratio	Construction Systems	
					Opaque Construction System	Glazed Construction System
PROTOTYPE 1						
Case 1	P1	O:1	OtoW-P:1	A-R:1	OC-S1	GC-S1
Case 2	P1	O:2	OtoW-P:1	A-R:1	OC-S1	GC-S1
Case 3	P1	O:3	OtoW-P:1	A-R:1	OC-S1	GC-S1
Case 4	P1	O:1	OtoW-P:2	A-R:1	OC-S1	GC-S1
Case 5	P1	O:1	OtoW-P:3	A-R:1	OC-S1	GC-S1
Case 6	P1	O:2	OtoW-P:2	A-R:1	OC-S1	GC-S1
Case 7	P1	O:2	OtoW-P:3	A-R:1	OC-S1	GC-S1
Case 8	P1	O:3	OtoW-P:2	A-R:1	OC-S1	GC-S1
Case 9	P1	O:3	OtoW-P:3	A-R:1	OC-S1	GC-S1
Case 10	P1	O:1	OtoW-P:1	A-R:2	OC-S1	GC-S1
Case 11	P1	O:1	OtoW-P:2	A-R:2	OC-S1	GC-S1
Case 12	P1	O:1	OtoW-P:3	A-R:2	OC-S1	GC-S1
Case 13	P1	O:2	OtoW-P:1	A-R:2	OC-S1	GC-S1
Case 14	P1	O:2	OtoW-P:2	A-R:2	OC-S1	GC-S1
Case 15	P1	O:2	OtoW-P:3	A-R:2	OC-S1	GC-S1
Case 16	P1	O:3	OtoW-P:1	A-R:2	OC-S1	GC-S1
Case 17	P1	O:3	OtoW-P:2	A-R:2	OC-S1	GC-S1
Case 18	P1	O:3	OtoW-P:3	A-R:2	OC-S1	GC-S1
Case 19	P1	O:1	OtoW-P:1	A-R:3	OC-S1	GC-S1
Case 20	P1	O:1	OtoW-P:2	A-R:3	OC-S1	GC-S1
Case 21	P1	O:1	OtoW-P:3	A-R:3	OC-S1	GC-S1
Case 22	P1	O:2	OtoW-P:1	A-R:3	OC-S1	GC-S1
Case 23	P1	O:2	OtoW-P:2	A-R:3	OC-S1	GC-S1
Case 24	P1	O:2	OtoW-P:3	A-R:3	OC-S1	GC-S1
Case 25	P1	O:3	OtoW-P:1	A-R:3	OC-S1	GC-S1
Case 26	P1	O:3	OtoW-P:2	A-R:3	OC-S1	GC-S1
Case 27	P1	O:3	OtoW-P:3	A-R:3	OC-S1	GC-S1
Case 28	P1	O:1	OtoW-P:1	A-R:1	OC-S2	GC-S1

Case 29	P1	O:1	OtoW-P:1	A-R:2	OC-S2	GC-S1
Case 30	P1	O:1	OtoW-P:1	A-R:3	OC-S2	GC-S1
Case 31	P1	O:1	OtoW-P:2	A-R:1	OC-S2	GC-S1
Case 32	P1	O:1	OtoW-P:2	A-R:2	OC-S2	GC-S1
Case 33	P1	O:1	OtoW-P:2	A-R:3	OC-S2	GC-S1
Case 34	P1	O:1	OtoW-P:3	A-R:1	OC-S2	GC-S1
Case 35	P1	O:1	OtoW-P:3	A-R:2	OC-S2	GC-S1
Case 36	P1	O:1	OtoW-P:3	A-R:3	OC-S2	GC-S1
Case 37	P1	O:2	OtoW-P:1	A-R:1	OC-S2	GC-S1
Case 38	P1	O:2	OtoW-P:1	A-R:2	OC-S2	GC-S1
Case 39	P1	O:2	OtoW-P:1	A-R:3	OC-S2	GC-S1
Case 40	P1	O:2	OtoW-P:2	A-R:1	OC-S2	GC-S1
Case 41	P1	O:2	OtoW-P:2	A-R:2	OC-S2	GC-S1
Case 42	P1	O:2	OtoW-P:2	A-R:3	OC-S2	GC-S1
Case 43	P1	O:2	OtoW-P:3	A-R:1	OC-S2	GC-S1
Case 44	P1	O:2	OtoW-P:3	A-R:2	OC-S2	GC-S1
Case 45	P1	O:2	OtoW-P:3	A-R:3	OC-S2	GC-S1
Case 46	P1	O:3	OtoW-P:1	A-R:1	OC-S2	GC-S1
Case 47	P1	O:3	OtoW-P:1	A-R:2	OC-S2	GC-S1
Case 48	P1	O:3	OtoW-P:1	A-R:3	OC-S2	GC-S1
Case 49	P1	O:3	OtoW-P:2	A-R:1	OC-S2	GC-S1
Case 50	P1	O:3	OtoW-P:2	A-R:2	OC-S2	GC-S1
Case 51	P1	O:3	OtoW-P:2	A-R:3	OC-S2	GC-S1
Case 52	P1	O:3	OtoW-P:3	A-R:1	OC-S2	GC-S1
Case 53	P1	O:3	OtoW-P:3	A-R:2	OC-S2	GC-S1
Case 54	P1	O:3	OtoW-P:3	A-R:3	OC-S2	GC-S1
Case 55	P1	O:1	OtoW-P:1	A-R:1	OC-S3	GC-S1
Case 56	P1	O:1	OtoW-P:1	A-R:2	OC-S3	GC-S1
Case 57	P1	O:1	OtoW-P:1	A-R:3	OC-S3	GC-S1
Case 58	P1	O:1	OtoW-P:2	A-R:1	OC-S3	GC-S1
Case 59	P1	O:1	OtoW-P:2	A-R:2	OC-S3	GC-S1
Case 60	P1	O:1	OtoW-P:2	A-R:3	OC-S3	GC-S1
Case 61	P1	O:1	OtoW-P:3	A-R:1	OC-S3	GC-S1
Case 62	P1	O:1	OtoW-P:3	A-R:2	OC-S3	GC-S1
Case 63	P1	O:1	OtoW-P:3	A-R:3	OC-S3	GC-S1
Case 64	P1	O:2	OtoW-P:1	A-R:1	OC-S3	GC-S1
Case 65	P1	O:2	OtoW-P:1	A-R:2	OC-S3	GC-S1

Case 66	P1	O:2	OtoW-P:1	A-R:3	OC-S3	GC-S1
Case 67	P1	O:2	OtoW-P:2	A-R:1	OC-S3	GC-S1
Case 68	P1	O:2	OtoW-P:2	A-R:2	OC-S3	GC-S1
Case 69	P1	O:2	OtoW-P:2	A-R:3	OC-S3	GC-S1
Case 70	P1	O:2	OtoW-P:3	A-R:1	OC-S3	GC-S1
Case 71	P1	O:2	OtoW-P:3	A-R:2	OC-S3	GC-S1
Case 72	P1	O:2	OtoW-P:3	A-R:3	OC-S3	GC-S1
Case 73	P1	O:3	OtoW-P:1	A-R:1	OC-S3	GC-S1
Case 74	P1	O:3	OtoW-P:1	A-R:2	OC-S3	GC-S1
Case 75	P1	O:3	OtoW-P:1	A-R:3	OC-S3	GC-S1
Case 76	P1	O:3	OtoW-P:2	A-R:1	OC-S3	GC-S1
Case 77	P1	O:3	OtoW-P:2	A-R:2	OC-S3	GC-S1
Case 78	P1	O:3	OtoW-P:2	A-R:3	OC-S3	GC-S1
Case 79	P1	O:3	OtoW-P:3	A-R:1	OC-S3	GC-S1
Case 80	P1	O:3	OtoW-P:3	A-R:2	OC-S3	GC-S1
Case 81	P1	O:3	OtoW-P:3	A-R:3	OC-S3	GC-S1
Case 82	P1	O:1	OtoW-P:1	A-R:1	OC-S1	GC-S2
Case 83	P1	O:1	OtoW-P:1	A-R:2	OC-S1	GC-S2
Case 84	P1	O:1	OtoW-P:1	A-R:3	OC-S1	GC-S2
Case 85	P1	O:1	OtoW-P:2	A-R:1	OC-S1	GC-S2
Case 86	P1	O:1	OtoW-P:2	A-R:2	OC-S1	GC-S2
Case 87	P1	O:1	OtoW-P:2	A-R:3	OC-S1	GC-S2
Case 88	P1	O:1	OtoW-P:3	A-R:1	OC-S1	GC-S2
Case 89	P1	O:1	OtoW-P:3	A-R:2	OC-S1	GC-S2
Case 90	P1	O:1	OtoW-P:3	A-R:3	OC-S1	GC-S2
Case 91	P1	O:2	OtoW-P:1	A-R:1	OC-S1	GC-S2
Case 92	P1	O:2	OtoW-P:1	A-R:2	OC-S1	GC-S2
Case 93	P1	O:2	OtoW-P:1	A-R:3	OC-S1	GC-S2
Case 94	P1	O:2	OtoW-P:2	A-R:1	OC-S1	GC-S2
Case 95	P1	O:2	OtoW-P:2	A-R:2	OC-S1	GC-S2
Case 96	P1	O:2	OtoW-P:2	A-R:3	OC-S1	GC-S2
Case 97	P1	O:2	OtoW-P:3	A-R:1	OC-S1	GC-S2
Case 98	P1	O:2	OtoW-P:3	A-R:2	OC-S1	GC-S2
Case 99	P1	O:2	OtoW-P:3	A-R:3	OC-S1	GC-S2
Case 100	P1	O:3	OtoW-P:1	A-R:1	OC-S1	GC-S2
Case 101	P1	O:3	OtoW-P:1	A-R:2	OC-S1	GC-S2
Case 102	P1	O:3	OtoW-P:1	A-R:3	OC-S1	GC-S2

Case 103	P1	O:3	OtoW-P:2	A-R:1	OC-S1	GC-S2
Case 104	P1	O:3	OtoW-P:2	A-R:2	OC-S1	GC-S2
Case 105	P1	O:3	OtoW-P:2	A-R:3	OC-S1	GC-S2
Case 106	P1	O:3	OtoW-P:3	A-R:1	OC-S1	GC-S2
Case 107	P1	O:3	OtoW-P:3	A-R:2	OC-S1	GC-S2
Case 108	P1	O:3	OtoW-P:3	A-R:3	OC-S1	GC-S2
Case 109	P1	O:1	OtoW-P:1	A-R:1	OC-S1	GC-S3
Case 110	P1	O:1	OtoW-P:1	A-R:2	OC-S1	GC-S3
Case 111	P1	O:1	OtoW-P:1	A-R:3	OC-S1	GC-S3
Case 112	P1	O:1	OtoW-P:2	A-R:1	OC-S1	GC-S3
Case 113	P1	O:1	OtoW-P:2	A-R:2	OC-S1	GC-S3
Case 114	P1	O:1	OtoW-P:2	A-R:3	OC-S1	GC-S3
Case 115	P1	O:1	OtoW-P:3	A-R:1	OC-S1	GC-S3
Case 116	P1	O:1	OtoW-P:3	A-R:2	OC-S1	GC-S3
Case 117	P1	O:1	OtoW-P:3	A-R:3	OC-S1	GC-S3
Case 118	P1	O:2	OtoW-P:1	A-R:1	OC-S1	GC-S3
Case 119	P1	O:2	OtoW-P:1	A-R:2	OC-S1	GC-S3
Case 120	P1	O:2	OtoW-P:1	A-R:3	OC-S1	GC-S3
Case 121	P1	O:2	OtoW-P:2	A-R:1	OC-S1	GC-S3
Case 122	P1	O:2	OtoW-P:2	A-R:2	OC-S1	GC-S3
Case 123	P1	O:2	OtoW-P:2	A-R:3	OC-S1	GC-S3
Case 124	P1	O:2	OtoW-P:3	A-R:1	OC-S1	GC-S3
Case 125	P1	O:2	OtoW-P:3	A-R:2	OC-S1	GC-S3
Case 126	P1	O:2	OtoW-P:3	A-R:3	OC-S1	GC-S3
Case 127	P1	O:3	OtoW-P:1	A-R:1	OC-S1	GC-S3
Case 128	P1	O:3	OtoW-P:1	A-R:2	OC-S1	GC-S3
Case 129	P1	O:3	OtoW-P:1	A-R:3	OC-S1	GC-S3
Case 130	P1	O:3	OtoW-P:2	A-R:1	OC-S1	GC-S3
Case 131	P1	O:3	OtoW-P:2	A-R:2	OC-S1	GC-S3
Case 132	P1	O:3	OtoW-P:2	A-R:3	OC-S1	GC-S3
Case 133	P1	O:3	OtoW-P:3	A-R:1	OC-S1	GC-S3
Case 134	P1	O:3	OtoW-P:3	A-R:2	OC-S1	GC-S3
Case 135	P1	O:3	OtoW-P:3	A-R:3	OC-S1	GC-S3
PROTOTYPE 2						
Case 1	P2	O:1	OtoW-P:1	A-R:1	OC-S1	GC-S1
Case 2	P2	O:2	OtoW-P:1	A-R:1	OC-S1	GC-S1

Case 3	P2	O:1	OtoW-P:2	A-R:1	OC-S1	GC-S1
Case 4	P2	O:1	OtoW-P:3	A-R:1	OC-S1	GC-S1
Case 5	P2	O:2	OtoW-P:2	A-R:1	OC-S1	GC-S1
Case 6	P2	O:2	OtoW-P:3	A-R:1	OC-S1	GC-S1
Case 7	P2	O:1	OtoW-P:1	A-R:2	OC-S1	GC-S1
Case 8	P2	O:1	OtoW-P:2	A-R:2	OC-S1	GC-S1
Case 9	P2	O:1	OtoW-P:3	A-R:2	OC-S1	GC-S1
Case 10	P2	O:2	OtoW-P:1	A-R:2	OC-S1	GC-S1
Case 11	P2	O:2	OtoW-P:2	A-R:2	OC-S1	GC-S1
Case 12	P2	O:2	OtoW-P:3	A-R:2	OC-S1	GC-S1
Case 13	P2	O:1	OtoW-P:1	A-R:3	OC-S1	GC-S1
Case 14	P2	O:1	OtoW-P:2	A-R:3	OC-S1	GC-S1
Case 15	P2	O:1	OtoW-P:3	A-R:3	OC-S1	GC-S1
Case 16	P2	O:2	OtoW-P:1	A-R:3	OC-S1	GC-S1
Case 17	P2	O:2	OtoW-P:2	A-R:3	OC-S1	GC-S1
Case 18	P2	O:2	OtoW-P:3	A-R:3	OC-S1	GC-S1
Case 19	P2	O:1	OtoW-P:1	A-R:1	OC-S2	GC-S1
Case 20	P2	O:1	OtoW-P:1	A-R:2	OC-S2	GC-S1
Case 21	P2	O:1	OtoW-P:1	A-R:3	OC-S2	GC-S1
Case 22	P2	O:1	OtoW-P:2	A-R:1	OC-S2	GC-S1
Case 23	P2	O:1	OtoW-P:2	A-R:2	OC-S2	GC-S1
Case 24	P2	O:1	OtoW-P:2	A-R:3	OC-S2	GC-S1
Case 25	P2	O:1	OtoW-P:3	A-R:1	OC-S2	GC-S1
Case 26	P2	O:1	OtoW-P:3	A-R:2	OC-S2	GC-S1
Case 27	P2	O:1	OtoW-P:3	A-R:3	OC-S2	GC-S1
Case 28	P2	O:2	OtoW-P:1	A-R:1	OC-S2	GC-S1
Case 29	P2	O:2	OtoW-P:1	A-R:2	OC-S2	GC-S1
Case 30	P2	O:2	OtoW-P:1	A-R:3	OC-S2	GC-S1
Case 31	P2	O:2	OtoW-P:2	A-R:1	OC-S2	GC-S1
Case 32	P2	O:2	OtoW-P:2	A-R:2	OC-S2	GC-S1
Case 33	P2	O:2	OtoW-P:2	A-R:3	OC-S2	GC-S1
Case 34	P2	O:2	OtoW-P:3	A-R:1	OC-S2	GC-S1
Case 35	P2	O:2	OtoW-P:3	A-R:2	OC-S2	GC-S1
Case 36	P2	O:2	OtoW-P:3	A-R:3	OC-S2	GC-S1
Case 37	P2	O:1	OtoW-P:1	A-R:1a	OC-S3	GC-S1
Case 38	P2	O:1	OtoW-P:1	A-R:2	OC-S3	GC-S1
Case 39	P2	O:1	OtoW-P:1	A-R:3	OC-S3	GC-S1

Case 40	P2	O:1	OtoW-P:2	A-R:1	OC-S3	GC-S1
Case 41	P2	O:1	OtoW-P:2	A-R:2	OC-S3	GC-S1
Case 42	P2	O:1	OtoW-P:2	A-R:3	OC-S3	GC-S1
Case 43	P2	O:1	OtoW-P:3	A-R:1	OC-S3	GC-S1
Case 44	P2	O:1	OtoW-P:3	A-R:2	OC-S3	GC-S1
Case 45	P2	O:1	OtoW-P:3	A-R:3	OC-S3	GC-S1
Case 46	P2	O:2	OtoW-P:1	A-R:1	OC-S3	GC-S1
Case 47	P2	O:2	OtoW-P:1	A-R:2	OC-S3	GC-S1
Case 48	P2	O:2	OtoW-P:1	A-R:3	OC-S3	GC-S1
Case 49	P2	O:2	OtoW-P:2	A-R:1	OC-S3	GC-S1
Case 50	P2	O:2	OtoW-P:2	A-R:2	OC-S3	GC-S1
Case 51	P2	O:2	OtoW-P:2	A-R:3	OC-S3	GC-S1
Case 52	P2	O:2	OtoW-P:3	A-R:1	OC-S3	GC-S1
Case 53	P2	O:2	OtoW-P:3	A-R:2	OC-S3	GC-S1
Case 54	P2	O:2	OtoW-P:3	A-R:3	OC-S3	GC-S1
Case 55	P2	O:1	OtoW-P:1	A-R:1	OC-S1	GC-S2
Case 56	P2	O:1	OtoW-P:1	A-R:2	OC-S1	GC-S2
Case 57	P2	O:1	OtoW-P:1	A-R:3	OC-S1	GC-S2
Case 58	P2	O:1	OtoW-P:2	A-R:1	OC-S1	GC-S2
Case 59	P2	O:1	OtoW-P:2	A-R:2	OC-S1	GC-S2
Case 60	P2	O:1	OtoW-P:2	A-R:3	OC-S1	GC-S2
Case 61	P2	O:1	OtoW-P:3	A-R:1	OC-S1	GC-S2
Case 62	P2	O:1	OtoW-P:3	A-R:2	OC-S1	GC-S2
Case 63	P2	O:1	OtoW-P:3	A-R:3	OC-S1	GC-S2
Case 64	P2	O:2	OtoW-P:1	A-R:1	OC-S1	GC-S2
Case 65	P2	O:2	OtoW-P:1	A-R:2	OC-S1	GC-S2
Case 66	P2	O:2	OtoW-P:1	A-R:3	OC-S1	GC-S2
Case 67	P2	O:2	OtoW-P:2	A-R:1	OC-S1	GC-S2
Case 68	P2	O:2	OtoW-P:2	A-R:2	OC-S1	GC-S2
Case 69	P2	O:2	OtoW-P:2	A-R:3	OC-S1	GC-S2
Case 70	P2	O:2	OtoW-P:3	A-R:1	OC-S1	GC-S2
Case 71	P2	O:2	OtoW-P:3	A-R:2	OC-S1	GC-S2
Case 72	P2	O:2	OtoW-P:3	A-R:3	OC-S1	GC-S2
Case 73	P2	O:1	OtoW-P:1	A-R:1	OC-S1	GC-S3
Case 74	P2	O:1	OtoW-P:1	A-R:2	OC-S1	GC-S3
Case 75	P2	O:1	OtoW-P:1	A-R:3	OC-S1	GC-S3
Case 76	P2	O:1	OtoW-P:2	A-R:1	OC-S1	GC-S3

Case 77	P2	O:1	OtoW-P:2	A-R:2	OC-S1	GC-S3
Case 78	P2	O:1	OtoW-P:2	A-R:3	OC-S1	GC-S3
Case 79	P2	O:1	OtoW-P:3	A-R:1	OC-S1	GC-S3
Case 80	P2	O:1	OtoW-P:3	A-R:2	OC-S1	GC-S3
Case 81	P2	O:1	OtoW-P:3	A-R:3	OC-S1	GC-S3
Case 82	P2	O:2	OtoW-P:1	A-R:1	OC-S1	GC-S3
Case 83	P2	O:2	OtoW-P:1	A-R:2	OC-S1	GC-S3
Case 84	P2	O:2	OtoW-P:1	A-R:3	OC-S1	GC-S3
Case 85	P2	O:2	OtoW-P:2	A-R:1	OC-S1	GC-S3
Case 86	P2	O:2	OtoW-P:2	A-R:2	OC-S1	GC-S3
Case 87	P2	O:2	OtoW-P:2	A-R:3	OC-S1	GC-S3
Case 88	P2	O:2	OtoW-P:3	A-R:1	OC-S1	GC-S3
Case 89	P2	O:2	OtoW-P:3	A-R:2	OC-S1	GC-S3
Case 90	P2	O:2	OtoW-P:3	A-R:3	OC-S1	GC-S3

Appendix 6

Simulation Results

Case	Cooling Plant Load (MWh) "Annual Summed Total"	Case	Cooling Plant Load (MWh) "Annual Summed Total"
PROTOTYPE 1			
1	14.1850	2	13.6238
3	9.0003	4	18.2933
5	9.8084	6	17.4685
7	9.5274	8	10.9558
9	6.9559	10	12.1006
11	15.3656	12	8.6175
13	11.6364	14	14.6763
15	8.3775	16	8.0082
17	9.5260	18	6.3826
19	10.2755	20	12.9848
21	7.9307	22	9.8921
23	12.4603	24	7.7000
25	7.1177	26	8.3851
27	6.0525	28	14.2784
29	12.2107	30	10.4059
31	18.3444	32	15.4389
33	13.0851	34	9.9678
35	8.7779	36	8.0959
37	13.7174	38	11.7418
39	10.0134	40	17.5211
41	14.7467	42	12.6720
43	9.6839	44	8.5319
45	7.8563	46	9.0927
47	8.1140	48	7.2433
49	11.0121	50	9.6011

51	8.4863	52	7.1001
53	6.5280	54	6.2059
55	14.4768	56	12.4390
57	10.6746	58	18.4299
59	15.5629	60	13.2615
61	10.3538	62	9.1608
63	8.4801	64	13.9117
65	11.9619	66	10.2687
67	17.6019	68	14.8631
69	12.6637	70	10.0646
71	8.9051	72	8.2259
73	9.2851	74	8.3340
75	7.5073	76	11.1119
77	9.7388	78	8.6813
79	7.4344	80	6.8637
81	6.5560	82	16.5684
83	14.0568	84	11.8348
85	21.4033	86	17.9668
87	15.1309	88	11.2357
89	9.7482	90	8.8877
91	15.8768	92	13.4793
93	11.3565	94	20.4145
95	17.1305	96	14.4212
97	10.8829	98	9.4520
99	8.6066	100	10.3090
101	9.0703	102	7.9550
103	12.6771	104	10.9447
105	9.5399	106	7.7426
107	7.0007	108	6.5703
109	18.5966	110	15.8409
111	13.3471	112	23.7048
113	20.0861	114	17.0366
115	12.6510	116	10.9197

117	9.9064	118	17.7720
119	15.1407	120	12.7601
121	22.5670	122	19.1075
123	16.1908	124	12.2094
125	10.5486	126	9.5570
127	11.8971	128	10.4117
129	9.0535	130	14.6223
131	12.6305	132	10.9799
133	8.7868	134	7.8439
135	7.2889		
PROTOTYPE 2			
1	20.8439	2	16.7223
3	27.9608	4	12.4670
5	21.9473	6	10.5237
7	19.8670	8	26.4579
9	12.1480	10	16.0087
11	20.8834	12	10.3271
13	18.0553	14	24.2370
15	11.2063	16	14.8164
17	19.4062	18	9.7155
19	20.9119	20	19.9315
21	18.1320	22	27.9637
23	26.4620	24	24.2569
25	12.6922	26	12.3479
27	11.4036	28	16.7956
29	16.0749	30	14.8926
31	21.9567	32	20.8927
33	19.4291	34	10.7392
35	10.5115	36	9.8992
37	21.0428	38	20.0615
39	18.2915	40	27.9486
41	26.4553	42	24.2810
43	13.1417	44	12.8444

45	11.8967	46	16.9351
47	16.2073	48	15.0482
49	21.9610	50	20.9015
51	19.4624	52	11.1530
53	10.9549	54	10.3451
55	24.2902	56	23.0434
57	20.9483	58	32.2769
59	30.4741	60	27.9751
61	14.3447	62	13.8487
63	12.7396	64	19.1073
65	18.4618	66	17.0700
67	25.3203	68	24.0065
69	22.3119	70	11.9867
71	11.6458	72	10.9261
73	26.6468	74	25.2497
75	23.0343	76	34.4109
77	32.5167	78	30.0208
79	16.1078	80	15.4434
81	14.2025	82	21.6280
83	20.4950	84	18.9624
85	27.5658	86	26.1087
87	24.3075	88	13.5457
89	13.0275	90	12.2025