Potentials of Retrofitting the Federal Buildings in the UAE to Net Zero Electricity Cost Buildings by Implementing Passive and Active Measures

إمكانية إعادة تأهيل المباني الفدرالية في الإمارات العربية المتحدة لمعايير صفر صافي تكلفة الكهرباء من خلال اعتماد استراتيجيات سلبية وإيجابية

By

Enas Ezziddien Alkhateeb

2013117041

Dissertation submitted in partial fulfillment of the requirements for the degree of MSc Sustainable Design of the Built Environment

Faculty of Engineering & IT

Dissertation Supervisor

Professor Bassam Abu-Hijleh

August -2016

DISSERTATION RELEASE FORM

Student Name Enas Ezziddien Alkhateeb	Student ID 2013117041	Programme Sustainable Design of the Built Environment	Date 6 August 2016

Title
Potentials of Retrofitting the Federal Buildings in the UAE to Net Zero Electricity Cost Buildings by Implementing Passive and Active Measures

I warrant that the content of this dissertation is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that one copy of my dissertation will be deposited in the University Library for permanent retention.

I hereby agree that the material mentioned above for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

Electronic Submission Copyright Statement
Please choose one of the following two licenses and check appropriate box.

☐ I grant The British University in Dubai the non-exclusive right to reproduce and/or distribute my dissertation worldwide including the users of the repository, in any format or medium, for non-commercial, research, educational and related academic purposes only.

Public access to my dissertation in the Repository shall become effective:
☐ Immediately ☐ 24 months after my submission
☐ 12 months after my submission ☐ 48 months after my submission

☐ I grant The British University in Dubai the non-exclusive right to reproduce and/or distribute my dissertation to students, faculty, staff and walk-in users of BUiD Library, in any format or medium, for non-commercial, research, educational and related academic purposes only.

Signature
Enas Khateeb

Abstract

The efforts of the United Arab Emirates' (UAE) government regarding sustainable developments are remarkable since the country was labeled with the highest ecological footprint in 2007. Many strategies and initiatives have been launched to manage the energy demand and to diversify energy supply as well. The buildings sector has received a huge amount of attention due to the fast pace development of the country. However, the challenge relies within the existing buildings. The electricity consumption doubled in the last 10 years, and the energy demand is expected to increase around 30% by 2020 compared to 2014. A promising initiative, which allows rooftop photovoltaic to be grid connected, is expected to play a key role in reducing electricity demand from the main grid and provide buildings with green energy.

This research aims to assess the potentials of retrofitting an existing office building to a net zero electricity cost building by implementing passive and active strategies to reduce the energy demand. This includes the use of photovoltaic technology to provide the building with energy supply in order to reduce its reliance on the grid electricity. A federal building has been chosen as a case study to deliver a broader message of the country's vision towards sustainability, both locally and globally.

IES VE simulation software is used to assess the impact of each strategy for both passive and active categories on reducing energy consumption. Different scenarios for each parameter are applied to highlight the optimal scenario prior to introducing the renewable energy. The results reveal that implementing passive measures, such as shading elements and upgrading walls and windows' thermal insulation, provide around 19% saving of the cooling energy consumption and 14.7% in total electricity consumption. Moreover, active measures, such as enhancing COP of cooling system and varying the cooling set-point, increase the savings in electricity up to 63.2% . The introduction of photovoltaic systems as an energy supply proved to be a great addition as an active measure. Since the base case is an office building, the energy demand corresponds with the energy supply; therefore, the majority of the produced solar energy was consumed on site. Different scenarios with different technologies are assessed to define the optimal scenario for this base case.

Ultimately, both passive and active strategies have played an important role in reducing electricity consumption. However, in newly constructed federal buildings with high internal gain, active measures proved to be more effective in reducing electricity consumption than passive strategies. However, with such a hot climate region, protecting the glazing from solar radiation is considered a priority as well, especially in buildings with large windows such as the base case.

In this research, since the building is a small sized office building (G+1) with a total area of $2251m^2$, PVs solar energy has proved to be a very efficient energy supply and can transform the building to a net zero electricity cost building.

ملخص

جهود حكومة دولة الإمارات العربية المتحدة بشأن التطورات المستدامة لافتة للنظر منذ صنفت البلاد بأعلى بصمة بيئية في عام 2007. وقد تم إطلاق مبادرات و استراتيجيات عديدة لإدارة الطلب على الطاقة وتنويع مصادر الطاقة. وقد أولت الحكومة قطاع البناء اهتماما كبيرا لمواكبة التطور العمراني السريع في البلاد. ومع ذلك، يعتمد التحدي الحقيقي داخل المباني القائمة والتي تشكل النسبة الأعلى من مجموع البيئة المبنية. لقد تضاعف استهلاك الكهرباء في السنوات ال 10 الماضية، ومن المتوقع أن يزيد الطلب على الكهرباء بنسبة 30٪ بحلول عام 2020 مقارنة بـ 2014. وفي الآونة الأخيرة، أطلقت حكومة دبي مبادرة واعدة والتي تسمح للطاقة الكهروضوئية المنتجة على اسطح الأبنية أن تكون مرتبطة بشبكة الكهرباء الرئيسة. من المتوقع ان تلعب المبادرة دورا رئيسيا في تشجيع القطاعات المختلفة على اعتماد الألواح الكهروضوئية كمصدر للطاقة مما سيؤدي بالتالي على الحد من الطلب على الكهرباء من الشبكة الرئيسية.

يهدف هذا البحث إلى تقييم إمكانات تقليل الطاقة المستخدمة في مبنى قائم من خلال تقديم بعض الاستراتيجيات (تدابير سلبية وإيجابية) التي تهدف الى زيادة كفاءة المبنى من ناحية استهلاك الطاقة وتوفير مصادر بديلة للطاقة في نفس الوقت حيث تكون صديقة للبيئة كالطاقة الشمسية وبالتالي تحد من الطلب على الطاقة من الشبكة الرئيسة.. وقد تم اختيار مبنى اتحادي (وزارة تطوير البنية التحتية في رأس الخيمة) كحالة دراسية لإيصال رسالة أوسع عن رؤية البلاد نحو الاستدامة محليا وعالميا على حد سواء.

IES VE هو برنامج لمحاكاة الطاقة لتقييم تأثير كل استراتيجية لكلا الفئتين السلبية والإيجابية على الحد من استهلاك الطاقة. يتم تطبيق سيناريوهات مختلفة لكل استراتيجية لتسليط الضوء على السيناريو الأمثل لأقل طاقة مع اعتبار الحالة المناخية للمنطقة قبل تقديم الطاقة المتجددة. بينت النتائج أن تنفيذ تدابير سلبية، مثل عناصر التظليل و تطوير العزل الحراري للجدران والنوافذ تعطي حوالي 19٪ توفير في استهلاك الطاقة اللازمة للتبريد و 14.7٪ في إجمالي استهلاك الكهرباء. وعلاوة على ذلك، هناك بعض التدابير فعالة، مثل زيادة كفاءة فعالية نظام التبريد بالإضافة الى تقليل ساعات عمله مع التأكيد على رفع الحرارة بما لا يؤثر على راحة المستخدمين قد يؤدي الى توفير في الكهرباء يصل إلى حوالي 63.2٪. وعلاوة على ذلك، استخدام الألواح الكهروضوئية كنظام لإمدادات الطاقة للمبنى المختار اظهر نتائج ايجابية عالية، بما ان المبنى هو مبنى للمكاتب، فالطلب على الطاقة يتوافق زمنيا مع إمدادات الطاقة الشمسية؛ وبالتالي، يتم استهلاك معظم الطاقة الشمسية المنتجة في الموقع. لقد تم اقتراح سينايوهات متعددة لتقديم الألواح الكهروضوئية . بالإضافة الى التقنيات المختلفة.

في نهاية المطاف، لقد لعبت كلا من الاستراتيجيات السلبية والإيجابية دورا هاما في الحد من استهلاك الكهرباء من الشبكة الرئيسة. ومع ذلك، في المباني الفيدرالية التي شيدت حديثا نسبيا ومع زيادة الطاقة المستخدمة لمعالجة الحرارة الداخلية الناتجة من الاجهزة المستخدمة والموظفين والمترددين عل المبنى، أثبتت الدراسة فعالية الاستراتيجيات الايجابية في الحد من استهلاك الكهرباء اكثر من الاستراتيجيات السلبية. غير ان هذا لا يمنع التأكيد على انه وفي هذه المنطقة ذات المناخ

الحار، حماية الزجاج من أشعة الشمس يعتبر من الأولويات ، خصوصا في مبنى ذو نوافذ كبيرة مثل المبنى المختار للدراسة.

في هذا البحث، وحيث ان المبنى المختار للدراسة هو مبنى للمكاتب بحجم متواضع (G + 1) ومساحة إجمالية قدرها 2251 متر مربع، فقد أثبتت الدراسة ان تحديث المبنى باستراتيجيات سلبية وإيجابية لاستهلاك طاقة أقل بالإضافة الى استخدام الطاقة الشمسية من خلال الألواح الكهروضوئية لتكون مصدر متجدد للطاقة هو فعال جدا ولديه امكانية لتحويل المبنى إلى مبنى يستخدم الكهرباء بدون تكلفة على مدار العام .

Dedication

I would like to dedicate this research to my loving and supportive family. Firstly, my husband Omar, for motivating me to continuously pursue my dreams. Secondly to my precious daughters, Jinan and Rana, for being my best friends throughout this educational journey. Furthermore, I would like to thank my father, Ezziddien, and my mother, Mariam (may God have mercy on her soul) for making me the person I am today. Lastly, I would like to give great appreciation towards my brother, Osama, for constantly supporting me while being miles away.

Acknowledgements

This research would not have been possible without God's guidance and grace; may He always support us to contribute positively to the humanity.

It has always been a dream of mine to pursue higher education; this dream has finally become a reality with the help and support of many colleagues, friends and family.

First and foremost, an overwhelming amount of appreciation is dedicated to my supervisor, Professor Bassam Abu Hijleh. His continuous professional guidance, motivation, time and valuable feedback are the backbone of this research. It was a pleasure working with him every step of the way.

Secondly, I would like to thank Professor Hasim Altan for his constant support and efforts to go above and beyond for his students by exposing them to conferences that further enhanced our theoretical knowledge.

I would also like to greatly thank Ms. Wafa AlAwadi, an employee in Ministry of Infrastructure Department RAK (MOID-RAK), for her kindness and generous cooperation.

Furthermore, I would like to give great thanks to MOID-RAK employees in Dubai, Engineer Anwar Mohamed Alshimmari the Director of Design department, and Engineer Ola Adel Alaraby for providing me with all the needed documents to make this research a success.

I would like to thank Ahmed Abou Shaaban, a fellow colleague, for being helpful and supportive throughout my entire journey. His constant and genuine help eased many obstacles and made this overall experience much smoother.

Finally, the biggest thanks is directed towards my family for bearing with me throughout the entire journey.

Table of Contents

List of Figures

List of Tables

List of Abbreviation

AAC	Autoclaved Aerated Concrete
AHU	Air Handling Unit
BAU	Business as Usual
BIM	Building Information Modelling
BIPV	Building Integrated Potovoltaic System
CBEC	China Building Energy Code
COP	Coefficient of Performance
DEWA	Dubai Electricity and Water Authority
DRRG	Distributed Renewable Resources Generation
DSM	Demand Side Management
EER	Energy Efficiency Ratio
EGBC	Emirates Green Building Council
EGWW	The Edith Green-Wendekk Wyatt
EIFS	Exterior Insulation Finishing System
EMSs	Energy Measure Savings
EPC	Energy Performance Contract
ESCO	Energy Service Company
ESM	Energy Service Management
ESPC	Energy Saving Performance Contract
EUI	Energy Unit Intensity
FEWA	Federal Electricity and Water Authority
GCC	Gulf Countries Council
GHG	Green House Gas
GSA	General Service Administration
HISG	Heat Insulation Solar Glass
HVAC	Heating, Ventilation and Air conditioning
IEQ	Indoor Environment Quality
IES VE	Integrated Environmental Solutions - Virtual Environment
IHC	International Humanitarian City

IMF	International Monetary Fund
LCA	Life Cycle Analysis
LEBs	Low Energy Buildings
LCCA	Life Cycle Cost Assessment
MOID	Ministry of Infrastructure Development
MOPW	Ministry of Public Work
NDER	Nationwide Deep Energy Retrofit
NOO	Notice Of Opportunity
NWH	Non Working Hours
n-ZEB	Nearly Zero Energy Building
PCS	Personal Comfort system
PV	Photovoltaic
RAK	Ras Al Khaimah
RE	Renewable Energy
SBCI	Sustainable Building and Climate Initiative
SC	Shading Coefficient
SDHW	Solar Domestic Hot Water
SHGC	Solar Heat Gain Coefficient
TE	Technical Efficiency
UAE	United Arab Emirates
UNEP's	United Nations Environment Programme's
WH	Working Hours
WWF	World Wildlife Fund
ZEN	Zero Net Energy

Chapter 1

Introduction

1 Introduction

1.1 Overview

In the last few decades, changes in the climates have been globally noticed as a hot topic that needed to be seriously addressed. The causes for these changes are varied and many theories highlight different key triggers for these changes. Eventually, the carbon footprint has been considered as a measurement tool to estimate the green house gases (GHG) (Wiedemann, 2009). Governments and policymakers worldwide were required to consider mitigating global warming and to provide initiatives to reduce GHG emissions. The built environment is responsible for 40% of global energy consumption, 25% of global water, and 40% of global resources, in total produce around 1/3 of global GHG emission. This in turn makes the building sector the largest contributor to GHG emissions (UNEP, 2015).

As a result, building codes have been designed in a way to mitigate the building's impact on the environment, with a chance of making them more efficient over time. Figure 1.1 shows examples of some energy codes for commercial buildings in the United States and their path of saving energy over the last 35 years (CxE, 2015).

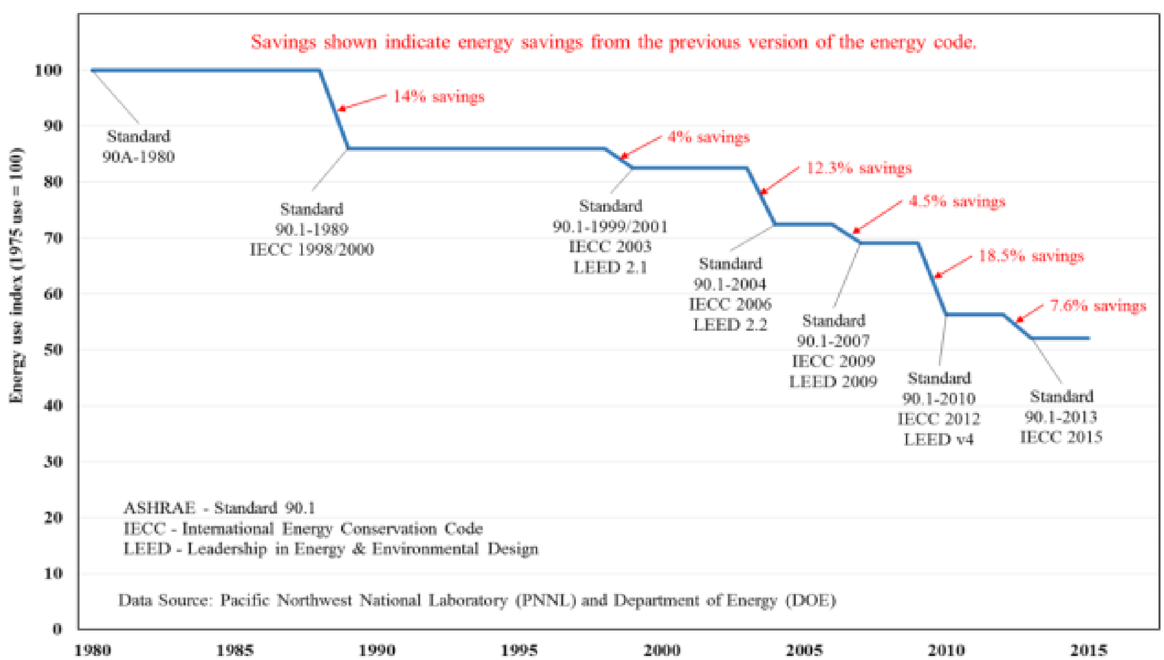


Figure 1.1: Comparison of commercial energy code in the United States (CxE,2015)

The United Arab Emirates (UAE) is among the leading countries in the Arab region regarding sustainable development. In 2007, the UAE was said to have the highest ecological footprint per capita worldwide (WWF, 2010), since then the country has witnessed provision of many polices, regulations and initiatives in different sectors that regulate energy consumption. The building construction sector was given great attention in order to provide regulations that enhance the thermal performance for the newly constructed buildings, thus mitigating their impact on the environment. Figure 1.2 shows the impact of building legislative requirements on the green building trends in some countries around the world; it is obvious that the UAE government shows a strong dedication towards green construction (McGraw Hill construction, 2013).

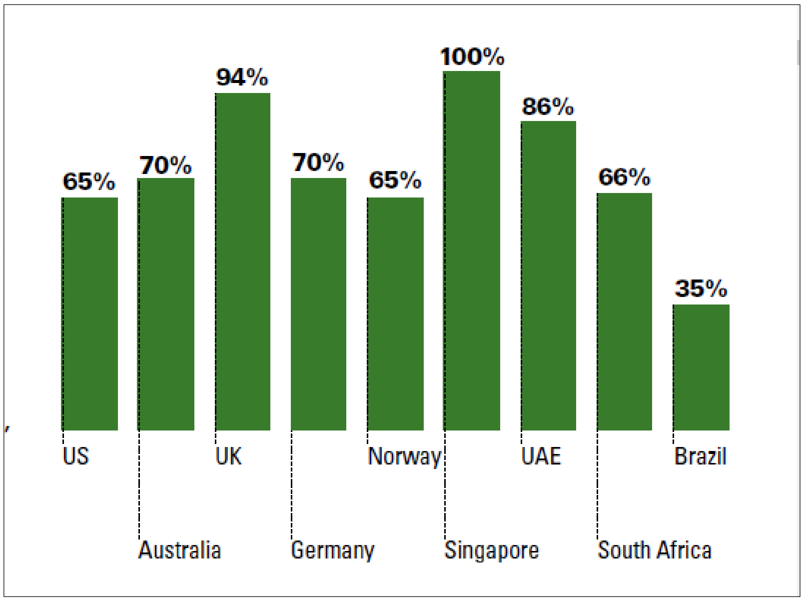


Figure: 1.2: Percentage of firms reporting that their government has requirements related to green building. (McGraw Hill construction, 2013)

This trend in sustainable construction has emerged as a natural response to cope with the fast and active growth in the country's building construction sector. However, Mr. Saeed Alabbaar, chairman of the Emirates Green Building Council (EGBC), explained that although building regulations are a progressive way of thinking, the challenges lie within the existing buildings. According to the United Nations Environment Program, around 30-80% of the energy can be saved if the proven green strategies are implemented in both new and existing buildings (UNEP, 2015).

1.2 Retrofitting the Existing Buildings

Energy efficiency is the management of energy usage in order to provide the intended task with minimal energy consumption and without compromising the individuals' thermal comfort. There are many passive and active measures that can be applied to both new and existing buildings. The main points that need to be considered are: the reduction in energy consumption, the reduction in CO2 emission, the indoor air quality, and the economic feasibility.

The National Renewable Energy Laboratory (NREL) proposed innovative energy-saving recommendations that allow achieving around 50% reduction in energy consumption in large buildings such as offices, schools, hospitals, etc. The recommendations include installing passive and active measures. The study was applied on all the United States eight climate regions and showed that the smallest savings were recorded in extreme cold climates, as well as humid climates (NREL, 2011).

Another study, also in the United States, emphasized the impact of these energy saving measures in retrofitting the existing as the most effective approach to achieve a plummet reduction in U.S. carbon emission (THE ROCKEFELIER FOUNDATION, 2012). However, the Mckinsey Institute (2009) declared that although buildings are subject to significant opportunities for energy savings, considerable financial incentives are needed to move the retrofit marketplace in an effective way.

1.3 Passive Design

Passive solar design is manipulating the sun's energy in order to heat or cool spaces through the building's design. There are many principles needed to be considered in such designs like the building orientation, fenestrations, building shades, insulation and building thermal mass (lfengspace Culture & Media 2012). Implementing passive techniques to retrofit existing buildings aims to upgrade the thermal performance of the building envelope, enhance thermal insulation, minimize air infiltration, increase daylight penetration and optimize benefits from shading elements. All these passive measures use no or minimal energy post installation. On the other hand, active retrofit strategies aim to upgrade the electrical and mechanical systems of the building and provide energy efficient equipment (WBDG, 2014). The active measures either require energy to function or provide energy. Retrofit measures need to be chosen carefully, taking into consideration the applicability, feasibility and outcome of each measure (Ma et al. 2012).

Moreover, to ensure capturing the maximum benefits from the retrofit, all the equipment and systems need to be properly commissioned, in addition to the occupants' important role in altering their behavior towards energy conservation lifestyle (Harvey, 2010).

1.4 Renewable Energy (RE)

According to IRENA's 2014 report "RE Thinking Energy", the rise in energy demand is an expected outcome for the growing populations, increasing urbanization, as well as constant economic growth. However, the climate change and fossil fuel impact on the environment have sustained big issues causing governments to look for alternatives with less impact on the environment. Renewable energy source is considered a clean energy resource that could replace fossil fuel with free negative impact on the environment and inhabitants (Manzano-Agugliaro et al. 2013). There are several types of renewable energy such as solar energy, wind energy, hydroelectric power, geothermal energy, biomass energy, ocean energy and nuclear energy. The last 15 years have shown a steady progress in renewable energy deployment to reach a 58% share in 2013 compared to 19% in 2001. In 2013, solar deployment beat wind for the first time as shown in Figure 1.3.

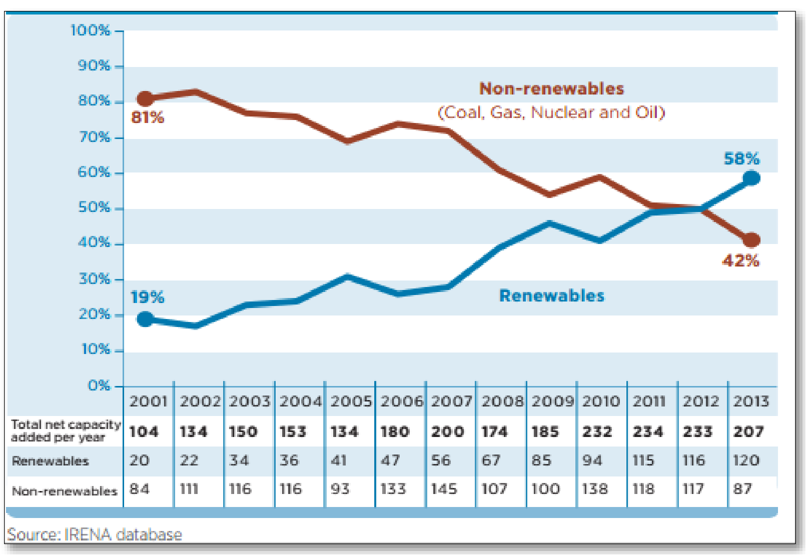


Figure 1.3: The share of global capacity additions (2001-2013), (IRENA, 2014)

According to Mokri et al. (2013), the main key drivers to consider renewable energy resources in the UAE can be summarized in few points: the high demand on energy and electricity, as well as the scarcity of water resources, and finally the country's desire to maintain its position in the global energy market. He added that because of the moderate wind speeds, wind energy may not be a feasible option for mass deployment. Moreover, depending on the nuclear energy program, as a solo source of RE, will not be able to meet the high demand of electricity.

1.5 Solar Energy

As the solar industry is developing around the world, the Gulf Countries Council (GCC) governments and energy stakeholders have shown more interest in promoting and investing in solar technologies. Based on AlNaser and AlNaser (2011), the UAE is lucky for having an average of 10 hours sunlight daily. Throughout the year, the country is exposed to an average 350 sunny days. The average total solar energy received is 6.5 kWh/m^2/day. In terms of the solar radiation, while also taking into consideration the location and the time of year, results range between 4-6 kWh/m^2/day. Figure 1.4 shows the solar resource and the high potentials of utilizing it as an energy supply.

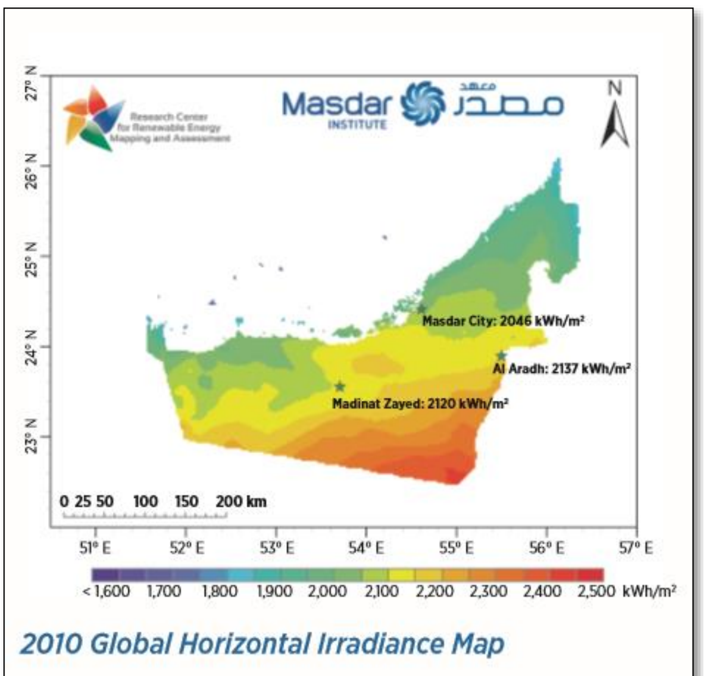


Figure1.4: UAE solar map, (IRENA, 2015b)

However, there are many challenges on the large-scale solar deployment in the region such as dust particles and high humidity which requires regular cleaning in order to not decrease the direct normal irradiance (IRENA, 2015 b).

1.6 Energy Consumption Profile in the UAE

In the last three decades, the UAE has witnessed an active development in the building construction sector. Unfortunately, the country was labeled as the highest ecological footprint worldwide, where the UAE's per capita footprint was found to be 11.68 global hectares in 2006, whereas the average ecological footprint per person worldwide is 2.6 hectares (EWS-WWF, 2015). As a result, in 2007, the country adopted the Ecological Footprint Initiative (EFI). Moreover, in 2010, the UAE's government has decided to partner with Copenhagen Accord and has shown commitment to reduce CO_2. (Ministry of Foreign Affairs, 2010). Lately, the ministry of Environment and Water announced that the ecological footprint in 2014 was dropped to 7.75 hectares (WAM, 2015).

A research conducted about the UAE determined that the emission of CO_2 will be reduced by 50% if the built environment begins to follow strict regulations regarding energy consumption, as well as, replacing fossil fuels with clean energy sources (Radhi, 2010). Therefore, the built environment sector has shown provision of standards and codes that regulate the newly constructed buildings such as the 2010 Abu Dhabi's Estidama with its 1-5 Pearls rating system and the 2011 Dubai Green Buildings Regulations. However, the majority of these efforts have focused on new buildings, whilst the existing buildings were neglected. The new construction will only make up 0.5-2% of the total building stock and will contribute 10-20% additional energy consumption by 2050 (Stafford et al. 2007).

Retrofitting existing buildings is the most practical and fastest approach to reduce CO_2 emission; as shown through Etihad super ESCO's accomplished work on refurbishing some projects. For instance, the executed project for lighting retrofit at DEWA power station in Jabel Ali and Al-Awir confirmed a saving of 75% compared to the previous consumption and 6,286 tons of CO2 reduction (Etihad ESCO, 2014a).

Statistics in 2011 showed that governmental buildings (offices and facilities) in Abu Dhabi alone consumed around 21% of total energy, followed by commercial buildings with 30%, whilst residential sector shows the highest consumption with 33% as shown in Figure 1.5. Moreover, in 2013, the Federal and Governmental buildings in the UAE consumed around 29% of electricity (Sachse, 2016, p.30).

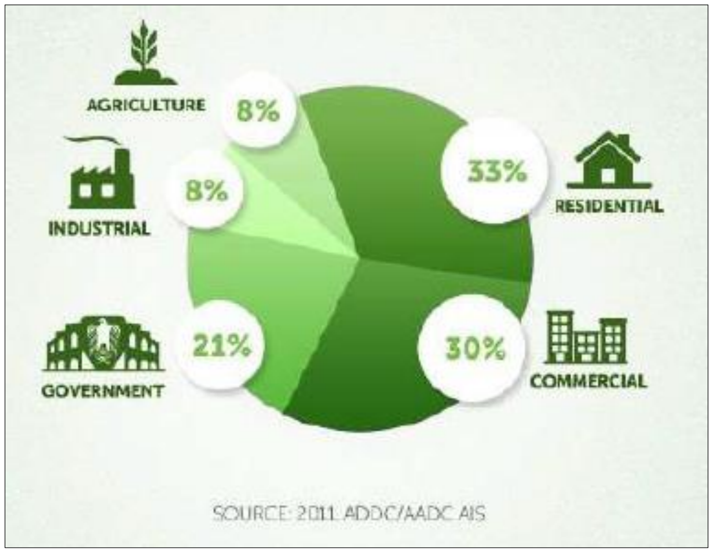


Figure 1.5: Electricity consumption in Abu Dhabi emirate

In an interview with Mr. Saeed Alabaar, chairman of Emirate Green Building Council (EGBC), he said that with the current regulations, many existing buildings try to meet these standards through implementing retrofit strategies. He added that some existing buildings in the UAE consume 220-360 kWh/m2/year. However, by considering retrofit measures, the consumption could be decreased to 160-260 kWh/m2/year. Some examples in the UAE have shown great results, with the most energy efficient building being 110-160 kWh/m2/year (Clarke, 2016)

Under the framework of the UAE Vision 2021, many strategic plans for each emirate have evolved. Demand Side Management (DSM) is one of Dubai's integrated energy strategies that promote energy conservation by affecting the behavior of consumption. The targets for 2030 are 30% saving in electricity consumption and 40% saving in water consumption vs. Business As Usual (BAU). Eight DSM programs have been targeted; building retrofit is one of these programs with an expected 9% potential saving during 2013-2030 (Dubai Supreme Council of Energy, 2015).

Recently the Supreme Council of Energy has issued a Directive for Energy Audits, followed by detailed Implementation Guidelines. The Directive targets 20% savings in government buildings, with 1.4 billion AED savings for the government by 2030. The retrofitting program for the existing buildings is focusing on the main drivers of energy consumption (Rashid, 2015).

1.7 Motivation of the Work

Managing the energy demand and diversifying the supply is one of the integrated strategies for Dubai 2030. Retrofitting existing buildings is one project of the DSM. It has shown a potential of 9% energy reduction by 2030. On the other hand, regarding energy supply mixture, the federations' two largest emirates (Abu Dhabi & Dubai) have adopted targets to scale up solar and other renewable energies. Dubai is aiming for 5% electricity capacity by 2030, and Abu Dhabi is aiming for 7% of electricity capacity from renewable sources by 2020 (Salman, 2015, P.67)

Moreover, in April 2014, Dubai electricity and Water Authority (DEWA) launched the first large scale program enabling solar grid-connection distributed generation in the region (State of Green Economy Report, 2015, p. 96). Connecting solar energy with the main grid offers great potentials in saving money and energy, which will reflect positively on the economy and environment.

In the literature, there are several studies which discuss the environmental and economical impact of implementing both passive (Alawadi et al. 2013, Alnaqabi, 2013), and active retrofit measures (Alawadi, 2014, Faraj,2015) for existing buildings in the UAE and. Feasibility studies have also been discussed (Manneh, 2013) and (Manneh, et al. 2014).

Although a zero energy building design was proposed (Baeza, 2013), the literature lacks any contribution regarding the potentials of extensive refurbishment that achieves the minimal energy demand which could be eventually fed by clean energy supply. The lack of such academic papers in the UAE has triggered this research.

According to Alabbar's latest interview, with all the available technology and the country's determination, it will become a leader in sustainability. Retrofitting existing buildings to be nearly zero energy building (n-ZEB) with 40-60 kWh/m2/year is certainly possible and should be the main goal (Clarke,2016).

By retrofitting the federal buildings in the UAE, a broader message of the country's vision towards sustainability will be delivered across the nation, which will increase the public's awareness towards the importance of energy efficiency and its potentials.

Globally, presenting the federal buildings in the UAE as sustainable buildings prove the country's serious efforts to contribute positively to mitigate the GHGs. It is important that the government leads by example and lays the ground work to make low energy buildings (LEBs) accessible to other building sectors which will allow the retrofit movement to progress.

1.8 Aims and Objectives

The aim of this research is to assess the potential of enhancing the energy performance of an existing federal building in the UAE through implementing passive and active strategies in order to reduce its energy demand. Moreover, the study will examine the potential of integrating different grid connected PV systems in order to provide clean onsite power further reducing the demand for grid electricity.

The identified objectives for the study include the following:

- To examine the unique characteristics of federal buildings that may affect the outline of choosing the retrofit measures.
- To identify possible areas to implement passive and active retrofit measures that reduce energy consumption in such buildings.
- To investigate the impact of implementing energy efficiency passive measures on reducing the building's energy demand;

- Passive measures will include:

  - Implementing shading elements.

  -Upgrading the thermal insulation proprieties for the existing building envelope by applying 1 pearl, 2 Pearls configurations and Passivhaus regulations.

- To investigate the impact of implementing some energy efficiency active measures on reducing the building's energy demand;
- Active measures will include the following:

  - Increasing the cooling set-point temperature while considering the different building zones orientation and functions.

  - Increasing chiller's COP.

- Diversifying energy supply by incorporating different PV technologies systems.
- To assess the energy performance of each implanted measure in terms of:

  - The total annual electricity consumption.

  - The total system energy reduction

  - The PVs' total annual electricity production.

  - The optimized solution to present a building with a net zero electricity cost.

1.9 Research Outlines

This work is presented in six chapters. An outline of the content for each chapter is listed below:

The first chapter

The chapter introduces an overview of the major topics that are tackled in general in this study and the reasons behind trigging this research. The chapter is concluded with the aim and the objectives as well as the research outlines.

The second chapter

This chapter reviews the literature to highlight the outcome of the previous studies that investigated the impact of implementing passive and active measures to existing buildings. Also the chapter reviews the related work to solar energy as a renewable alternative energy and PV deployment. Finally, the chapter will examine some retrofitted federal buildings in Europe and United States. Also, some examples of retrofitted governmental buildings in the UAE will be discussed.

The third chapter

This chapter identifies and analyzes the different methods that have been used to cover different aspects that are related to existing buildings' retrofits. The method's pros and cons are compared in order to choose the most appropriate methodology that will achieve the research objectives. The chosen method will be highlighted, in addition to presenting the validated approach.

The fourth chapter

This chapter introduces the case study, the simulation input data and the different simulation scenarios.

The fifth chapter

This chapter presents the obtained results and provides a critical analysis for these results.

The sixth chapter

Based on the outcome in chapter five, the chapter provides the conclusion of this research followed by recommendations as the closure.

The conclusion of this chapter will enlighten the potentials of retrofitting the existing buildings to nearly zero energy cost buildings by minimizing energy demand and optimizing and diversifying energy supply.

Chapter 2
Literature Review

2 Literature Review

2.1 Overview

The built environment is responsible of consuming around 40% of the total energy used in all different sectors. A great effort has been conducted to mitigate the impact of the building sectors on the environment. Globally, mandated regulations have been assigned to all new buildings. All these efforts have paid off through positive results regarding energy efficiency performance. However, all the related studies to the built environment agreed on the significant impact of retrofitting the existing stock in reducing the CO_2 emission, since it forms the bigger portion of the built environment. Moreover, including the retrofit of smaller buildings will greatly contribute to the reduction of CO_2 emission (Petersdorff et al. 2006). Many researchers investigated the impact of different retrofit measures, both active and passive, on reducing energy demand. Furthermore, some papers discussed the potentials of reaching net zero buildings through optimizing energy supply and including renewable energy.

Many aspects which are related to energy demand reduction in existing buildings are discussed and investigated such as thermal comfort, occupants' behavior, passive strategies, mechanical and electrical systems, economic feasibility, and policies and regulations. On the other hand, solar energy has had great attention as a renewable energy supply. Many papers discussed this matter from different angles. Moreover, some retrofitted case-studies addressed the interlinked relation between reducing energy demand and optimizing clean energy supply.

Firstly, the chapter reviews the previous research that relates to principles of passive design, as well as the passive and active retrofit strategies for existing buildings. Secondly, the renewable energy progress will be reviewed, as well as the progress in using photovoltaic PVs as a source of electricity. Thirdly, the chapter will present the current status of the refurbished stock in the UAE, in addition to the renewable energy market. Fourthly, reviewing the previous studies on refurbishing buildings and their impact environmentally and economically. Fifthly, the status of the federal buildings in the UAE and the reasons behind choosing them as a case study with unique characteristics. Eventually, the chapter is concluded with defining the problem statement.

This following chapter will focus on highlighting the previous research results regarding retrofitting existing buildings, installation of PVs to produce clean energy supply which eventually may lead to a nearly Zero Energy Buildings (nZEBs). The collected data aims to explore and identify the gap in such a topic and the opportunities to contribute to this field.

2.2 Principles of Passive Design

The n-ZEB concept could be considered a progressive growth of passive designs with low energy demand. For thousands of years, the vernacular architecture, with its passive techniques, provided thermal comfort to its occupants before having the mechanical cooling and heating systems (Kylili & Fokaides, 2015). Passive design is a very effective approach to reduce the energy demand for heating and cooling purposes. The climatic differences recall for different approaches to meet the thermal comfort. Santamouris & Asimakopoulos (1996) pointed out the importance of the buildings' arrangements as well as their layouts. They added that passive cooling techniques are able to control and modulate the heat gain. Although in summer times controlling the ambient air temperature is the main concern, while lowering the air temperature is another desirable step. Lechner (2008) created the hierarchy of sustainable design through three tiers. In passive cooling, the first tier prioritizes reducing heat gain while maintaining the maximum daylight. This can be achieved through different strategies such as: building orientation, insulation, exterior shading, construction materials and air tightness. The second tier introduces the passive systems such as comfort ventilation, cooling towers and night flush ventilation. The last tier deals with the mechanical and electrical systems. On the contrary, passive heating focuses on maximizing heat gain and using passive systems such as trombe wall, direct gain and sunspace.

Lechner (2008) insists that energy efficiency is the most important key factor in controlling the global warming concerns. He says: "Efficiency is the low-hanging fruit. We should not put all our effort in going after the high fruit (photovoltaic, wind, hydrogen, etc.) until we have picked all the low-hanging fruits (orientation, insulation, shading etc.)".

It is important to mention that passive energy efficiency strategies are highly affected by metrological factors. As a result, a deep understanding of the climatic factors is required to obtain the maximum outcome. (Sadineni et al. 2011). Although, Chan et al (2011) stated that there are limitations for such strategies and thermal comfort is hard to be achieved in extreme weathers, some studies found that even simple techniques can minimize the thermal discomfort dramatically (Kaklauskasa et al., 2012 and Stevanovic, 2013).

Implementing passive techniques in the early design stages provide lots of advantages such as the ability to deploy the proper orientation and consider the best building's form. However, employing other passive measures to retrofit the existing buildings can still can very effective in reducing the total energy consumption.

2.3 Retrofitting the Existing Buildings

In the ROCKFILLER FOUNDATION report 2012, the meaning of retrofit is explained as upgrading the buildings' operational and physical systems to become more efficient. Retrofit measures could be passive which are applied to the buildings envelope, or could be active which focus on upgrading the mechanical and electrical systems. Also, any changes in the occupants' lifestyle towards energy conservation are considered as behavioral measures (STBA, 2015). McKinsey (2007) explained that with simple measures such as more efficient building insulation and glazing, upgraded HVAC system, and enhanced energy use of lighting system could reduce CO2 emission drastically, in addition to the great benefits both economically and socially.

The main objectives that need to be achieved at all times in order to provide successful projects are: the reduction in energy consumption, the reduction in CO2 emission, the measures' feasibility, and the indoor air quality.

Serious research work is available, some focus on analyzing polices as well as barriers that hold this market from tangible progress (Buys, 2008 and Iwaro &Mwasha, 2010). Others tackled the technical aspects and their impact on environment (Techato et al., 2009). Financing retrofit projects in terms of providing the initial capitals and handling the long pay back periods are among the biggest barriers in the retrofit market (Stieb & Dunkelberg, 2012).

Although a great number of innovations for energy saving measures are available, retrofitting the existing building is still a very challenging task due to the amount of uncertainties as well as the broad diversity of the existing stock. Many key factors need to be considered such as the building's age, location, orientation, function, occupants, materials, and polices. Moreover, the building's systems and their interaction between each other add to the complexity of this task (Ardente et al., 2011and Ma et al., 2012).

Different building sectors demand for different priority measures. A study conducted by Ballarini & Corrado (2012) investigated the buildings' parameters that has the most effect on the cooling load demand. Two case studies were chosen for this work, the first one is a residential building, whilst the other is an office building. The amount of transmitted energy through the building envelope to the building's cooling demand is compared to the amount of energy not transmitted through the envelope. The impact of each parameter that relates to the envelope and the effect of thermal insulation level were investigated. It was found that in office buildings, due to the prevalent effect of the internal heat gain, the whole building envelope's impact on the building's energy performance was weak. On the contrary, retrofitting the building envelope shows significant impact on reducing cooling load demand in residential buildings (Manneh, 2013).

Mannah, (2013) stated that there are many factors that affect choosing a specific measure over the other such as applicability, feasibility , and the measures outcomes. She added that although upgrading HVAC system could be a costly, it offers big savings in energy consumption especially in commercial buildings. On the contrary, enhancing the building envelope's thermal performance through implementing passive measures could be more feasible despite the less energy savings. However, many case studies provided great examples that follow simple low investment conservation measures with good operational and maintenance practices in existing buildings which will provide great amounts of energy saving (EGBC, 2014).

2.4 Passive Retrofit Measures

According to Gong et al. (2012), who investigated the impact of implementing different passive strategies in different climatic zones in China, the passive measures showed great influence in minimizing the amount of total energy consumption to achieve the occupants' thermal comfort. They are considered among the most effective and viable strategies to save energy and money. The measures include shading elements, wall insulation, roof insulation, glazing materials and the windows' ratio to walls. According to Taleb (2014), the total energy consumption could be reduced by 23.6% if passive cooling measures are implemented.

2.4.1. Shading Devices

Solar heat gain is considered among the main factors in heating up spaces; therefore, the increase in the cooling load is inevitable to achieve thermal comfort. Shading elements are considered very important, yet simple strategy that can minimize the solar gain impact on buildings.

Santamouris and Asimakopoulos (1996) state that shading has more priority than ventilation in hot arid areas. It is noted that different orientations demand different designs of external shadings. According to Givoni (1994), regarding the northern hemisphere, over hangs shading elements are considered the most appropriate for the southern elevations. On the other hand, to protect east and west facades from the low sun, a frame that has horizontal overhang and a 45 degree slanted vertical fins is the right solution to produce perfect shading to such orientations.

Moreover, in regards to the impact of shading devices on reducing energy demand, it was found that the best result in saving energy appears in the areas with hot summer region. The savings in energy, due to implementing shading devices, ranges between 8% for the coldest areas in Italy and 20% for the warmest (Bellia et al., 2013).

Another study was conducted in Egypt to evaluate the impact of shading devices on the indoor thermal comfort in residential building in hot arid regions. Three types of shading devices were evaluated through simulation software for all the four orientations during the hot period. It was found that using vertical fins on north, east and west elevations are the most efficient choice with 1.5C° reduction in the air temperature in unconditioned low rise buildings. However, on the southern elevation, in order to reach the same reduction in air temperature, horizontal overhangs combined with the vertical fins are needed (Ali & Ahmed, 2012).

Alzoubi & Alzoubi (2009) explained that excessive daylight penetration of buildings' spaces can provide a negative impact on the energy consumption if it doesn't combine with simple solutions such as external shadings or internal blinds to control the solar gain. He added that the optimal solution is the one that provides the interior spaces with the sufficient daylight with minimal heat gain. For that, shading devices' impact as a strategy was found to be more noticeable and tangible in buildings that are located in hot summer region (Bellia et al. 2013).

Furthermore, Cho et al. (2014) studied the impact of implementing horizontal and vertical shading devices on high-rise residential buildings in reducing cooling demand. The reduction in cooling energy recorded 19.7% and 17.3%, respectively.

Both Hammad & Abu Hijleh (2010) and Firlag et al. (2015), worked on assessing the impact of implementing dynamic shades with different approaches and different climates. Both researches show positive results in maximizing the time of shade, in addition to reducing in energy demand. Also, David et al. (2011) discussed the importance of compromising between providing the efficient daylight and minimizing the solar heat gain. He added that an assessment method is needed to evaluate the shading devices' impact on cooling demand, and the occupants' thermal and visual comfort.

From another perspective, Yao (2014) investigated the impact of movable solar shades on energy indoor thermal and visual comfort improvement. He explained that the impact of such devices in saving energy is equal to reduce the level of wall insulation to half of the required energy standard level while providing the most energy efficient low-e windows. The indoor thermal comfort improved by 21% as well.

In the UAE, a study conducted by Awadh (2013), investigated the impact of external shading devices and the windows' different elements on reducing energy consumption for cooling purposes. It was found that by providing simple passive strategies on either new or existing buildings' windows, the reduction in bill for the cooling load could reach up to 10%.

The buildings could be exposed to different forms of external shadings such as nearby buildings or trees, sometimes the building itself could be self-shaded due to its form and design. Chang (2012) explained that all the previous points need to be considered since over shaded buildings could suffer from inefficient daylight. Although less solar gain will minimize the cooling load, the demand for the artificial lightings in such cases will increase, which will eventually affect the heating and cooling loads causing more energy consumption.

2.4.2 Walls and Roofs' Thermal Insulation

Insulation materials have great impact in reducing the energy demand that is required to keep the indoor environment thermally comfortable. The buildings' walls and roof's thermal behaviors are very important aspects that need to be addressed when considering energy efficiency in buildings. There are many different factors that could affect the outcome result of implementing these passive measures such as: the climatic zones, the type and the thickness of the insulation materials, and their locations (Sadinine et al., 2011 and Gong et al., 2012).

The role of insulation materials extends beyond minimizing the energy load for heating and cooling purposes, it can increase the thermal comfort's time without relying on any mechanical system support. Kumar & Suman (2013) investigated different scenarios for different insulation materials for walls and roofs. They explained that the quality of the thermal insulation has a great effect on the thermal conductivity. As a result, some insulating materials could provide a high U-value with a modest thickness of 50 mm. However, other insulation materials demand higher thickness to meet the required U-value. The paper showed the importance of providing an adequate insulation, especially to the roof since it is responsible for 60% of heat transferee. However, Chidiac et al. (2011) point out that in the case of massive buildings, the gained benefits from upgrading roofs is less than upgrading the external walls. Also, in another work they compare the reduction of energy consumption as a result of implementing single and multiple measures. It is found that the reduction, regarding multiple measures, is not the sum of the effect of each individual measure (Chidiac, 2011)

Paragana et al. (2014) investigated the thermal behavior of the most common insulation material in the Portuguese market taking into consideration their environmental impacts. Life cycle analyses (LCA) were applied considering the most recent European standards. The results presented the comparison of the environmental impact per functional unit of expanded lightweight aggregates and expanded cork agglomerates with the most common used materials in Europe such as: extruded polystyrene, polyurethane and expanded polystyrene. Moreover, Tettay et al. (2014) suggested reducing the fossil fuel usage as an energy source in producing such materials and replacing it with renewable energy sources. He added that a careful choice of materials with renewable based raw materials can reduce primary energy 6-7% and 6-8% of CO2 as well.

The walls' thermal insulation layer location (internal or external) should be considered because of their impact on energy consumption. Kolaitis et al (2013) explains that both external and internal insulation show great impact in reducing energy demand; however, external layer outperforms the internal layer's configuration by 8% on average. On contrary, the payback period was lower in the internal insulation layers due to the less investment required compared with the external insulation layers.

The rate of the heat transfer is represented by the U-value. Taleb & Sharples (2011) explained that reducing this value will lead to saving energy for cooling or heating purposes. They studied different scenarios of implementing thermal insulations for walls and roofs in a residential building in Saudi Arabia. It was found that insulating external walls and roofs could provide a higher energy saving compared to other passive elements such as external shading and efficient glazing.

Another study conducted by Sallee et al. (2014), explained that although the external insulation layer could be more effective in tackling thermal bridges, but for retrofitting existing buildings with special architectural facades, a slim thermal breaker for indoor use yields around 30% reduction of the whole U value while 50% reduction is achieved by external thermal insulation complex system.

The optimal thermal insulation thickness needs to consider the economical aspect. The literature is rich with work that focuses on evaluating the energy savings achieved by applying the thermal insulation materials for the external walls, to their cost (Kaynak, 2012).

However, a prefabricated retrofit module to insulate the facades of existing buildings could be a more feasible solution if it shows the ability to suite the specific needs of the building stock. Such a fabricated module was developed in Portugal. The U-value of the exteriors opaque envelope reduced from 1.2 to 0.2 W/m2.k. Moreover, this application shows 14% reduction in energy consumption for retrofitted single-family building whilst this percentage increased to 16% in case of a multi-family building. Alternative solutions of the used materials were proposed to adjust the module to suite the different countries' needs (Silva et al., 2013).

Nevertheless, Li et al. (2013) highlight some points regarding the differences in effective thermal insulation in cooling-dominant buildings and heating-dominant buildings. Over-insulation needs to be avoided to prevent extra need for space conditioning. Moreover, Stazi et al. (2013) point out the importance of considering the differences between traditional wall construction materials and how they can interact differently with climate changes before deciding on the thermal insulation thickness.

From another angle, to enhance the existing building's energy performance, Marino et al. (2015) studied the influence of surface finishes on mitigating the solar heat gain, thus the energy demand of HVAC system. By applying innovative surface finishes on opaque surfaces (interior & exterior) saves not only energy, but also enhances the indoor thermal comfort of the building. The study explains that applying cool paint on exterior walls and roof will reduce the cooling demand in summer times by 60%, while the winter thermal requirements will be reduced by 12.5% when low infrared emissivity coating is applied on internal surfaces.

In the UAE, with the country's energy conservation approach, thermal insulations have been brought in as energy efficiency measures. However, few papers investigated the impact of thermal insulation in such a region.

Alawadhi et al. (2013) examined the energy performance of five houses that were built in different decades in the UAE. The main objective of their study is investigating the impact of lowering the U-value on total energy consumption. The study follows the pearls rating system of Estidama regulations. This building regulation was established in Abu Dhabi in 2010. The minimum requirements for 1 pearl and 2 pearls are shown in Table 2.1

Table 2. 1: The minimum requirements for 1 & 2 pearls (Al Awadhi et al. 2013)

Building element	1 Pearl	2 Pearls
Wall U-value (W/mC°)	0.32	0.29
Roof U-value (W/mC°)	0.14	0.12
Glazing U-value (W/mC°)	2.2	1.9
Glazing Solar Heat Gain coefficient (SHGC)	0.4	0.3
Minimum Window /Wall area ratio (%)	15%	10%

The study shows that energy savings could reach between 27.5-30.8%. Although 2 pearls requirements could provide more reduction in energy consumption, upgrading to 1 pearl is considered the most economical approach. See Figure 2.1.

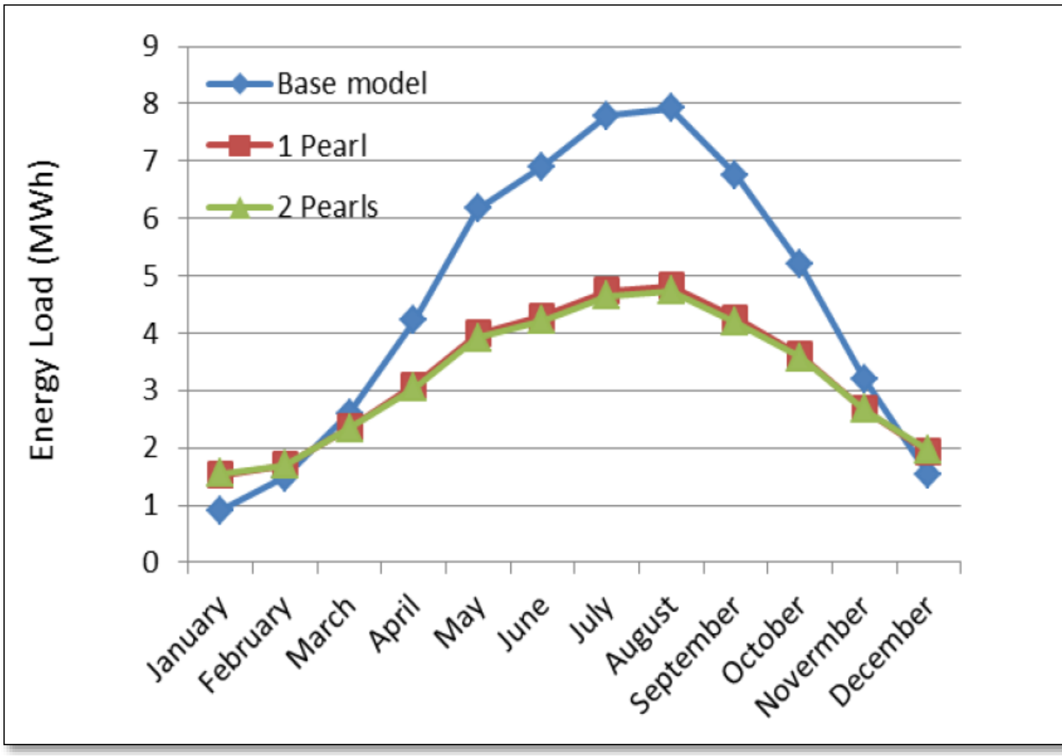


Figure 2.1: Reduction in energy as a result of applying 1 pearl & 2 pearls standards (Alawadhi et al. 2013)

However, an older study conducted by Radhi (2011) explained that the autoclaved aerated concrete (AAC) which is presented as a green material could meet Emirati energy code requirements without any additional thermal insulation materials. He added that by using AAC, the energy savings in the residential sector could reach up to 7%. Moreover the saving in CO2 emission is about 350kg for each square meter of ACC wall through its lifecycle.

From another perspective, the thermal bridging effect on the building's energy performance has always been an important issue to be considered. Friess et. al. (2012) worked on a residential villa in Dubai which was built in 2009; they investigated the impact of implementing thermal insulation to control thermal bridging effect on energy consumption. They found that the amount of energy savings could vary depending on the thermal insulation material used. The best case scenario will increase the energy savings by 30%. Figure 2.2 shows the different scenarios of insulating walls compared to the baseline (as built), while Figure 2.3 shows the Energy unit intensity (EUI).

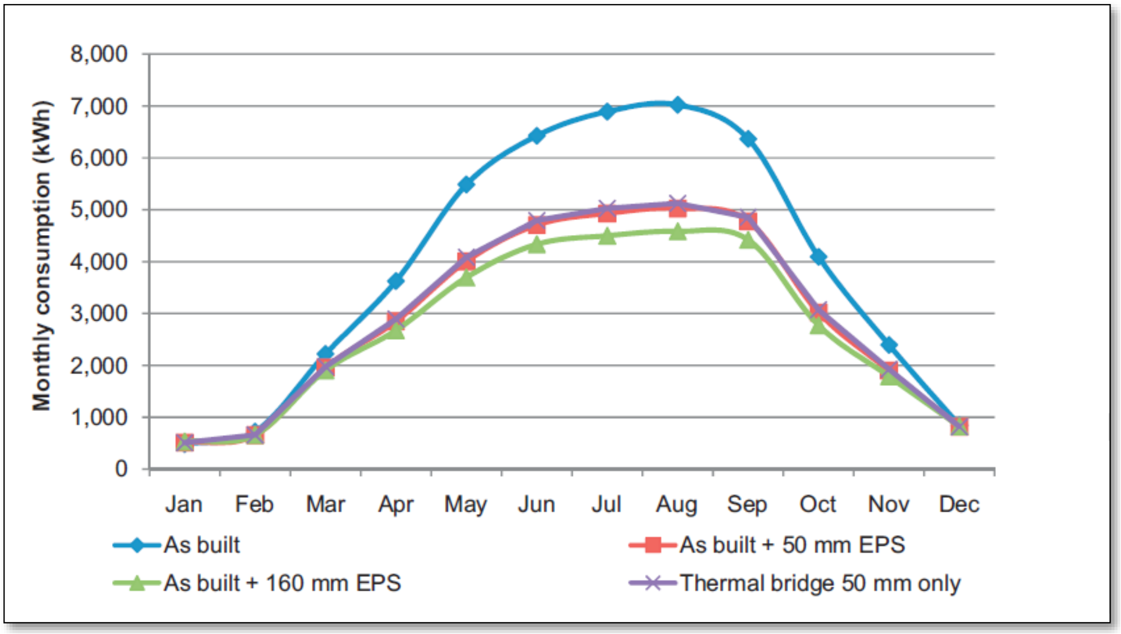


Figure 2.2: Energy consumption with retrofit alternatives (Friess et al. 2012)

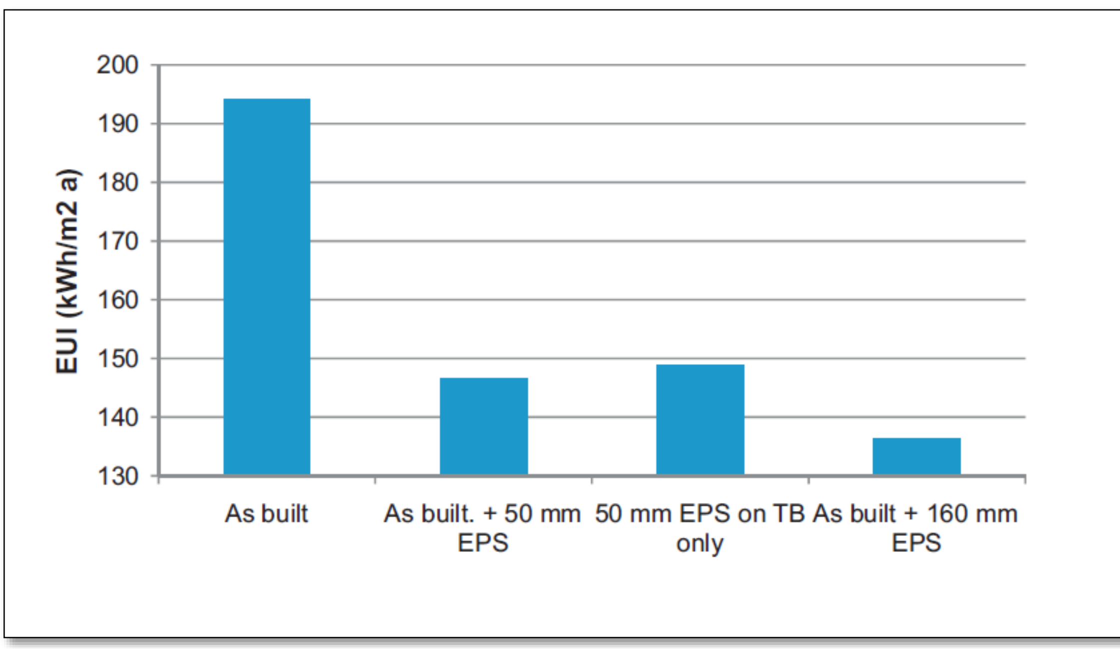


Figure 2.3: EUI for an as built case vs. exterior insulation alternatives (Friess et al. 2012)

Reddy and Kayal (2013) evaluated the performance of the solar insulation materials in the UAE, CSEM-UAE developed building materials' test facility to define the impact of different thermal insulation types in reducing energy consumption. The thermal performance of reflective coating, retrofitting insulation and exterior insulation finishing system (EIFS) are implemented. Through testing surfaces, the results show reduction in heat load by 23.1%, 69% and 76% respectively. The reflective coating proves to have an energy saving impact during the daytime.

Afshari et al., (2014) conducted a Life Cycle Analysis of building retrofits on a case study in the UAE. They developed a Business As Usual (BAU) model based on data extracted from the UPC-ARUP report. Many retrofit measures were tested, among them wall sheathing was used as an insulation measure. This technique consists of adding the insulation material for the external wall between the outermost and innermost layers. Different insulation layer thicknesses was tested (30, 50 and 80 mm), and their effect on reducing energy was evaluated. Although insulating the opaque materials provides a significant reduction in total energy consumption, in this work particularly the impact of this measure on reducing cooling load is low and does not exceed 2.6% with the highest thickness of insulation material. This happens because of the building's high ratio of window-to-wall (70%), in addition to the good level of insulation for BAU building,

2.4.3 Windows' Thermal Performance

According to Lechner (2009), installing high performance glazing provides the needed balance between the required natural daylight and mitigating the effect of undesirable heat gain. As with opaque envelope component, the lower the U-value for the entire window, the less heat flow transfer through this window. Many factors could influence the U-value such as the air gap (if existing), the gas fill between glazing, the coating on the glazing, and the frame construction. A low U-value is the most important window property to obtain in the cold regions. On the contrary, in warmer regions, the Solar Heat Gain Coefficient (SHGC) comes in as the lead priority since solar radiation is more critical than conduction through windows (Autodesk, 2015).

However, according to Lip Ahn et al., (2015), by analyzing the correlation between the windows' proprieties and the rate of energy savings, the window retrofit measure has been standardized. They explained that by changing the windows' U-value in poorly insulated homes, the cooling or heating demands decrease by 7.9-16.7%, regardless of the window size. However, in better insulated houses with large windows, the percentage in energy saving increased to reach 18.4-29.7% by using a lower SHGC. They concluded that for the retrofitted windows, the U-value and the SHGC need to be adjusted considering the thermal performance, in addition to the window-wall ratio to obtain the maximum energy efficiency. They explained that for well insulated houses with large windows, the U-value effect decreases and the effect of SHGC increases.

It is important to mention that multi layered glazing does not provide the same energy efficiency in all climates. Mingotti et al. (2013) investigated the impact of the climate and wall insulation on cooling or heating demand level of a room with different glazing layers (single & double). It is clear that double glazing provides a great impact in mitigating the solar gain and is as important as the opaque material insulation. However, in cold climates with considerably weak solar radiation, double glazing is considered an efficient measure, especially if the walls are poorly insulated and the occupancy is limited. However, in hot climates with high solar radiation, the double glazing accompanied with good insulated walls could reduce the cooling demand, especially if the outer layer is highly reflective.

On the other hand, regarding poor wall insulation in warm and hot climates, the savings in energy is small because of the double glazing. Moreover, Lopez and Molina (2013) explained that using double glazing with chamber water over the regular air will increase the efficiency of this measure to reach up to 18.26% on energy savings in residential buildings.

However, according to the United Kingdom assessment for commercial buildings, it is estimated that energy savings could reach up to 53% due to replacing single glazing windows with double glazed windows. This percentage can increase with more efficient window frames (Tsagarakis et al. 2012).

Using innovative materials for energy efficiency is a choice that is always considered to obtain more reduction in energy consumption. Berardi (2015) analyzed the impact of implementing monolithitic silica aerogel in the double pane glazing cavity. He studied the thermal and lighting characteristics for such glazing. The study took place in an educational building in a cold climate region in the United States. By assessing the building with level 3 energy auditing, a reliable energy model is created and calibrated for further simulation studies by including different climate region analysis. He concluded that aerogel system could be very useful for the glazed system as it is effective in wall insulation.

In hot regions, although the result shows lower energy efficiency in introducing the aerogel material in the windows compared to 1 cm aerogel retrofit for the walls' insulation, from an energy savings aspect, this glazing system has the potential to be an appropriate measure in hot climates because of its lower SHGC that controls solar heat gain. He added that even in cooling periods, this type of glazing is very effective in reducing solar heat gains in buildings that lack shading elements. Also, more daylight penetration is noticed with using aerogel glazing. A 40% aerogel filled window is found to be a good compromise between the daylighting availability and reducing energy consumption.

Heat Insulation Solar Glass (HISG) is another recent invention for an amazing glazing technology which has been developed in Taiwan by professor Chin Huai Young. What differentiates this technology from the traditional glazing ones is the ability to provide thermal and acoustical insulation, self-cleaning, energy savings and on the top of all of that, producing electricity (Cuce et al., 2015).

A study was conducted by Cuce et al. (2014) to investigate the thermal insulation, optical performance and power generation of HISG. Standardized co-heating test methodology is used to analyze the thermal insulation. To assess the optical performance and the power generation, two samples were used, one is an air filled HISG and the other is an argon filled HISG. The result shows that the efficiency is good in providing insulation, as well as producing power to reduce energy consumption from fossil fuel.

According to the thermal, visual and cost issues, double and triple glazing come as a first choice in the cold regions with dominant heating loads. However, the combination of aerogel and vacuum glazing could provide an optimum solution to control the solar radiation and provide high thermal resistance as well (Jelle et al. 2012). Moreover, both vacuum glazing and aerogel glazing are expected to dominate with remarkable U-values around 0.30 W/m2 k (Cuce & Riffat, 2015).

However, Hee et al. (2015) stated that the variety of the available glazing (dynamic & static) helps building designers choose the best alternative, which is still considered a challenging task. Because of the contradictory in some these two glazing types features, optimization process is a necessity, which means sacrifices on some areas to obtain advantages of other areas. It is crucial to obtain a climatic background to determine the suitable glazing. For most orientations, internal vacuum glazing has lower heating requirements than super-windows. On the other hand, for southeast, south and southwest directions, the conventional low e window outperforms the super-windows. Performing techno-economics evaluation to choose the suitable glazing alternative is considered a wise approach when it comes to replacing old existing windows with new ones. Moreover, a recent study explains that windows' orientation impacts their energy performance (Jalili et al. 2015).

However, a study conducted in the United States by NTHP (National Trust for Historic Preservation, 2012) disagreed with the replacement approach. Their main objective is to analyze the energy, cost and carbon savings for seven retrofit measures related to windows and compare them with new high energy performance replacement windows. The selected measures for the existing windows are: weather stripping, exterior storm windows, interior window panels, insulating cellular shades, a combination of insulating cellular shades and exterior storm windows and interior applied surface films. Five U.S. cities that present different climate regions were chosen to address the impact of climate factor as well. The economic feasibility is evaluated for each measure and the report concludes with very important recommendations. From cost effectiveness and energy efficiency perspective, buildings' owners should focus on whole building air sealing, insulation, and HVAC system upgrading as first priorities.

Moreover, retrofit over replacements can achieve energy savings at a tangible lower cost. In addition, the environmental impact due to new window production will be eliminated if existing buildings are saved and retrofitted. It is very important to keep in mind the difference in climatic conditions. Windows' measures that suite hot arid region may not be right for cold regions.

Solar window film is among the measures that are used to mitigate the solar gain through windows. A study conducted by Chan et al. (2008) to investigate the impact of applying solar window films in a hotel room in southern China as a way of mitigating tourism's impact on climate change and global warming. It was found that by applying these films, around 155 kWh per room could be saved annually. Furthermore, the study proved that sticking solar control films to windows is a beneficial measure environmentally and financially.

Moreover, Yin et al. (2012) investigated the amount of energy saving as a result of implementing such a measure in a commercial building's curtain wall glazing system. They found that the type of the film and the way it is applied will affect the performance of the glazing system to a great extent. They found that the shading coefficient can be decreased 22% and 44% if applied inside and outside respectively. However, in the case of double pane low-e curtain wall glazing system, the cooling load is reduced by 27.5% for applying the film outside; whereas, the reduction is 2.2% for inside window films. They conclude that applying solar window films inside is not as effective as outside.

In the Gulf region, specifically in Saudi Arabia, Al-Ghamdi et al (2015) analyzes the effect of glazing factor in an office building. They explain that in hot regions, by reducing the facades' glazing area from 31% to 10% & 20%, a reduction in energy consumption could be achieved.

However, in case of having a high percentage of facades' glazing, a high solar gain heat coefficient (SHGC) glazing can contribute 6% in energy reduction.

Moreover,, in the UAE, a couple of studies simulated the reduction of energy as a result of replacing single glazing with double glazing on some residential villas in Dubai; the reduction in cooling demand reached up to 15% (Alkhateeb & Taleb, 2013). Moreover, through Awdah's (2013) study on a residential villa window's elements in Abu Dhabi to investigate their impact on reducing energy consumption, he found that 6% of the annual total energy consumption of the country can be saved through providing an optimal solution for all residential buildings. It consists of triple glazing with PVC frame windows' system and egg-crate shading device with 60 cm projection. Figure 2.4 compares between the optimal solution and the reference case.

Afshari et al. (2014) examined the impact of two different types of glazing to upgrade Business As Usual (BAU) building with 70% glazed facades. Although the type of window that is used in the BAU is a relatively efficient (U-value: 2.4 & SHGC: 0.36), a noticeable reduction in the annual cooling load by 4.6% is achieved. The best scenario for glazing consists of: double pane, low gain low E, insulated frame and filled with argon. The window U-value=1.47 and the SHGC=0.3.

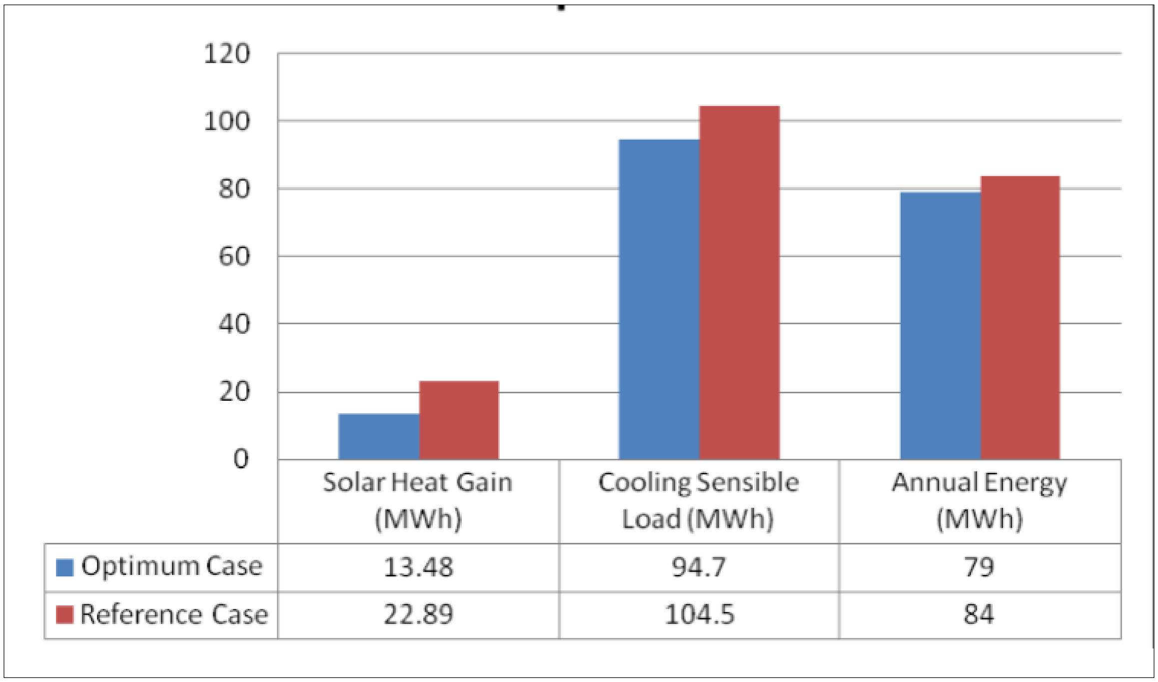


Figure 2.4: Reference and Optimum scenarios for efficient windows (Awdah et al., 2013)

However, some researchers looked at the facades' glazing from a different perspective. They investigated the potentials of implementing curtain wall system as an effective energy efficiency approach through considering Heat Insulation Solar Glass (HISG) as a novel glass curtain wall (Cuce et al. 2015). Others believed that some curtain wall applications could lead existing buildings to zero net energy (ZNE) performance, Patterson et al. (2014) explain that adapting Cassette systems will require some incremental cost; however, this type of system is capable of providing a wide range of offsetting benefits. Applying Life Cycle Cost Assessment (LCCA) is important in such projects. This type of adaptive facade strategy with its high performance can help the progress towards ZNE goal. Moreover, some researches go further steps by evaluating the impact of implementing a solar thermal curtain wall which allows providing a dual task (Li et al. 2015).

2.5 Active Retrofit Measures

Active retrofit measures deal with the building's electrical and mechanical systems which provide lighting, domestic hot water, heating, cooling and ventilation (HVAC). Improvements could include upgrading the HVAC elements such as: chiller's performance sequencing, heat recovery, Programmable thermostats, and volume speed drive on air handling units. . However, and to insure capturing the maximum benefits of implementing different schemes of active measures, upgrading the thermal performance of the building envelope should be applied as an initial step and evaluated at the same time along with the energy efficiency measures of the HVAC systems (Wang et al. 2014).

Moreover and regarding electrical systems, measures vary between providing efficient lighting fixtures, implementing occupancy and lighting sensors. Also the installment of solar domestic hot water (SDHW) is a very important active measure that needs to be considered especially in sunny regions.

The scope of this work will focus on few active measures which are: varying the cooling set point, the air conditioning's coefficient of Performance (COP), and provision of photovoltaic panels (PVs). This section reviews the literature that focus mainly on the selected active strategies to highlight their impact on reducing energy demand.

2.5.1 Varying the cooling set-point

The impact of the occupants' behavioral change, as a retrofit approach, may exceed physical improvement on energy saving. (Teng et al., 2012 and Ben &Steemers, 2014). However, the scope of this work will focus on the behavioral change towards the appropriate thermal comfort temperature.

ASHRAE RP-884 field study database has defined that occupant satisfaction in a narrow temperature range indoor environment is not higher than wide ranges' environment. Providing personal comfort system (PCS), such as ceiling and fan desk, can increase the occupants' convective cooling, PCS systems have proven to be very energy efficient while maintaining the required thermal comfort (Huang et al., 2013).

Hoyt et al., (2014) investigated the impact on saving energy by varying the thermostat cooling and heating set-points in a typical medium office building. Benefits in saving energy are expected by increasing the cooling set point in hot regions and decreasing the heating set-point in cold regions. Itani et al. (2013) explained that increasing the cooling set-point 1°C will reduce the cooling load by 7.3% and the total energy consumption will be decreased by 3.4%. Moreover, Kwong et al. (2014) pointed out that increasing the set-point temperatures in tropical areas 2C° will reduce of 2150 GWh of energy demand per year. They add that this measure is the easiest one with no cost and without compromising thermal comfort. Energy consumption of the air conditioning could be reduced between 6%-17.2% for 1 C° increment (Kwong et al. 2014).

However, in temperate climates, a broader thermostat set-point range will provide greater benefits. It was noticed that by increasing the cooling set-point around 3 °C, an average of 29% saving of cooling energy could be achieved. On the other hand, reducing the heating set-point around 1°C saves terminal heating energy by 34%. Moreover, a saving in HVAC energy consumption by 32%-73% could be achieved (depending on the climate) as a result of a wide thermostat set- point range such as 18.3-27.8°C. Moreover, it should be noted that using efficient types of PCS will make the needed energy for using them extremely minimal. Considering PCS system may allow representing the cooling and heating effect as corrective power (CP) values, expressed in Kelvin. Although there are limited work that discus the comfort at the segment level (such as face or foot), the literature lacks any work related to the sub-segment level of comfort (Zhang et al. 2015).

2.5.2 Coefficient of performance (COP)

Energy for cooling purposes is a very major component of energy demand. The climate and the power demand have a strong relationship, Figure 2.5 shows the climatic components data of Abu Dhabi and the adjusted electrical demand for cooling.

The literature review provides plenty of work that discus the efficiency of the cooling system and the related aspects.

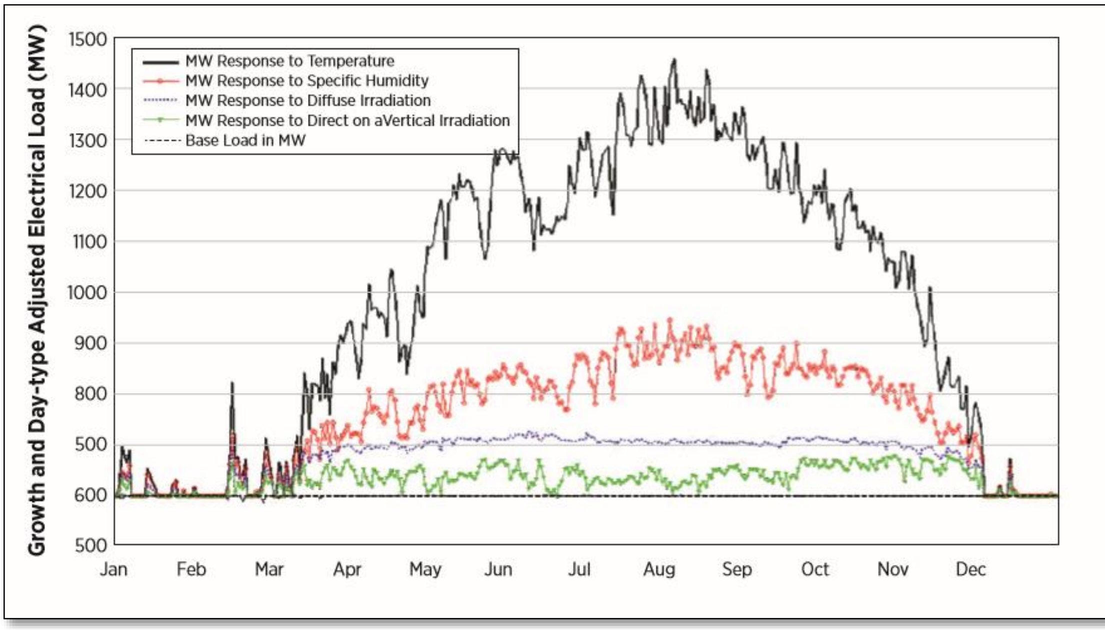


Figure 2.5: Power cooling demand according to climatic components, (Mokhtar et al. 2010)

Different environmental assessment schemes require different standards and criteria, The LEED in general has shown more stringent requirements than China building energy code (CBEC) in many aspects including the air-conditioning system features. It is found that the energy use for air conditioning is the dominant area in the assessment result. By evaluating various building end uses in China and comparing the impact of different environmental schemes, it is noted using more energy efficient measures for air condition systems could provide 2 to 5% reduction of the building total energy consumption (Chen et al. 2015).

The efficiency of air conditioning systems varies with the different operating conditions. However, chillers consume up to 35% of HVAC energy (HVAC HESS, 2013). The cooling efficiency of the chiller is identified as its coefficient of performance (COP) or energy efficiency ratio (EER) which is the refrigeration capacity at full load (in watts/electrical input power (in watts).

The COP is the amount of heat moved divided by power needed to do so. For that the COP represent the efficiency of the system, the higher the COP, the more efficient the system is (Shekarchian et al. 2011). Chiller efficiency has increased in a steady pace, due to compressors and heat exchanger technologies' enhancement, in addition to a better control. The improvement in chillers between 1970n and 2010 is shown in Figure 2.6

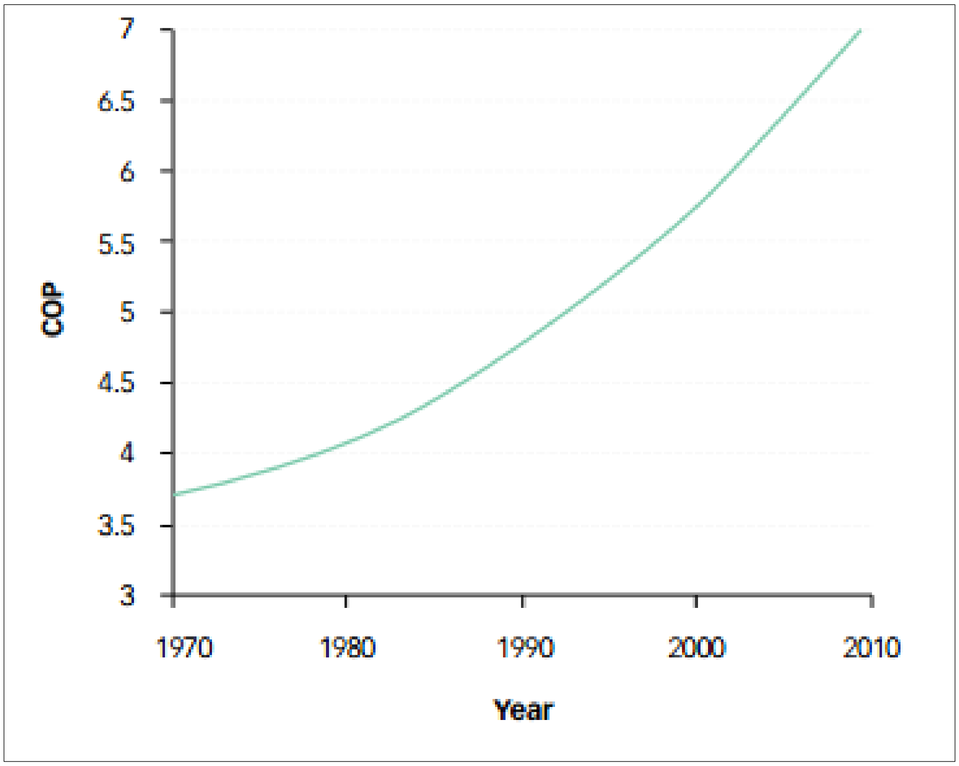


Figure 2.6: Chiller efficiency gain (GHD cited in HVAC HESS, 2013)

According to ASHRAE standards 90.1-2010, the COP needs to comply with 3.8, which shows a remarkable improvement in COP of Air conditioning split unit comparing to 1.7 in back then in 1977. See Figure 2.7

Since the chiller system has many major component, considering all aspect of as a holistic approach, will provide a great benefit towards achieving a low energy input per cooling achieved. Chua et al. (2013) presented a valuable review of recent innovative technologies for cooling systems that have potentials to lower the existing mean of 0.9 kW/R ton cooling towards 0.6 kW/R or even lower. Moreover, and since the chiller is responsible of consuming around half electricity demand, Yu and Chan (2011) focused on studying air cooled chillers and the impact of mist-pre cooling on the condensing temperature control and head pressure control. Moreover, Yu & Chan (2013) studied and evaluated the energy efficiency performance of the chiller system and its components' impact in saving energy. They conclude that Fine-tuning the temperature- related controllable variables could provide an extra 0.36% saving of electricity as a result of increasing the chiller COP from 5.73 to 5.85.

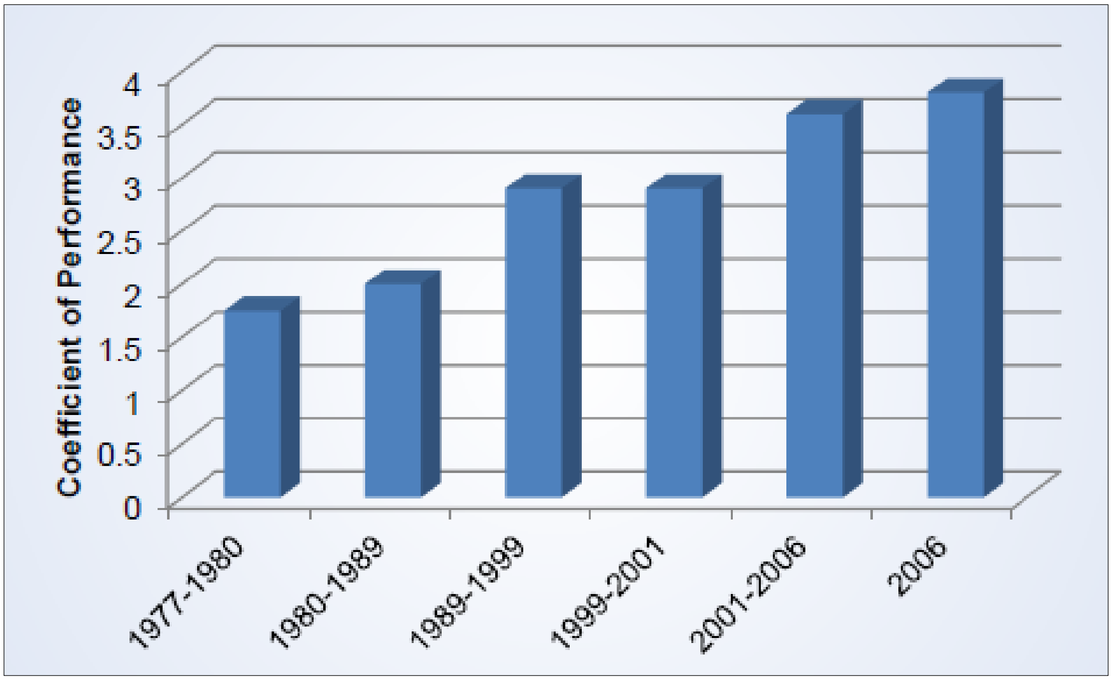


Figure 2.7: AC COP Improvement (ASHRAE 92.1, 2010)

Kung et al., (2014) and Yu et al., (2015) stated that the COP improvement could be affected by operation conditions. Yu et al. (2015) added that the Technical efficiency (TE) for the COP of an air-cooled chiller can provide a source of benchmarking chiller performance with different inputs, and the potential of broaden improvement as a result of the weather responsive control.

Regarding renewable cooling, two main pathways can be approached: provide renewable electricity into vapour compressor chiller, and renewable heat into absorption chillers. In both cases the COP can be affected significantly by the type and the technical level of advancement of the chillers (Mokhtar et al. 2010). Currently, and at a pilot level, two renewable cooling schemes with absorption chillers are in use. Due to the increasing demand of renewable electricity at the utility scale in the coming future, the normal operation of the vapour compression chillers will be partly depending on renewable electricity (Masdar Institute/IRENA, 2015).

2.6 Combined Passive and Active Retrofit Measures

Many research papers aim to tackle the whole deep retrofit approach and to investigate the interrelation between the different passive and active measures. Ma et al. (2012) provide an overview of previous studies that investigate and evaluate different types of retrofit measures and their energy performance as well as their economic feasibility. Figure 2.8 shows the classification of these different measures.

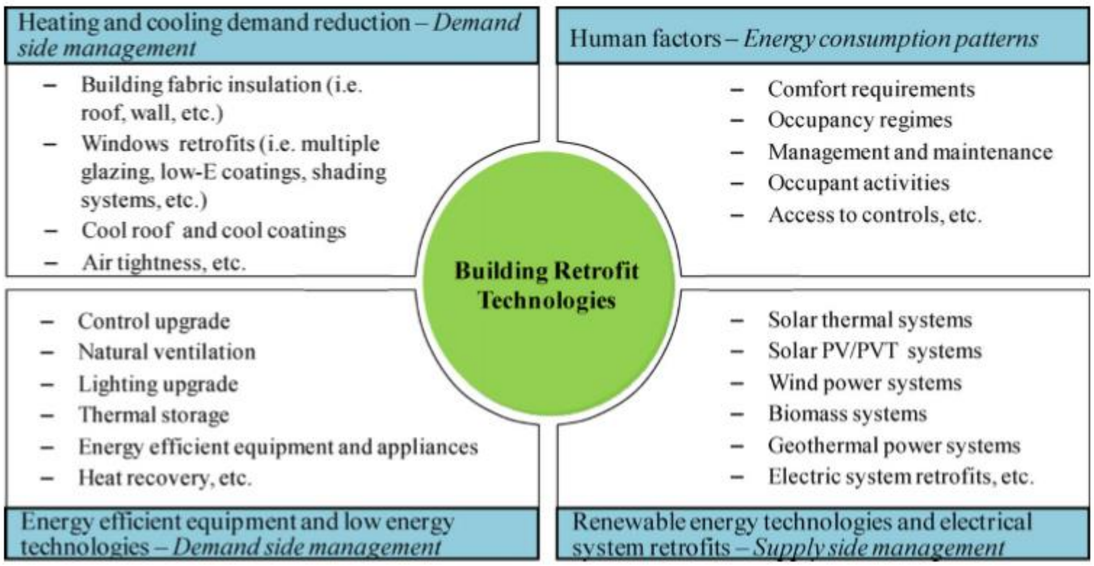


Figure 2.8: Main categories of building retrofit technologies (Ma et al. 2012)

They state that although the literature is rich with other researches' works that focus on buildings' retrofit; in reality the progress rate in upgrading such buildings is very slow. Moreover, the modest level of confidence regarding these measure need to be increased by providing more actual energy retrofit savings cases rather focus only on numerical simulation. On the contrary, they explain the importance of the energy simulation in case of whole building retrofit to identify the most effective solutions.

Silva et al. (2013) explained the importance of evaluating and assessing the existing building's system in addition to the occupants' survey prior any decision regarding any retrofit action. A Portuguese commercial building that is located in the middle of a big city is chosen as a case study. They followed the "in situ" approach to assess the operating conditions and the Indoor Environment Quality (IEQ). Based on the assessment, retrofit options are defined to tackle the building's deficiencies which combine passive measures that deal with the envelope quality as well as active measures that handle the lighting system, appliances and the HVAC system. Two retrofit options were studied and both showed great reduction in energy consumption. They concluded that upgrading the envelope, replacing the light bulbs, the appliances and the HVAC with more efficient ones would reduce up to 47% in the final energy consumption and 37% reduction of the energy bill.

Aste and Del Pero (2013) proposed a new methodological approach which is technical and empirical at the same time to help pave an effective retrofit path for existing buildings, this method based on studying a successful retrofitted office building namely the ERGO building in Italy. The study analyzed the envelope retrofit which can be summarized in a general increase in the insulation level for all the opaque materials, in addition to an enhancement of the wall's thermal inertia. The walls U-value were reduced by 38% down to value of 0.26 W/m2 k. The roof was also insulated to reach the U-value 0.32 W/m2 k. Moreover, better thermal performance glazing (clear double glazed filled with argon) was implemented. All the proposed insulation materials have been choosing taking into consideration the building constraints and the cost-benefit aspects.

Regarding the day-lighting system application and to exploit the maximum benefit of the daylight while avoiding glare and overheating in summer, a dynamic solar shading systems were implemented outside all windows. Three dynamic double skin facades on the south vertical surface have played an important role of ventilating that facade as well as the overhead PVs during summer times.

The roof of the double skin facades has equipped with a 3-kW_p BIPV plant allowing producing around 3,250 kWh/year. As a result for all the previous measures the energy consumption for artificial lighting and the HVAC system reduced remarkably by 40%. It is worth mention that this case study had the honor of being a finalist in the international competition Zerofootprint Re-skinning Award in 2011.

A recent study conducted by Nagy et al. (2014) focused on providing a simple model for retrofitting the existing building for zero emission by balancing the buildings' envelope and the heating system parameters. The main objective was to provide a holistic view by combining different parameters that include the passive side (insulation) and the supply side.

The provided method aimed to define the needed retrofit measures to minimize the heating system's supply temperature. Moreover, this method was applied on a case-study building, and to obtain the current U-value of the building's envelop, a low cost flexible sensor network was developed. It was found that the building is candidate for a low temperature heating system. The outcome result was confirmed by the result of the energy simulation of the whole building. The authors believe that this proposed method and if it is applied on the whole building stock, has a great potential to reduce the impact of the existing built environment on the green gas emission.

The successful retrofit should consider the humans' behaviour as important as the passive and the active retrofits measures. And although the occupants' behaviour role has been highlighted in many previous researches, but quantifying specific benefits based on the occupants' actions are still not exploited. For that, Pisello and Asdrubali (2014) developed a model that focuses on the human-based retrofit. A 3-year numerical - experimental campaign was held in a village in central Italy, where it is known with its green buildings that have the most innovative and efficient green technologies, where further passive and active retrofits approach is not consider a cost- effective one. In such a case, the authors demonstrate that through a theoretical- experimental modelling, and with zero- cost simple action, a considerable further energy saving could be achieved easily.   Energy waste reduction through ordinary actions is described within the proposed model. They concluded that the combination of these human-based energy retrofit actions could produce annual energy saving of 239KWh/person which is equivalent to 84€/person.

Reducing the energy demand in the existing building by implementing different categories of measures (passive, active & behavioural) is inevitable. However, is it possible to upgrade existing buildings to reach a nearly zero energy buildings? Morelli et al. (2012) tried to answer this question by investigating the possibility of retrofitting a Danish old building to a nearly zero energy building. An apartment was chosen to implement the intended measures, three types of measures were provided, and the first one is insulating the building internally with two different types of insulation. The second measures focus on upgrading the different elements of the windows. The third measured focused on ventilating the building with decentralized mechanical system with heat recovery. Theoretically, these measures were able to reduce the energy use by 68%. The theoretical energy use after retrofitting 51.5KWh/m2 meets the needs for new constructed building in that region. The practical approach of the retrofit highlighted some points need to be considered such as: controlling the noise of the ventilation system components as well as the insulation materials need to be provided with the exact needed sizes. The paper concluded with the importance of a whole retrofit approach before any installation of renewable energy system.

However, with the many retrofit market constraints specifically the funding aspect, applying the deep retrofit may not be the appropriate approach. For that, comparing between the different measures to prioritize their impacts is considered a necessity. To quantify the energy measure savings EMSs a study sponsored by the United State Government which took place in Earnest Orlando Lawrence Berkeley National Laboratory aimed to provide a tool that is built based on a building performance database.

The proposed tool allows users to assess the different EMCs individually or as a package. The tool covers building envelope, lighting system, HVAC system, plug loads, domestic hot water, and renewable energy. A commercial building in shanghai was chosen as a prototype building. It is noted that in the retail prototype building, the air-side economizer contributes the largest savings in energy, with its ability to provide free cooling hours most of the year. Retrofitting the lighting system as well as the internal plug loads offer great potential in saving energy. Regarding the HVAC system and although improving pump performance and installing variable speed control for fans are considered the most cost effective improvement, in this building with a chiller reference COP value equals 5.0, upgrading the chiller performance was less impact compared to some other elements. Figure 2.9 shows the impact of each measure on electricity intensity reduction.

Also, since the chosen building is internal load rather than shell dominant and meets the terms of the Chinese commercial building energy efficiency code, the energy saving as a result of upgrading the building envelope component is limited. However, the potential of retrofitting the building envelope is still noteworthy if the target building is poorly insulated (Liu& Guo, 2013 and Levine et al. 2014).

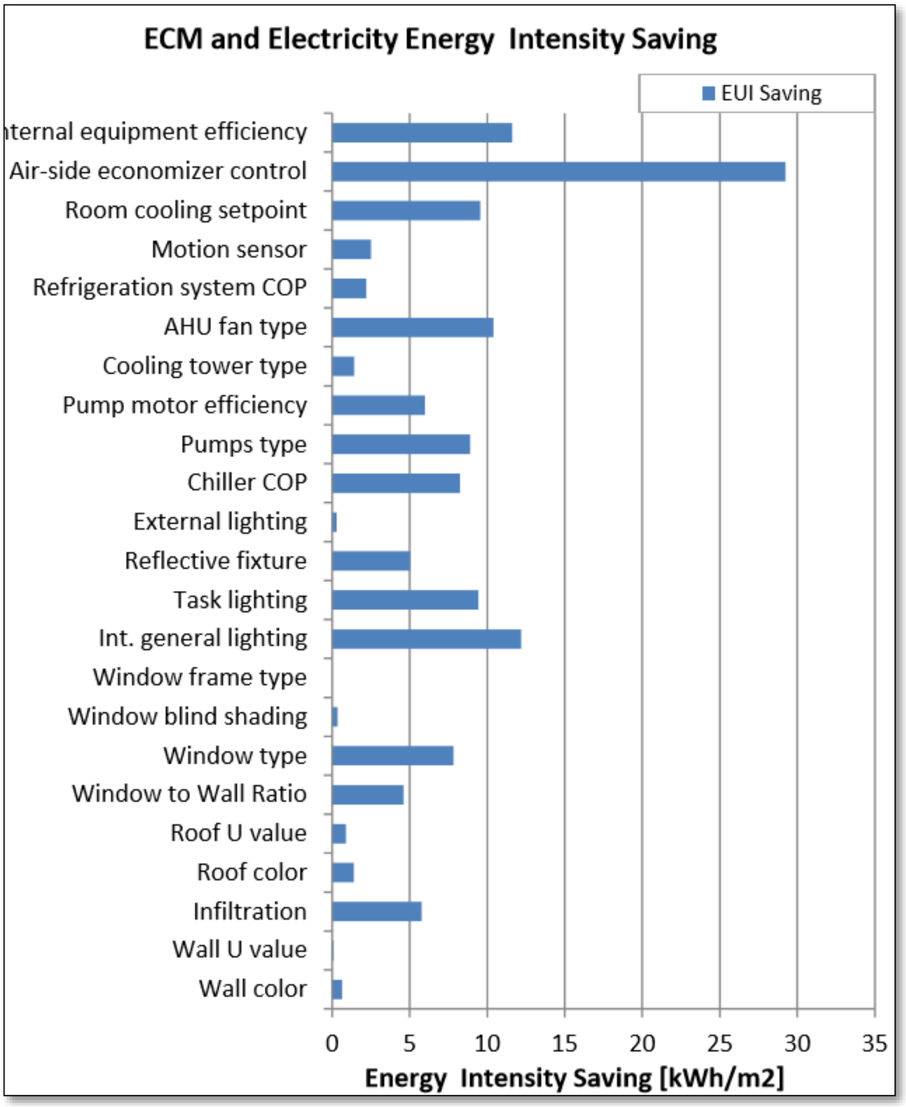


Figure 2.9: energy Intensity saving (KWh/m2), (Levine et al. 2014)

However, not all measures require high initial cost to implement, some low cost energy conservation measures could provide a descent saving in electrical energy consumption. This is was proved by Itani et al. (2013) who evaluated some low investment energy conservation measures ECMs that do not require any changes to the building envelope. It is noticed that annual electrical energy can be reduced by 7.2% as a result of implementing the air economizer. Also a 2.6% reduction can be achieved through installing occupancy sensors with scheduled lighting system. Night purging to flush heat out could give a 0.9% reduction in energy demand. Moreover, using condensed air which is cooled by condensate drain adds an additional annual saving of 2.1%. They also added that a zero cost measure such as increasing the cooling set-point could save up to 3.4% of the total energy consumption.

Lots of constraints could face any retrofit projects, funding such projects comes in the first rank based on a survey was conducted in Europe (BPIE, 2011). Evaluating the feasibility of the proposed measures play a very important role in choosing some measures over other measures. It is advisable to learn from some successful retrofitted case studies that could provide some important lessons and tips before taking any major decision. For example, the Empire State Building retrofit present unique strategies those go beyond the measures' impact. By considering the highlighted points, the chance to obtain a successful retrofit building will increase definitely (Fluhrer et al., 2010).

Eicker et al. (2015) investigated the impact of the geographic location on the technical and economical performance of some combined passive and active energy efficiency measures. It is noticed that building upgrade become energy efficient and economically viable with less geographical latitude whilst integrating renewable is still significant. On the contrary, in more northern locations, provide insulation measures provide more savings than renewable production.

From an environmental point view, the optimal retrofit scenario is the one that consider the deep retrofit approach with implementing a renewable resource to offset the needed energy to reach to a nearly zero or zero energy building (BPIE, 2011). However, from an economic perspective, a case-study in Portugal showed the retrofitting the low efficiency existing buildings to a medium level with a renewable resource is the most effective economically (Leal et al. 2015).

2.7 Renewable Energy

The energy is the main vessel of the economic development and industrialization processes. As a result, and by also considering the growth rate of the world's population as well as the improved living standards, the demand for energy has increased at a fast rate as well. Actually, the demand for electricity has exceeded expectation and expected to rise more (World Bank, 2014 and IEA, 2014 and IRENA, 2014a). The demand for electricity could be contained closer to 40% by 2030 instead of the expected 60% by through implementing energy efficiency measures (IEA, 2012).

The negative impact of relying on fossil fuel is tremendous on climate change, health and environment. Many studies tackled the health issue impact of global energy use from different aspects (Machol & Rizk, 2013, and Treyer et al., 2014, and Bridges et al., 2015).

On the other hand and regarding the environmental impact Figure 2.10 can summarize and compare the amount of CO2 with each kWh of generating electricity with different source of energy. Although it is very challenging to adapt more sustainable energy resources (Harvey, 2010), it appears that Renewal energy represents the solution for reducing the GHG emissions globally.

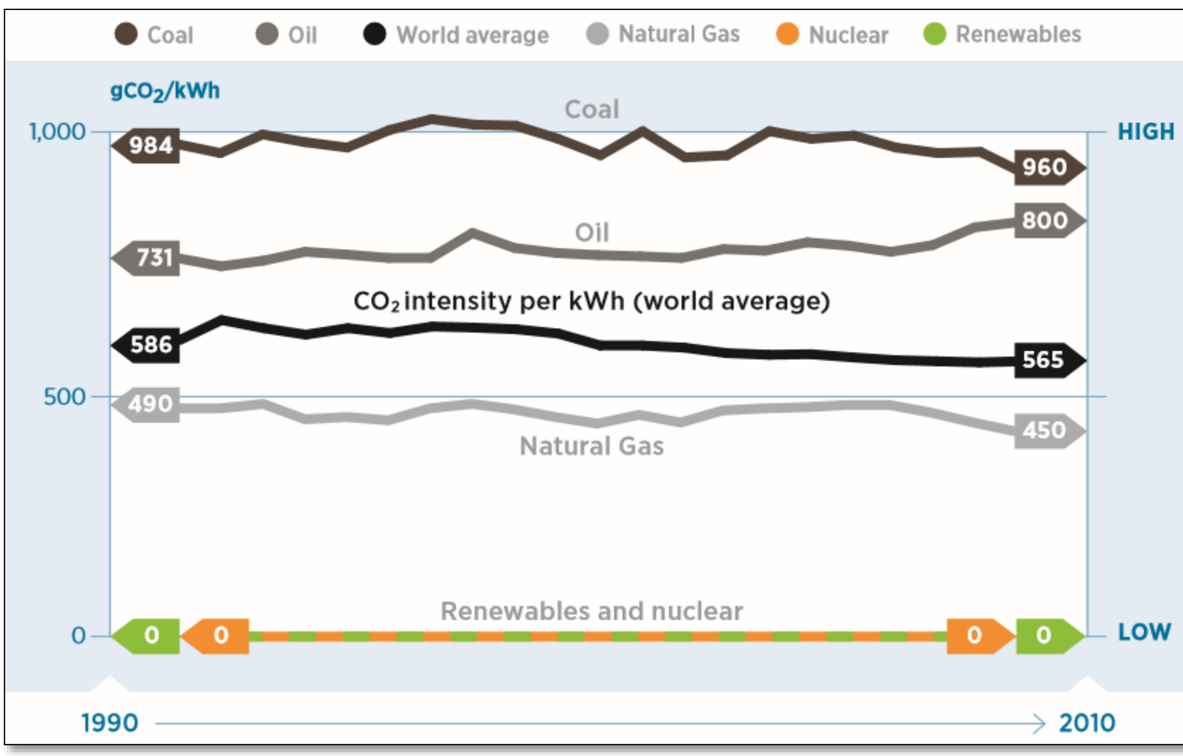


Figure 2.10: Direct electricity emission intensity (1990-210)
(IEA 2010 Cited in IRENA 2014)

Renewable energy (RE) has attracted great attention globally due to its ability to overcome significant negative aspects of using fossil fuels (IPCC, 2013). According to Rethinking

Energy report, doubling the renewable' share by 2030 could reach half of the needed emission reduction. And with the addition to the energy efficiency could prevent catastrophic climate change (IRENA, 2015).

In the Gulf region, incorporating RE solutions starts taking more serious attention taking into consideration the Gulf countries' economic plans in addition to the increment of needed energy to meet the people lifestyle. According to IEA Key World Energy Statics (2010), it is estimated that an average Gulf Cooperation Council (GCC)'s household energy supply is around double the amount in Europe.

The momentum for RE started in 2008-2009, when Abu Dhabi and Dubai set their targets of RE power generation to be achieved by 2020 and 2030 respectively. Setting such targets was a first in the Gulf region; however, the UAE seems to be short of the urgent financial case that available in some neighboring GCC countries, such as Saudi Arabia (Masdar Institute/IRENA, 2015). Figure 2.11 shows the UAE statistics regarding RE and how it has shown a remarkable leap in 2013.

Al Naser & Al Naser (2011) reviewed the major RE projects in each of the GCC countries, these projects allow the researchers and investors to define precisely the cost of KWh from RE (thermal, PVs, and wind). It is noticed at the time how much is challenging for investors and governments and citizen to choose RE resources as an alternative for fossil fuel.

Bahrain				1	1	1	1	1	1	1
Iran (Islamic Republic of)	2 018	6 631	7 497	7 763	7 812	8 598	8 862	9 924	10 447	10 984
Iraq	910	2 225	2 273	2 513	2 513	2 513	2 513	2 513	2 513	2 513
Israel	7	12	13	14	38	93	213	260	444	694
Jordan	11	18	18	18	18	18	19	18	20	25
Kuwait							0	0	0	0
Lebanon	221	221	221	221	221	221	221	222	224	224
Qatar							25	28	28	28
Saudi Arabia								19	25	25
Syrian Arab Republic	940	1 570	1 570	1 570	1 570	1 570	1 572	1 572	1 572	1 572
United Arab Emirates					10	11	20	20	135	135
North America	194 170	212 980	221 583	231 702	244 909	253 026	264 067	281 667	292 185	309 281
Canada	69 048	75 971	76 929	78 462	79 782	81 010	83 014	83 380	85 421	89 518
Mexico	10 849	12 340	13 134	13 028	13 590	13 808	13 890	14 572	14 959	16 295
St. Pierre and Miquelon				1	1	1	1	1	1	1
United States of America	114 273	124 669	131 520	140 211	151 536	158 207	167 162	183 714	191 804	203 467
Oceania	15 930	16 869	17 579	17 894	18 449	19 129	20 508	22 032	22 915	24 500

Figure 2.11: Renewable Energy Capacity statistics, (IRENA, 2015a)

Despite the fact that the Gulf region have tremendous solar power that are equivalent to 1.5 million barrels of crude oil, the GCC's governments' subsidies for fossil fuel make any transition to other RE resources is unworthy. However, recently, all of the GCC countries governments have agreed on the importance of being sustainable through their economic and energy sources. As a result, different strategies for conserving energy have been emerged; moreover, energy diversification has been approached as a strategy that minimizes the reliance on current trend of fossil fuel. As a result many research and development R&D projects have been conducted in the gulf area (Bachellerie, 2013). Figure 2.12 shows that the majority of such research work has focused on photovoltaic.

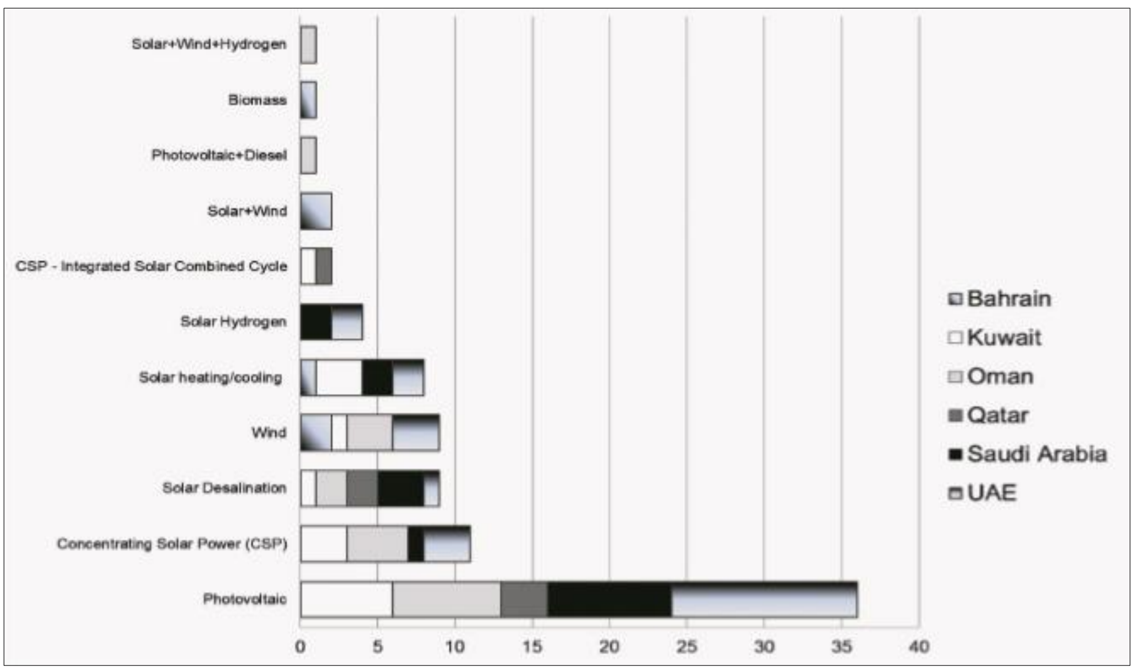


Figure 2.12: Main renewable energy R&D projects
in the GCC (Bachellerie, 2013)

However, with all the awareness of the RE's positive impact on many different life aspects, the slow pace towards a RE mass deployment in the GCC is what the region has experienced so far. National and regional policies can provide a significant role in accelerating the development and the implementation which will be helpful for the GCC in expanding their roadmap for RE in the energy portfolio rather than identifying priorities and pathways for the market. A study conducted by Abdmouleh et al. (2015), summarize the current status for the GCC countries. They explain that each country should develop their own policies by considering the individual specification for each market.

Also researches on RE resources have increased to address their potential and the related challenges. (Al Amir & Abu Hijleh, (2013), Rohani & Nour, (2014), Jamil et al., (2016) and Juaidi et al. 2016).

A recent research work presented by Sgouridis et al., (2016), where they conducted a remapping of the available technology options of the RE that in the UAE. The study includes a cost analysis based on projected demand and considering the actual costs of fossil fuel (unsubsidized). By considering cumulative options, and by 2030, it is possible that RE contribute with 10% of the final energy consumption of the UAE.

In this study a general literature review will be conducted over the major common RE in the UAE, however, the main deep focus will be aiming the solar energy and specifically, the photovoltaic systems (PVs).

2.7.1 Wind energy

Although The UAE's wind resource is modest compared to solar resource, yet they show a considerable potential, particularly in the off-shore application as well as in the Northern emirates. In the UAE, there are potential to produce on average 500 MW using personal wind turbine with efficient and economical blades with total length of 4.5 m and 3 m for the disk diameter (Zafar& Gadalla, 2013).

Janajreh et al. (2013) worked on assessing the potential of wind energy in Masdar city; they found that with the same turbine's height at 50m, the production ranges between 3307, 08MWh for the large size turbine and 28.73 for the small turbine. Considering the efficiency and the feasibility, small size is favored over the large size in the selected area.

Moreover, and based on an overview research of wind energy in the Middle East, UAE is labeled among the countries that shows low feasibility of wind energy, and small size applications is recommended (Shawon et al. 2013 and Moki et al. 2013).

However, Quarda et al., (2015), and in order to evaluate the wind energy potential accurately, they advice to apply the appropriate probability density function (pdfs) to reduce the error in estimating the wind power.

2.7.2 Waste to energy

Turning waste into energy is considered a big business; the high generation of non recyclable waste per capita in the UAE could provide a dependable yet limited energy source. This kind of energy that could be used for base load power is controlled by the expected volume of the available waste, which may provide an approximate amount of 900 MW (Atkinson, 2013).

The new plan of TAQA in Abu Dhabi that could provide 100MW waste to energy plant is expected to handle one million tons/ year of solid waste. Ed Atkinson, Head of Waste-To Energy at TAQA says: "Overall, the project size is around 200 meters by 500 meters. That, of course, includes the roads to access the plant and the bunkers to store the waste before it's burnt. But when this facility comes online it will operate 24/7 and 365 days a year, so you could argue that it is more efficient than solar or wind power." (TAQAWORLD magazine, 2013).

2.7.3 Geothermal energy

The first geothermal project in the GCC region is in Masdar City with drilling two wells (Stanton, 2009). Despite of the UAE's location away of a high geothermal gradient, there are some areas with potential of providing an adequate contribution of hot water for thermal application. This kind energy could be used for based-load cooling using absorption chillers, as well as for thermal desalination for a lesser extent, however, it is unlikely to obtain any substantial contribution by 2030. (Masdar Institute/IRENA, 2015)

2.7.4 Solar photovoltaic (PV)

Steve Griffith, an executive director in Masdar Institute of Science and Technology (Griffith, 2013) stated that clean energy including natural gas, nuclear, and renewable are the key factors for sustainable supply, however, the opportunities of the solar energy are beyond expectations.

Over the Last decade, generating electricity from solar resource either directly using PVs or indirectly using (CSP) has grabbed a great attention and interest all around the world. In china and because of the big concern of climate change, many research studies have been developed and put for practice, which result in forming a very promising solar energy market. As a result, China has got its spot as the biggest PV cells and solar water heaters (SWHs)'s producer. Fang & Li (2013) stated that China was able to produce 2/3 of the world PV amount in 2011. With this fast growing, it is expected to integrate SWHs with the building structure. The United States has witnessed a steady growth in the last decades; however it turns to a rapid growth in recent years. Figure 2.13 shows the almost double jump in using solar systems between 2009 and 2010 (Hernandez et al. 2014).

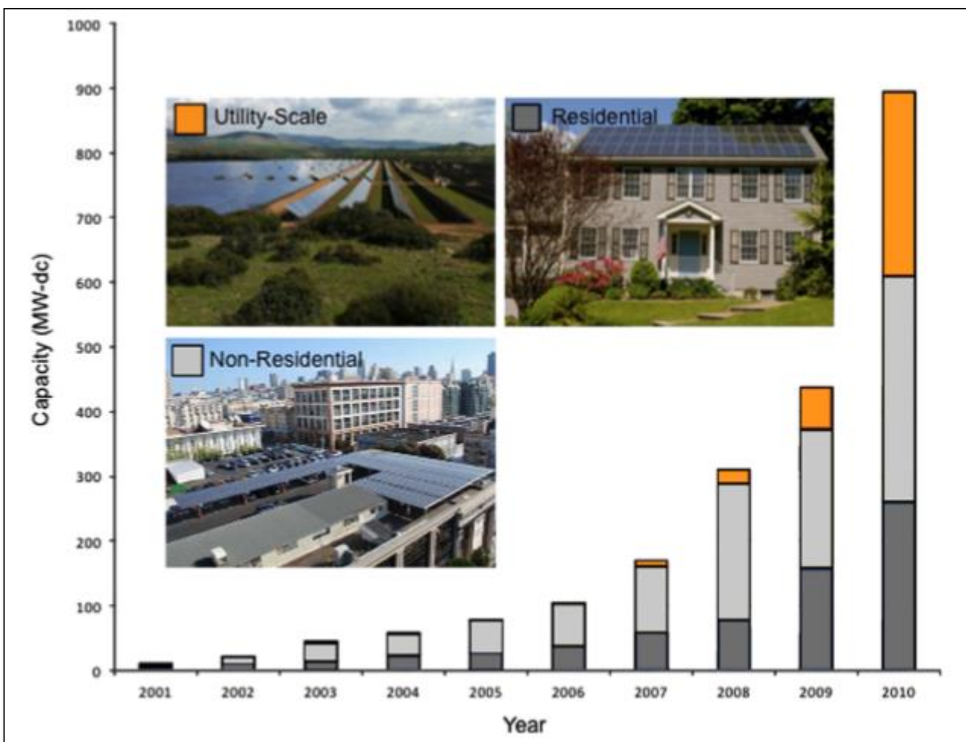


Figure 2.13: Annual installed grid- connected (PVs) capacity for different shames. (Photo credits: RR Hernandez, Jeff Qvale, National Green Power)

Tsalikis & Martinopoulos (2015) investigated the solar potential of utilizing solar thermal and PV in typical residential buildings. They explained that the PVs are capable of covering the annual electricity demand with less than 7 years as payback period. However, this the payback period will be decreased to a range between 5.5-6.5 years in the case of solar combi systems

When it comes to solar thermal vs. PV, it is important to mention that both offer advantages, however, mixing use of these two systems will allow to obtain the maximum benefits (Griffith, 2013). PV systems (and in case of surplus generation), have a great advantage of exporting electricity to the grid (Eicker et al. 2015).

Grid Connected PVs within the urban fabric allows residents of buildings to produce and use their own solar electricity as well as the access to the main utility grid. Moreover, any excess solar energy could be used in other places through the distribution systems. However, to have such an efficient, sustainable and bankable projects, models that include policies and frameworks that consider the local market are required (IFC, 2014).

This emerging technology can be classified into two types: Building Integrated PV systems (BIPV) and Building attached PV systems. Both categories provide plenty of advantages (Breyer et al., 2015) & (IEA/PSPV, 2009) in addition to some disadvantages, limitations and challenges, (SolarEdge, 2012 and Miyatake et al. 2011, and Orioli & Gangi, 2013, and Ioannou et al. 2014).

Cellura et al. (2012) proposed a methodology that allows overcoming some of the challenges that corresponding with implementing PV systems in a dense urban area, whilst Mirhashani et al. (2015) reviewed all the efforts to enhance the quality of PV solar power.

According to the European Photovoltaic Association estimation, roof top PV system could meet 40% of the EU's demand of electricity by 2020 (Prayas, 2012). Moreover, the latest report by Fraunhofer, ISE (2016116.96) stated that 7.5% of net electricity demand in Germany is provided by PV solar energy.

All PV system share essential elements despite their size or category as followed:

- PV module, An array consists of multiple modules (DC electricity)
- Inverter (s) (DC electricity is converted to AC electricity)

- Electrical panel and meter, in addition to some optional elements such as: battery bank and monitoring system. Figure 2.14.

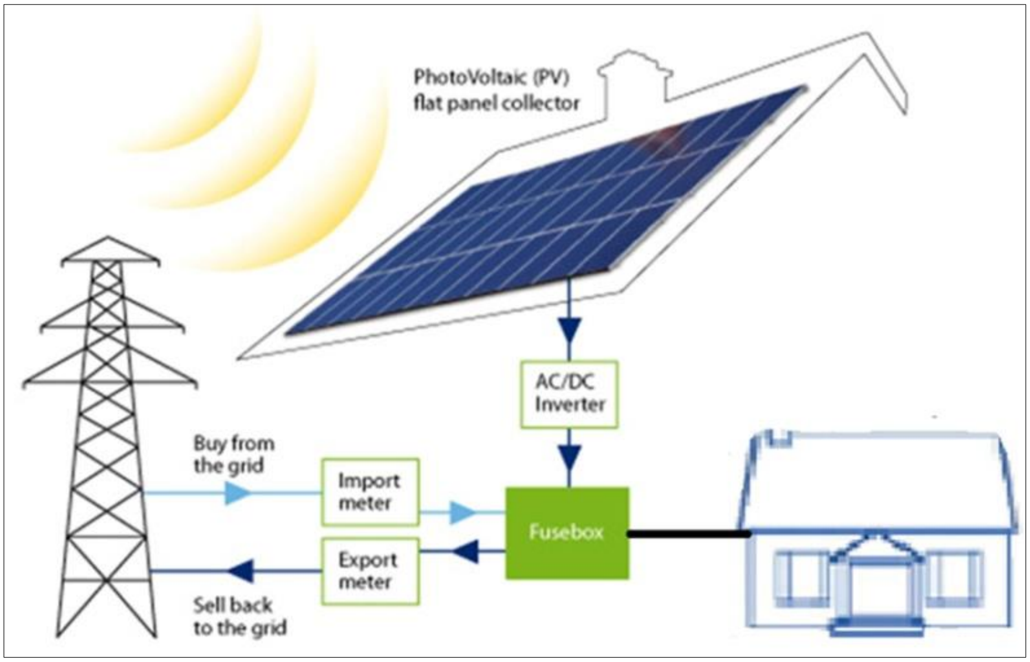


Figure 2.14: Grid connected PV concept (Tanweer, 2016)

The PV modules can be attached to the buildings in different ways such as tilted on a flat roof which requires a supportive structure, or could be installed on facades. On the other hand BIPV could be part of the building construction materials such as skylights in atria (Harvey, 2010)

The literature is rich with researches about the rooftop PV grid connected systems with its different applications. For example, a study by Mandalaki et al. (2012), focused on finding the balance between the needed energy for cooling load as well as lighting system for a designated space with the energy produced by the PV system that is integrated within the shading devices for the same space. This study helped defining the geometrical parameters for optimal fixed shading devices that are integrated with PV panels, also the benefits of the southern shading devices could be doubled when achieving the balance between providing the needed daylight and reduce the cooling demand at the same time.

Although, some studies on residential buildings have shown that regardless the solar energy system (PV or solar thermal), 75% of the primary energy demand could be provided (Tsalikis & Martinopoulos, 2015). However, some commercial buildings seem to be more challenging in providing the needed energy due to the premises large size as well as the high internal load. However, the different PV generations with their various efficiencies and cost, provide more flexibility in deciding upon the appropriate type based on the project's parameters. It is stated that between 2008-2009, the demand on PV modules have increased by 30%. Mono-crystalline cells were on the lead with 46%, followed by Multi-crystalline with 32%, while thin films comprised 22% (Gaur & Tiwari, 2013).

The local region is rich with solar resources, which direct the UAE's government effort to be focused more on solar energy. This could be noticed through the 100 MW Shams 1 CSP plant, which is considered the largest renewable project in the Middle East, in addition to the provision of the first phase of Mohammad Bin Rashid Solar Park in Dubai with 13MW. This phase is the beginning towards eventually 1000MW of solar power. In general, solar PV and due to cost and the availability of resources is considered the most attractive solar technology in the UAE. However, CSP remains attractive to provide base load power because of its thermal energy storage potential (Masdar Institute/IRENA, 2015). However, Moki et al. (2013) who reviewed different methods for assessing solar radiation in the UAE pointed out the importance of considering the sun-path in designing SCP system.

Moreover, and despite the PV's sensitivity to temperature increase, they are considered the most suitable for the local environment of the UAE. However, the big challenge in deploying large-scale solar in such an area is the dust particles and humidity. Although dust deposition does not affect the open circuit voltage of PVs systems, the short circuit current is affected, and as a result of the current output's drop, the power output drops as well. Eventually this will affect the PVS performance efficiency (Rao et al. 2014).

Self-cleaning coating and wet cleaning are among the methods that are offered to tackle the effect of the dust (Moki et al. 2013).

A recent study pointed out the importance of having a general model which can simulate the impact of different types of dust on the PV performance including: voltage, current, efficiency and power (Darwish et al. 2015).

Based on the latest statics by IRENA, Figure 2.15 shows the significant jump in solar power capacity in 2013, which indicates that solar power in the UAE, has acquired the most attention and efforts over other RE sources (IRENA, 2015).

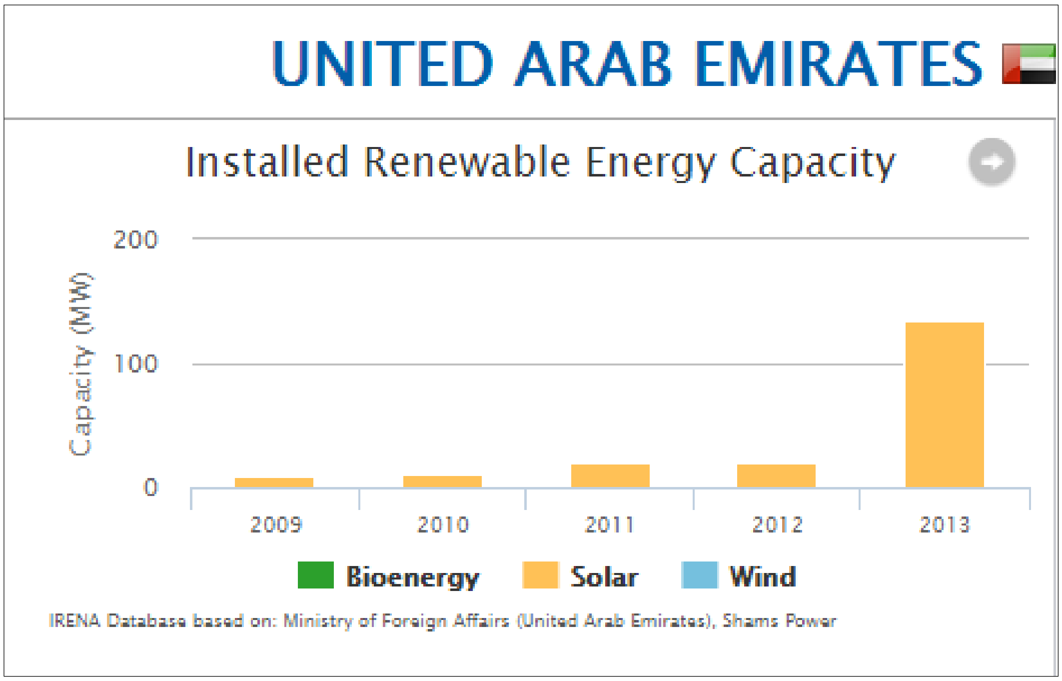


Figure 2.15: Solar power capacity in the UAE (IRENA, 2015)

2.8 Energy Efficiency Retrofit of Federal and Governmental Buildings

The structural analysis for non-residential buildings proved that the majority of government and Federal buildings are accounted for consuming a big amount of energy. According to Frauhofer Institute for Building Physics (2011), many of these buildings share construction similarities in many countries where their layout design should consider accommodating not only their employees, but also the expected frequent visitors without neglecting public safety, health, welfare as well as functional performance.

Nevertheless, these buildings share some operational similarities as well. For example, and regardless the minor local differences, the working hours profiles start and finish earlier than other commercial buildings. Moreover, they are projected to a high internal load which increases proportionally to the buildings' size and the number of occupants. Eventually, some of these buildings that deal with public, are projected to a high rate of air infiltration at building's entrances that could reach 1.00 cfm/sf for swinging or revolving doors (Gowri et al., 2009)

For that, lessons and experiences from renovated buildings could be used internationally with some minor modifications that consider regions differences

In Europe and specifically in Germany, Bòttcher (2012) reviewed the status of the energy efficient and sustainable Federal Buildings in Germany. He explained that the attention to retrofit federal buildings started when the government chose to move from Bonn to Berlin in 1991. A commissioner for Energy in Federal Buildings was established by Federal government with certain tasks such as:

- Reducing the energy demand in Federal Buildings
- Optimizing the energy supply concepts in Federal Buildings
- Monitoring of assorted Federal Buildings in the first years of operation
- Certifying the Federal Building according to their energy demand.

In 2001 a "Guidelines for Sustainable Buildings" was published. After 20 years, in 2011, the energy efficiency of the governmental buildings in Berlin were analyze and thirty nine assorted German Government Buildings were certified as shown in Figure 2.16 as an example for two buildings.

All the observed buildings have shown high energetic values compared to the German Energy saving Ordinance 2007. For that and to meet the 2007 requirements, strategies were more stringent and the cut in energy demand reached up to 60%. To achieve that, reducing the energy demand to the minimum was the most important task to start with, then implementing the most efficient energy supply. Examples of the used strategies are listed below:

- No domestic hot water
- Maximization of using daylight
- Use RE
- Provide high level of thermal protection for summer and winter.

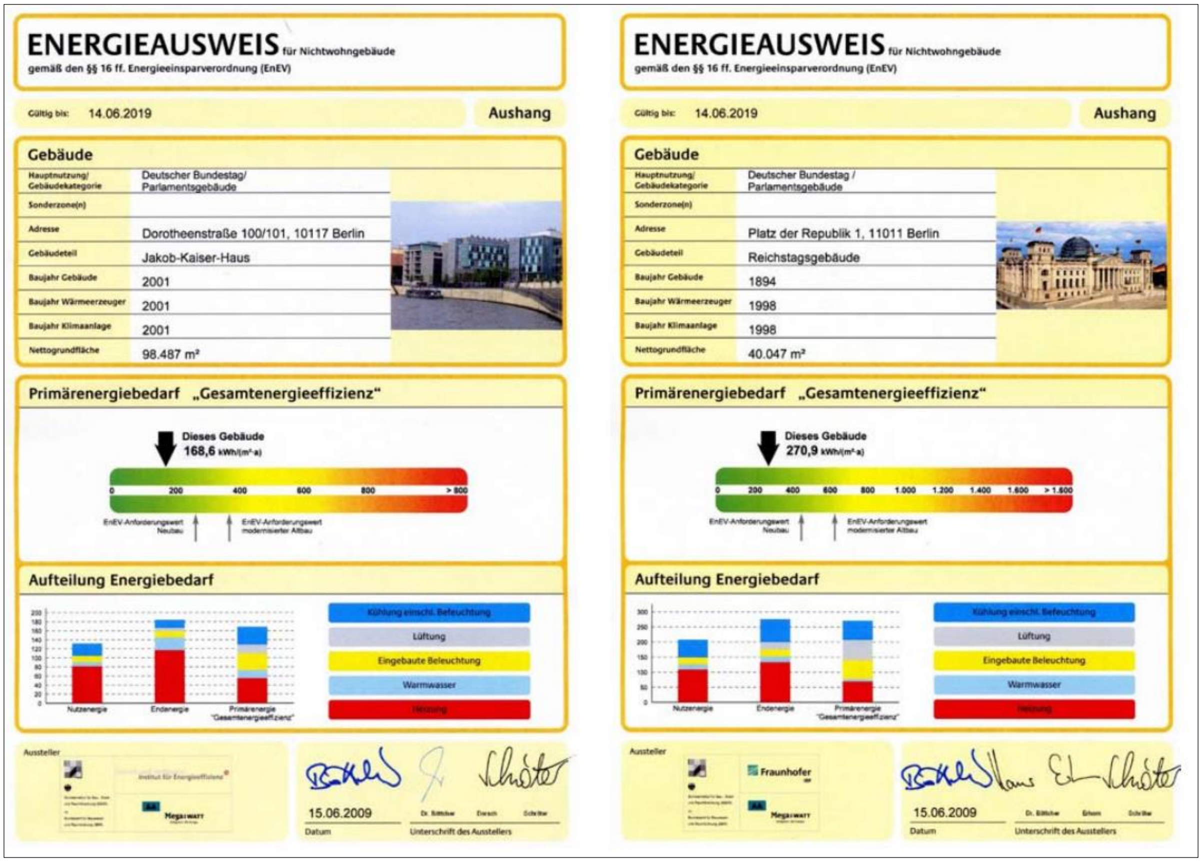


Figure 2.16: Energy Certificate in Germany Government Buildings (Source: BBSR cited in Bὸttcher 2012)

Based on the revealed results of the latest lighthouse project, the Germany Federal government in 2010 felt the importance to develop the Federal Existing Buildings into a climate neutral one. As a result, and starting from 2012, all new Federal Buildings will be constructed as a "Nearly Zero Energy Standard". Moreover, all the Federal existing stock will be refurbished to reduce heating demand 20% by 2020, and reducing the primary energy demand 80% by 2050 (Bὸttcher, 2012).

The General Services Administration (GSA) and as a manager of around 10,000 federal building across the USA, has a distinctive position to move the needle on energy use within the government. "Green Proving Ground" is a project that focuses on assessing the retrofit measures as well as RE and their impact on reducing electricity consumption in governmental buildings. The GSA in partnership with the U.S. government labs has installed many of retrofit measures in its buildings such as: variable speed chillers, solar, PV, on-site water treatment...etc., in order to determine which ones are suitable to widespread adoption. GSA installed five PV systems at Bean Federal Center in Indianapolis, Indiana. The major PV system was a 2-megawatt crystalline PV, while the other four were 3-kilowatt systems. The result after one year revealed that 8% of the federal center's electricity consumption was offset by the 2-megawatt system. In general, and despite the four season climate, it was found that solar is a practical choice for on-site energy generation. Also it was found that variable refrigerant systems could save around 34% or more on cooling or heating costs (Lacey, 2013).

On 2012, The US (GSA) issued a Notice of Opportunity (NOO) for a nationwide deep energy retrofit (NDER) program which aims on providing retrofit plans that move federal buildings to net zero energy consumption. Also, it encourages using innovative technologies as well as RE technologies. These approaches respond to a number of certain Federal goals such as:

- Reduction 30% in Federal Agency Agencies use intensity by 2015 compared with a 2007 baseline (The Energy Independence and Security ACT 2007).
- Reduction 16% in Federal Agencies water use by 2015 compared with a 2007 baseline. (Executive Order 13423)
- A 7.5% of the Federal Government's electrical energy use comes from RE resources (The Energy Policy Act of 2005).

Shonde (2014) analyzed data from the ten NDER projects and highlighted their savings and compared to other federal energy saving performance contract (ESPC) projects. The analysis showed the urgent need for deeper energy savings. The analyze project showed double the saving compared to federal ESPC project. Supportive policies and strategies were behind the success of the NDER projects.

The Edith Green - Wendekk Wyatt (EGWW) Federal Building is an example of a very recent renovated Federal Building in downtown Portland, Oregon. It was built in 1974 and finished renovation in 2013. It won the 2016 Top Ten+ project of the AIA's Committee on the Environment. Figure 2.17 shows the reduction in energy after retrofitting. A major design strategy which using hydronic radiant ceiling panels with DOAS was estimated to save 10% - 15% of energy use over the variable air volume mechanical system.

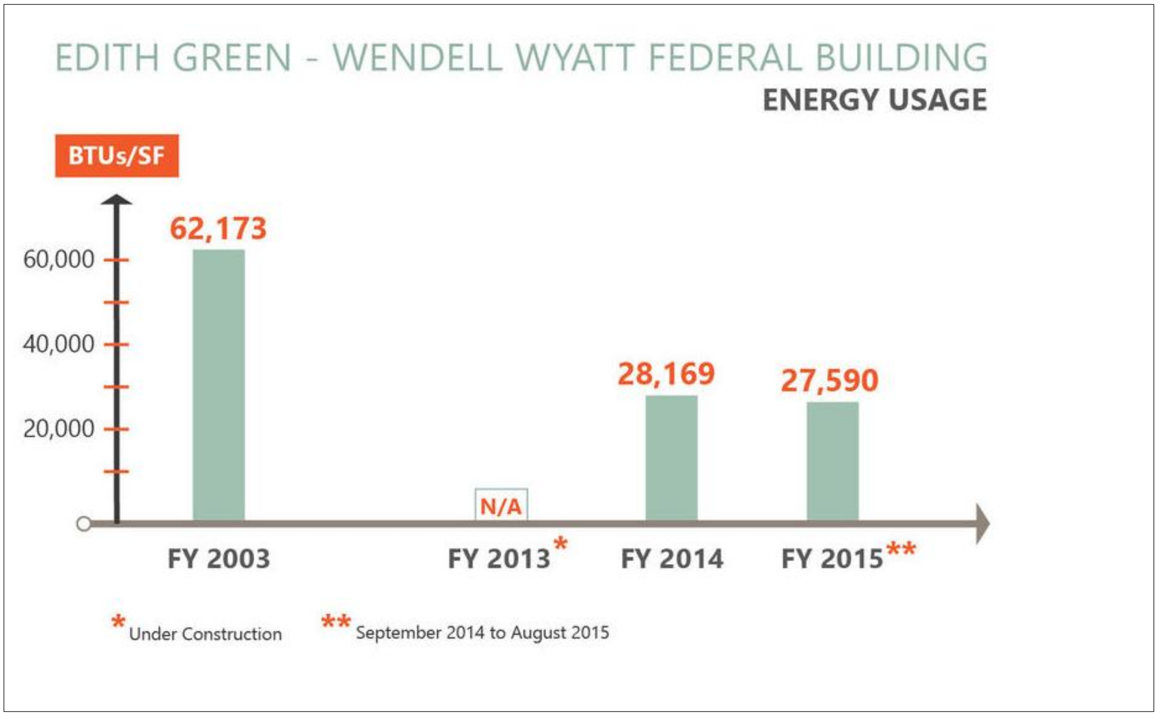


Figure 2.17: EGWW Federal building energy consumption (The American Institute of Architects, 2016)

By considering the retrofit design, analysis and construction process alone, EGWW seems to be an outstanding successful refurbishment. However, the most remarkable result was the increased number of the occupants' satisfaction (The American Institute of Architects, 2016)

Many federal buildings in the United States have set 50,000 Btu/ft2/year as their goal which is equal to 157 KWh/m2/year. Moreover, a highly energy efficient buildings could have an energy use of 40,000 Btu/ft2/year which is equal to 126 KWh/m2/year. (Graham, 2014)

2.9 Energy Consumption Profile in the UAE

Since declaring independence from the United Kingdom and uniting in 1971, the UAE has relied on its large oil and natural gas resources to support its economy. According to the International Monetary Fund (IMF), hydrocarbon export revenues were $123 billion in 2013, increasing from $75 billion in 2010. In the meantime, the UAE is ranked in sixth place as a petroleum producer worldwide (eia, 2015).

The primary energy consumption in the UAE increased rapidly in the mid of 1990, and this happened due to multiple growths such as population, urbanization and economy. (Kazim, 2007), Moreover, the electricity consumption between 1990-2000 increased by 10% rate which beats the world average growth by 7% (Al-Iriani, 2005). Figure 2.18 shows the percentage of the electricity consumption for each building sector in 2013.

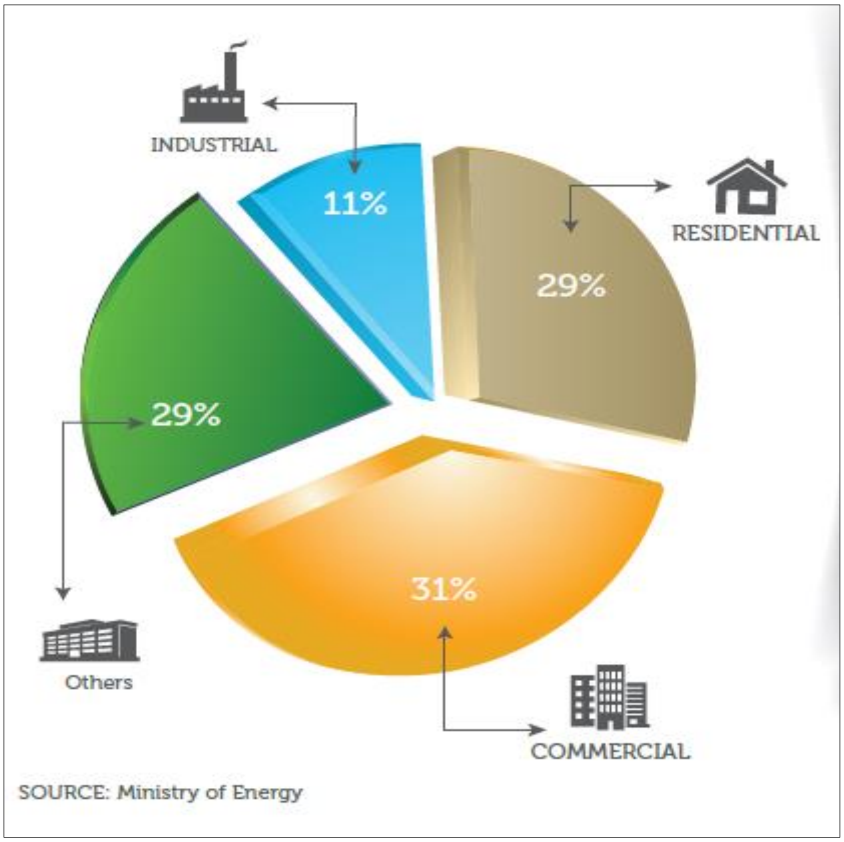
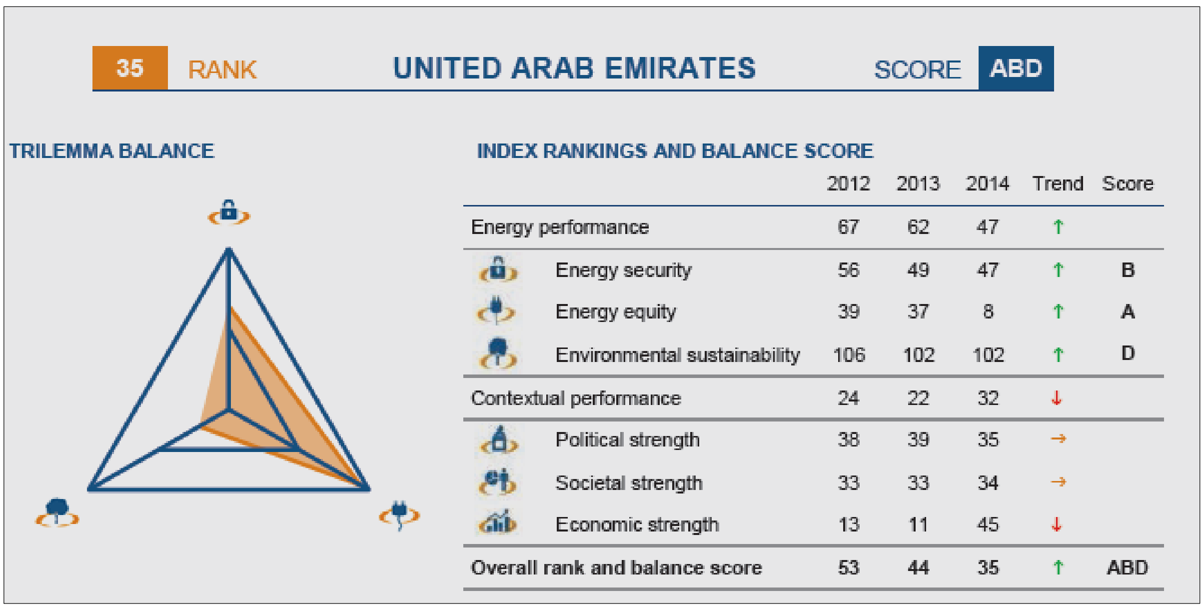


Figure 2.18: UAE electricity consumption 2013 (Sachse, 2016, p.30))

According to the latest news of UAE electricity consumption and which was published in GULF NEWS ENERGY magazine, the analysts have warned from the significant growth of electricity usage. A study revealed that electricity consumption was doubled in the last 10 years. According to estimates, the UAE's gross domestic electricity consumption will reach 141 terawatt-hours in 2020, up from 103 terawatt-hours in 2014 (Maceda, 2015).

Per-Ola Karlsson, a senior partner with Strategy& in Dubai mentioned that for decades, the abundance of hydrocarbon resources meant that energy efficiency was not a pressing topic in the UAE. However the steady population and economic growth have changed attitudes. Today, sustainability is a critical issue, and the UAE government needs to reinforce its efforts to create a more sustainable future for the country and for generations to come (WAM, 2015a)

However, and according to the latest State of Energy report (2016), by considering the "world Energy Trilemma", the UAE has shown a positive steady progress continuing the trend of the previous years which resulted in moving the country to another nine places to an overall index position of rank 35. Figure 2.19



	2012	2013	2014	Trend	Score
Energy performance	67	62	47	↑	
Energy security	56	49	47	↑	B
Energy equity	39	37	8	↑	A
Environmental sustainability	106	102	102	↑	D
Contextual performance	24	22	32	↓	
Political strength	38	39	35	→	
Societal strength	33	33	34	→	
Economic strength	13	11	45	↓	
Overall rank and balance score	53	44	35	↑	ABD

Figure 2.19: UAE Index Rank and Balance Score (State of Energy, 2016)

2.8.1 UAE's buildings energy efficiency

The importance of Building energy efficiency as an essential aspect to reduce electricity demand has been highlighted strongly in the government agenda, therefore, In 2009 Green Buildings Guidelines were provided by Ministry of Public Work (MOPW). In 2010, ESTIDAM was established in Abu Dhabi with the different pearl ratings. In 2011, Green Building Regulations was established in Dubai in addition to many supporting initiatives.

According to the SmartMarket Report, the UAE is considered at the top rank regarding requiring green buildings in government buildings, and this show the significant influence of government on increasing green buildings in the country (MCGraw Hill Construction, 2013) Figure 2.20 shows the UAE's triggers for green building activities.

Source: McGraw-Hill Construction, 2013

	US	Australia	Europe	UAE	Singapore	Brazil	South Africa
Top Reason	Client Demand	Market Demand	Client Demand	Regulations	Regulations	Market Demand	Right Thing to Do
	41%	37%	39%	55%	41%	52%	44%
Second	Corporate Commitments	Client Demand and Lower Operating Costs	Market Demand	Client Demand	Client Demand and Corporate Commitments	Client Demand; Lower Operating Costs; Market Transformation; and Higher Building Value	Lower Operating Costs
	32%	35%	37%	50%	35%		42%
Third	Market Demand and Lower Operating Costs	Corporate Commitments	Branding/Public Relations	Market Demand	Lower Operating Costs		Regulations
	30%	31%	34%	32%	31%	26%	34%

Figure 2.20: Top three triggers driving future green building activity (McGraw Hill Construction, 2012)

Although all the regulations are mandatory for the new constructed buildings, the existing stock still lacks energy efficiency. Figure 2.21 shows the expected green building activities between 2012-2015. It is clear how retrofitting existing buildings sector in UAE calls for more attention and efforts.

The electricity consumption in the UAE is increased around 200% in the last two decades. A statistics shows that both actual population (from 4.1 million - 8.2 million) and the population density (from 58 - 116) have doubled within five years 2005-2010 (Dirioz &Reimold, 2014) as shown in Figure 2.22. The good news that there are potentials of savings in energy by 20% through low or no cost retrofit measures alone. Moreover, in 2014 the UAE electricity consumption was 85.17 billion kWh, with simple mathematics, it is clear that a modest reduction in electricity by 15% would save around 4 billion AED

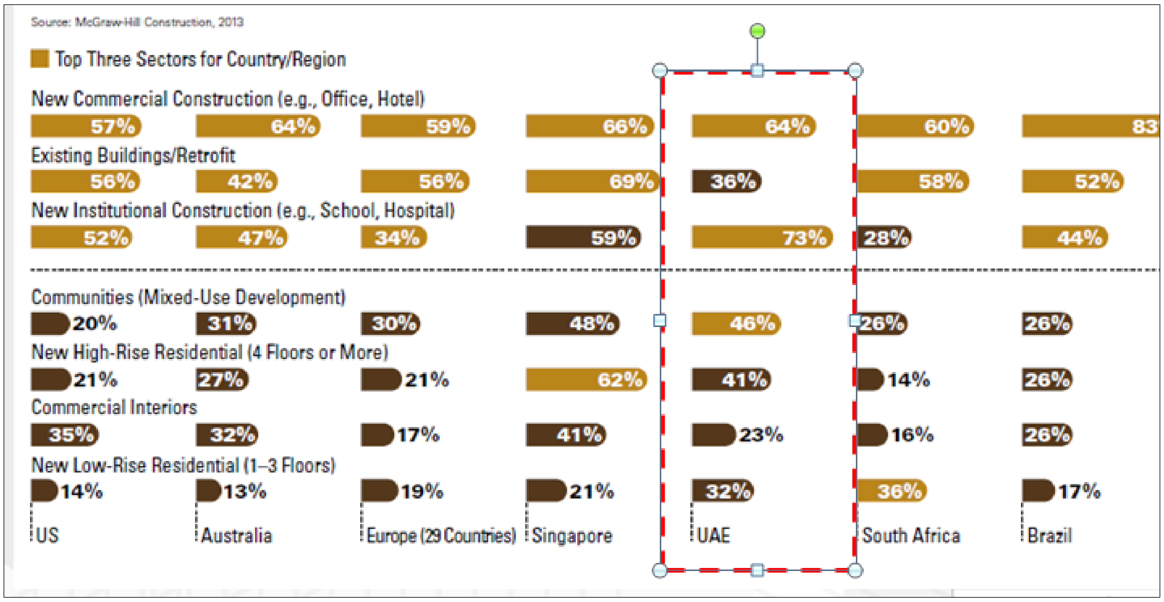


Figure 2.21 Sectors with planned green building activities between 2012-2015 (McGraw Hill Construction, 2013)

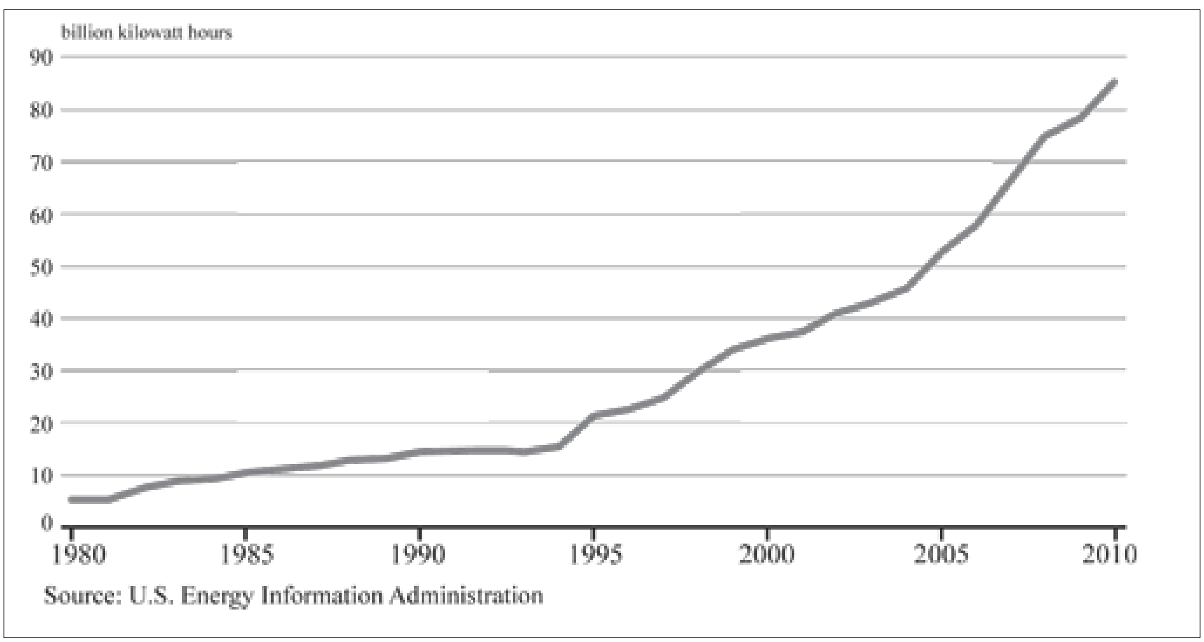


Figure 2.22: Electricity consumption in the UAE (U.S. EIA cited in Dirioz & Reimold, 2014)

.In 2014 the WWF estimated that the UAE is the third highest ecological footprint in the world. Moreover, another study was conducted the same year by the United Nations

Environment Programme's (UNEP's) Sustainable Buildings and Climate Initiative (SBCI) estimated that existing buildings are responsible of producing around 40% of the world's GHG output (Tariq,2015).

The last couple of years, the government of the UAE government has shown great efforts to manage energy consumption, For example, Abu Dhabi has installed advanced electric metering system to help monitoring consumption over time. Dubai as well, has a number of programs in place to reduce electricity demand. Moreover, some initiatives have been introduced to influence occupants' behavior through awareness programs such as the Emirates Energy Award by the Dubai Supreme Council of Energy, which offers monetary prizes for innovative work in projects of all sizes across both the public and private sectors." (Maceda, 2015). However, more additional strategies need to be implemented to help harvest the full benefits.

2.8.2 Energy supply

Diversification into RE and nuclear energy in addition to the enhancement of the fossil fuel supply are the main targeted activities to mitigate the GHG in the UAE. As a result of the government's vision, many polices have been provided that aim on increasing the share of the RE up to 7% in Abu Dhabi by 2020, and up to 5% in Dubai by 2030. Although these targets are considered relatively low, but with a country that used to be 100% reliable on burning fossil fuel to generate electricity, this percentage represent a major step towards change and transition to RE (Wouters, 2015). By considering the full potential of the country and using the available technologies today, it is clear that achieving 15% renewable power generation by 2030 is achievable. However, in the "United Arab Emirates, REmap 2030" report explains the reasons behind these modest targets and the considerable stride towards the long term energy sustainability (Masdar Institute/ IRENA, 2015).

As it was mentioned in section 2.7.4, solar is currently viewed as the most attractive source of RE for the UAE. In July 2014, His Highness Sheik Mohammed Rashid Al Maktoum, the Vice-President, Prime Minister of the UAE and Ruler of Dubai, declared the foundation of the UAE Water Aid Foundation. This establishment has the point of directing research and studies to booster the generation of clean water utilizing sun powered vitality (Ministry of

Environment & Water, 2014). Moreover, in April, 2014 the International Humanitarian City (IHC) partnered with Panmed Renewable Energy LLC to launch a 56 MW Rooftop Solar Photovoltaic power project in Dubai (State of Green Economy, 2015). DEWA customer in the coming future will be allowed to have their own PV grid-connected systems.

2.9 Retrofitting Federal and Governmental Buildings in the UAE

By law, in the current time, implement energy saving measures are mandatory to all the federal buildings in the UAE. In 2009, a green building code has been established based on the request of the Ministry of Public Work back then and recently in 2016, the name change to Ministry of Infrastructure Development.. This code has been the base regulates all green building codes in all emirates while leaving a room for local authorities to set their specific needs as long as they do not contradict the federal regulations. Providing such regulation emphasizes on the UAE united vision towards sustainability and green buildings. This code could be reached at www.moid.gov.ae/EPublications/GBGUIDELINESENGLISH. The main intent of this code is to save energy and conserve water. However, it handles the new constructed federal buildings not the existing ones.

The Ministry of Energy is taking multiple actions to encourage retrofit projects throughout the UAE. "Energy Conservation of Federal Governmental Buildings" is a new project has been established in line with UAE Vision 2021 and the UAE Green Growth Strategy, which target retrofits in government buildings in different sectors. Moreover, the Supreme Council of Energy has issued a Directive for Energy Audits, followed by detailed Implementation Guidelines. The Directive targets 20% savings in government buildings, with 1.4 billion AED savings for the government by 2030. Improvements in lighting, air- conditioning and thermal insulation are among the areas targeted in the retrofit program (Yammahi, 2015 and Rashid, 2015)

Dubai emirate is on the lead in the retrofit field as it has the highest of technical expertise. Moreover, it is worth mentioning, that in 2008 the energy pricing and the introduction of slab tariff program by Dubai Electricity and Water Authority (DEWA) has motivated the building owners to consider the retrofit program due to its economic benefits.

In 2013, DEWA established Etihad Energy Service Company (Etihad ESCO) which initiated not only a number of retrofit projects, but also paved the way for an energy performance contracting (EPC) business to grow and develop through being supported from banks for funding retrofit projects. Based on the latest statistics, there are 120,000 buildings in Dubai, amongst which 30,000 buildings were identified with high energy saving potential. Etihad ESCO currently focuses on the few thousand buildings related to 28 governmental authorities, (Etihad ESCO, 2014b). DEWA's seven buildings recently have been retrofitted with around Fifty-five energy conservation measures. Around 31% reduction of the current energy consumption was achieved with 5GWh reduction/year, thereby saving 2.6 Million Dhs annually. The investment of 16 Million Dhs by DEWA will be paid back through the savings within 6 years. Eventually, 2,245 tons of CO2 emission was avoided (Etihad ESCO, 2015).

In June 2015, Technical Guidelines have launched by EGBC for retrofitting the existing buildings. This document has been designed to suite the specific requirements of the local buildings as well as the region's climate. The guidelines offer a well planned of economically viable strategies that will help the UAE's buildings' owners move towards sustainable and efficient buildings. They offer thirty one retrofit measures under five categories: Energy, Water Management, Air quality, Materials and waste and innovation and Management. (EGBC, 2015)

Although the UAE shows a slow pace in the retrofitting buildings' field, there are some examples of existing retrofitted buildings and their economic, as well as environmental benefits. For instance, the Dubai Chamber of Commerce and Industry building is one of these examples. It was opened in 1995 and earned LEED certified Existing Building 2.0 from the USGBC in 2009. Many energy retrofit measures were implemented such as:

- Optimization the chiller operating load and the building management system.
- Air-conditioning are shut off after working hours, and cleaning and maintenance are provided during working hours.
- Instalment of CFL & LED lights
- Optimizing the lift weighting loads which lead to 20% in energy consumption.

- Cooling set point temperature is kept at 24°C.

A 47% saving in electricity consumption was achieved. The Dubai chamber of commerce building is a great example that a building in the Middle East and without any major retrofit can be operated sustainably through precise operational and maintenance practices. (USGBC, 2016)

Eventually, the benefits of retrofitting the existing buildings are enormous and go beyond reducing energy demand, for that, the UAE government needs to take further steps in implementing more policies to speed up improving the quality of the existing stock.

2.10 Problem Statement

Since the UAE was labeled as the highest ecological footprint in the world, the government has shown a remarkable response to the climate change through many actions that aim to mitigate the country's impact on environment. At the federal level, the UAE has developed two key frameworks: the Green Growth Strategy and the Federal Energy Policy.

According to IRENA REmap UAE report (2015), the total energy used for the building sector was 0.2 EJ, with the majority coming from electricity use, and it is expected to reach 0.5EJ by 2020 and 0.7 by 2030. Moreover, the majority of the electricity in 2030 will be consumed by residential and commercial buildings (IRENA, 2015). Furthermore, and based on the population growth rate, it is expected that UAE population will reach 12, 5 million by 2030 (50% increase from 2010).

Although the new constructed building sector has regulated with many strict codes and regulations, the main concern sustains within the big percentage of the existing stock that lack any consideration of thermal insulation or has minimal standards. This problem in addition to the local harsh hot arid climate, increase the energy demand which basically goes for cooling purposes.

There are several governmental retrofit projects that have been launched the last couple of years such as DEWA Buildings in Dubai where they has shown very decent saving results. However, all the implemented measures focus on reducing the energy demand without introducing any RE resource as an energy supply.

Recently, the country has witnessed a new program, "Distributed Renewable Resources Generation (DRRG) ", which is a Dubai Initiative and expects to start paving the path for deep levels of retrofit. It aims to regulate the generation of distributed solar energy that is produced on building rooftops by the owners. The generated solar electricity is supposed to be consumed on-site, while in case of any surplus, would exported to DEWA's grid. It is expected that the introduction of SPV Grid Connected power will revolutionize the Dubai energy sector. It will encourage the use of RE and contribute to diversifying the energy supply. Eventually DEWA and Energy Services Companies (ESCOs) will support the inclusion of SPV on residential and commercial buildings.

It is important to show the impact of the extensive retrofit approach which considers RE such as solar PV for electricity supply. Being connected to the grid provides great flexibility and practicality. The benefits that will be gained environmentally and economically could motivate the government to consider a certain percentage of PV electricity in their federal and governmental buildings. This could set an example which may influence a broad segment of private building sector.

The study chose a Federal office Building as case study, by doing so a broader message of the country's vision towards sustainability will be delivered across the country as well as the world.

Chapter 3

Methodology

3. Methodology

3.1 Overview

There are different methodologies that can be applied to assess the impact of implementing passive and active retrofit measures on energy consumption. However, selecting the most appropriate one that considers the research parameters, as well as the related limitations is the key for a successful work. This chapter discusses the different methods that can be used according to the research parameters to evaluate the impact of retrofit measures both passive and active on energy demand. The pros and cons for each method will be highlighted to eventually justify the selected method.

3.2 The Research Parameters

The research will assess the impact of implementing passive and active strategies to reduce the electricity demand. Moreover, a further step is taken through diversifying the electricity supply by introducing PV solar electricity. The study will evaluate the net balance of consumed electricity (solar and grid) annually.

Passive strategies consist of the following:

- Shading elements.
- Window films.
- Upgrading the envelope thermal properties according to Estidama 1 pearl and 2 Pearls configuration and Passivhaus regulations.

Active strategies consist of the following:

- Varying the cooling set-point.
- Upgrade the cooling system coefficient of performance (COP).
- Installing PV solar panels on roof and BIPV for atrium's skylight

3.3 Methodologies and Energy Efficiency

Reviewing the literature provided immense examples of research papers that focused on evaluating energy efficiency measures in the retrofitted buildings. The different methodologies in these papers were chosen based on the specific parameters for each case.

The applied approaches are: literature review method, case-study method, experimental method, field-monitor method and modeling & simulation method.

3.3.1 Literature review method

This method reviews the previous works that study a particular area. This approach could be theoretical or empirical. Regardless of the type, it is important to conduct the review from an explicit angle and recognized themes to ensure provision of a distinctive review (UNC, 2014).

Regarding implementing strategies to retrofit the existing buildings and their impact on reducing energy demand, some researches approach the literature review method to analyze certain areas in this topic. For example: Ma et al. (2012) reviewed the literature in a systematic approach to define the most appropriate retrofit strategies that can be implemented to the existing stock. Many points were explained meticulously through examples from others' work. Each point was concluded with the authors' highlights. Eventually, examples of retrofitted buildings from different buildings sectors were provided as an evidence of the impact of retrofit measures on the existing buildings' energy efficiency.

Wang et al. (2012) approached the literature review method to summarize the methods of quantitative energy performance of the existing buildings. Two categories were investigated: the used methods in quantifying energy in existing stock and the used methods in assessing the energy performance. The authors explained that measuring the energy demand and highlighting the building energy performance are the main objectives in all quantitative methods in reviewed papers. Eventually, by comparing their pros and cons, the authors proposed the most efficient tool for quantifying energy.

Gohardani & Bjork (2012), worked on reviewing the researchers contributions regarding retrofitted buildings in order to highlight the areas that need more examination and that may affect decision making. It is worth mentioning that this multilateral review was conducted and set in specifically three European countries which represent different regions: north, middle and south of Europe. The review focused on examining the different regional cases, without neglecting the impact of population density as well as the average heating days. Eventually, the authors concluded that using a high performance thermal insulation is a promising measure that works efficiently in all different regions.

Tuohy & Murphy (2014) approached this method to investigate the Building Information Modeling (BIM) as a possible way to close the gap in building energy performance. By reviewing and comparing between many initiatives that aim to increase the energy performance of buildings with the BIM, the authors were able to underline the gap and propose a potential solution.

This method offers many advantages such as learning from others' works and experiences which can influence any potential success or failure. Moreover, it is not costly and requires minimum resources compared with others methods; in addition, it could be applied to a constrained timeframe research.

This method can be used for comparison, validation, as well as justification reasons. Moreover, the numbers of previous studies that relate to this area conducted in the UAE specifically and in the gulf region in general are limited, which means that reviewing the literature will not be that much helpful in providing the needed sufficient information. Also, quantitative results cannot be obtained through this method.

3.3.2 Case-study method

This approach involves a great deal of studying, observing and analyzing the energy performance of a specific selected building. This observation may be conducted through monitoring the building's data, in addition to interviewing the building's occupants. According to Yin (2003, p.15), conducting a case-study method helps in obtaining general characteristics of the current situation, especially if the researcher shows no bias towards results.

Fluhrer et al. (2010), focused on presenting the retrofitted Empire State (ES) building as a unique case-study that provides great lessons that could help increase the potential in energy savings than the retrofitted typical buildings could offer. The authors tend to compare between the typical approaches in building retrofit with the ES retrofit approach. The differentiating elements between two approaches were identified and highlighted.

Although the case-study works as a great example and provides plenty of lessons to overcome some of the challenges, the authors emphasize on the importance of considering the differentiating elements as a starting point that may help achieve an effective retrofit process.

Based on the study outcome, the authors proposed some changes to the typical retrofit process. Also they recommended analyzing the opportunities through detailed research work, which will eventually help executing deep, viable and successful retrofitted buildings.

Another case-study has been chosen to assess the impact of implementing retrofit measures on energy consumption, as well as indoor environment quality. Silva et al. (2012) chose the building carefully to represent the majority of office buildings in Portugal. Since the study investigated energy related and non energy related issues, many methods have been used in this case study in order to capture an accurate whole result such as field-monitoring, in-situ measurements, occupants' questionnaire and energy simulation. The authors admitted facing some difficulties in achieving parts of their objectives; however, the results in general provided a complete idea of the problems that may occur in such buildings and the options to achieve the optimal efficient building.

The case study approach employs a holistic analysis, in which any method can be applied; both quantitative and qualitative results can be obtained from such a method. However, this method, in case of in-situ monitoring, demands a lot of time and effort, in addition to the high cost for measuring equipments. Moreover, the outcome results in such a method present specific case with its related parameters, which could be helpful in giving a general idea of the impact of the retrofit strategies but doesn't help in identifying other alternative solutions and compare their impact. Also, since this method engages other methods, their cons may be an issue.

3.3.3 Experimental method

This method has been applied in many studies that investigate the impact of building refurbishing and their energy efficiency. Usually, it is best used to assess the thermal comfort parameters. It is very important to calibrate the measurement tools to assure obtaining accurate results.

Cabeza et al. (2010) investigated the impact of three different types of insulation as a passive strategy to reduce the demand of used energy for heating or cooling purposes. Cubicles were constructed under a conventional Mediterranean system with different insulation materials. Thermal performance was measured throughout the time between 2008 and early 2009.

Another work based on experimental method was conducted by Sadineni et al. (2012), which investigated the PV orientation impact on the building's peak load. 200 homes were developed to this study. The study focus on the building's energy performance with relation to the PV direction, which is greatly influenced by the building orientation.

Ibrahim (2011) used this approach to investigate the impact of the shadow and dust on the PV energy output. The experiment was conducted within an indoor environment by providing a controlled illumination that falls on the PV panel and offering shades on different areas to mimic the natural situation. Eventually, the outcome results were compared with the results that were obtained from applying this experiment under a natural environment.

The experiment method is a good approach which offers real results for the case itself or for a duplicate model. However, especially when talking about academic researches, the main limitation in this approach is the high cost of the tools and the mockup as well. Moreover, monitoring the data calls for time and expert staff which are both considered tight in such researches. For that, this method is inapplicable for this study for its wide range of parameters, as well as restrained time frame.

3.3.4 Field-monitor method

This approach is a kind of observation and collection of data from the actual physical location through professional tools and qualified staff. Many parameters could be monitored and documented at the same time.

Many researchers have used this method to assess the impact of implementing some retrofit strategies on the buildings' energy demand. For example, Larsen et al. (2008) applied this approach to assess the thermal behavior of a bioclimatic auditorium of the National University in Argentina. The building was monitored during winter, and a simulation was applied to assess the impact of using SIMEDIF code for windows. The results were used in designing a new project with a similar building where passive solar strategies were applied to reduce heating and cooling loads. The new building's thermal behavioral was monitored during summer and winter and the savings in energy was highlighted.

Moreover, Ardent et al. (2011) used this method to assess the impact of implementing retrofit strategies to six existing buildings in different cities. Questionnaires were used to collect more data from occupants regarding issues related to the design and implementing stages.

Although this type of method allows monitoring of several parameters, choosing the right period of time to do so is crucial in order to obtain accurate results. Also, this method calls for a significant budget to cover the needed equipment cost. However, the long-term monitoring with limited time-frame is considered the main limitation in using such a method especially for academic researches. Finally, by considering the multiple parameters with the different scenarios of the study, this approach is not the most suitable one.

3.3.5 Computer simulation method

Computer energy simulation is proved to be among the most efficient methods in assessing many variables and comparing their impact on the building energy efficiency. Many scenarios could be studied with a broad range of parameters (Eisenhower et al. 2012). Many designers tend to follow this approach prior to building construction to evaluate the energy efficiency of the proposed design. This method can provide results that are not easy to be measured through experimental approach with the existing level of technology. It offers shorter processes with minimal trials and errors. Moreover, it assesses expected results and optimizes alternatives. For that, researchers have found the simulation method a very reliable one if the model and results are validated. Plenty of simulation softwares are available such as: ECOTECT, ENERGY-PLUS, eQUEST, DOE-2, Design-Builder and IES Virtual Environment, where each one has its own potentials and drawbacks.

Utamah et al. (2011) approached modeling simulation method by using ECOTECT simulation software to assess the expected savings due to applying the Indonesian Building Code for the buildings' envelope. To find the potential reduction in electricity demand, a modeling tool was integrated: LEAP (Long-range Energy Alternative Planning). Whereas, Stazi et al. (2012) used Energy-Plus software to find the optimal retrofit solution. The simulation software was calibrated with complete detailed data of the analyzed building. In order to evaluate the LCA (Life Cycle Analysis) and the building impact on environment, the authors used "Sima Pro" software. Moreover, Stazi et al. (2013) used the same software to assess the impact of wall thermal insulation with different types of construction materials.

Designer-builder software was used by Yasar & Kalfa (2012) to study the impact of glazing properties on reducing energy demand for cooling and heating purposes, and how it may affect the building economy in high-rise residential buildings. Whereas, Ballarini & Corrado (2012) used the same software to assess the insulation materials' contribution in reducing energy demand in summer conditions. However, Kima et al. (2012) were able to explore the optimal design of shading devices and its impact on daylight level by using IES-VE simulation software. However, Shameri et al. (2013) used IES-VE software to assess the impact of 12 double skin facade systems on the day lighting characteristics. They explained that increasing the energy efficiency of buildings should not compromise other important aspects such as ventilation and day lighting.

Stevanovic (2013) conducted a review on the previous studies that aim to optimize the passive solar design measures and assess their impact through simulation method. However, Kirimtat et al. (2016) was more specific and presented a review of simulation modeling for shading devices in buildings. The study focused on the previous shading device types that are commonly used in the building sector. The study underlined the importance of using simulation modeling method for assessing shading devices in buildings.

In the UAE, many studies used simulation methods (Hammad & Abu Hijleh, 2010, AlNaqabi et al. 2012, Al Awadhi et al. 2013, and Manneh et al. 2014), all of these studies used IES-VE software to assess the impact of implementing different passive retrofit strategies to existing buildings. However, AlBadri (2013) conducted a simulation study with IES-VE software as well to evaluate the impact of passive and active measures at the same time on reducing the energy consumption for a residential building in Bagdad, Iraq.

It is worth mentioning that the errors in simulation tools as well as providing weather data are among the disadvantages of using this type of method. Moreover, the obtained results are quantitative which limits the usage of this method in social and behavioral aspects. Finally, the invalidated results lack any credibility.

3.3.6 Numerical method

This approach is heavily dependent on other investigation methods for collecting data that will be applied to the mathematical analysis.

Menassa (2011) used this method to present a quantitative approach that helps evaluate sustainable retrofit in existing stock under uncertainty. A case study was used to validate the result. Whilst, Asadi et al. (2012) followed a multi objective optimization model in order to help define the retrofit measures with a goal of reducing the energy consumption in building in a feasible way while considering the occupants' needs satisfactions.

The difficulty of this approach increases with the high number of parameters. Also, result accuracy is affected by the approximation approach that is usually used in this method. Moreover, validating the obtained results could be a complicated process which may involve other methods such as comparing with results from the literature review or apply field measurements.

Although this method could be very helpful in some areas such as economic and feasibility work, it is considered an inapplicable method for the research aim and objectives.

3.4 Preferred Research Methodology

The potentials of the previous methods are analyzed through understanding their pros and cons while keeping in mind the research parameters that were discussed earlier. Modeling simulation method has proven to be the most suitable for such a study.

Unlike the literature review method which depends on previous work, modeling simulation is the only method that can predict results that may appear in the future (Fong & Alwan, 2013). It is a time efficient method with a wide range of flexibility that allows assessing and comparing many parameters at the same time. The research parameters can be adjusted for multiple simulations within short time period with different layouts (numerical, graphs, etc.)

On the contrary, despite that field monitor method is a very sufficient approach to this type of work; it requires more time to collect enough data to form a building performance profile.

Moreover, modeling simulation method requires human resource, in addition to simulation software, which requires reasonable cost comparing to experiment or field monitor methods which both need the involvement of expensive tools and require more time.

3.4.1 Selection of building performance simulation tool

In the last few decades, a wide range of building energy simulation programs have been emerged and developed. According to Hirsh et al. (2011), these programs could be classified into a primary tool that is used for a whole building simulation, whilst the other simulation tools deal with a specific area that focuses on a certain aspect or to complement the primary tool, such as day lighting, ventilation thermal bridging, and generated electricity by PVs modules.

Crawley et al. (2008) reviewed and compared between the features, as well as the capabilities, of twenty major energy simulation software which are: BLAST, DOE-2.1E, BSim, DEST, Ener-Win, ECOTECT, Energy Express, Energy-10, EnergyPlus, eQuest, IDA ICE, ESP-r, IES VE, HEED, HAP, PowerDomus, Tas, SUNREL, TRACE, and TRANSYS. The comparison specified the pros and cons of each program in 14 different categories. The research outcome (See Tables A1-A5 in Appendix A) shows that there are few programs that are capable of conducting the majority of the related solar analysis such as IES, TRANSYS and EnergyPlus.

Moreover, the study showed that IESVE is the only software that considers inside radiation factors when conducting general calculations related to the building envelope. Also, the outside surface convections calculations are based on the requirements of ASHRAE standards. Eventually, Table 5 in the study shows the potentials of IES VE software in analyzing the buildings systems as well as the renewable energy.

Attia et al. (2009) conducted a survey to rank ten of the popular simulation software based on their status as "Architect Friendly". Based on the result of 249 responses from architects, designers, LEED AP and others, the majority agreed that IES VE is considered the most "Architect Friendly" software (85%), followed by HEED (82%) and then eQuest (77%). Figure 3.1.

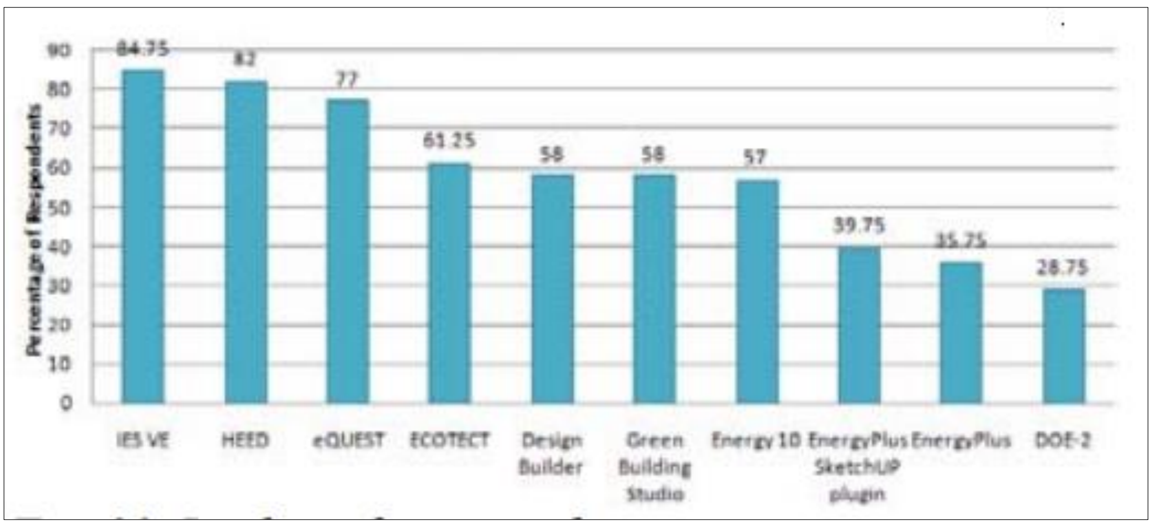


Figure 3.1: "Architect Friendly" simulation software (Attia et al. 2009)

Another work conducted by Attia & Herde (2011) where they compared between ten tools to evaluate their capabilities in early design stage simulation for net zero energy buildings NZEB. The result revealed that IES VE has shown high rating in usability and accuracy. Figure 3.2. Table A-7 in Appendix A shows the results of the NZEB tool matrix.

According to Jenkins et al. (2013), calculations by using IES VE software can be performed at hourly resolution in addition to the other advantages such as CAD-complaint, largely intuitive and user-interface.

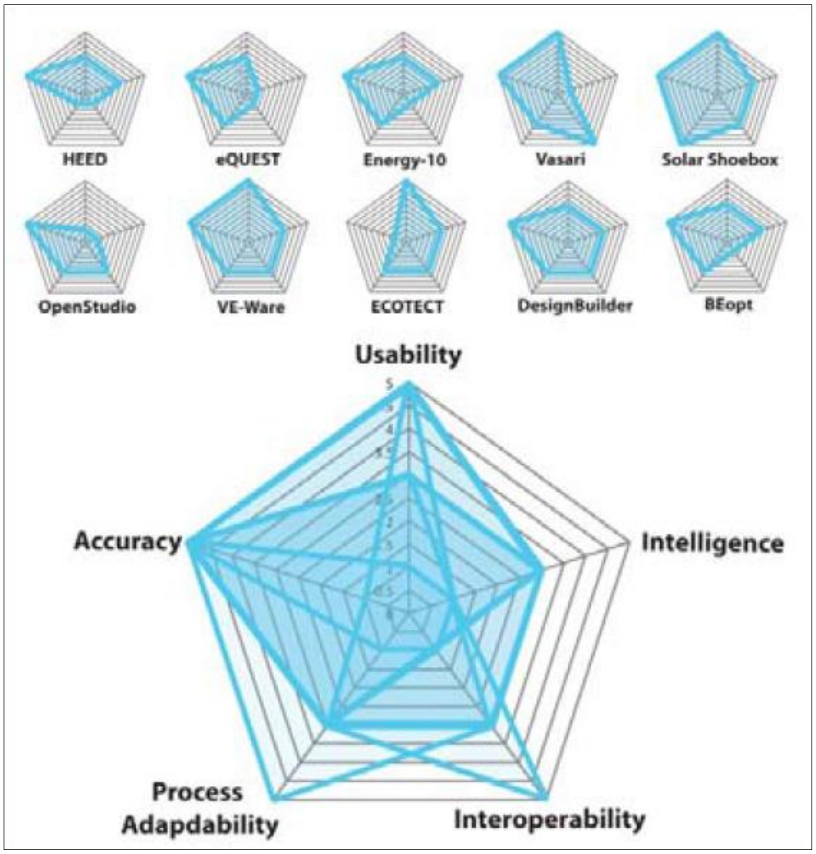


Figure 3.2: Comparison of 10 simulation tools (Attia & Herda, 2011)

Nowadays, being used in over 80 countries, this software is considered one of the most popular among the simulation programs worldwide (Schwartz & Raslan, 2013).

The presented work is based on evaluating the impact of implementing passive and active strategies on the building energy performance, for that IES VE has been chosen as a modeling simulation tool for its reliability, accuracy and its high potential in dealing with many interlinked parameters. Although the IES VE software is relatively expensive, a special student version with a very reasonable cost is offered by the provider. For all the previous reasons, IES VE will be utilized in this research.

3.4.2 Integrated Environmental Solutions - Virtual Environment (IES VE)

IES VE is a dynamic simulation program that is widely used in building construction businesses due to its advanced potentials. This program includes many modules such as: ModellT for building and editing geometrical models, SunCast for shading analysis and visualization, ApacheCalc for analyzing loads, ApachSim for thermal analysis, MicroFlo-3D computational fluid dynamics, DEFT for model optimization, FlucsPro/Radiance for lighting design and analysis, in addition to other modules that facilitate conducting different analysis.

Moreover, this software offers environmental data of many different locations for the detailed assessment of the buildings' design and systems. Based on the assessment, the building's design and systems could be optimized to save energy and without compromising occupants' comfort (Crawley et al. 2008).

The obtained results from the IES VE software can be categorized according to the study's scenarios and parameters. Total energy consumption, electricity consumption, and cooling load are some examples of the results that IES VE software offers. The ability to define the different types of energy demand allows the analysis of the impact of different variable parameters on energy consumption. Moreover, energy production via renewable sources is another offered category, where solar PVs electricity can be assessed through different parameters such as different technologies and orientation.

In U.K., a comparison study was conducted by Schwartz & Raslan, (2013) to evaluate the popularity among the users of the top three simulation tools in the country (EnergyPlus, TAS, and IES VE). It was found that 19 out of the top 20 engineering firms use IES VE *software*. Also, 18 out of the top 20 consultancy firms go with this software. Regarding architectural firms, 15 out of the top 20 in the UK use IES VE.

Katanbafnasab & Abu-Hijleh (2013) used IES VE to compare the energy benefits of using BIPV and Elctrochromic Glazing. They explained the reasons behind choosing this software over the others.

A recent study suggested saving in electricity demand up to 37% through energy retrofitted simulated in IES VE software (Aldosary et al. 2014). Also, many researchers chose IES VE software (Moran et al., 2014, Cho et al., 2014 and Shameri et al. 2013) in addition to what was highlighted previously in section 3.3.5.

3.5 IES VE Software Validation

According to Zahi et al. (2011) , more accurate validation of simulated models is required to ensure providing credible results. And in order to ensure accurate results, it is important to validate the software within the research context.

For that, the electricity bills for the chosen case study (MOID- RAK) for the year 2015 were collected to validate the software simulation. The building was simulated by author business as usual (BAU) (all the building inputs will be listed in the next chapter). The obtained results were compared with the actual electricity consumption bills (Appendix B). The building was simulated with two profiles for different cooling set-point in summer and winter. Based on the obtained results which are presented in Table 3.1, the IES model shows some deviations of 6.8% of average annual energy consumption.

This deviation could be justified due to the building's typology with the high possibility of unpredicted infiltration that may reach 1.0 cfm/sf through entrances doors (Gowi et al. 2009).

As it shows in Figure 3.3, the biggest difference appears in winter months, where the cooling set-point temperature is 24°C, however, in the actual situation, people tend to leave entrances' doors opened to enjoy the winter breeze which increase the air infiltration and increase the cooling load as well.

Moreover, the usage of lighting / occupancy sensors which makes it difficult to predict the exact lighting profile, all of these factors justify the minor deviation of the simulated results and validate the IES model. (All the implemented profiles will be presented and explained in detail in the next chapter).

Table 3.1: Simulated and Actual Annual Energy Consumption results.

Month	Simulated consumed electricity MWh	Actual consumed electricity MWh
Jan	12.161	23.8
Feb	13.74	24
Mar	29.41	28
April	35.66	37.9
May	51.15	52.2
June	64.20	60.8
July	75.60	75
Aug	77.35	85.6
Sep	70.51	63.1
Oct	49.64	52.5
Nov	35.75	38
Dec	14.08	27.5
Total	529.29	568.4

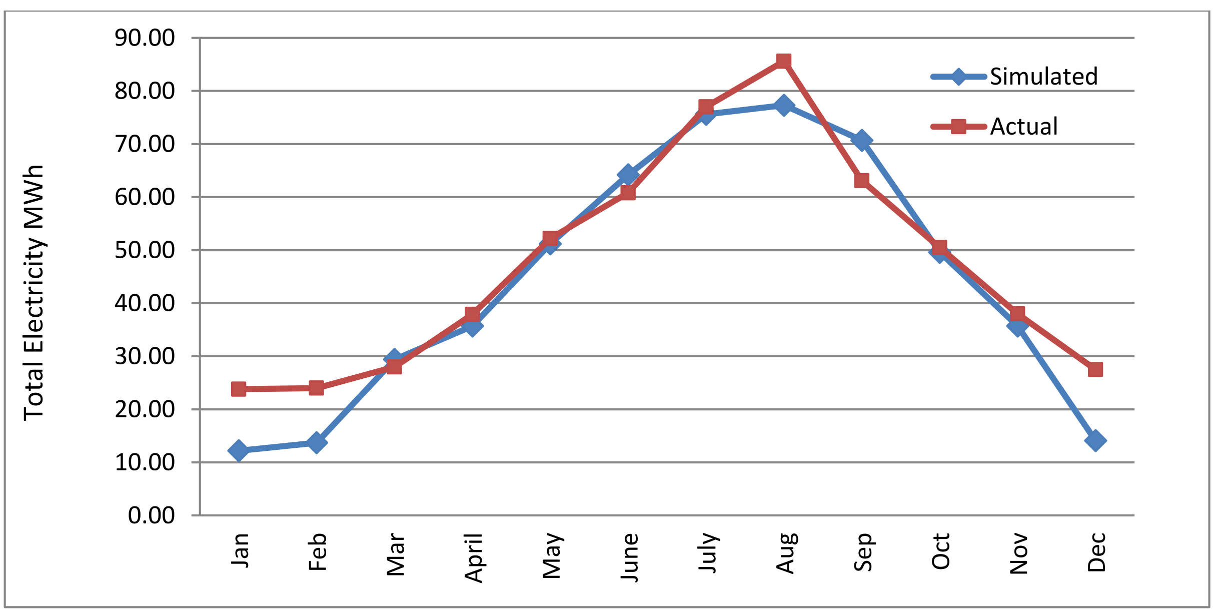


Figure3.3: IES Software Validation (by the author)

3.6 Summary of Selected Research Method

Computer modeling is the best method to be applied to such a study in which collected data will be studied through a quantitative analysis.

Two sets of building simulations are conducted using IES VE software; the first one represents the building without any modification. Whereas the second one assesses the proposed measures both passive and active and their impact on reducing energy demand through different simulation scenario which will be explained in detail in the next chapter.

Renewable energy will be introduced to the building through Photovoltaic panels. Different PVs types will be assessed to feed the building during the working hours; however, after working shift ends, the solar energy production will be sent to the grid and save as a credit. The annual net energy demand will be determined.

The next chapter introduces the different models, input parameters, scenarios, and their related outcomes.

Chapter 4

Simulation Models

4. Simulation Models

4.1 Introduction

Analyzing the impact of building retrofit strategies calls for many important aspects to be included such as: location, orientation, building type, occupancy profile and internal gain. Defining and understanding the needed input parameters of the case study is very essential to start the computer modeling which is supposed to reflect the building's exact condition.

The research aims to simulate an existing federal building in Ras Al Khaimah as a baseline model. Multiple scenarios will be proposed to evaluate the impact of each strategy on reducing energy consumption by comparing it to the baseline model. Eventually, the optimal proposal will include all the implemented strategies. The annual building electricity consumption balance will also be evaluated.

4.2 The Case Study

The Ministry of Infrastructure Development (MOID) building at Ras Al Khaimah (RAK), (previously known as Ministry of Public Work), has been chosen as a case study for multiple reasons. The government of the UAE has shown serious efforts towards developing green buildings and sustainability. Few recent studies have been conducted in the UAE which focused on retrofitting some residential and commercial buildings. (Manneh, 2013, Alnaqabi, 2013, Manneh, 2014, Alkateeb et al. 2014 and Alkhateeb & Taleb, 2015). Only one federal building has been chosen as a case study for retrofitting the electrical system (Alawadi, 2014). This is surprising due to the fact that the country's vision is all about development and sustainability. Keeping this in mind, it is essential to perform a holistic retrofit study on all federal buildings in order for them to become an ideal representation for other buildings to follow.

The research will aim to look at the MOID building from another perspective in order to evaluate the impact of passive and active retrofit strategies, as well as implementing PVs as an electrical supply. By doing so, a complete image can be obtained from a holistic retrofit approach. Moreover, this building is relatively newly constructed. It was built in 2010, according to MOPW Green Building Guidelines (2009). However, the electricity bills for 2015 were 568.4 MWh (Appendix B for electricity bills). This building with 252.5 KWh/m2/year consumption is considered relatively high when comparing it to the best practice in the UAE. It shows that the most energy efficient buildings consume 110-160 KWh/m2/year (Clarke, 2016). Figure 4.1 shows the actual building, where the main entrance is oriented northeast, whereas Figure 4.2 shows the IES model of the building and the solar path.

Figure 4.1 :MOID-RAK Front View (Author, 2016)

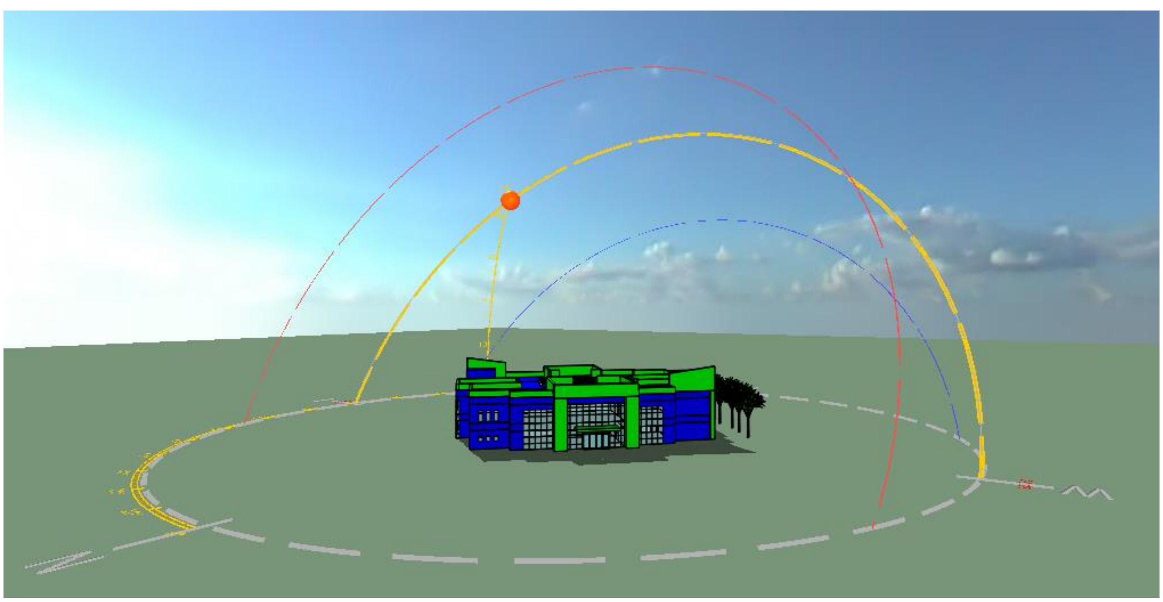


Figure 4.2: IES VE modeling and Annual Sun-Path (IES, Model Viewer)

The building is located on a 43 × 31 m² plot, and consists of G+ 1 level with a total area of 2251 m². The ground floor covers an area of 1196 m², while the external walls' surface area is 1308 m² and the net glazing area is 483 m². A 246 m² central atrium consists of a 108 m² skylight. Figure 4.3 shows the building layouts.

Figure 4.3: MOID-RAK Layouts Ground(left) and First level (right)

Based on the building's documents, the building consists of 13 offices, 2 meeting rooms, 2 receptions, 1 library, 1 nursery, 1 multipurpose room and 4 storage rooms. However, after visiting the building, it was established that not all rooms are being used for their intended function.

As mentioned earlier, the building is equipped with relatively new systems. On the ground floor, a ducted split HVAC system is installed which provides a zone controlled central temperature. Furthermore, packaged air conditioning systems are provided in some rooms.
Analyzing the power consumption profile from the building documents shows that the HVAC system is responsible for consuming around 70% of the total energy. For that, this study focuses on reducing the air conditioning electricity demand through passive and active strategies.

4.3 Ras Al Khaimah Geographical and Climatic Conditions

Ras Alkhaimah is the fourth largest emirate in the UAE and covers an area of 1684 sq Km, which is equal to 3.16% of the total area of the UAE. The building's orientation is 45° degrees North-West.

In order to get the exact location and design weather data, the computer model utilized the IES VE tool "APLocate". This tool allows linking the site location data to the software built-in data that is related to required site or to the nearest area. In this research, "Abu Dhabi simulation weather file" will be used since Abu Dhabi is the nearest location with a simulation weather file to the location of the case study in RAK. Abu Dhabi is located between longitude 54.65°E and latitude 24.43°, whereas Figure 4.4 shows the site location of RAK.

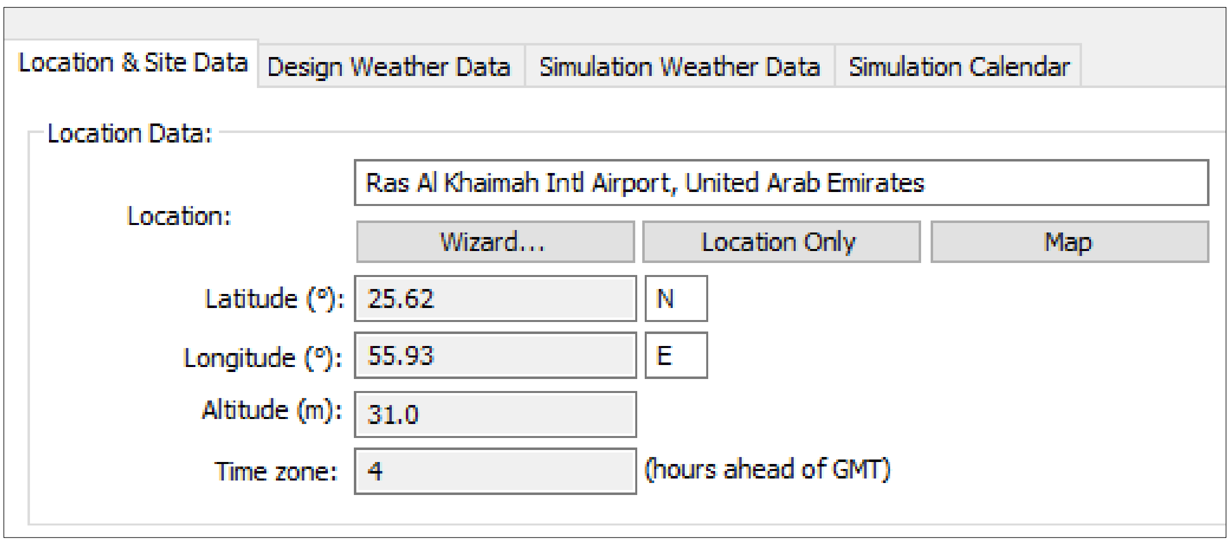


Figure 4.4: Location of RAK-UAE

The United Arab Emirate is generally known to have very hot arid desert climate with high temperatures and low levels of rainfall. In general, the climate features two major seasons with slight variations, a hot summer and mild winter. Summer usually begins in late April with an average high temperature around 30°C. However, in July there is a drastic increase with temperatures normally around 40°C, (Figure 4.5). Furthermore, the humidity becomes very high in the summer months and goes as high as 90%. On the other hand, during the winter, the highest temperature fluctuates between 19°C and 28°C and could drop to its lowest at night in the months of January and February to be aroun12°C.

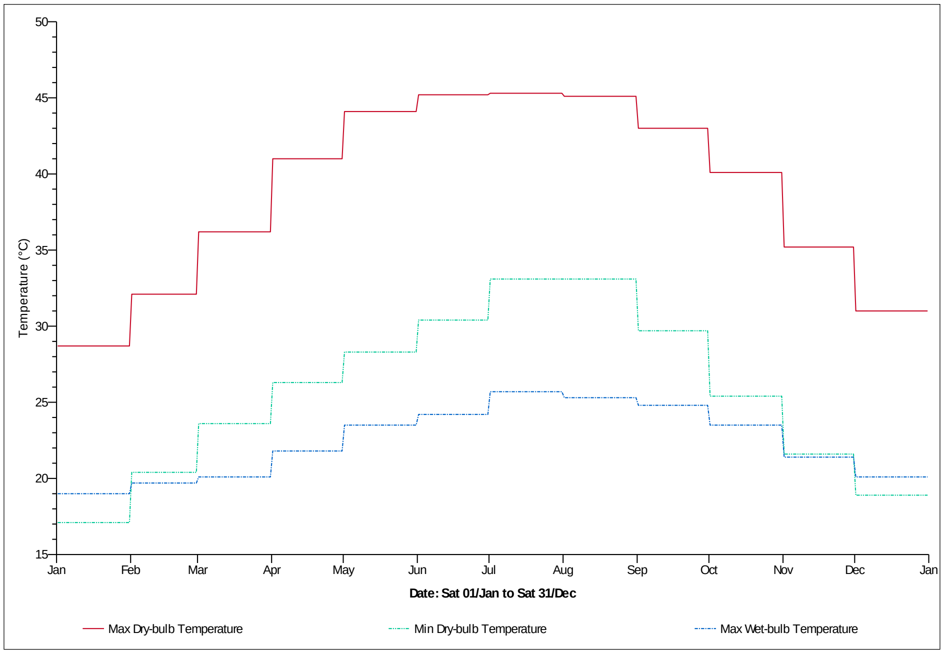


Figure 4.5: Dry and Wet Bulb Temperature (IES VE Weather Database)

Figure 4.6 shows the annual sun path for RAK whilst Table 4.1 is generated by IES VE from the baseline model and shows the weather data design file which is based on ASHRAE standards.

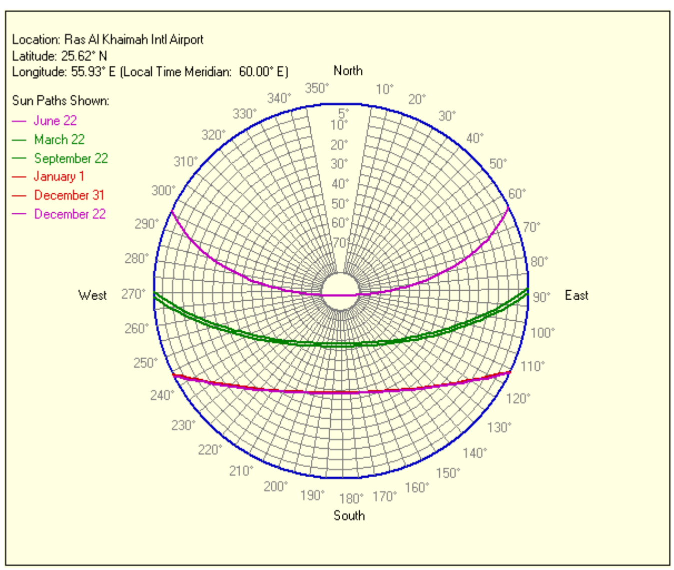
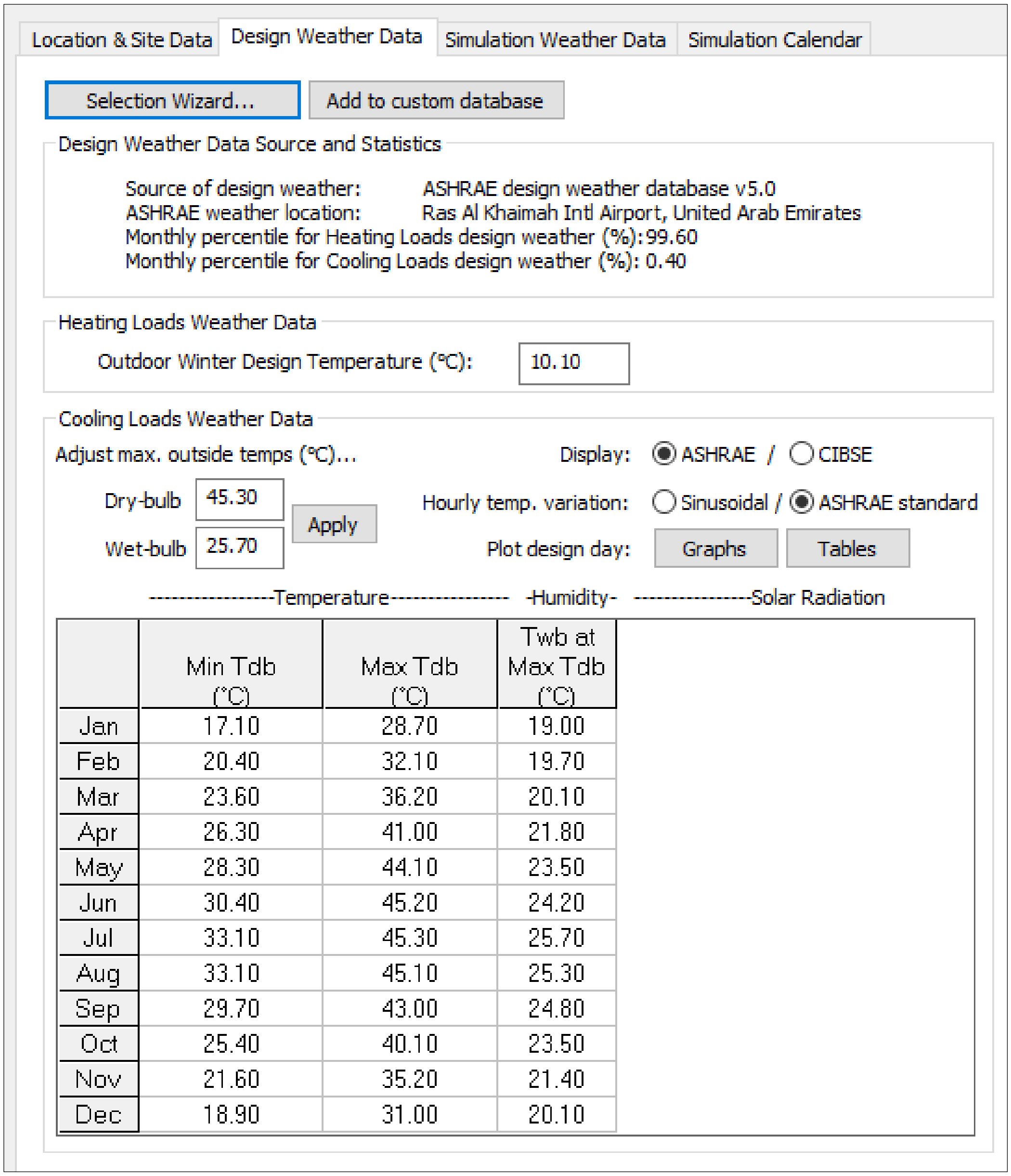


Figure 4.6: Sun Path for RAK/UAE (IES Database)

Table 4.1: Design Weather Data (Source: IES VE (APLocate)



Location & Site Data | Design Weather Data | Simulation Weather Data | Simulation Calendar

Selection Wizard... | Add to custom database

Design Weather Data Source and Statistics

Source of design weather: ASHRAE design weather database v5.0
ASHRAE weather location: Ras Al Khaimah Intl Airport, United Arab Emirates
Monthly percentile for Heating Loads design weather (%):99.60
Monthly percentile for Cooling Loads design weather (%): 0.40

Heating Loads Weather Data

Outdoor Winter Design Temperature (°C): 10.10

Cooling Loads Weather Data

Adjust max. outside temps (°C)... Display: ASHRAE / CIBSE

Dry-bulb 45.30 Apply Hourly temp. variation: Sinusoidal / ASHRAE standard

Wet-bulb 25.70 Plot design day: Graphs Tables

----------------Temperature--------------- -Humidity- ---------------Solar Radiation

	Min Tdb (°C)	Max Tdb (°C)	Twb at Max Tdb (°C)
Jan	17.10	28.70	19.00
Feb	20.40	32.10	19.70
Mar	23.60	36.20	20.10
Apr	26.30	41.00	21.80
May	28.30	44.10	23.50
Jun	30.40	45.20	24.20
Jul	33.10	45.30	25.70
Aug	33.10	45.10	25.30
Sep	29.70	43.00	24.80
Oct	25.40	40.10	23.50
Nov	21.60	35.20	21.40
Dec	18.90	31.00	20.10

The peak dry bulb temperature was recorded on the 23rd of July. Figure 4.7 shows both the peak dry bulb temperature, in addition to other weather variables, such as wet-dry temperature, solar direct radiation, solar diffused radiation, and relative humidity. Moreover, the same variables are presented for the month of January, which has the lowest recorded temperature of the year, see Figure 4.8

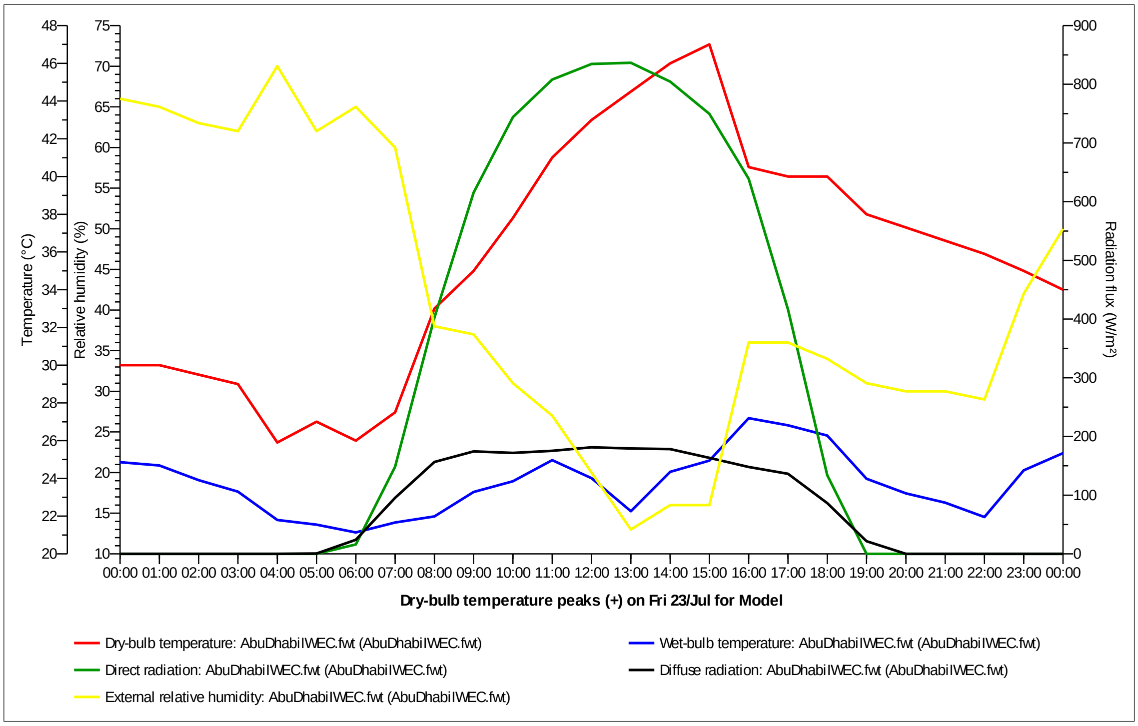


Figure 4.7: Peak dry-bulb temperature (IES VE Weather Database)

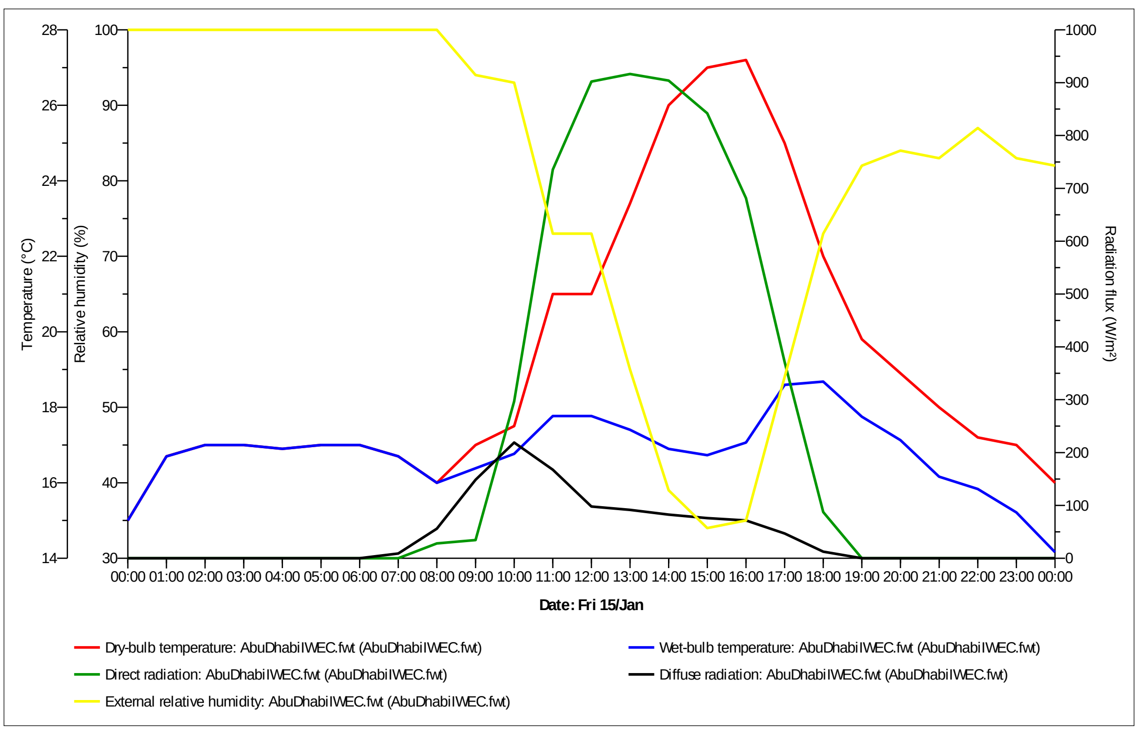


Figure 4.8: Weather data of mid-January (IES VE Database)

It is noted that even with a big drop in dry-bulb temperature; the solar direct radiation is almost the same and revolves around 850 W/m2. Spring and autumn also have shown high levels of solar direct radiation, see Appendix A. These results give a clear image of the region's ample resource of direct solar radiation, regardless of the temperature itself. This indicates the importance of deploying solar energy to generate electricity.

4.4 Baseline Model Input Templates

4.4.1 Construction template

The building was constructed according to the Federal Green Guidelines that was introduced in 2009 (Appendix C for more detailed data). Table 4.2 lists all the construction materials' U-values.

Table 4.2: MOID baseline construction materials U-values

Building Element	U-Value W/m2k
External walls	0.47
Partition	2.13
Typical floor	1.38
Roof	0.21
Insulated ground	4.41
Double Glazed Reflective	2.1
Shading Coefficient SC	0.35

4.4.2 Thermal Templates

This section will present all the simulation inputs that are related to thermal proprieties. Most of the parameters are based on the building's documents, occupancy and the building's system profiles. Four related sections, excluding "Building Regulation" which is only used in the UK and Ireland, are completed as follows (Figure 4.9).

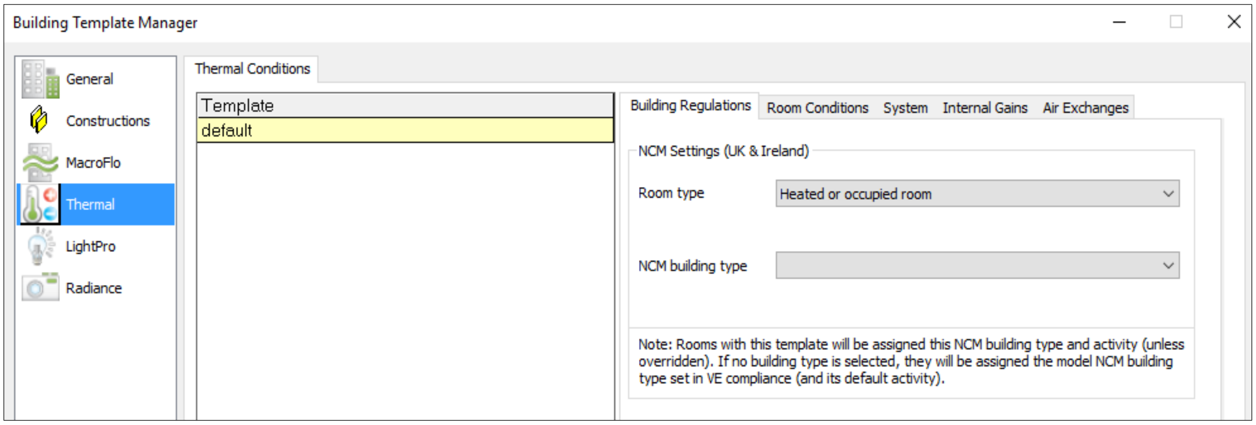


Figure 4.9: Thermal Template (IES VE)

4.4.2.1 Room conditions

All building zones are set to one profile as follows:

- Heating profile is set to "off continuously".
- DHW is set to zero consumption.
- Cooling profile is set with constant profile "on continuously" with cooling set point 21°C for The months of March-November, and 23°C for December-February for all spaces except stairways in which the system is set to "off continuously".
- Plant Auxiliary System set to "off continuously" since the building has none.
- Model setting has been set as model defaults whereas 0.05 is set for solar reflected fraction and 1.00 for furniture mass factor.
- Relative humidity is set according to ASHRAE guidelines within 30% & 70%.

4.4.2.2 Systems

A system for cooling air conditioning is used as the main system, with EER = 8.44, which is equivalent to COP: 2.46.

4.4.2.3 Internal Gain

The building was divided into multiple zones based on their functions, as well as their relevant thermal conditions:

- *Entrances*

This template includes fluorescent lighting which is assigned to a power consumption of 13W/m2. Also, in the miscellaneous section, an elevator with 5W/m2 is assigned to the simulation model.

- *Central Zone*

The atrium area works as a public area where special activities could be held occasionally. Fluorescent lamps are assigned for this zone to a power consumption of 11W/m2.

- *Offices*

The offices have been grouped together in zones, while neglecting the internal partitions and including corridors within their zones to ease the simulation process. Offices are occupied most of the time, according to the building occupancy profile (to be introduced in the next section). In terms of people occupancy, a 16 m2/person is assigned with maximum sensible gain of 90W/person and latent sensible gain of 60W/person. For lighting, fluorescent lamps are assigned according to the Society of Light and Lighting requirements (High Technology Lighting, 2016), and based on luminance level of 500 lux for offices spaces, with 11w/m2 as a maximum power consumption. Since the building is equipped with occupancy sensors, the dimming profile has been set to 80% of the lighting profile.

For office equipments, computers have been set at 10 W/m2 for maximum power consumption, as well as sensible gain and is set to the same occupancy profile.

- *Manager Rooms*

The internal gain in these rooms for people occupancy is assigned to 45m2/person, while lighting and computers are assigned the same type and power as the office template.

- *Washroom*

The internal gain in this zone is based on the fluorescent lighting which is set at 9W/m2 for both maximum power consumption and sensible heat gain.

- *Kitchen*

Florescent lighting is assigned to a maximum power consumption of 13w/m2. Also, cooking is assigned to 10W/m2 as maximum power consumption.

- *Services*

This template covers the electrical and telephone rooms. Florescent lighting is assigned 13W/m2 as maximum power consumption. Also, a low-voltage breaker 50-100 amp with 20 W/m2 (Engineering Toolbox, 2016).

- *Stair-cases*

The internal gain in this zone is based on the fluorescent lighting which is set at 9W/m2 for both maximum power consumption and sensible heat gain.

- *Nursery and Meeting Rooms*

This template is applied for meeting rooms, as well as the nursery. The internal gain for these spaces includes florescent lighting with 11W/m2. Since the nursery is not occupied most of the time and the meeting rooms are used internally, no internal gain from occupancy was assigned for this template.

4.4.2.4 Air exchanges

- All zones are set to a 0.35 air change per hour ACH as an infiltration except entrance zones, where infiltration is set o 0.5 ACH
- Auxiliary Ventilation is set to 3 ACH (external air + 2°C offset temperature) working according to the cooling system profile.

4.4.3 Simulation profiles

Many different profiles can be created by the APpro, the profile database to describe the time variation of thermal input parameters; they include daily, weekly and annual profiles.

For MOID building, many multiple profiles have been created to schedule the HVAC system, lighting, building's equipment, in addition to defining varying set-points. MOID's baseline occupancy profile has been created based on the Federal buildings' occupancy profile in the UAE. However, the other profiles were created based on interviews with people in charge of operating this building.

For occupancy, HVAC and lighting, *Modulating type* profile has been followed. However, *Absolute type* profile has been used to define the building's different set points in summer, winter, as well as daytime and nighttime.

For daily profile, the occupancy and equipment follow the same modulating profile as shown in Table 4.3.

Although the working hours for all federal buildings are 7 hours, there is flexibility in choosing whether to start the shift at 7 AM-2 PM or 9AM-4 PM. which makes the actual building operating hours stretches to 9 hours. Figure 4.10 shows the weekly profile that was created based on these working hours.

Table 4.3: MOID Occupancy/Equipments Profile (IES VE, APpro Database)

MOID Occupancy 7-4 PM
DAY_0006 Modulating

	Time	Value
1	**00:00**	**0.000**
2	**07:00**	**0.000**
3	**07:00**	**1.000**
4	**16:00**	**1.000**
5	**16:00**	**0.000**
6	**24:00**	**0.000**

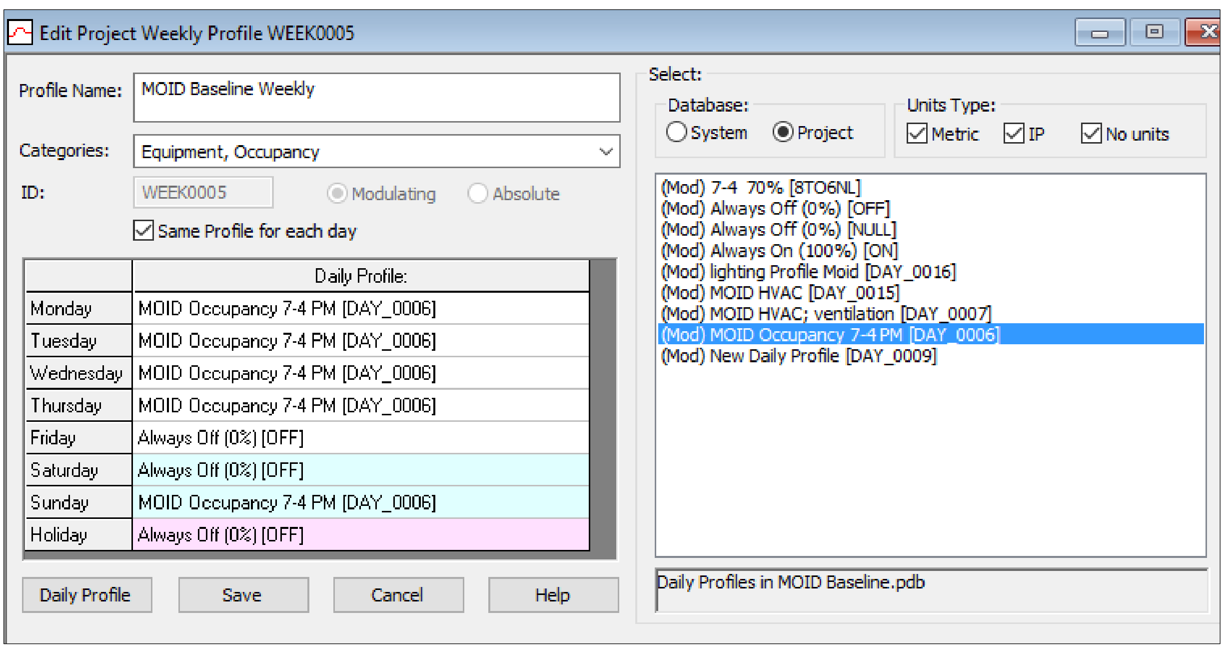


Figure 4.10: MOID Occupancy and Equipment Weekly Profile (IES VE, APpro Database)

On the other hand, for the HVAC system, the absolute profiles for summer and winter are show in Figure 4.11. It is clear that HVAC used to work 24/7 most of the time with 21°C as a set-point for summer period and 24°C for winter time.

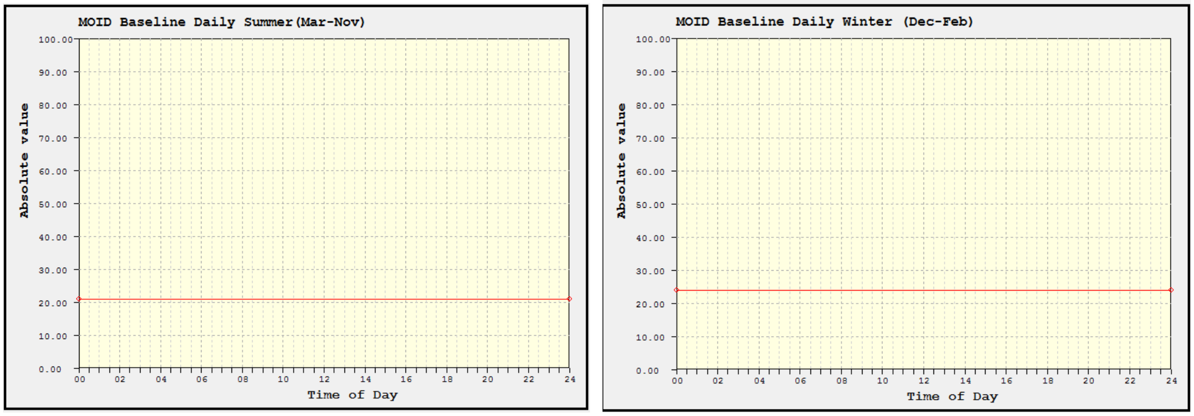


Figure 4.11: Daily HVAC Profile Summer & Winter (IES VE, APpro Database)

Since the HVAC system relies on manual operation, most of the time it was left working, even on the weekends. Moreover, the annual profile is a repetition of the weekly profile; however, two profiles were set one for summer (Mar-Nov) and the other for winter (Dec-Feb). (Figure 4.12)

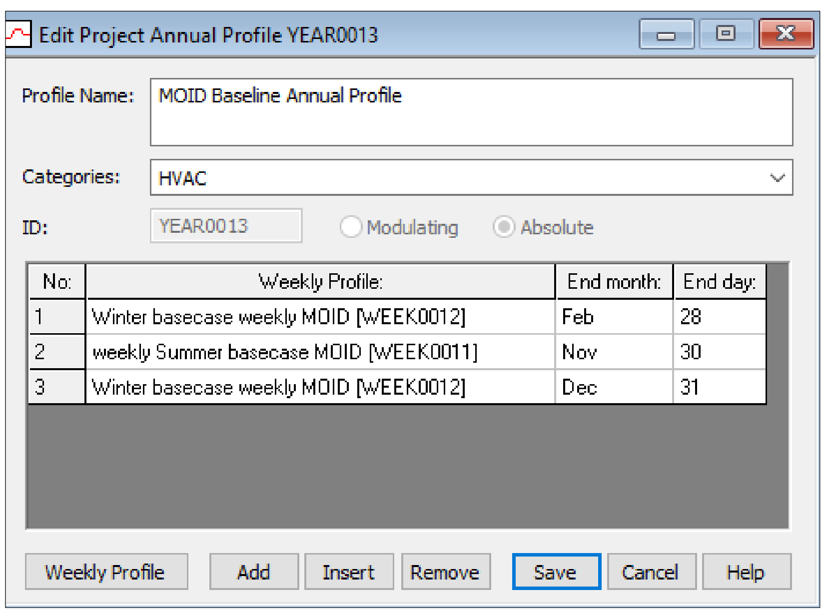


Figure 4.12: Annual Profile (IES VE, APpro Data base)

Regarding the lighting profile, it is worth mentioning that the building is equipped with occupancy motion sensors. For that, the lighting system variation profile is set as the occupancy profile from 7-14 weekdays. The dimming profile is set to 80%, as shown in Figure 4.13 for some areas such as offices, where the nature of work for many employees demands site visits several times during the week. Also, this dimming profile was set to meeting rooms that are only used occasionally.

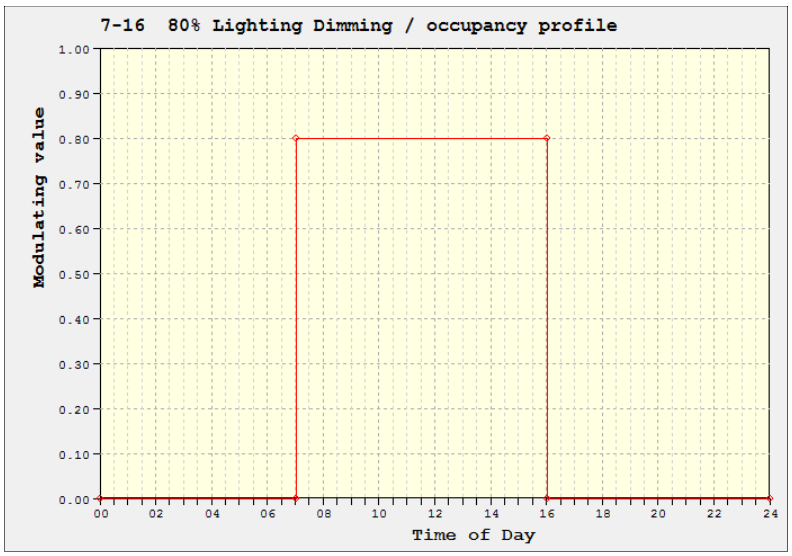


Figure 4.13: Lighting Dimming Occupancy Profile

4.5 Simulation Scenarios

Different sets of scenarios are designed to analyze some selected retrofit measures and their impact on reducing energy demand or producing energy supply. These sets are grouped into three categories: baseline, passive measures and active measures with 33 scenarios in total.

The first category consists of the baseline scenario (used for software validation in Section 3.5) which presents the existing building as it was constructed. This scenario will be the reference to which all other scenarios will be compared to.

The passive category has three sets of simulation with multiple scenarios under each set. The first set: offers different approaches to mitigate the solar radiation. It consists of seven scenarios to assess the following:

- Vertical shading elements

- Horizontal shading elements

- Egg-crate shading elements

- PV self-shading

- The optimal shading

- Window films (assessing two values)

The second set of simulation from the passive category consists of five scenarios. The first one is to upgrade the existing building code to 1 Pearl rating configuration for opaque materials, glazing and air tightness, whilst the second one is to apply 2 Pearls configuration (Abu Dhabi Urban Planning Council, 2010). The third scenario introduces the Passivhaus standard, which is a low energy standard with EUI≤15 KW/m2/year (Building Research Establishment, 2011). Table 4.4 presents the minimum U-values for 1 Pearl, 2 Pearls and Passivhaus standards.

The fourth scenario of the third set is to use Passivhaus standards with different shading coefficient. The last scenario of this category is about applying Passivhaus standards, except for glazing, where 2 Pearls glazing standards will be used instead.

Table 4.4: Building Codes Thermal Performance values

Design Component	MIOD Base case	1 Pearl Target Value	2 Pearls Target Value	Passivhaus Limiting Values
Walls (U-values)	0.47 W/m2k	0.320 W/m2k	0.290 W/m2k	≤ 0.15 W/m2k
Floor	1.38 W/m2k	0.150 W/m2/k	0.140 W/m2/k	≤ 0.15 W/m2k
Roof	0.21 W/m2k	0.140 W/m2k	0.120 W/m2k	≤ 0.15 W/m2k
Glazing	2.1 W/m2k	2.200 W/m2/k	1.900 W/m2/k	≤ 0.8 W/m2k
Infiltration	0.35 ach	0.350 ach	0.200 ach	≤ 0.042 ach
Glazing SHGS	0.35	0.40	0.30	0.50

The fourth set of the passive category consists of one scenario which offers the optimal approach for the passive category. For "Optimal Passive" the input parameters will be chosen based on the obtained results of passive category simulations

The active category consists of 4 sets of simulation. The first one focuses on varying the cooling set-point with eight different scenarios. The second set has two scenarios about upgrading the cooling system COP with two different values. The third set of simulation offers an optimal active scenario that combines the best result of varying set point and COP.

The optimal retrofit model will consist of both optimal active and optimal passive in one scenario. The obtained result will be analyzed and the electricity energy will be offset through PV electricity production.

The last simulation set consists of eight scenarios. The first one evaluates the impact of the PV absolute installment in producing solar energy by using different PV technologies according to IES default efficiencies, whereas the second scenario will examine the absolute approach with the highest recorded efficiency for mono crystalline technology. The third and fourth scenarios follow the optimal installment that considers the south orientation using mono crystalline technology, with the default efficiency and with the highest recorded one. The fifth scenario deals with the BIPV system on the atrium skylight. The sixth scenario will evaluate combining PV panels and BIPV together using the mono crystalline technology. The seventh simulation will assess the economical approach using poly crystalline technology. Eventually, the last scenario will consider increasing the PV m2 in order to reach zero cost energy. Table 4.4 shows the matrix simulation for all categories and scenarios.

4.6 Simulation Process

The MOID's building consists of two levels with a central atrium. Its layout shows lots of partitions that are used to define office zones. It was noticed during the site visit that all these zones are connected thermally, and the doors are opened all the time. For that, to ease the IES modeling process, the researcher decided to ignore some of these partitions in areas where they share the same thermal properties such as grouping offices together and services together.

Also by understanding the employees' nature of work and the approximate pattern of utilizing some zones such as: nursery and meeting rooms, it helps provide these zones with the appropriate conditions to design their thermal templates to reflect the actual condition as much as possible.

The simulation scenarios will run for the whole building according to Table 4.5. The obtained data will be presented using Microsoft Excel program and compared to the baseline results. Table 4.4 summarizes the simulation matrix for the suggested scenarios for the different three categories.

4.7 Simulation Validation

Since all the obtained results for the proposed strategies will be compared to the results of the baseline, validating the base-case is essential in its credibility for the obtained simulated results. There are different ways and levels for validating such a project; however, the highest rank is to compare the result of the existing building simulated results to the actual electricity bills that are collected from Federal Electricity and Water Authority (FEWA). This validation issue has been clarified earlier in section 3.5.

Table 4.5: Simulation Matrix

Baseline Category			Passive Category											
			Shading Elements							Building Codes				
Scenario 1			Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13
MOID			Vertical	Horizontal	Egg-crate	PV self-shading impact	Optimal Shading	Films on Windows	Films on Windows	1 Pearl	2 Pearls	Passivhaus 1	Passivhaus 2	Opaque (passive)+ Glazing (2 Pearls)
0.47	Building elements U-values W/m^2k	External walls	Baseline U-values	Baseline U-values	Baseline U-values	Baseline U-values	Baseline U-values	Baseline U-values	Baseline U-values	0.32	0.29	0.15	0.15	0.15
0.21		Roof								0.14	0.12	0.15	0.15	0.15
1.38		Typical Floor								0.15	0.14	0.15	0.15	0.15
2.1		Glazing								2.200	1.9	0.8	0.8	1.9
0.35	SHGC		0.35	0.35	0.35	0.35	0.35	0.20	0.15	0.40	0.30	0.50	0.20	0.20
0.35	Infiltration ACH		0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.20	0.042	0.042	0.042

	Active Category																	
	Varying Cooling Set-point								Upgrading COP: 2.88		Optimal Active Strategy	Photovoltaic System						
	WH: 24°C NWH AC off	WH 21/24°C Sum/win NWH 28°C	WH 24&25 NWH AC off	WH 24&25 NWH 28°C	WH 24 NWH 26°C	WH 24 NWH 28°C	WH 24 NWH 30°C	WH 24 NWH 32°C	COP 3.8	COP 5.3		Absolute PV (IES default efficiency)	Absolute PV (High Efficiency)	Optimal PV (IES default efficiency)	Optimal PV High efficiency	BIPV High Efficiency	PV+ BIPV Optimal case	PV+ BIPV Economical case
Baseline	Sc. 15	Sc. 16	Sc. 17	Sc. 18	Sc. 19	Sc. 20	Sc. 21	Sc. 22	Sc. 23	Sc. 24	Sc. 25	Sc. 27 A-D	Sc. 28	Sc. 29	Sc. 30	Sc. 31	Sc. 32	Sc 33
Optimal Passive	–	–	–	–	–	–	–	–	–	–	Sc. 26							

* WH: Working Hours

* NWH: None Working Hours

Chapter 5

Results and Discussion

5. Results and Discussion

5.1 Overview

This chapter presents the simulation results according to the provided matrix in the previous section. The simulation scenarios have been grouped into three categories: baseline, passive and active. A comparison will be held within each category's scenarios. The optimal scenario of each category will be defined and highlighted. Eventually, a simulation scenario will be conducted which consists of the optimal passive and active scenarios. Comprehensive and critical analysis of the obtained results is essential. Figures, tables and graphs will be provided to support the outcomes.

5.2 Baseline (Scenario 1)

The baseline's input parameters were explained in detailed in Chapter 4, whereas the simulation's results show that the total annual energy consumption reached up to 547.4 MWh. The majority of energy, around 75%, is dedicated for cooling purposes. Both the equipment and lighting system together consume around 25% of the total energy, as shown in Table 5.1.

Table 5.1 Energy consumption of the Baseline

Date	Total Energy MWh	Total Electricity MWh	Total System Energy MWh	Total Equip. MWh	Total Lighting MWh
Jan 01-31	12.3247	12.161	2.6816	5.4132	4.2299
Feb 01-28	13.8882	13.7403	4.7358	5.1239	4.0285
Mar 01-31	29.575	29.4113	19.0746	5.8676	4.6328
Apr 01-30	35.8229	35.6644	26.2005	5.3925	4.2299
May 01-31	51.3222	51.1585	41.6791	5.4132	4.2299
Jun 01-30	64.3606	64.2022	54.3095	5.6197	4.4313
Jul 01-31	75.767	75.6033	66.9812	4.9587	3.8271
Aug 01-31	77.5216	77.3579	67.0211	5.8676	4.6328
Sep 01-30	70.673	70.5146	61.9079	4.938	3.8271
Oct 01-31	49.8125	49.6488	40.1695	5.4132	4.2299
Nov 01-30	35.9111	35.7527	25.86	5.6197	4.4313
Dec 01-31	14.245	14.0813	4.6019	5.4132	4.2299
Total	531.2238	529.2961	415.2227	65.0405	50.9605

Figure 5.1 shows that the energy consumed by either equipment or lighting are almost in the same range all year round and do not get affected by weather changes. On the other hand, the energy consumed by the cooling system increases with the increment of dry-bulb temperature.

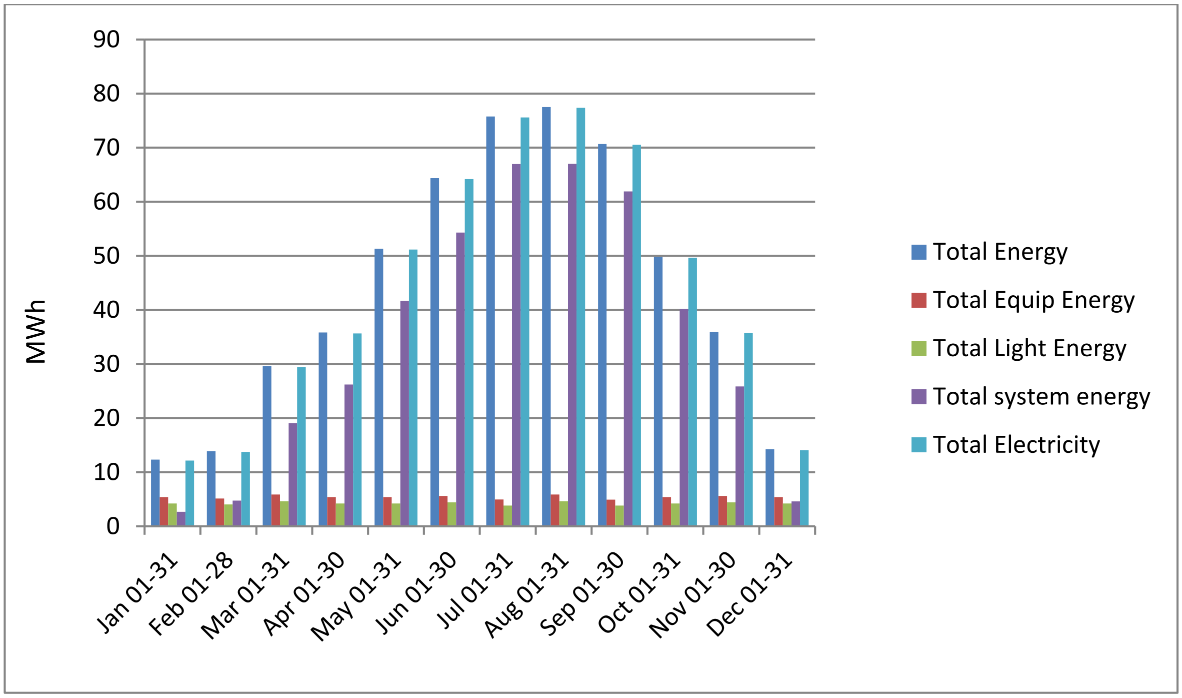


Figure 5.1: The Total Annual Energy Consumption

The maximum demand reaches its peak in the months of July and August. Although this is expected in a region with such harsh weather, the percentage is higher than average which is usually a round 59% (Alawadhi, 2014). This could be justified due to the HVAC system's continuous operation in 2015 where it worked for 24 hours year-round.

According to the previous study that was conducted on the same building by Alawadhi (2014), retrofitting the HVAC system has the greatest potential to save energy. However, Al Awadhi explained that the reason of choosing the lighting system to be assessed and retrofitted in her research over the HVAC was due to it being easier and less costly. Managing the HVAC system performance from different angles is very important when it comes to energy efficiency. By doing so, great savings in energy and money is expected.

5.3 Passive Category

This category includes passive strategies that will mitigate the impact of solar heat gain on the building, through either shading elements, window films or upgrading the thermal proprieties of the walls, glazing and roof. Protecting the building from solar heat gain in hot climate regions will reduce the energy demand for cooling purposes. However, energy saving due to shading devices is considered limited compared to other passive strategies such as well insulated envelope. It is found that a well insulated commercial building envelope could reduce around 25% of the cooling energy (Radhi, 2009). However, the bigger the percentage of the glazing, the more important it is to provide shading. According to the previous simulation matrix Table 4.4, shading scenarios will examine the impact of different shading approaches such as: horizontal, vertical, egg-crate and the impact of the PV panels self shading on the roof.

The first step is to analyze the building's orientation to define the needed windows for shading. Figure 5.2 shows how the building's front elevation oriented at angle of 45° west from the Northern direction.

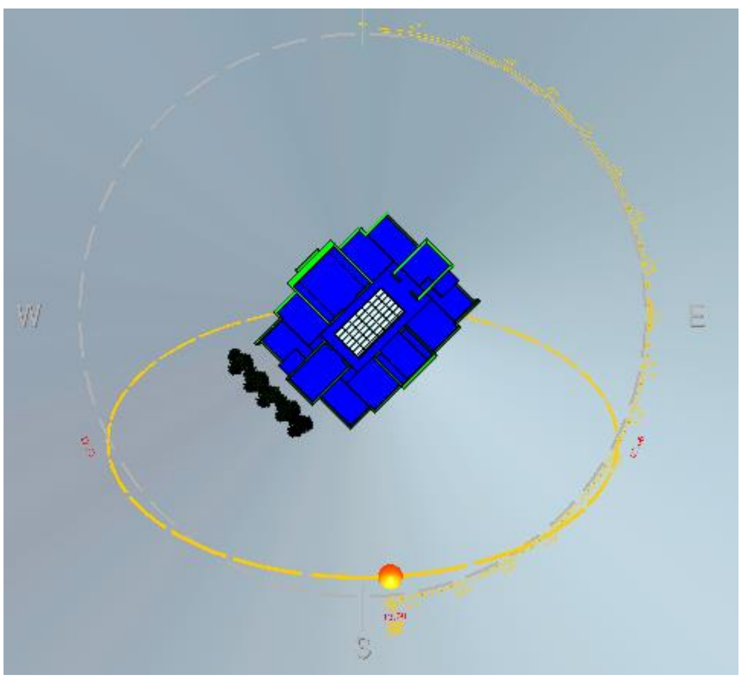


Figure 5.2: Sun path and building orientation. (IES VE, Model Viewer)

As a result, the building's southeast and southwest elevations are exposed to the sunlight, thus more heat gain is expected than the other two elevations. Table 5.2 shows the percentage of glazing of the wall area and their orientation. It is clear that the higher percentage of glazing 35.2% is facing south; since it lacks any protection from sun, solar heat gain is more likely to occur.

Table 5.2: The Baseline walls and glazing areas and orientation. (IES VE, ModelIT)

Orientation	Above-grade wall area (m^2)	Vertical glazing area (m^2)	Vertical glazing area (%)
North	376.5	110.7	29.4
East	277.9	60.7	21.8
South	376.5	132.4	35.2
West	277.9	66.2	23.8
Horizontal	1196.4	106.5	8.9

5.3.1 Shading measures (Scenarios 2-6)

The baseline building lacks any consideration for any kind of shading elements, except horizontal shading for the main entrance which is orientated northwest as shown in Figure 5.3. The main concern is to focus on the affected elevations which are exposed to solar gain, for that, only southeast and southwest are chosen to be implemented with shading strategies.

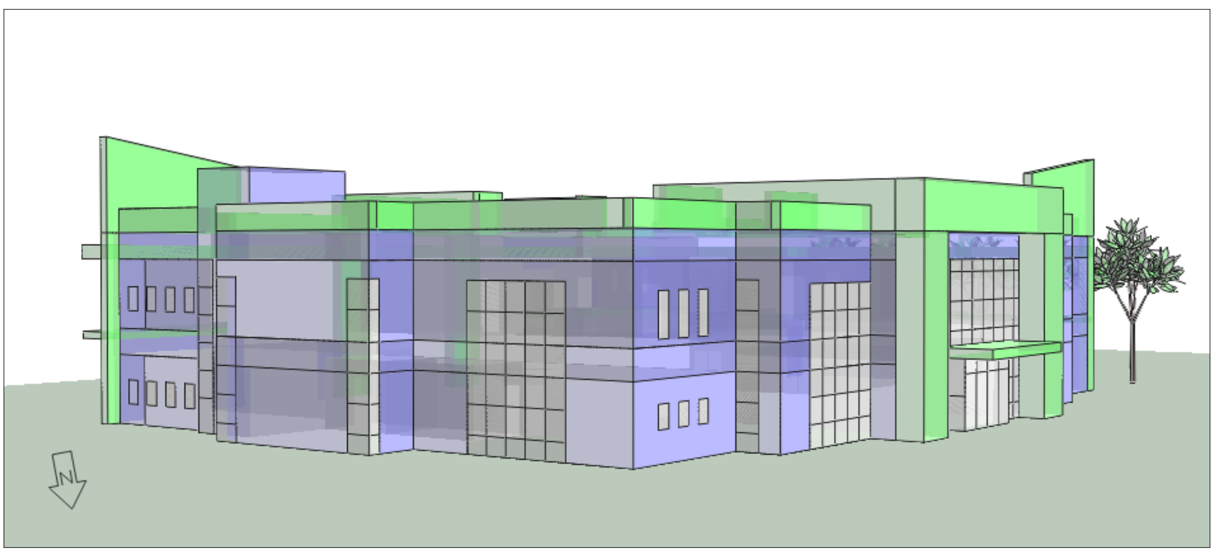


Figure 5.3 The only shading element on the main entrance (IES VE, ModelIT)

Shading elements come in diverse shapes that suit different orientations. Overhang elements provide good protection for southern elevations in the northern hemisphere; on the other hand, vertical fins are considered a better choice for east and west elevations. However, both types could not provide full protection from the sun rays. According to Givoni (1996), a frame that consists of overhang, in addition to vertical fins which are 45° slanted towards the north, is the best shading shape that could provide full protection. In this work, horizontal, vertical and egg-crate will be examined and their impact on reducing the HVAC system's energy will be evaluated.

Scenario 2 proposes a horizontal 2 m. cantilever for both levels on the southeast and southwest elevations as shown in Figure 5.4, whilst Scenario 3 proposes vertical fins with two meters depth. (Figure 5.5).

Figure 5.4: Scenario 2 proposes 2m.Cantilever (IES VE, ModelIT)

Individual simulations have been conducted for both scenarios to highlight the impact of each design on reducing the system's cooling load. It is found that the horizontal cantilever reduces the system's total energy from 415.2 MWh to 410.4 MWh which is equivalent to 1.2% reduction. On the other hand, the vertical fins in Scenario 3 shows a reduction in the system's energy from 415.2 MWh to 411.0 which equals to 0.99% reduction.

Scenario 4 proposes the egg-crate style as a shading alternative as it shows in Figure 5.6.

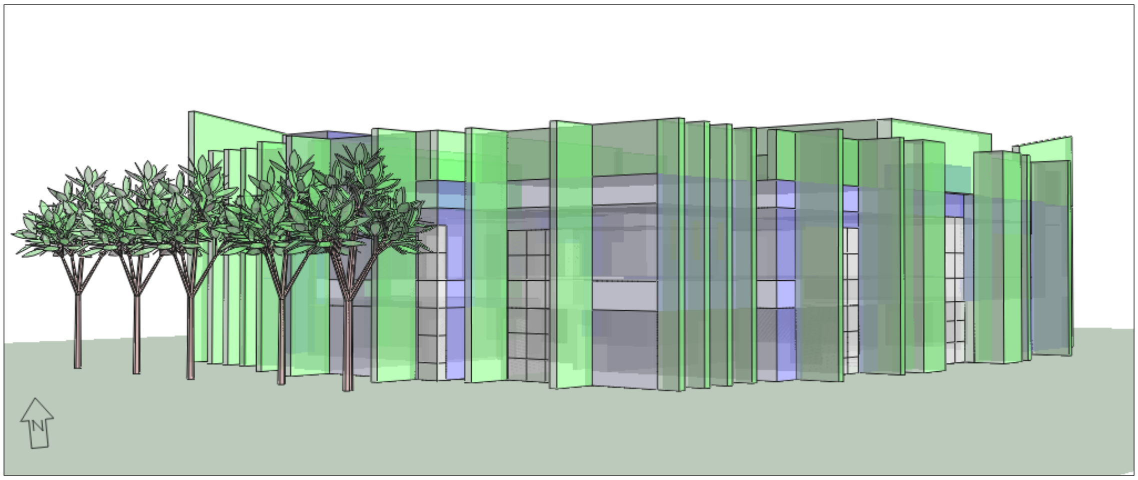


Figure 5.5: Scenario 3, 2m. vertical fins (IES VE, ModelIT)

Figure 5.6: Egg-crate shading (IES VE, ModelIT)

Egg-crate style consists of overhang and vertical fins. It is found that such a type of shading could reduce the system's energy demand from 415.2 MWh to 407.3 MWh, which is equivalent to 1.9%.

Also, since providing PVs are among the implemented active strategies, it is expected to cast shading on roof. In case of PV absolute shading that follows the roof shape, it is found that PV modules will reduce the cooling system energy by 0.58%. The last scenario consists of both

Scenarios 4 and 5 combined in one simulation where the egg-crate type shows the best performance in reducing the cooling demand compared to horizontal and vertical shading elements, in addition to the PV self-shading. Table 5.3 summarizes the saving in energy for each scenario, while Figure 5.7 shows the impact of each shading design on reducing the system's energy demand. Appendix D contains more detailed values for electricity and total energy reduction.

Table 5.3: Monthly total system energy MWh with different shading scenarios

Date	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
	Baseline	Horizontal shading	Vertical shading	Egg-crate shading	PV self-shading	Optimal shading
Jan 01-31	2.6816	2.5666	2.5624	2.3772	2.6761	2.3593
Feb 01-28	4.7358	4.4838	4.5284	4.2162	4.6734	4.1901
Mar 01-31	19.0746	18.6642	18.7274	18.3569	18.8762	18.322
Apr 01-30	26.2005	25.7359	25.8144	25.4596	25.9675	25.4289
May 01-31	41.6791	41.2007	41.2595	41.0025	41.4224	40.9764
Jun 01-30	54.3095	53.8946	53.9119	53.7424	54.056	53.7194
Jul 01-31	66.9812	66.5337	66.5669	66.3614	66.71	66.3328
Aug 01-31	67.0211	66.5045	66.6115	66.2714	66.7534	66.2396
Sep 01-30	61.9079	61.3681	61.5222	61.0726	61.651	61.0352
Oct 01-31	40.1695	39.6337	39.7535	39.2813	39.9112	39.2329
Nov 01-30	25.86	25.4435	25.4332	25.071	25.6308	25.0214
Dec 01-31	4.6019	4.4025	4.3579	4.1169	4.5307	4.0871
Total	415.2227	410.4319	411.0491	407.3293	412.8586	406.9452
System Energy saving		1.2%	0.99%	1.6%	0.58 %	1.99%

It is noted that the shading on roof by PV panels doesn't offer the expected reduction, whereas the roof is considered the most building's element that is exposed to solar heat gain and responsible alone for around 60% of cooling energy (Maneewan et al. 2004).

To investigate more on the impact of PV self shading on reducing heat gain, an office zone facing north in the upper level has been chosen for further analysis. The analysis was conducted in two parts: the occupied zone and the attached false ceiling zone. It was found that the external conduction gain dropped from 1.44 MWh to1.21 MWh, which is equivalent to 16% reduction. However, it is important to mention that this happened in the void zone that is designated for the false ceiling. Figure 5.8 shows the conduction gain, both external and internal, for the upper void zone.

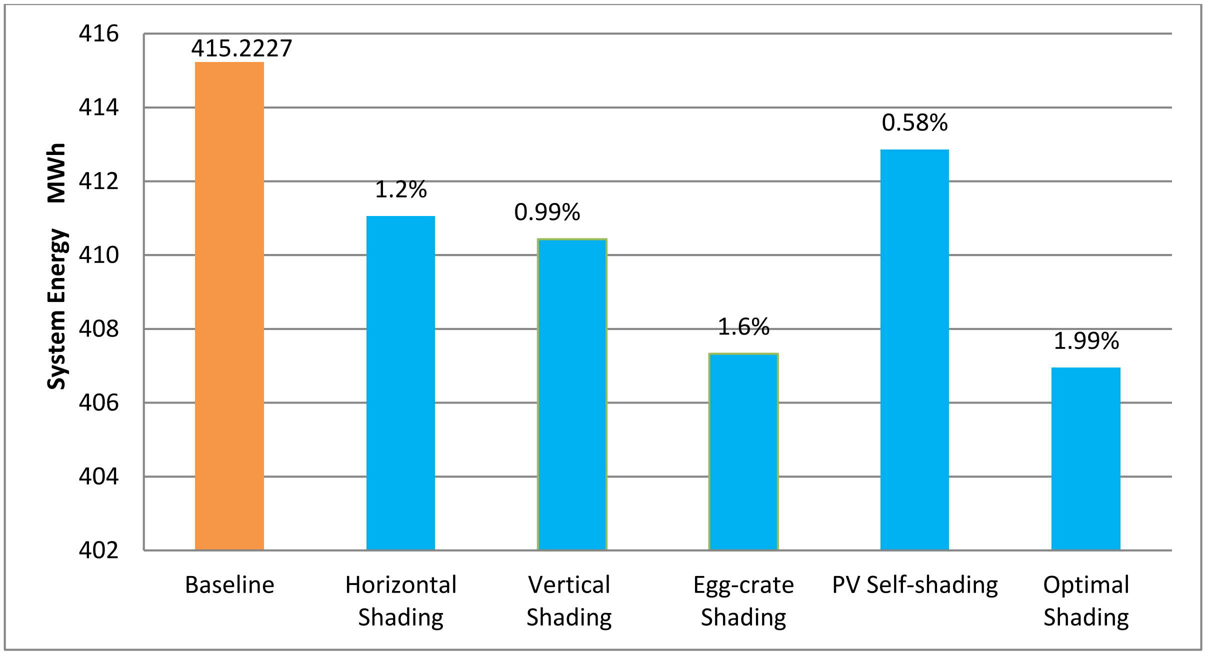


Figure 5.7: The impact of shading on total system energy (source: Author)

However, by analyzing the occupied air-conditioned office zone, it was found that the external conduction gain was almost the same with a total around 2.5 MWh. This could be explained due to the zone's orientation where it is facing north, in addition to being topped with a void zone for mechanical installments. On the other hand, the total internal gain for this zone dropped from 2.8 MWh to 2.6 MWh as a result of the PV self-shading. See Figure 5.9.

In terms of PV shading impact on the total HVAC system energy reduction, it is noticed that the impact was limited and does not exceed 0.6%. It is worth mentioning that PV modules occupy around 514.2 m2, which is around 50% of the roof's total area. Moreover, the baseline roof's U-value is 0.21 W/m2k, which is considered a green value since Dubai's Green Regulation roof's U-value is 0.3 W/m2k. All of these factors minimized the effect of the PV self-shading impact on the total system energy.

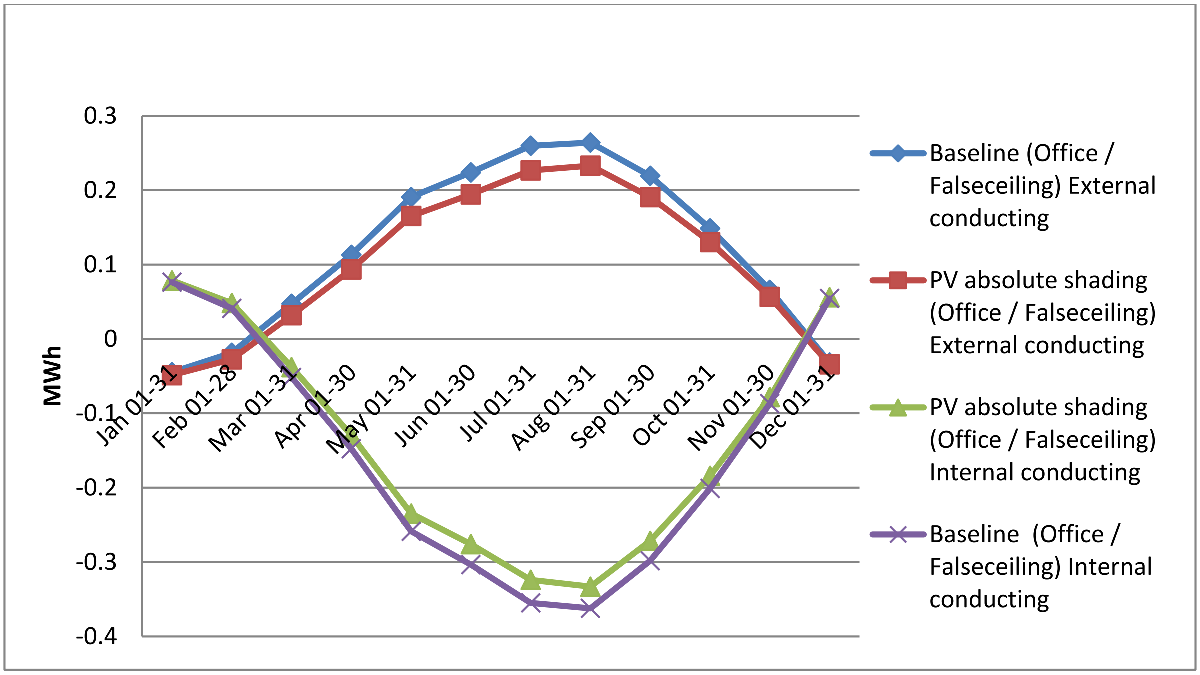


Figure 5.8: Impact of PVs shading on external and internal conduction gain for office false ceiling zone.

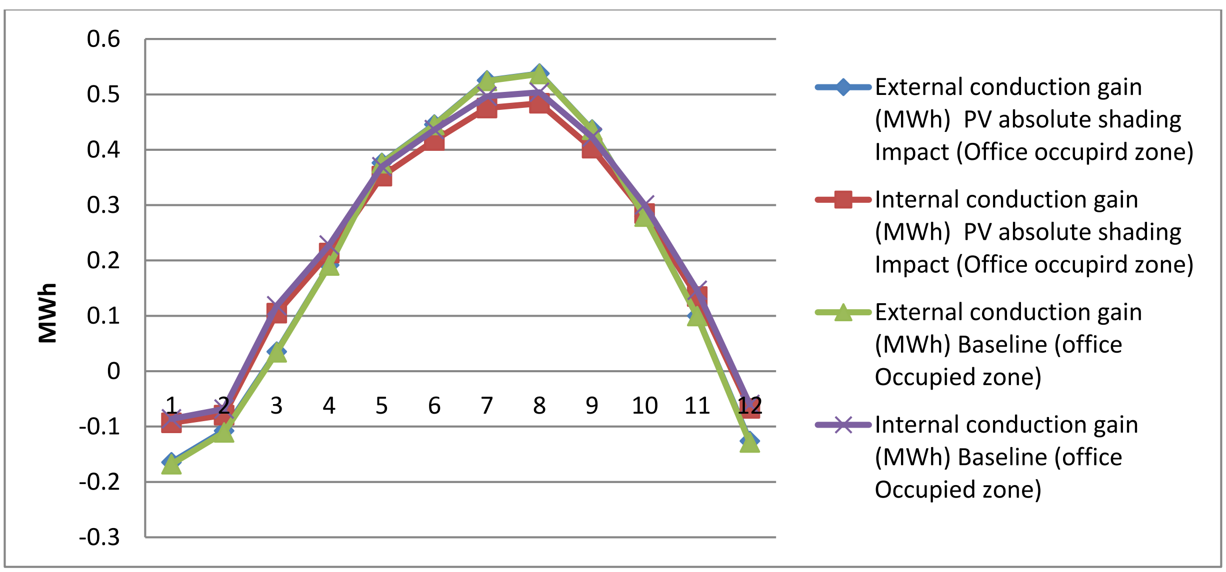


Figure 6.9: Impact of PV self-shading on Internal and External Conduction Gain for an office air-conditioned zone

5.3.2 Window Films (Scenarios 7&8)

Solar window films are another approach that is being used to mitigate the solar gain through windows. Using this strategy is beneficial both environmentally and financially (Chan et al. 2008). The closer the solar shading coefficient (SC) is to zero, better protection from solar heat gain could be achieved. However, a balance between blocking solar gain and providing the needed daylight is a very important aspect (David, et al. 2011).

For this study, window films are applied on the Southeast and Southwest glazing. The films are installed on 70% of the glazing area, keeping the upper part with its baseline SC = 0.35 in order to allow daylight to penetrate deep inside the building.

Scenario 7 proposes window films with SC=0.2, whilst Scenario 8 offers window films with SC=0.15. The SC values have been chosen based on the available films with the lowest SC in the UAE local market (EMS, 2016).

Applying window films with SC = 0.20 on 70% of the glazing provides 3% reduction in total system energy, whilst the reduction could reach up to 4.2% if the films were applied on all the glazing area. On the other hand, window films with SC=0.15 on 70% of the glazing could offer 4.1% saving in total system energy. (Figure 5.10).

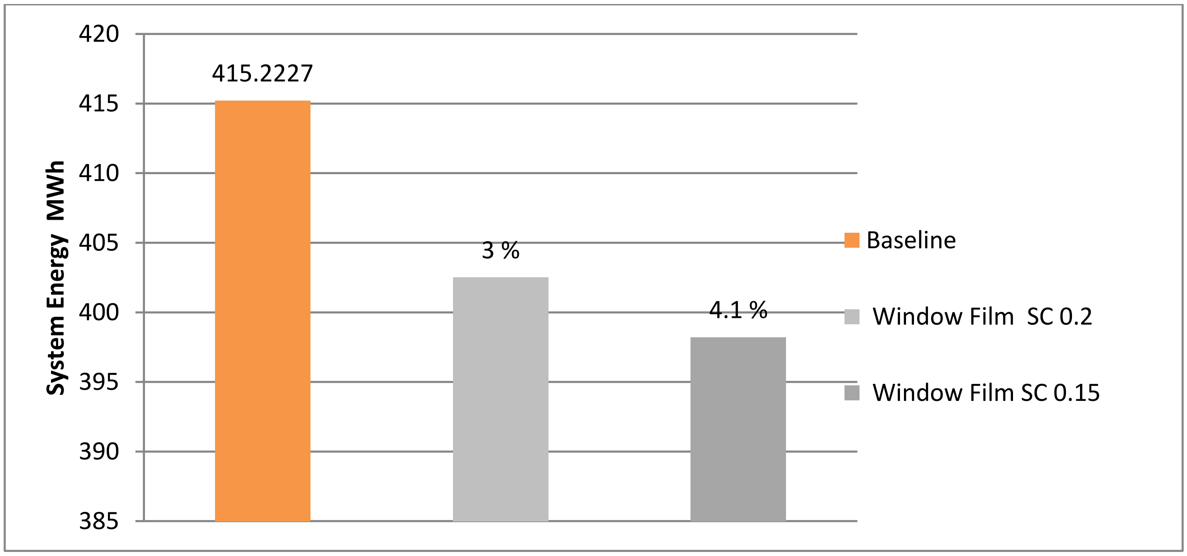


Figure 5.10: window films on 70% of glazing (southeast &southwest) on reducing system energy

However, in the UAE local market, the most common type of window films are the ones with SC=0.2. A Senior Engineer in Energy Service Management (ESM) Company mentioned that, although SC=0.15 offers more saving, the SC=0.2 allows for better view which clients prefer (EMS, 2016).

5.3.3 Upgrading the Building Code (Scenarios 9-13)

Building codes worldwide have been designed in a way to reduce the building's impact on the environment, with a chance of making them more efficient over time. For example, some energy codes for commercial buildings in the United States such as standard 90.1.2013 and IECC 2015 offer extra savings by 7.6% comparing to standards 90.1.2010 and IECC 2012 (CxE, 2015).

This set of simulation will examine the impact of applying more energy efficient building codes. As a first step, Estidama building regulations with its Pearls configuration (1 Pearl & 2 Pearls) will be applied. The input parameters for Scenarios 9 &10 consider the values for 1 Pearl and 2 Pearls configuration for external walls, roof, glazing, SC, and air infiltration respectively. However, Scenario 11 implements the German Passivhaus standards. Scenario 12 follows Passivhaus standards as well, with some alterations on the glazing SC by using SC= 0.2 instead of SC= 0.5 to suit the harsh hot climate of the local region of UAE. The last Scenario 13, examines the impact of replacing the triple glazing of the Passivhaus with double glazing with SC=0.2 while maintaining the other Passivhaus standards for the opaque elements. All of these values are mentioned in Table 4.3 in the previous chapter. Figure 5.10 shows the different scenarios with their impact.

It is noted that by applying 1 Pearl values, the total cooling system energy was dropped from 415.22 MWh to 408.69, which is equivalent to 1.4%. However, 2 Pearl values offer more saving where the system's energy was reduced from 415.22 MWh to 382.75 MWh which is equal to 7.8 % saving.

Regarding Passivhaus standards in Scenario11, it is noted that in the winter months (December, January and February) the system consumed more energy than 1 Pearl and 2 Pearls. This happened because of the type of glazing used in this Passivhaus standard (triple glazing with SC=0.5). In winter, when the sun is low, more solar radiation is penetrated and trapped, which eventually adds up to the internal heat gain. However, aside from the winter months, Passivhaus standard has shown more reduction in the system's energy. The annual consumption dropped to 376.23 MWh with a 9.4% reduction. Using Passivhaus standards are expected to provide more reduction in energy with smaller glazing SC.

For that, to reduce the solar radiation, Passivhaus values are used again in Scenario 12 with a glazing SC=0.2. It was found that this change was very effective, due to the building's glazing area which is around 485 m2 of the total external walls (1300 m2), 35% of this glazing is facing south. The reduction of Scenario 12 reached 16.2%.

It is important to mention that multi layered glazing does not provide the same energy efficiency in all climates Mingotti et al. (2013). Since Passivhaus standards, with its triple glazing, is more appropriate for cold climates, the last scenario will examine using Passivhaus values for opaque building elements; however, glazing will be replaced with double glazing (DG) windows with SC=0.2. The obtained result was impressive. It was found that DG with a low SC could provide better solar protection than triple glazing with a high SC. Also, such a glazing combined with the opaque Passivhaus standard was able to reduce the system's energy by 15.3%. Figure 5.11 shows the impact of each scenario on reducing the system's energy demand. Table 5.4 summarizes the results of all previous passive strategies to define the optimal scenario.

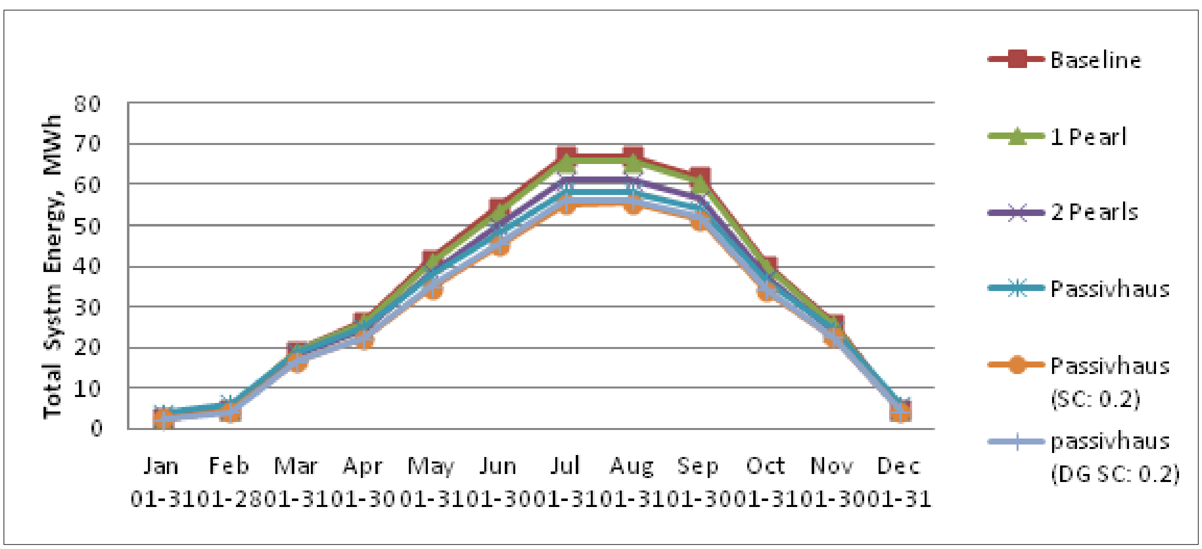


Figure 5.11: The impact of different building codes on reducing total system energy

Table 5.4: Summary for the impact of passive strategies on total system energy consumption.

Summary of Passive Strategies and Total System Energy MWh													
Date	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13
	Baseline	Horizontal Shading	Vertical Shading	Egg-Crate Shading	PV Self-Shading	Optimal Shading	Window film SC 0.2	Window film SC 0.15	1 Pearl	2 Pearls	Passivhaus Sc 0.5	Passivhaus Sc 0.2	Passivhaus Sc. 0.2 D.G
Jan 01-31	2.6816	2.5666	2.5624	2.3772	2.6761	2.3593	2.2757	2.1236	2.7255	2.6922	3.8478	2.5771	2.4294
Feb 01-28	4.7358	4.4838	4.5284	4.2162	4.6734	4.1901	4.0279	3.7744	4.8785	4.7034	6.1086	4.353	4.18
Mar 01-31	19.0746	18.6642	18.7274	18.3569	18.8762	18.322	18.0391	17.6909	19.0702	18.033	18.8935	16.618	16.5764
Apr 01-30	26.2005	25.7359	25.8144	25.4596	25.9675	25.4289	25.0061	24.6081	25.9716	24.427	24.7398	22.1633	22.3497
May 01-31	41.6791	41.2007	41.2595	41.0025	41.4224	40.9764	40.2878	39.8203	41.0246	38.388	37.6807	34.6351	35.0895
Jun 01-30	54.3095	53.8946	53.9119	53.7424	54.056	53.7194	52.973	52.5244	53.2797	49.773	47.9851	45.0085	45.6096
Jul 01-31	66.9812	66.5337	66.5669	66.3614	66.71	66.3328	65.6468	65.2003	65.5924	61.148	58.2287	55.2822	56.0584
Aug 01-31	67.0211	66.5045	66.6115	66.2714	66.7534	66.2396	65.6792	65.2278	65.6075	61.226	58.3346	55.4468	56.2531
Sep 01-30	61.9079	61.3681	61.5222	61.0726	61.651	61.0352	60.6596	60.2421	60.66	56.577	53.9742	51.3633	52.0215
Oct 01-31	40.1695	39.6337	39.7535	39.2813	39.9112	39.2329	38.9925	38.6019	39.5324	37.032	36.2366	33.8401	34.2352
Nov 01-30	25.86	25.4435	25.4332	25.071	25.6308	25.0214	24.9092	24.5983	25.6352	24.164	24.3153	22.4064	22.5107
Dec 01-31	4.6019	4.4025	4.3579	4.1169	4.5307	4.0871	4.0193	3.811	4.7133	4.5883	5.8867	4.4404	4.2683
Total	415.222	410.4319	411.049	407.3293	412.858	406.945	402.514	398.223	408.690	382.75	376.2316	348.1341	351.5818
Saving		1.2%	0.99%	1.6%	0.58 %	1.99%	3%	4.1%	1.6%	7.8 %	9.4 %	16.2 %	15.3 %

Figure 5.12 shows the impact of each passive strategy on reducing the cooling system's energy. The blue color represents the shading elements and window films scenarios, whilst green color represents building codes scenarios.

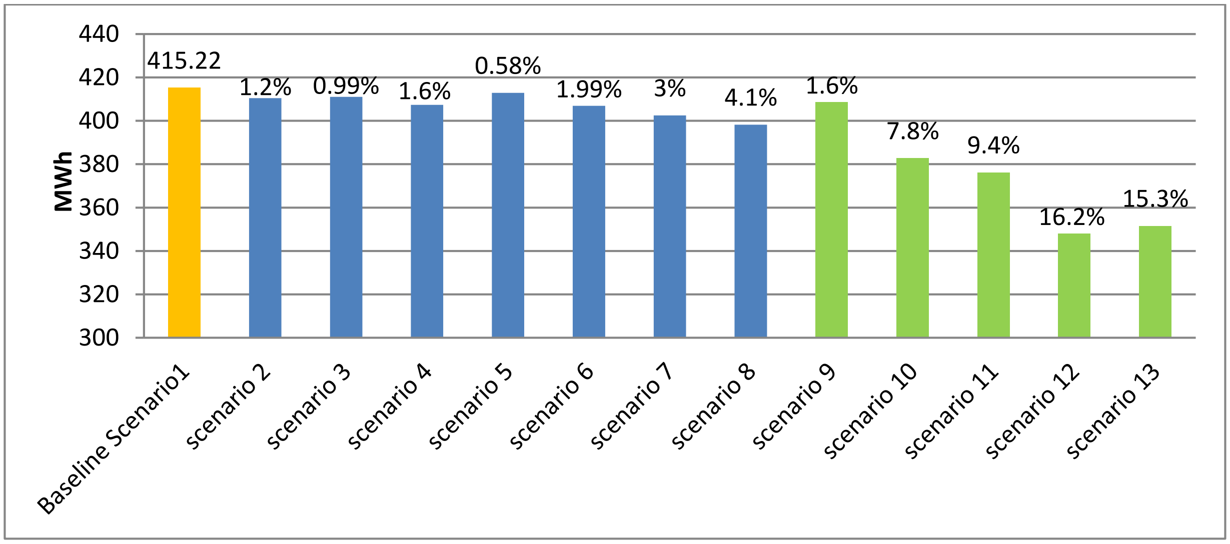


Figure 5.12: Passive scenarios and their impact on reducing cooling system energy.

5.3.4 The Optimal Passive Scenario (Scenario 14)

When defining the optimal scenario, many aspects need to be considered, such as the availability of materials as well as their cost. The highlighted strategies in the previous Table 5.4: Optimal shading, Shading Coefficient SC=0.2 and Passivhaus with double glazing are chosen to be part of the optimal scenario of the passive category (Scenario 14). Although, Passivhaus regulation with SC=0.2 (Scenario 12) could provide more saving; however, from an economical point of view, it is stated that using double glazing with a low SC is more suitable for the UAE climatic condition. Based on the obtained results, it was found that combining these strategies together could reduce the total cooling system energy from 415.22 MWh to 337.6 MWh, which is equivalent to 18.7%.

As a result, the electricity consumption dropped from 529.29 MWh to 451.7 MWh which represents 14.7% reduction in electricity consumption. Table 5.5 shows the monthly system energy, electricity and total energy consumption of the optimal passive strategies Scenario 14 compared to baseline Scenario 1.

Table 5.5: The impact of the optimal passive scenario on reducing consumed energy

	Total System Energy MWh		Total Electricity MWh		Total Energy Mwh	
	Scenario 1	Scenario 14	Scenario 1	Scenario 14	Scenario 1	Scenario 14
Date	Baseline	Optimal Passive	Baseline	Optimal Passive	Baseline	Optimal Passive
Jan 01-31	2.6816	2.1517	12.161	11.6311	12.3247	11.7948
Feb 01-28	4.7358	3.5997	13.7403	12.6042	13.8882	12.7521
Mar 01-31	19.0746	15.6585	29.4113	25.9952	29.575	26.1589
Apr 01-30	26.2005	21.1435	35.6644	30.6075	35.8229	30.766
May 01-31	41.6791	33.5882	51.1585	43.0675	51.3222	43.2313
Jun 01-30	54.3095	44.1018	64.2022	53.9945	64.3606	54.1529
Jul 01-31	66.9812	54.4649	75.6033	63.087	75.767	63.2507
Aug 01-31	67.0211	54.558	77.3579	64.8947	77.5216	65.0584
Sep 01-30	61.9079	50.4263	70.5146	59.033	70.673	59.1913
Oct 01-31	40.1695	32.7736	49.6488	42.253	49.8125	42.4167
Nov 01-30	25.86	21.4075	35.7527	31.3001	35.9111	31.4586
Dec 01-31	4.6019	3.7565	14.0813	13.2359	14.245	13.3996
total	415.2227	337.6304	529.2961	451.7038	531.2238	453.6313
Reduction		18.7 %		14.7 %		14.6 %

Figure 5.13 compares the total system's energy, electricity and total energy for Baseline Scenario 1 and the optimal passive Scenario 14.

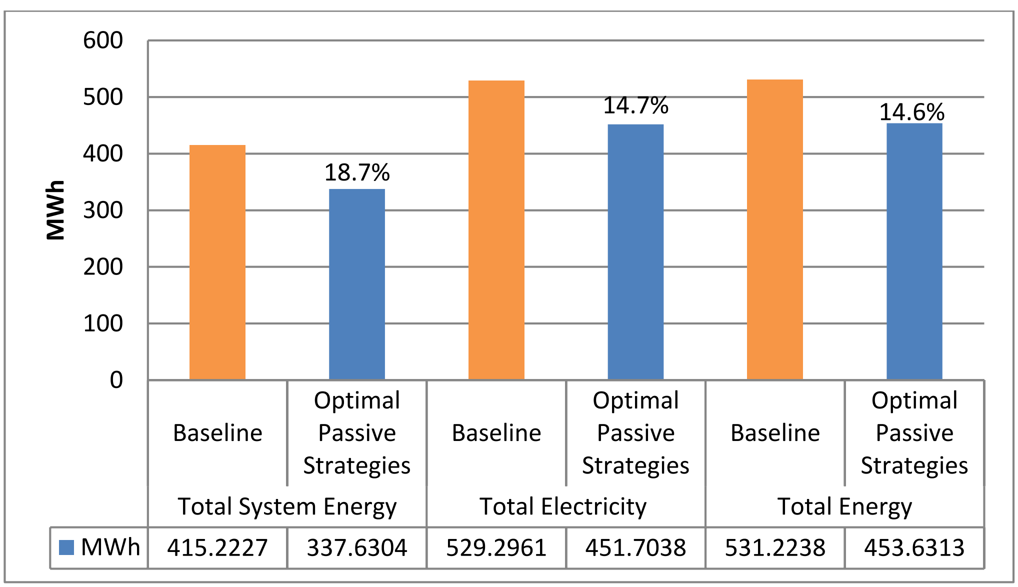


Figure 5.13: Comparison between the Baseline and the optimal passive strategies scenario.

5.4 Active Strategies Category

Three sets of simulation, with many scenarios for each set, will be conducted. The first set is about varying the cooling set-point, eight scenarios will be assessed. The second set of simulation consists of two scenarios which focus on upgrading the cooling system (COP). Finally, the last set will assess different approaches of implementing PVs.

5.4.1 Varying Cooling Set-Point (Scenarios 15-20)

The big portion of the buildings' total energy consumption goes for cooling purposes. Increasing the cooling set-point is the easiest retrofit measure with no cost and without compromising thermal comfort.

Although the working hours for MOID-RAK are from 7 AM- 4 PM, the cooling system is usually left on continuously. Also, after interviewing some people in charge, it was found that employees have an easy access to the cooling set-point thermostat and can change it according to their personal thermal comfort. The building's cooling system set-point is supposed to be set 23°C ± 1°C, but in reality, during most of the year 2015, the system was working with a cooling set-point temperature of 21°C for the nine summer months, whilst in winter months, the set-point is usually set for 24°C.

Increasing the cooling set points is considered among the measures that provide great saving with zero initial cost. According to Itani et al. (2013), a 1°C increment in the cooling set-point will offer a 7.3% saving in cooling load and 3.4% in total energy consumption.

Analyzing the Dubai Chamber of Commerce and Industry building as a successful retrofitted case shows that among the retrofit strategies that have been implemented is increasing the cooling set point to 24°C all year round; also, air conditionings have been shut off after working hours (USGBC, 2016). For this research, many scenarios have been proposed to control the cooling system profile during working hours (WH) and non working hours (NWH) which are summarized in Table 5.6.

Table 5.6: Summary of varying cooling set-point scenarios

Scenario 15	**Scenario 16**	**Scenario 17**	**Scenario 18**	**Scenario 19**	**Scenario 20**	**Scenario 21**	**Scenario 22**
WH: 24°C NWA: AC off	WH; 21/24°C (Sum/win) NWH : 28°C	WH: 24 / 25°C NWH: AC off	WH: 24/ 25°C NWH: 28°C	WH: 24°C NWH : 26°C	WH: 24°C NWH : 28°C	WH: 24°C NWH: 30°C	WH: 24°C NWH : 32°C

For Scenario 15, the cooling system's profile designed to work according to occupancy profile where the set point is kept 24 °C all year. For simulation, modulating style profile is used for this scenario, figure 5.14.

It was found that the total system energy plummeted dramatically from 415.22 MWh to 149 MWh which is equal to 64% reduction. However, shutting off the cooling system in such a hot region such as the UAE needs to be combined with other precautions to prevent any damages for the interiors due to the high temperature and humidity during summer times.

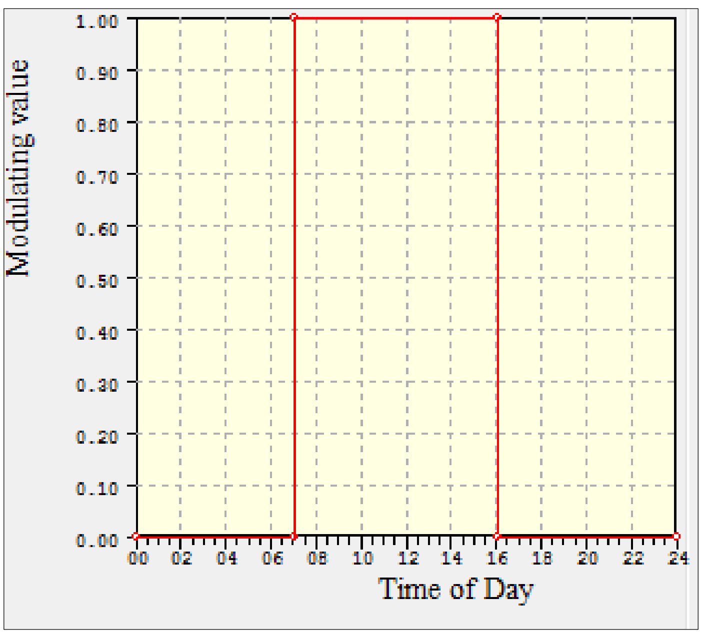


Figure 5.14: Cooling system working profile.
(IES VE, AP pro)

The atrium central zone has been chosen to analyze the air temperature during non working hours for Scenario 15. It was found that the maximum value of air temperature could reach 47.03°C on 24 July at 3:30 PM, which is almost the same as the dry bulb temperature of 47°C.

The second scenario in this set (Scenario 16) is to keep the cooling set-point profile BAU from 7-16: 21°C in summer and 24°C in winter during working hours only; however, the cooling set point will be set higher for non working hours and weekends to reach to 28°C. Figure 5.15 shows the absolute profiles that are designed for input parameters.

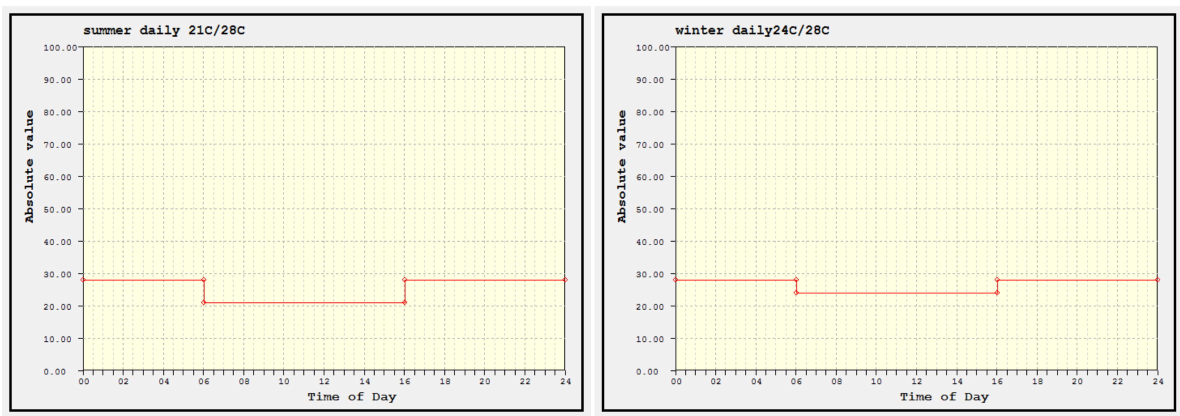


Figure 5.15: Scenario 16 daily cooling set point for summer and winter (IES VE- AP pro)

In this scenario the HVAC system shows around 38% energy saving, where the total energy consumption reduced from 415.22 MWh to 258.42 MWh.

It was found that increasing the set-point from 24°C to 25°C in all MOID building's zones could offer an extra 5.3% saving in system's energy more than Scenario 15; however, in order to not compromise the occupants' thermal comfort, 25°C as a cooling set point will be assigned only to specific zones. Analyzing the building orientation shows that the offices zones are mainly facing Northeast and Northwest, which means less solar heat gain comparing to other zones that are facing Southeast and Southwest. Also, some zones that are used for short periods of time (transit zones), regardless their orientation, can handle higher cooling set points such as washrooms and service rooms. For Scenario 17, the same profile of Scenario 15 will be used; however, 24°C will be set only for zones that are expected to be exposed more to solar gain including the central atrium. On the other hand, the other zones will be set to 1°C higher for the cooling set-point to reach 25°C, in addition to NHW; the AC will be shut off. This scenario has shown a drop in the system's energy from 415.22 MWh to 143.02 MWh, which is 65.5% saving. This shows that increasing 1°C cooling temperature for some zones adds an extra saving of 4%.

Scenario 18 follows the same profile of Scenario 17 for WH only; however, for NWH, the system cooling set point is set to 28°C. This approach reduced the system's energy from 415.22 MWh to 214.22 with 48.4% saving of the baseline case.

To analyze the impact of varying cooling set point during non working hours (NWH) on reducing system's load while considering the air temperature. A few more Scenarios (19-22) have been conducted to define a trend for NWH cooling set point. The cooling set point during WH will be set as 24°C for all scenarios; however, for NWH including weekends and holidays, the system's cooling set point will be set to 26°C, 28°C, 30°C, 23°C for scenarios 19, 20, 21, 22, respectively. Figure 5.16 shows the absolute profile for Scenario 20 as an example.

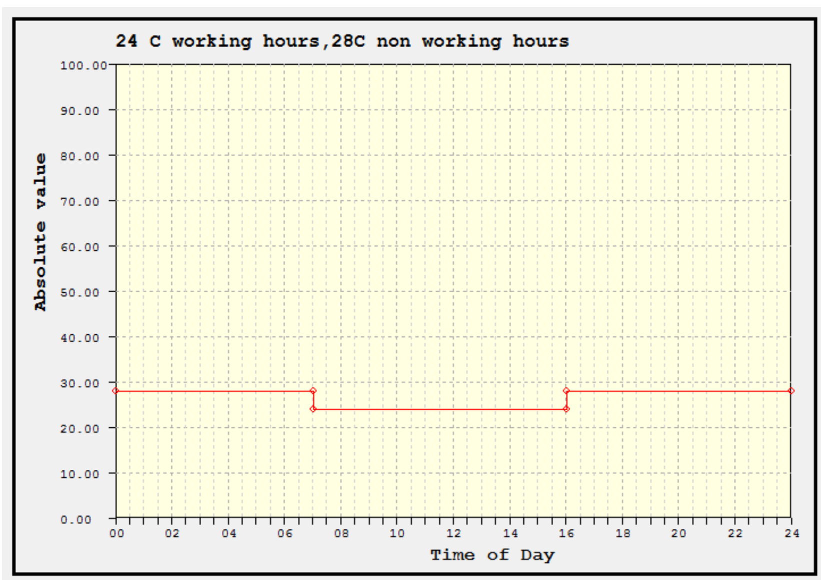


Figure 5.16: Daily profile for scenario 20,
7-14:24°C, 14-7:28°C (IES VE- AP pro).

Figure 5.17 presents Scenarios 19-22 to analyze the impact of increasing the cooling set point for non working hours in case of leaving the AC on continuously. It is noted that the higher the temperature, the more saving. However, at a certain temperature, the reduction becomes only minimal.

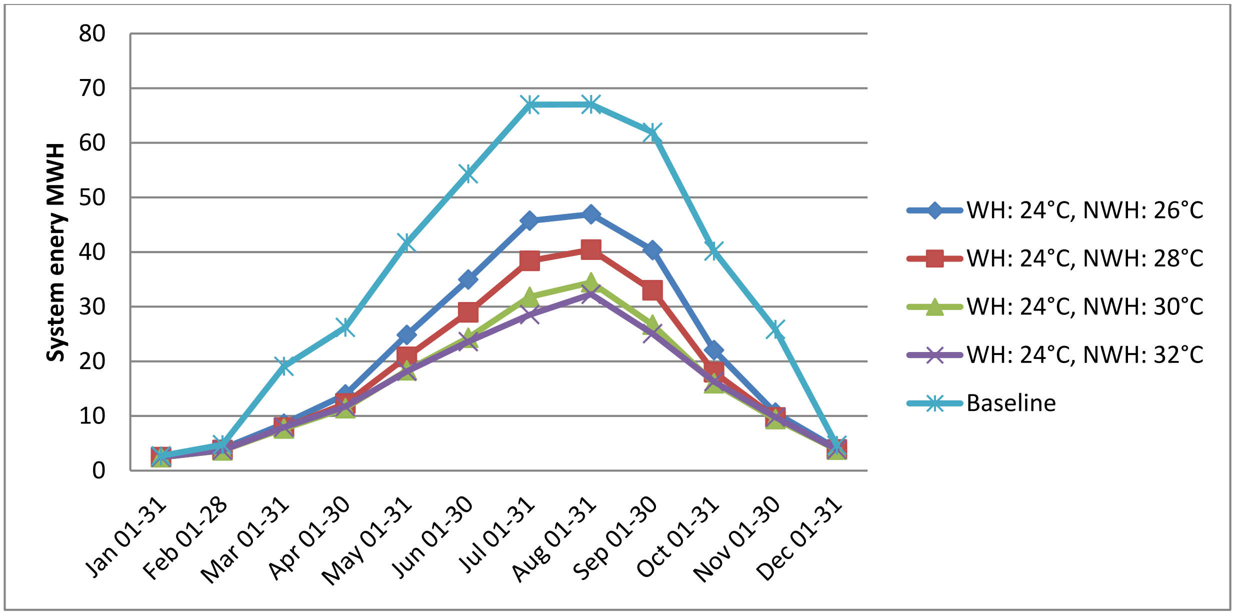


Figure 5.17: Baseline and scenarios 19-22 and the impact of varying non working hours cooling set point on cooling system.

To form a complete picture of this retrofit measure, it is important to evaluate the air temperature with each scenario. High temperature during nonworking days could cause undesirable damages for the building interior. Table 5.7 summarizes some of the obtained results for each scenario, including system energy as well as the air temperature for a selected zone (the atrium central zone).

AS it shows in Table 5.7, the air temperature could reach up to 47°C (Scenarios 15 & 17) when the cooling system is off. Although these two scenarios recorded the highest energy saving by 64% & 65.5% respectively, managing this high temperature which is expected to be combined with humidity in a region of UAE is very important. The damage that may happen if this issue is neglected, may cost more than the obtained savings. On the other side, Scenario 22 shows a big percentage of saving that reaches 55.8%, whilst the air temperature does not exceed 32°C. Figure 5.18 shows the impact of each scenario (19 -22) graphically.

Table 5.7: varying cooling set point scenarios (15-22), (energy savings and Max. air temp.)

Varying Cooling set point								
	15	16	17	18	19	20	21	22
Scenarios	WH: 24°C NWH: AC off	WH; 21/24°C Sum/win NWH : 28°C	WH: 24 / 25°C NWH: AC off	WH: 24/ 25°C NWH: 28°C	WH: 24°C NWH : 26°C	WH: 24°C NWH : 28°C	WH: 24°C NWH: 30°C	WH: 24°C NWH : 32°C
System Energy	149.04 MWh	258.42 MWh	143.02 MWh	214.22 MWh	258.38 MWh	219.45 MWh	190.02 MWh	183.38 MWh
Savings	64%	37.76%	65.55%	48.4%	37.77%	47.1%	54.3%	55.8%
Max. Air Temp.	47.03	28	47.05	28	26	28	30	32
Time	15:30, 24 Jul	12:30 05/Feb	15:30, 24 Jul	12:30 05/Feb	16:30, 16/Jan	12:30 05/Feb	02:30, 09 Aug	14:30, 20/Feb

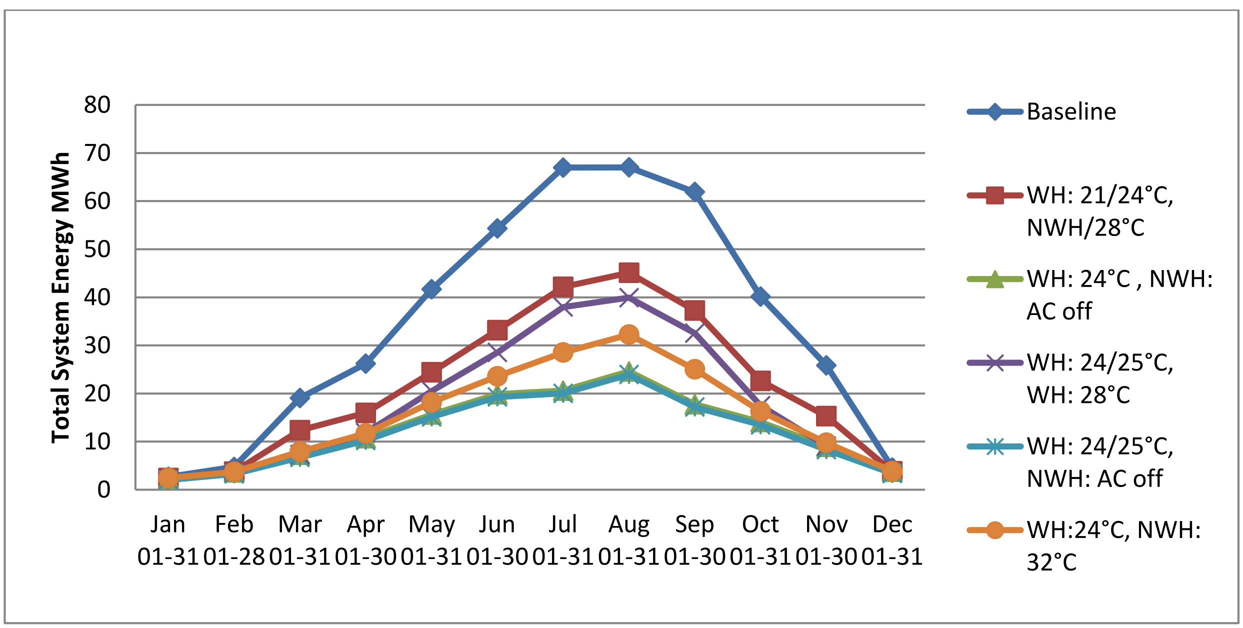


Figure 5.18: The impact of varying cooling set point on reducing total system energy

Having such a big saving in this particular strategy calls for more investigation to define the reasons behind the baseline's actual AC profile. After interviewing some employees, it was found that there were three main causes of this huge wasted energy. Firstly, the employees' easy access to controlling thermostats. Secondly, according to a mechanical engineer employee, the thermostats' location in relation to the AHU shows some defects, whereas the furthest areas from the thermostat's location always suffers from reaching the assigned set-point which causes employees to lower the cooling set-point themselves. Finally, since the building cooling system is controlled manually, individuals in charge forget to turn off the AC or raise the cooling set-point after working hours.

Eventually, deciding upon the best scenario for this strategy should consider many related issues beside energy savings. For this research the scenario with the best saving has been chosen, bearing in mind that any needed related actions are considered.

5.4.2 Coefficient of Performance COP (Scenarios 23&24)

HVAC systems typically consumes around 70% of the building's total energy consumption, where as chillers are responsible of consuming 25-35% of this energy ((HVAC HESS, 2013)

The higher the COP, the more efficient the system is. In another way of evaluating air conditioning systems, the higher the SEER, the higher the energy conservation. The SEER is defined as the total cooling output (in British thermal units or Btu) provided by the unit during its normal annual usage period divided by its total energy input (in watt-hours) during the same period. The change from SEER 10 (COP 2.9) to SEER 13 (COP 3.8) represents around 30% improvements in energy efficiency (EESI, 2002).

Since 2006, the federal government in the U.S. has required a minimum SEER rating of SEER-13 for all new air conditioners (All Climate, 2015). However, and according to ENERGY STAR, the most efficient 2016 manufactured central air conditioners, the SEER rating ranges between SEER 18 (COP 4.7), and SEER 23(COP 6.0), with few models could reach SEER27. These high efficient models could save energy in average around 30% over federal minimum (ENERGY STAR, 2016).

For MOID-RAK case study, the system's COP is 2.88 which. Two scenarios will be proposed to enhance the energy efficiency performance of the cooling's system: Scenarios 23 where the COP will be upgraded from 2.88 to the US federal minimum COP 3.8, whilst Scenario 24 will consider a COP value based on the average of the most recent efficient systems. For that, SEER 20 (COP 5.3) has been chosen for Scenario 24. The obtained results of this measure show a significant saving with simple action. For Scenario 23 with COP 3.8, the total system energy saving was 100 MWh which is equal to 24.1%, and the saving in total energy reached 18.8%.

For Scenario 23 with COP 5.3 the result showed more saving in total system energy that reached 45.4%, where the consumption dropped from 415.22 MWh to 226.51 MWh. The saving in total energy consumption recorded 35.5%.

Figure 5.19 shows the significant reduction in system's energy consumption through a simple strategy that focuses on increasing the chiller's energy efficiency performance. Moreover, Table 5.8 summarizes all the active scenarios and their impact on saving system's energy. whilst figure 5.20 presents the values of table 5.8 as a bar-graph diagram.

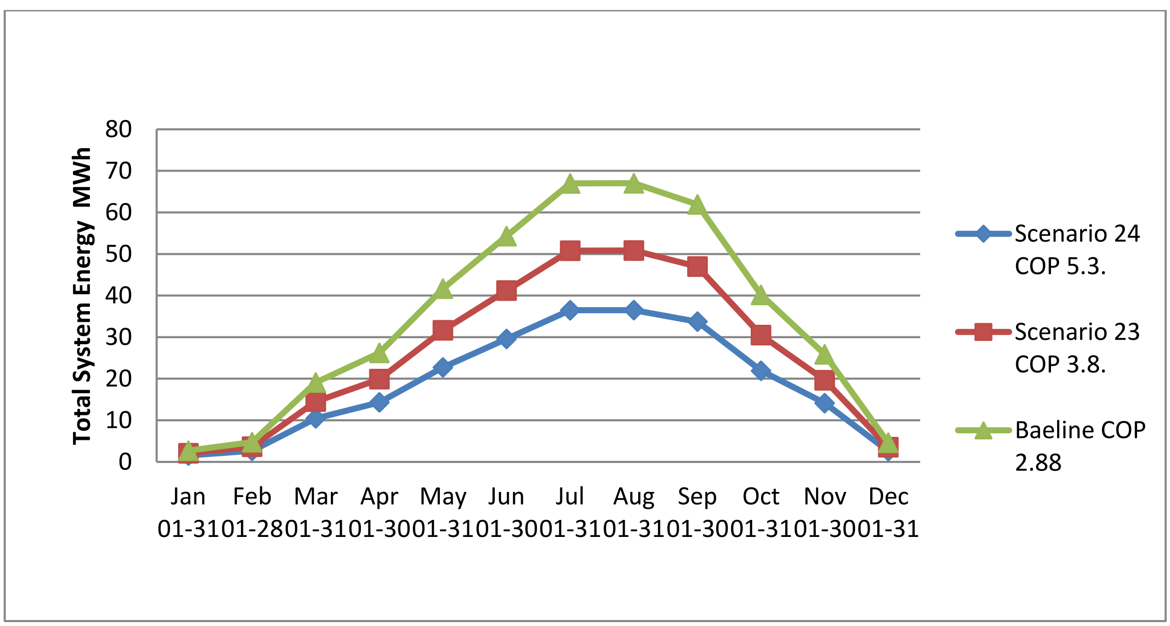


Figure 5.19: The impact of upgrading COP on total system energy.

Table 5.8: Summary of the monthly total system energy with different active retrofit measures

Total System Energy MWh											
		Varying Cooling Set-point								Upgrading COP	
	Scenario 1	Scenario 15	Scenario 16	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22	Scenario 23	Scenario 24
Date	Baseline	WH: 24°C NWH: AC off	WH; 21/24°C Sum/win NWH : 28°C	WH: 24 / 25°C NWH: AC off	WH: 24/ 25°C NWH: 28°C	WH: 24°C NWH : 26°C	WH: 24°C NWH : 28°C	WH: 24°C NWH: 30°C	WH: 24°C NWH : 32°C	COP 2.88 to COP 3.8	COP 2.88 to COP 5.3
Jan 01-31	2.6816	2.3006	2.4439	2.0162	2.146	2.4752	2.4439	2.4439	2.4548	2.072	1.5319
Feb 01-28	4.7358	3.5995	3.7583	3.2834	3.4371	4.0071	3.7573	3.6778	3.7232	3.625	2.6409
Mar 01-31	19.0746	7.2514	12.3749	6.7182	7.3178	8.5796	7.8712	7.6816	7.9406	14.4962	10.4398
Apr 01-30	26.2005	10.7208	15.9795	10.2422	11.841	13.9144	12.2538	11.41	11.7097	19.8955	14.3096
May 01-31	41.6791	15.6244	24.4111	15.1299	20.4816	24.8324	20.8233	18.3371	18.1685	31.628	22.723
Jun 01-30	54.3095	19.872	33.1688	19.2854	28.5303	34.9472	28.9667	24.3059	23.5932	41.1993	29.5839
Jul 01-31	66.9812	20.5958	42.1755	20.0433	37.9757	45.7247	38.3836	31.7952	28.5407	50.8043	36.4721
Aug 01-31	67.0211	24.5873	45.0988	23.9438	39.926	46.9178	40.4195	34.4552	32.2685	50.8346	36.4938
Sep 01-30	61.9079	17.7719	37.2671	17.1984	32.5526	40.358	32.9854	26.7099	25.0483	46.958	33.7129
Oct 01-31	40.1695	14.0668	22.6371	13.4817	17.4794	22.0366	17.9896	15.9916	16.2959	30.4838	21.9027
Nov 01-30	25.86	8.9305	15.2948	8.3117	9.0552	10.5788	9.7112	9.4236	9.7722	19.6375	14.1246
Dec 01-31	4.6019	3.7196	3.8103	3.3689	3.4833	4.013	3.8454	3.8109	3.8646	3.5274	2.5754
Total	415.2227	149.0406	258.4201	143.023	214.226	258.3848	219.4509	190.0426	183.3802	315.1618	226.5105
Saving		64%	37.76%	65.55%	48.4%	37.77%	47.1%	54.3%	55.8%	24.1%	45.4 %

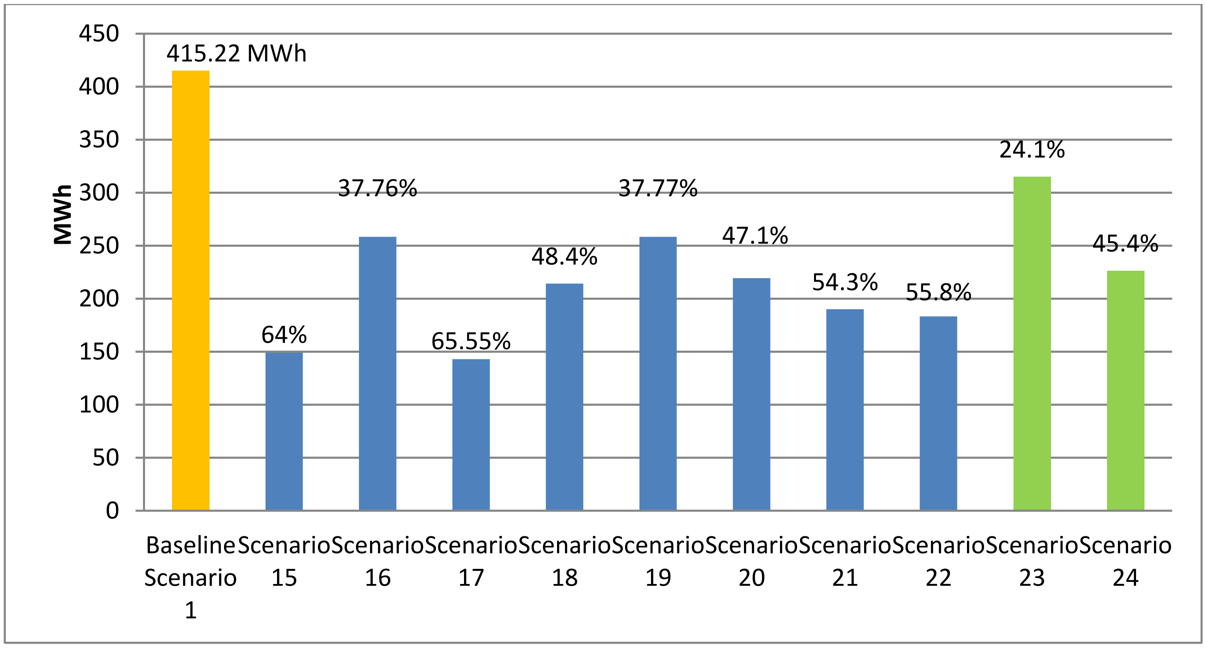


Figure 5.20: Active category with many scenarios and their impact on reducing system energy consumption

5.4.3 The Optimal Active Strategy (Scenario 25)

This scenario utilizes the input parameters of the previous active measure scenarios with the best energy saving results in each set, which are highlighted in Table 5.8. The values of Scenario 17 and Scenario 24 will be used for an optimal active scenario. Figure 5.21 compares the reduction in each type of energy with the baseline's energy.

The obtained result from Scenario 25 shows that the total system energy plummeted from 415.22MWh to 81 MWh with 80.4% reduction. The total energy consumption reduced from 531.22 MWh to 197 MWh which is equivalent to 62.9 % reduction and the total electricity went down from 529.29 MWh to 195 MWh which equals to 63.2 % reduction.

Figure 5.22 shows graphically the amount of electricity saved through two active measures: raising the cooling set-point and increasing the system COP.

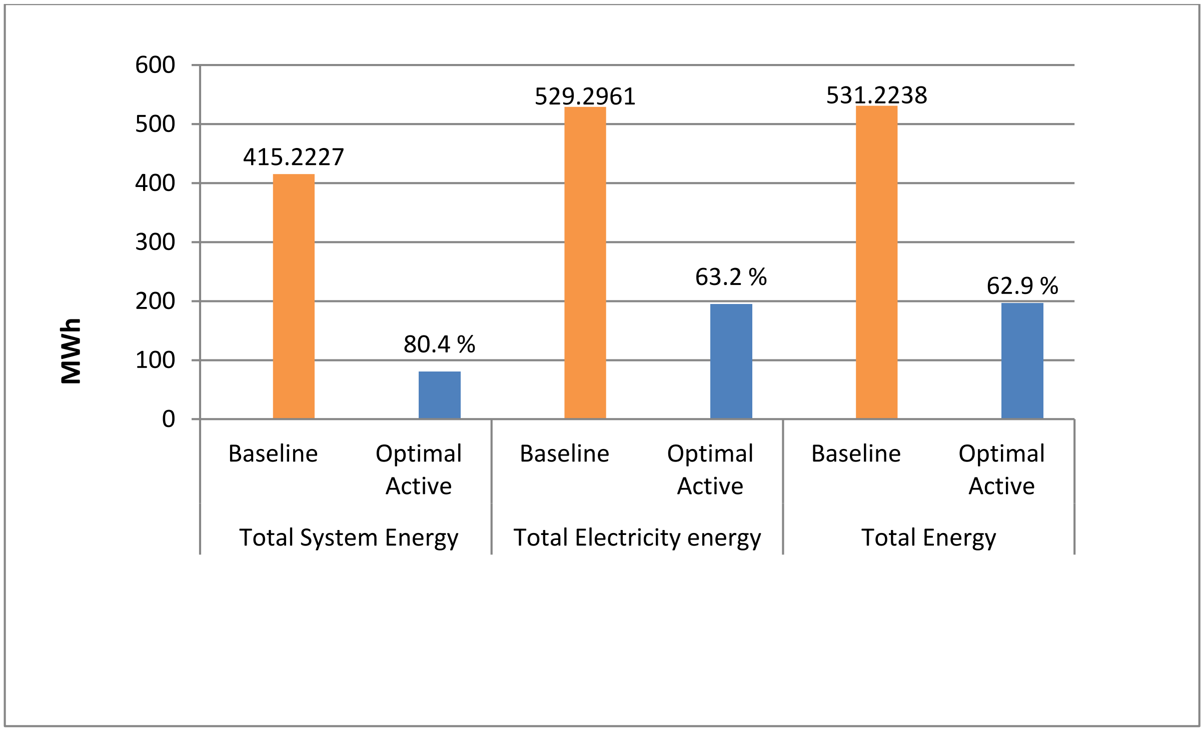


Figure 5.21: The impact of optimal active (Scenario 25)on reducing different types of energy.

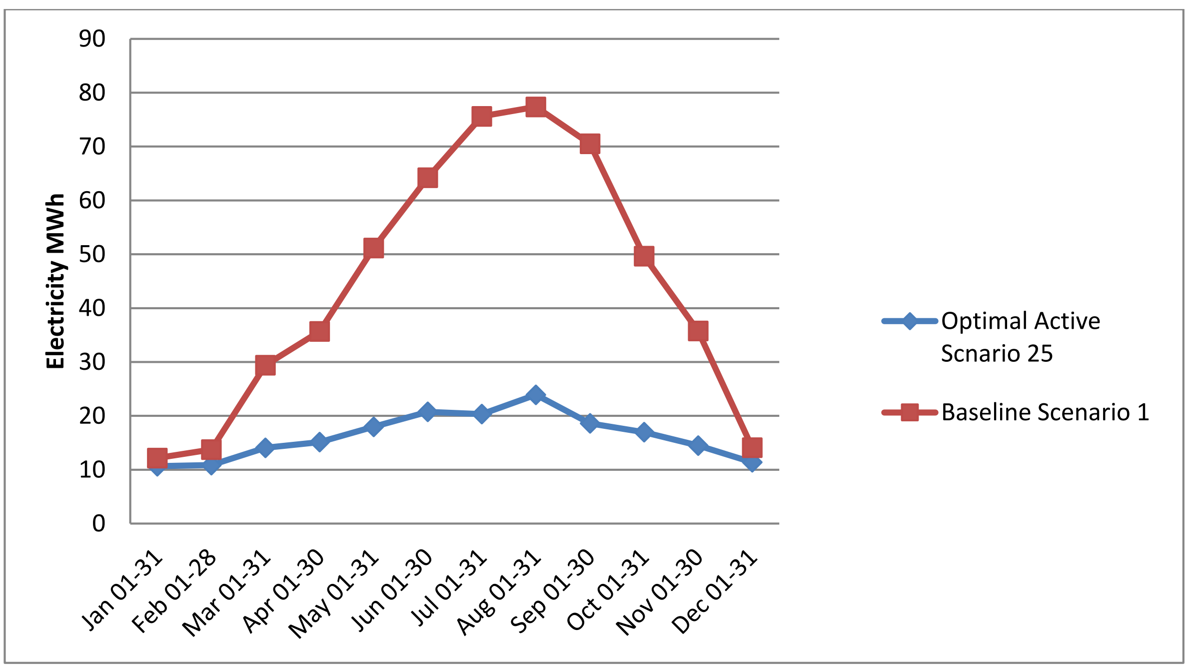


Figure 5.22: Electricity reduction as a result of varying cooling set pointand upgrading COP (optimal active scenario)

5.4.4 Optimal Retrofit Proposal (Scenario 26)

This scenario aims to combine Scenario 14, the optimal passive scenario, and Scenario 25, the optimal active scenario, in a single simulation. This simulation is the optimal retrofit proposal that suits the UAE's local region.

The obtained results have shown a major reduction in the total system energy from 415.22 MWh to 69.23 MWh, which is equivalent to 83%. The reduction in total energy has reached 65%, and the total electricity reduction reached 65.3% as shown in Table 5.9.

Table 5.9: The different types of energy for baseline and the optimal retrofit scenario that combines both passive and active measures

Date	Baseline (Scenario 1)			Optimal Retrofit Impact (Scenario 26)		
	Total System Energy	Total Electricity	Total Energy	Total System Energy	Total Electricity	Total Energy
Jan 01-31	2.6816	12.161	12.3247	1.0355	10.5149	10.6786
Feb 01-28	4.7358	13.7403	13.8882	1.558	10.5626	10.7104
Mar 01-31	19.0746	29.4113	29.575	3.2026	13.5393	13.703
Apr 01-30	26.2005	35.6644	35.8229	4.898	14.362	14.5204
May 01-31	41.6791	51.1585	51.3222	7.1714	16.6508	16.8145
Jun 01-30	54.3095	64.2022	64.3606	9.2145	19.1072	19.2656
Jul 01-31	66.9812	75.6033	75.767	9.7892	18.4113	18.575
Aug 01-31	67.0211	77.3579	77.5216	11.483	21.8197	21.9834
Sep 01-30	61.9079	70.5146	70.673	8.4651	17.0718	17.2302
Oct 01-31	40.1695	49.6488	49.8125	6.5172	15.9966	16.1603
Nov 01-30	25.86	35.7527	35.9111	4.1356	14.0283	14.1867
Dec 01-31	4.6019	14.0813	14.245	1.7617	11.241	11.4048
total	415.2227	529.2961	531.2238	69.2319	183.3054	185.2329
Reduction				83 %	65.3 %	65 %

Figure 5.23 shows the significant saving in all types of energy due to passive and active measures combined in one optimal retrofit scenario.

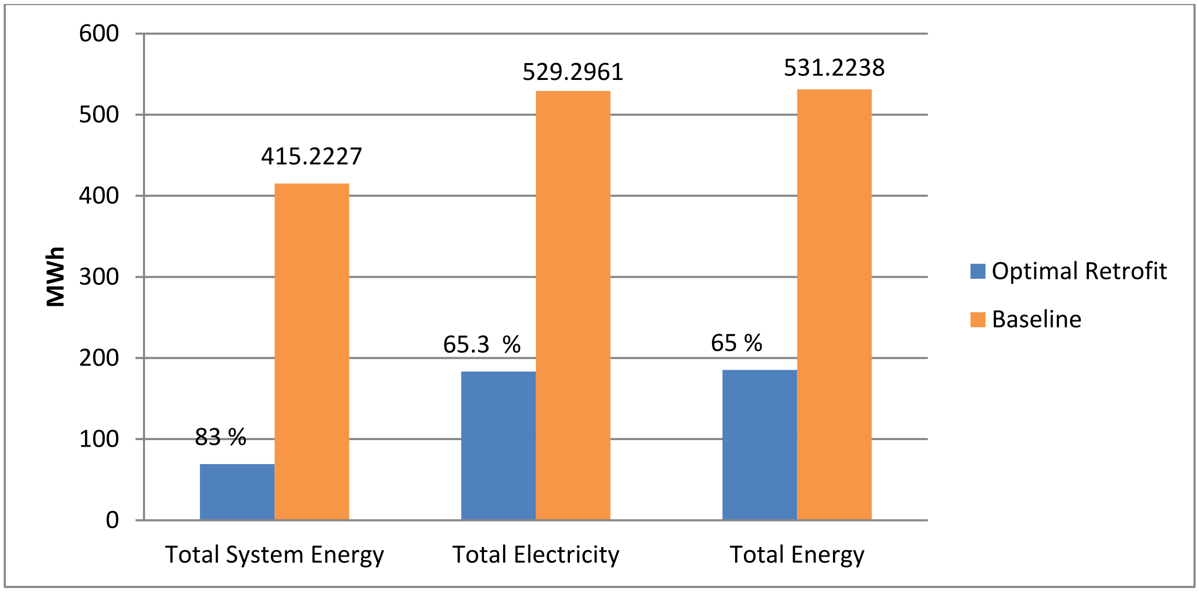


Figure 5.23: The impact of combined passive and active retrofit measures to define the optimal retrofit scenario.

The scope of this research focuses on retrofitting two areas: the building's envelop and the HVAC system; however, the optimal refurbishment in any project should consider retrofitting the lighting system as well, prior to introducing any RE as an energy supply (Ma et al. 2012).

An earlier study was conducted on the same building MOID-RAK which focused on upgrading the lighting system (Al Awadhi, 2014). The results have shown that lighting electricity could be reduced by 25% if daylight sensors and dimming systems were provided. Al Awadhi's results will be used in this project, and the savings from retrofitting the lighting will be deducted from the total lighting electricity.

The lighting energy is 50.9605 MWh. Retrofitting the lighting system could save 25% which is equivalent to 12.74 MWh. The net lighting electricity is 37.26 MWh. The total electricity will be calculated as followed:

Total electricity= lighting electricity + equip. electricity + system electricity (optimal retrofit)

= 37.26 MWh + 65.04 MWh + 67.3 MWh = 169.6 MWh

Thus, the total electricity after all retrofit actions (Building envelope, HVAC and Lighting) is equal to 169.6 MWh

5.4.5 PV Energy supply (Scenarios 27-33)

Solar PV has become a competitor with conventional forms of energy such as natural gas. This has happened due to the dramatic drop in prices of this technology. In fact, the Dubai clean energy strategy 2050 was launched, and the government has declared that every roof in the emirate (around 114,000 of them) would be equipped with PVs (Graves, 2016).

There are different types of PV solar cells. The higher the efficiency, the more costly they are. Mono-crystalline silicon is considered the most efficient solar cell compared to poly-crystalline, amorphous and thin films; however, poly-crystalline keeps on leading other technologies for its quality as well as the reasonable efficiency and cost. The efficiency of crystalline PVs (c-Si) commercial modules ranges between 14% - 21.5% (Fraunhofer ISE, 2016). However, Thin Films technology, with its 10% share of the market, offers commercial modules with 12% - 14% efficiency. The Amorphous is a type of thin film, with the lowest efficiency within its category, which that reaches 7% (IEA PVPS, 2015).

Many parameters need to be considered when planning to install rooftop photovoltaic modules, including the optimal PV's orientation to the sun, the PV's angle of inclination and the shading from nearby buildings or objects.

The last set of simulations will present different scenarios that examine different PV technologies, as well as different approaches for installment, in order to define the most optimal scenario. Therefore, a site solar radiation analysis is required to define the available efficient areas. It is important to keep in mind that any source of shading such as trees, other buildings, or any obstruction of the building's roof itself, may reduce the efficiency of PV production significantly (Stapleton and Neill, 2012). SunCast is an IES VE application that helps assess the site regarding the amount of solar radiation during any time of the year as well as for the whole year. Figure 5.24 shows the shaded area of the roof during the middle of the day, in mid January. Whilst, Figure 5.25 shows the solar radiation for the MOID-RAK roof where the majority of the available area receives around 2176.4 KWh/m2 annually; however, some areas receive as low as 1113.3 KWh/m2 due to the shading effect. This analysis helps in choosing the most efficient areas for PV installment.

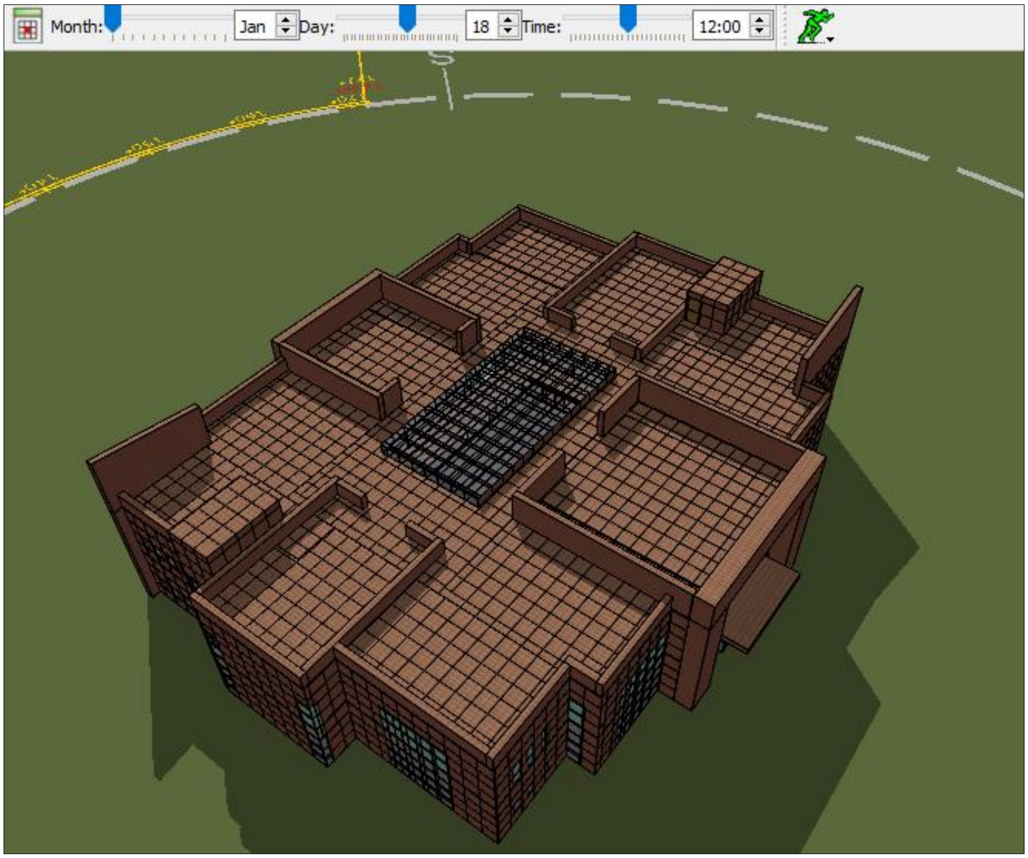


Figure 5.24: Analyzing the shaded area on MOID building roof (VE IES, SunCast)

As mentioned in Table 4.4, the PV modules will be introduced in two ways: as PV panels on the available area of the roof, and as BIPV on the central atrium skylight. In placing PV panels, avoiding the shaded area is a key factor. Moreover, considering an empty zone that surrounds panels is essential for cleaning and maintenance purposes (Stapleton and Neill, 2012).

As shown in figure 5.25, the building is oriented at an angle of 45° from the north. For that, there are two approaches to install PV modules: the absolute approach and the optimal approach. The absolute approach follows the roof shape in laying PVs regardless of the south orientation. In this scenario, the PVs' total installed area is found to be 514.2 m2. On the other hand, the optimal approach where the PV panels are installed towards the optimal direction which is south. Figure 5.26 shows the two approaches to install PV panels.

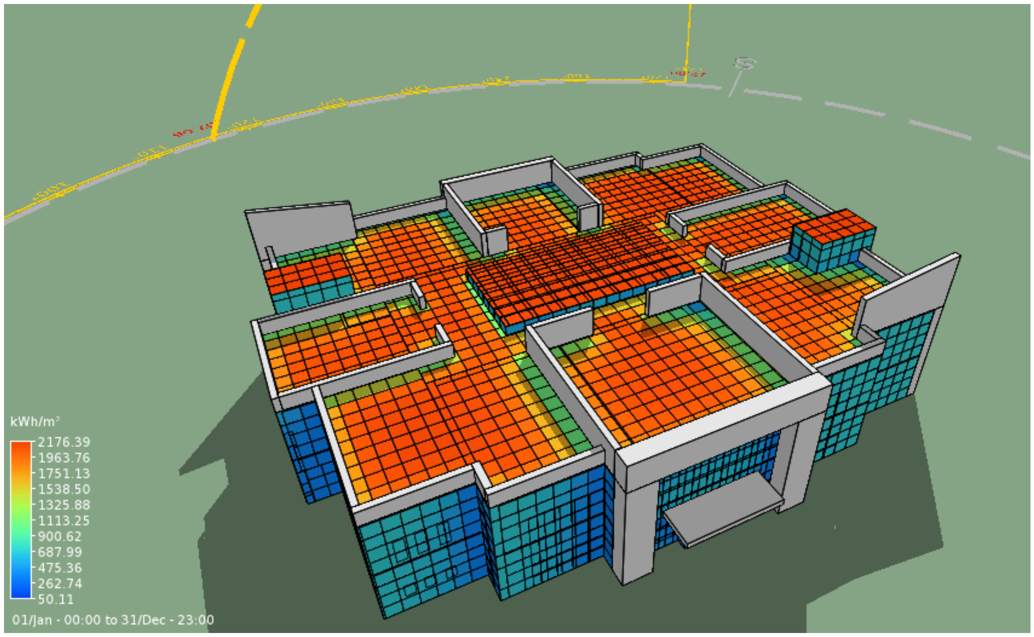


Figure 5.25: Solar Radiation Analysis (IES VE, SunCast)

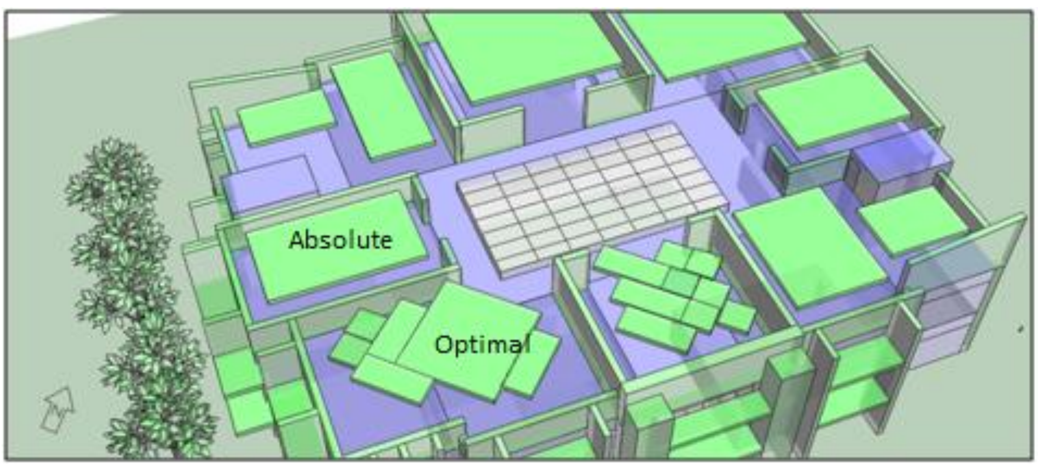


Figure 5.26: Different Scenarios for installing PV panels.

For Dubai, which is very close to RAK, the favorable orientation (azimuth) for fixed solar panels is 0° S, with an inclination of about 24° with respect to the horizontal plane (DEWA,2014). This data will be used for MOID-RAK since Dubai's location is 25.2048°N, 55.2708°E, and RAK's location is 25.8007°N, 55.9762°E.

For all PV technologies' efficiency, the IES VE default values will be used in this study, in addition to the latest efficiencies in the PV market.

5.4.5.1 Absolute PV (Scenario 27 A-D)

In this scenario PV modules occupy around 514 m2. Since the building is tilted 45° from the north, PV panels could be oriented towards south east or south west; therefore, in case of facing southeast, the azimuth is 135° clock wise from the north and the inclination from the horizontal is 24.0° (DEWA, 2014).

Different PV technologies are available and can be assessed by IES. As a first step, the absolute PV area will be simulated for all PV technologies (A-D). The IES default efficiencies will be used in this simulation as shown in Table 5.10.

Table 5: 10 Absolute PV annual production with different types of PVs

Scenario 23Absolute PV	**Mono-Crystalline A**	**Poly- Crystalline B**	**Thin Films C**	**Amorphous D**
IES Default PV Efficiency	13%	11%	7%	5%
Total Production 514 m2	106.076 Mwh//yr	89.7569 Mwh//yr	59.894 Mwh//yr	44.3462 Mwh//yr

Figure 5.27 shows the annual production for scenario 27 with all 4 cases (A-D). See appendix E for more detailed data.

It is obvious that the mono C-Si technology offers the best performance according to PV efficiency. For that and since the work scope for this study does not consider the cost, the mono-crystalline technology will be used for scenarios (27-29 and 31). However, if the cost is an issue, poly C-Si technology will be a better alternative (Fraunhofer ISE, 2016). Scenario 32 will offer an economical approach.

It was found that PV absolute scenario with mono-crystalline cell (scenario 27A) has produced 106.076 MWh electricity. This helps in reducing the demand from the electricity grid from 169.6 to 63.5 MWh as it shows in Figure 5.28.

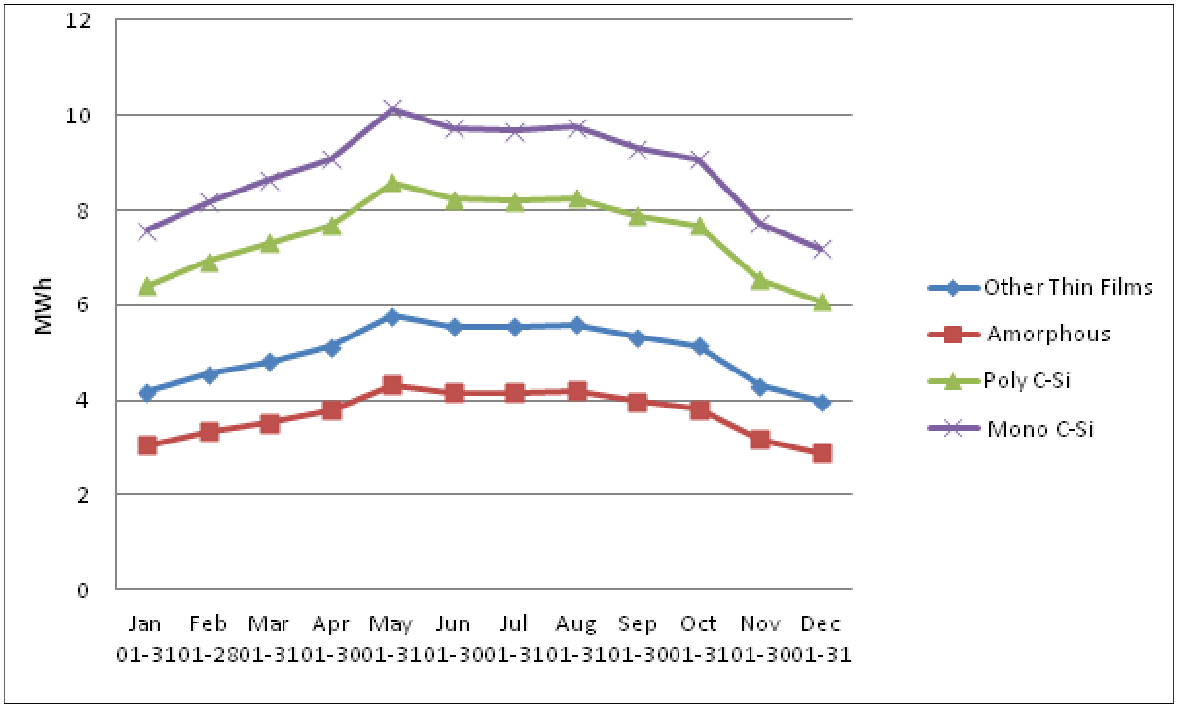


Figure 5.27: Monthly PV production for absolute PV instalment

As shown in Table 5.10, the efficiencies provided by IES VE are relatively low. According to Fraunhofer institute, the latest recorded lab cell efficiency of the mono-crystalline solar panel is 25.6% (Fraunhofer ISE, 2016); however, for commercial panels applications, SunPower in the U.S. has released recently the X-series at a record-breaking efficiency of 21.5% for commercial use (the ecoexperts, 2016).

For a better result, Scenario 28 will run a simulation to the absolute PV approach using mono-crystalline with 21.5% efficiency. The result has shown an increment in producing solar electricity than the previous scenario (27A with efficiency 13%) by 39.5%, where the production has increased from 106 MWh to 175.4 MWh.

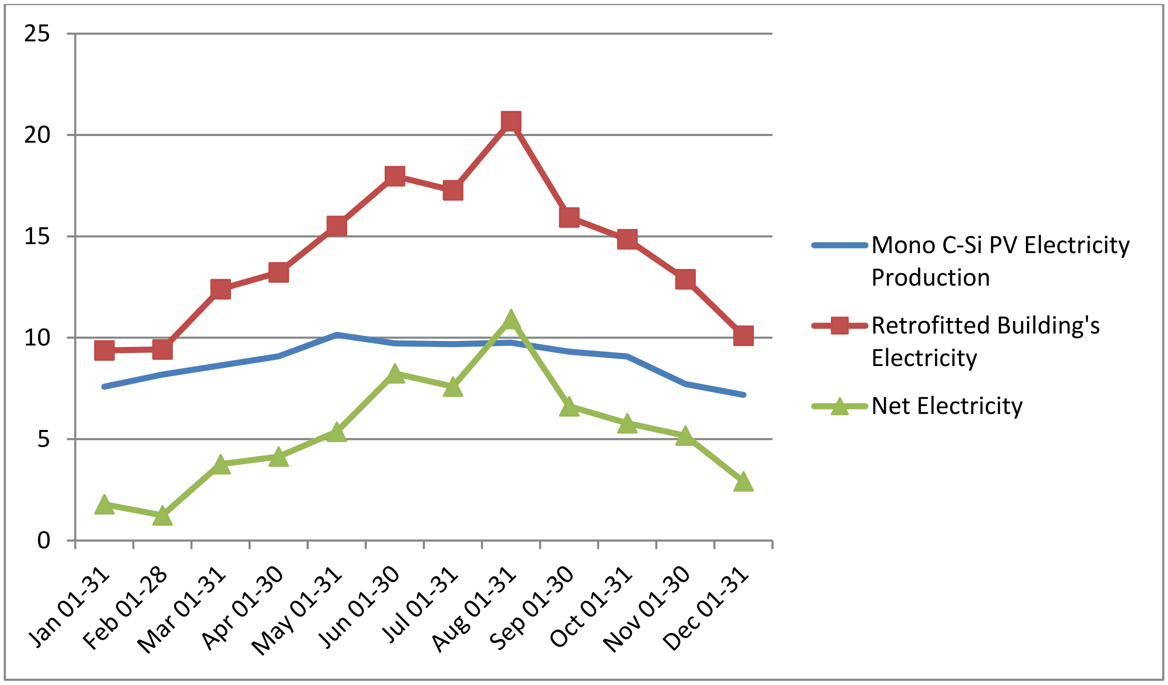


Figure 5.28: PV absolute scenario and retrofitted building's energy demand

5.4.5.2 Optimal PV orientation (Scenario 29)

This scenario will examine the optimal PV orientation, facing south. Although placing the PV slanted at 45°, with the roof's shape, may offer the optimal orientation, the available area to such an arrangement would be around 230 m2. The mono-crystalline technology with the highest commercial efficiency 21.5% will be used for this scenario. The result has shown a solar energy production of 81.54 MWh. By comparing between the two different approaches (absolute and optimal), it is clear that following the absolute PV approach would allow the utilization of the maximum area of the roof. This could produce more solar energy regardless of the lack of the south optimal orientation. With an extra 55% PV m2, the absolute PV installment would provide more solar energy by 53.5%. Also, according to DEWA, only a maximum 5% energy loss could occur as a result of varying the azimuth of PV modules from -60° to +60° if the tilt angle is kept at 24° (DEWA, 2014).

5.4.5.3 BIPV (Scenario 30)

The baseline building has a central atrium covered with 116.96 m2 skylight. Scenario 30 will assess the potential of producing solar energy through the skylight BIPV. Thin film technology will be used for this simulation. According to the latest data, thin film technology efficiencies have reached between 7-13% (Maehlum, 2016). Therefore, in this simulation, the highest recorded efficiency for this technology, 13%, will be used. The result shows a solar energy production of 23.4 MWh.

5.4.5.1 Optimal PV (Scenario 31)

Scenario 31 proposes the optimal scenario of implementing PVs, where mono-crystalline panels with 21.5% efficiency will be used with its absolute approach (514 m2), in addition to having the same PV cell technology on the skylight (BIPV). The result shows a solar energy production of 214.22 MWh which is more than the retrofitted building's electricity demand of 169.6 MWh

5.4.5.1 Economical approach (Scenario 32)

The previous scenarios focused on using the best PV performance in order to capture the maximum solar production. Using poly-crystalline technology would reduce the initial cost; however, more PV m2 is required to reach the mono-crystalline solar energy production level. Scenario 32 will examine the poly-crystalline technology as an economical alternative for the same absolute PV area in scenario 32. The efficiency of this technology will follow the latest best value which 17% and was recorded by Phono Solar manufacturer (the ecoexperts, 2016). The obtained result has shown a solar energy production of 169 MWh, which is almost about to meet the building electricity demand that reaches 169.6 MWh. Table 5.11 shows the PV annual performance with different technologies for all scenarios, whilst figure 5.26 shows their performance graphically.

By considering the result of Scenario 32, the building could be labeled as nearly zero cost energy. However, in order to classify it as zero cost energy, meeting the building's electricity demand is required. By using poly-crystalline technology, more PV m2 is needed. To add more PV panels, a thorough analysis was conducted to the building's site to define a suitable efficient area for installing PV panels. It was found that the parking lot is located behind the building with southeast orientation as shown in figure 5.29. The furthest parking row from the building that is designated for 16 cars could offer 220 m2 for PV installment.

Table 5.11: Annual retrofitted baseline demand and PV technologies production (MWh)

Date	Optimal Retrofit Baseline Electricity Demand	PV Scenarios					
		Scenario 27 A	Scenario 28	Scenario 29	Scenario 30	Scenario 31	Scenario 32
		Absolute PV Panels MonoCSi 13%	Absolute PV panels MonoC-Si 21.5	Optimal PV Panels MonoC Si 21.5	Skylight Thin Film 13%	Optimal case Mono-C-Si Panels/skylight	Economical Case Poly-C Si Panels/skylight
Jan 01-31	10.5149	7.5878	12.549	3.7498	1.4317	14.9217	11.7985
Feb 01-28	10.5626	8.1833	13.5339	3.9467	1.6263	16.2288	12.8321
Mar 01-31	13.5393	8.636	14.2827	4.0337	1.8895	17.4132	13.7686
Apr 01-30	14.362	9.0825	15.021	4.1075	2.0987	18.4978	14.6262
May 01-31	16.6508	10.1441	16.7768	4.5359	2.4923	20.9053	16.5297
Jun 01-30	19.1072	9.7244	16.0827	4.2909	2.4422	20.128	15.9152
Jul 01-31	18.4113	9.6801	16.0093	4.3008	2.3947	19.976	15.795
Aug 01-31	21.8197	9.755	16.1332	4.4193	2.3208	19.9777	15.7963
Sep 01-30	17.0718	9.3095	15.3965	4.3208	2.0788	18.8405	14.8971
Oct 01-31	15.9966	9.0735	15.0061	4.3245	1.867	18.0998	14.3115
Nov 01-30	14.0283	7.715	12.7595	3.7436	1.456	15.1724	11.9968
Dec 01-31	11.241	7.1851	11.8831	3.5347	1.3143	14.0614	11.1183
total	183.3054	106.076	175.433	49.3082	23.4123	214.2225	169.385
With Lighting Retrofit	169.6						

Scenario 33 considers using poly- crystalline technology within a PV total area of 851 m2 between panels and BIPV. The produced solar energy was 228.8 MWh, which exceeds the building's electricity demand which is 169.6 MWh. Figure 5.30 shows how poly-crystalline technology, when including part of the parking lot (Scenario 33), was able to meet the building's energy demand and lead all other scenarios. The furthest parking row from the building that is designated for 16 cars could offer 220 m2 for PV installment.

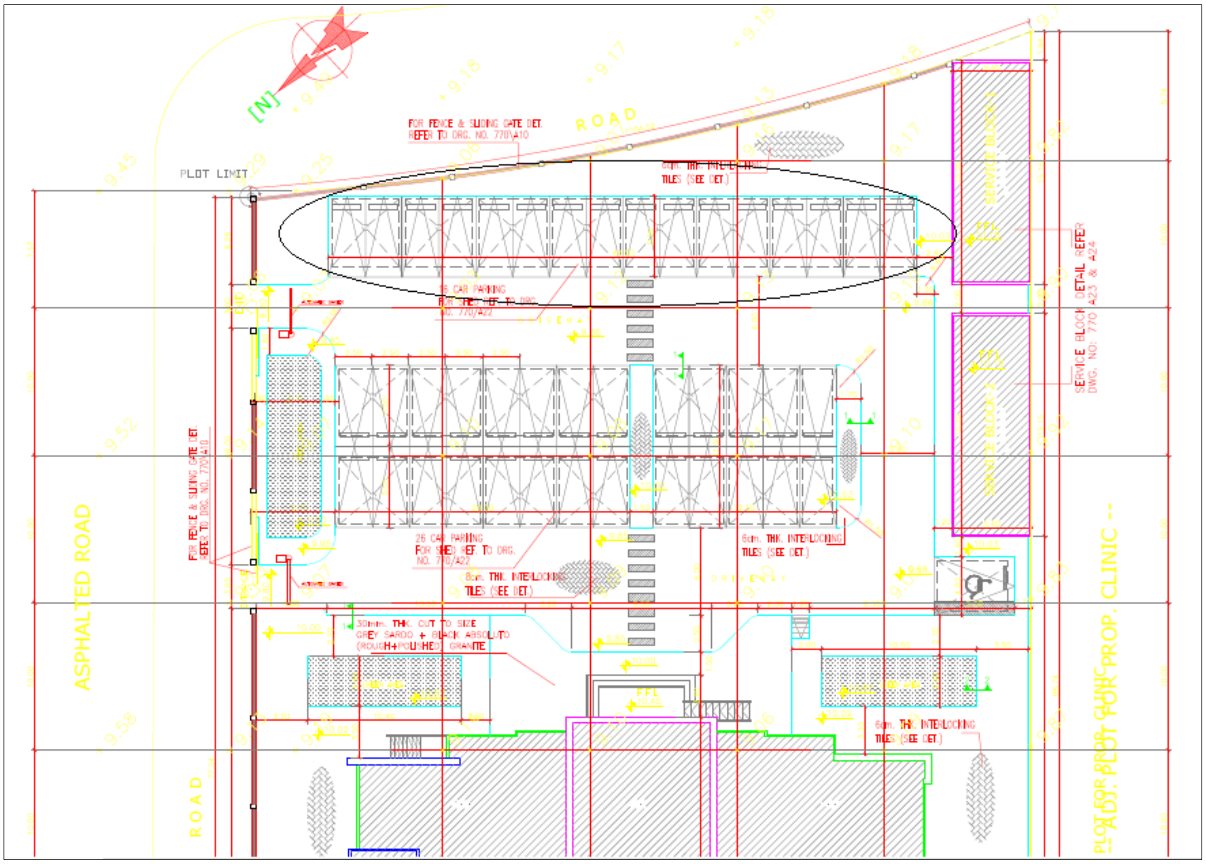


Figure 5.29: Parking lot chosen area for PV instalment

Scenario 33 considers using poly- crystalline technology within a PV total area of 851 m2 between panels and BIPV. The produced solar energy was 228.8 MWh, which exceeds the building's electricity demand which is 169.6 MWh. Figure 5.30 shows how poly-crystalline technology, when including part of the parking lot (Scenario 33), was able to meet the building's energy demand and lead all other scenarios.

Figure 5.31 shows the peak electricity demand during the month of August. It is obvious that the building's peak demand is synchronized with the PV peak production.

Having the building's PV system connected to the utility grid provides great benefits for eliminating the need for storing batteries; whereas any excess energy could be sent to the grid and saved as a credit so it could be used during peak times.

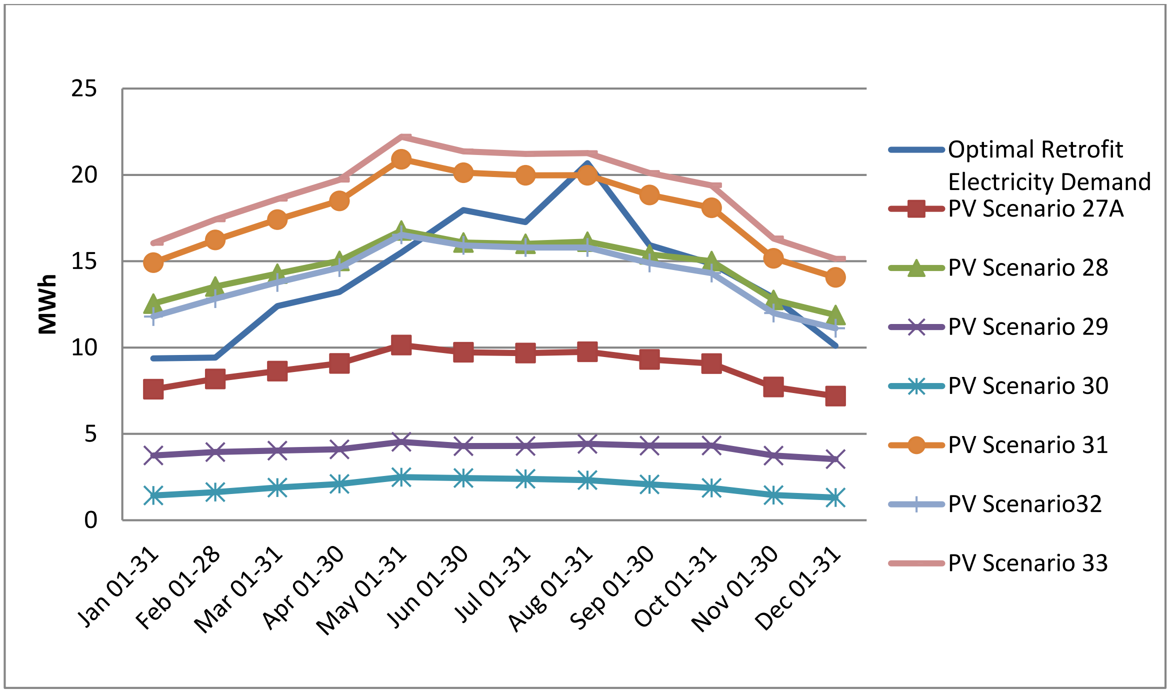


Figure5.30. PV energy production with all different scenarios.

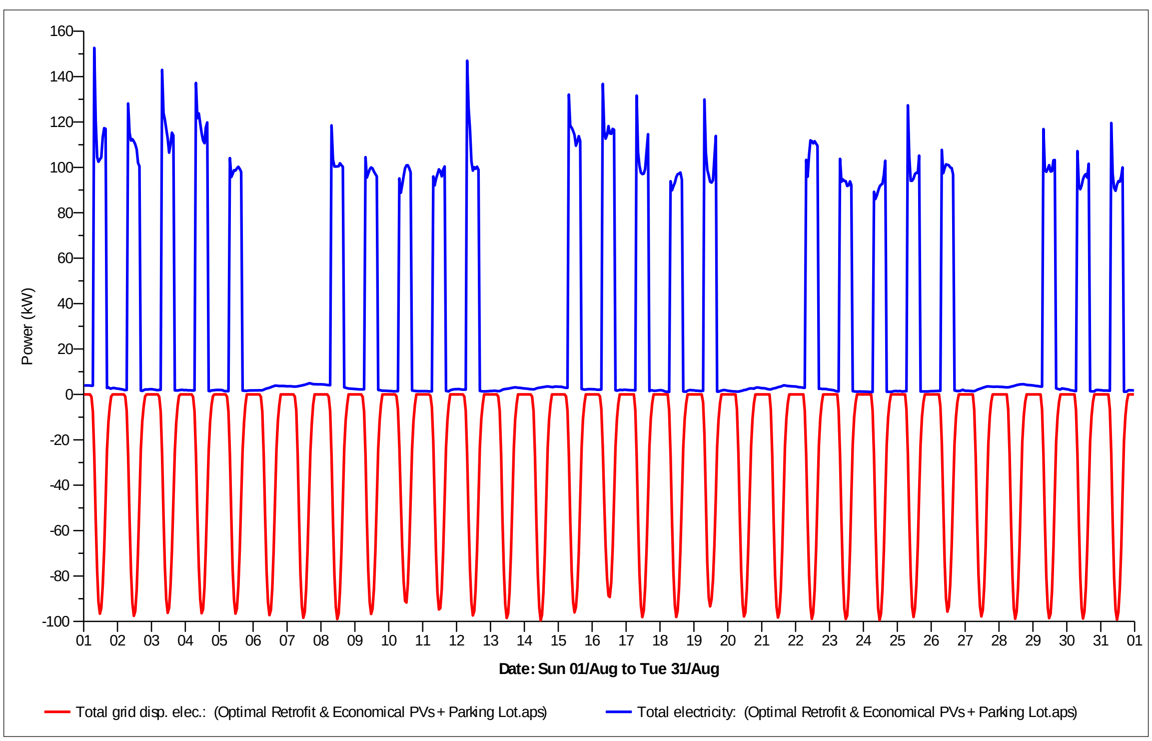


Figure 5.31: Electricity demand and PV production of scenario 32 during month of August.

Chapter 6

Conclusion and Recommendations

6.1 Overview

As the population continues to grow, the demand on electricity increases. This is especially true when it isn't very expensive, which is the case in the UAE regarding electricity consumption. The demand on electricity has doubled in the last 10 years and is expected to continue rising unless serious actions are considered. Reducing the energy demand and diversifying the energy supply has now become a priority in the UAE.

Although all federal buildings in the UAE are currently obligated to be equipped with energy saving measures, the energy consumption still shows higher levels than expected. The provision of the "Distributed Renewable Resources Generation (DRRG)" program has the ability to transform some buildings to nearly zero electricity cost or even zero electricity cost through a holistic retrofit approach.

In this research, a newly constructed federal building, MOID-RAK, was chosen as a case study to assess its energy performance and analyze areas of improvement in order to transform it into a net zero electricity cost building. There were two main reasons for choosing this specific building. Firstly, due to its manageable size for simulation, and secondly, due to a previous study already conducted on the same building where the lighting system was retrofitted. Its results were taken into consideration in this research to form a holistic retrofit image.

The building was analyzed business as usual (BAU) through simulation modeling method. Implementing both passive and active measures, providing photovoltaic technology as an energy supply, and benefiting from being connected to the grid utility to find the net electricity consumption were the main aspects in this study. The next section will summarize the obtained results, as well as the recommended actions for a sustainable building sector in the future.

6.2 Conclusion

To meet the dissertation objectives, two sets of retrofit measures scenarios have been assessed, both passive and active. For passive strategies, 13 scenarios under three sets (shading elements, window films and building codes) were simulated individually or combined to define the best passive approach to retrofit buildings. On the other hand, the active category was formed of 20 simulation scenarios under three sets (varying cooling set point, upgrading COP, and PV application).

Regarding the first passive set (shading elements), it was found that implementing 2m cantilever as a shading element for both the southeast and southwest elevations has proven to be slightly more effective than vertical fins. However, the egg-crate style has shown to have the best performance over all with a 1.6% reduction in the system's energy. The impact of the PV self shading on the roof was assessed too, very limited energy reduction was found due to the baseline's roof low U-value.

Window films were assessed, although the local market has the ability to provide window films as low as SC=0.15 which offer up to 1% more savings, yet there are other issues which are just as important as energy savings to be considered like the view and the daylight factor. For that, window films with SC=0.2 were applied on 60% of the glazing (lower part) in order to allow the daylight to penetrate deep inside the building. This measure offers 3% savings in the system's energy.

Upgrading the building code, U values, air infiltration and glazing SC, to be more energy efficient were applied with 4 different scenarios. The first simulation in this set is by implementing 1Pearl configuration. It was not a surprise to get very little saving around 1.6%, because of the building elements' green U values of the baseline. On the contrary, applying 2 Pearls configuration offers a very descent saving in system's energy of 7.8%.

Applying Passivehaus regulations was expected to offer more than the obtained saving due to the harsh U-values. Comparing to the 2Pearls configuration, there was a 1.6% increase in energy reduction. In total, the system's energy consumption by was decreased by 9.4%; however, this value was lower than expected which could be explained as a result of the high shading coefficient of Passivhaus guidelines which are needed in cold regions, yet negatively affecting hot regions. This result further worsens when the building has a higher percentage of glazing area, as in MOID-RAK case.

Tweaking the building guidelines to cope with the region's requirements is the main objective behind replacing the actual Passivhaus SC from 0.5 to 0.2. The result was impressive, the impact on the system's energy saving increased from 9.4% to 16.2%. This high percentage of saving shows the impact of properly treating highly glazed buildings.

The last simulation scenario of building codes revolves around manipulating the Passivhaus glazing standards to replace the triple pane glazing with 2 pane glazing, while maintaining the low SC=0.2. The result was very promising, although the saving was 1% less when using double pane glazing, this scenario is still considered optimal among all other scenarios of the same set due to the high saving, as well as the usage of more viable building elements (low-e double pane glaze) that suite the climatic conditions.

The optimal scenario, among all the 13 passive scenarios, consists of combining the optimal shading (Scenario 6) and Passivhaus with low-e double glazing (Scenario 13). The optimal passive approach provides a saving in the system's energy by 18.7%, whereas the electricity saving was 14.7%.

On the contrary, the active strategies category has offered great savings through different approaches and scenarios. Since the HVAC system of the baseline case runs all year round, different scenarios for the cooling set-point has offered great potential in saving energy. Eight scenarios have been applied; Scenario 17 shows the best results with savings up to 65.55% in the system's energy. This scenario was designed to have the cooling set-point between 24°C and 25°C based on the zones' function and orientation while the system shuts off after working hours.

Increasing the Coefficient of Performance (COP) has reduced the energy demand significantly. Changing the baseline COP from 2.88 to COP 3.8 reduced the total energy around 19% and the system's energy around 24%. Moreover, using COP 5.3, which is the average value for the most recent efficient system, increased the savings in energy consumption by 35.5%. This shows that some simple strategies can provide immediate savings. Although, such retrofit is costly, the obtained saving in energy and money is tempting. The proposed scenario for an optimal retrofit consists of combining the optimal passive and the optimal active in one scenario (Scenario 26); the saving in total energy consumption reached up to 65%.

The result of Al Awadhi's work (2014), which focused on retrofitting the lighting system for the same building, is used in this research to help provide a holistic image. The result of 25%

saving in lighting electricity consumption is deducted in this project to find out the total reduction in electricity consumption before introducing the photovoltaic system. The total electricity demand after the holistic retrofit is 169.9 MWh.

Implementing photovoltaic energy supply system for this case study was a great addition as an active measure. Since the base case is an office building, the energy demand corresponds with the energy supply; therefore, the majority of the produced solar energy was consumed on site. Utilizing the absolute available efficient area of the roof using the highest recent recorded efficiency of mono crystalline panels produced 175.4 MWh solar electricity. This energy could increase up to 214.44 MWh if the skylight glazing was replaced with mono crystalline BIPV, thus potentially making the base case a surplus energy building. However, from an economical point of view, replacing mono crystalline PV panels with poly crystalline ones could be a better alternative; however, more PV m2 are required. By using the highest commercial efficiency for such technology, the building barely meets the electricity demand by 169.38 MWh. Utilizing some qualified surfaces for collecting solar energy such as parking lot pergolas could increase the chance for more solar energy supply.

Eventually, both passive and active measures have played an important role in reducing electricity consumption. However, in newly constructed federal buildings with high internal gain, active measures proved to be more effective in reducing electricity consumption than passive strategies. The optimal passive scenario reduced electricity by 14.7%, whilst the optimal active scenario reduced electricity consumption up to 63.2%. However, with such a hot climate region, protecting the glazing from solar radiation is considered a priority as well, especially in a building with large windows like the base case (Lip Ahn et al. 2015).

A holistic retrofit approach is recommended when considering renewable energy as an energy supply (Ma et al. 2012). In this research, since the building is a small sized office building (G+1) with a total area of 2251m^2, PVs solar energy has proved to be a very efficient energy supply and can transform the building to a zero cost electricity building.

6.3 Recommendation and Future Research

Reducing energy demand through energy efficiency measures and introducing renewable energy as an energy supply show great potentials for transforming governmental and federal office buildings into zero cost electricity buildings. However, a few points need to be considered in order to drive such projects to success:

- Enhance the public's general understanding of the importance of saving energy is the first step. This could be delivered through social and multimedia, in addition to advertisements. On the other hand, governmental and federal employees need to be educated through conferences, seminars and workshops on how they could be more energy efficient in using the buildings, which may set an example for other commercial buildings. It is vital for employees to understand the power of behavioral measures in saving energy and how they are just as important as implementing passive and active measures.
- Energy dashboards could be a great addition to governmental and federal buildings where they can allow employees to track their energy consumption; this could motivate them to enhance their behavior towards more a sustainable style.
- Some extra practices can contribute particularly to energy saving in federal buildings with no additional cost. For example, changing the working hours by eliminating the 2 hour flexibility range will reduce the working shift from 7 hours to 9 hours. This saving could be more critical in bigger sized building, especially if the target is to reach zero or nearly zero electricity cost.
- Evaluating the system's AHU design, as well as the thermostat locations, is very important in order to meet the occupant thermal satisfaction. Moreover, providing personal comfort system (PCS), such as ceiling and fan desk, can enhance the occupants' convective cooling. PCS have been verified to be very energy efficient while still maintaining the needed thermal comfort (Huang et al., 2013). Finally, by implementing building management system (BMS), which controls the mechanical and electrical equipment, many individuals' mistakes could be overcome.
- Update the local building regulations toward more efficiency and flexibility is recommended, where a certain percentage of the building energy demand should be obtained from renewable energy sources.
- In case of multi story governmental or federal buildings with high internal gain, understanding the building's form potentials is important to increase the PV area for more energy production. For example, utilizing the façades with the proper orientation to integrate PVs is one approach. Shading elements for the east, west and south oriented windows could be another approach, as

well as parking pergolas. In fact, any shading in public areas nearby could be used to integrate PV systems to meet the high demand.

- Poly crystalline PV technology is the economical approach for integrating PVs in small federal office buildings. However, in case of big office buildings, mono-crystalline PV technology could be the best choice for its effectiveness with the lowest required area.

For future studies, some areas could benefit from further investigation as follows:

- The proposed optimal shading devices and window films could be assessed in the context of the daylight level. It is important to define the maximum energy that could be saved without compromising natural daylight and view quality.
- Assess the combination of the opaque Passivhaus standards and the 2Pearls glazing standards as an effective approach in the local region. Different types of insulations that are available in the UAE local market could be investigated in this context.
- The relation between air infiltration and occupants' behaviors and lifestyle in local governmental and federal office buildings could be studied more thoroughly to define some strategies that may decrease the impact of infiltration in public zones on energy consumption.
- The impact of shutting off the AC after working hours on the indoor environment quality could be investigated and compared to the case of setting the cooling set point as high as 30°C for non working hours

References

References

Abdmouleh, Z., Alammari, R.A.M. and Gastli, A. (2015) 'Recommendation on renewable energy policies for the GCC countries', *Renewable and Sustainable Energy Reviews*, 50, pp. 1181-1191.

Abu Dhabi Urban Planning Council, Estidamah, (2010), [Accessed on 8 April 2016], Available at: http://estidama.upc.gov.ae/pearl-rating-system-v10.aspx

Afshari, A., Nikolopoulou, C. and Martin M. (2014) 'Life-cycle analysis of building Retrofits at the urban Scale - A case study in United Arab Emirates', *Sustainability*, 6(1), pp. 453-473

Al-Amir, J. and Abu-Hijleh, B. (2013) 'Strategies and policies from promoting the use of renewable energy resource in the UAE', *Renewable and Sustainable Energy Reviews*, 26, pp. 660-667.

Al Awadi, W., AlNaqabi A., Manneh A., Ayoub K. and Abu-Hijleh B.A.K. (2013) 'Energy Saving Potential Due to Refurbishment of Federal Public Housing in the UAE', *Engineering*, 5, pp. 132-136

Al Awadhi, W., (2014), *Reducing the energy consumption in the federal buildings in UAE using lighting and control system*, M.Sc. Thesis. British University in Dubai.

Al Badri, N., Grid electricity demand reduction through applying passive and active strategies for a house in Bagdad, Iraq. M.Sc. Thesis. British University in Dubai.

Aldossary, N.A., Rezgui, Y. and Kwan, A. (2014) 'Domestic energy consumption patterns in a hot and humid

Al-Ghamdi S. A., Al-Gargossh A. and Al-Shaibani K. A. (2015) 'Energy Conservation by Retrofitting: An Overview of Office buildings in Saudi Arabia', *Proc. of International Conference on IT, Architectural and Mechanical Engineering (ICITAME 2015*), Dubai, 22-23 May, 2015

Al-Iriani, M.A. (2005) 'Climate-related electricity demand-side management in oil-exporting countries—the case of the United Arab Emirates', *Energy Policy*, 33(18), pp. 2350-2360.

climate: A multiple-case study analysis', *Applied Energy*, 114, pp. 353-365

Ali, A.A.M. and Ahmed, T.M.F. (2012) 'Evaluating the Impact of Shading Devices on the Indoor Thermal Comfort of Residential Buildings in Egypt', *Research Gate*, publication/258513352

Alkhateeb, E. and Taleb, H. (2015) 'Redesigning of building envelope: tree bark as a biomimicry concept', *Proc. of Int. Conf. of Sustainable Development and planning VII*, Istanbul, 19-21 May, 2015.

Alkhateeb, E., Taleb, H. and Altan, H. (2014) 'Optimizing the efficiency of building envelopes as an effective strategy for passive designs in hot climates', *Proc. of 7th Int. l Conf. on Sustainable Energy & environment Protection SEEP*, Dubai, 23-25 November, 2014

All Climate Heating and Air Conditioning, (2015), What Does SEER Stand For? [Online], [Accessed on Jun,2016], Available at: http://allclimate.net/2014/11/26/seer-stand/

Alnaqbi, A. (2013), Investigating Energy Savings Due to Implementing Green Roof on Existing Residential Buildings in UAE. Thesis. British University in Dubai.

Alnaqbi, A., AlAwadi, W., Manneh, A., Kazim, A. and Abu-Hijleh, B. (2012) 'Survey of the existing residential buildings stock in the UAE', *International Journal of Environmental Science and Development*, 3(5), pp. 491-496.

Alnaser, W.E. and Alnaser, N.W. (2011) 'The status of renewable energy in the GCC countries', *Renewable and Sustainable Energy Reviews*, 15(6), pp. 3074–3098.

Ardente, F., Beccali, M., Cellura, M. and Mistretta, M. (2011) 'Energy and environmental benefits in public buildings as a result of retrofit actions', *Renewable and Sustainable Energy Reviews*, 15(1), pp. 460-470.

Arens E, Zhang H, Hoyt T, Paliaga G, Tully B, Goins J, Bauman F, Zhai Y, Toftum J, Webster T, West B, (2012), Thermal and air quality acceptability in buildings that reduce energy by reducing minimum airflow from overhead diffusers.TRP-1515 Final Report to American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE); 2012. https://escholarship.org/uc/item/3jn5m7kg

Asadi, E., da Silva, M.G., Antunes, C.H. and Dias, L. (2012) 'Multi-objective optimization for building retrofit strategies: A model and an application', *Energy and Buildings,* 44, pp. 81-87.

Atkinson, E. (2013), "Abu Dhabi Waste to Energy Opportunities and Challenges" May 2013, TAQA, Abu Dhabi. [online]. [Accessed on January 2015], Available at; http://wastetoenergy.rethinkevents.com/wpcontent/uploads/2013/05/Ed-Atkinson.pdf.

Attia, S. G. M. and De Herde, A. (2011), Early Design Simulation Tools for Net Zero energy Buildings: A comparison of ten tools, IBPSA, vol. 1(1)

Attia, S., Beltran, L., De Herde, A. and Hensen, J. (2009), " Architect Friendly": a comparison of ten different building performance simulation tools. *Proc. of eleventh International IBPSA* Conference, July 27-30, 2009,Glasgow, Scotland

Awadh, O.F., (2013), *The impact of external shadings and windows' glazing and frame on thermal performance of residential house in Abu-Dhabi*, M.Sc. Dissertation, British University in Dubai.

Ayoub, N., Musharavati, F., Pokharel, S. and Gabbar, H.A. (2014) 'Energy consumption and conservation practices in Qatar-A case study of hotel building', *Energy and Buildings*, 84, pp. 55-69.

Bachellerie, I.J., (2013), *sustainability and Competitiveness: A Pragmatic Approach to Solar energy Transition in the GCC Countries*, Gulf Research Center GRC, GULF PAPER, 2013

Baeza, A. (2013), *A zero energy house for UAE*, Master of Science Thesis, SE-100 44 STOCKHOLM

Ballarini, I. and Corrado, V. (2012) 'Analysis of the building energy balance to investigate the effect of thermal insulation in summer conditions', *Energy and Buildings*, 52, pp. 168-180

Bellia, L., De Falco, F. and Minichiello, F. (2013) 'Effects of solar shading devices on energy requirements of standalone office buildings for Italian climates', *Applied Thermal Engineering*, 54 (1), pp. 190-201.

Ben, H. and Steemers, K. (2014) 'Energy retrofit and occupant behavior in protected housing: A case study of the Brunswick centre in London', *Energy and Buildings*, 80, pp. 120-130.

Berardi, U. (2015) 'The development of a monolithic aerogel glazed window for an energy retrofitting project', *Applied Energy*, 154, pp. 603-615.

Bȍttcher, O. (2012), Energy Efficient and Sustainable Buildings in Germany, REHVA Journal, Federation of European Heating, Ventilation and Air-conditioning Associations. [Accessed on 30 April,2016], Available at: http://www.rehva.eu/publications-and-resources/hvac-journal/2012/032012/energy-efficient-and-sustainable-federal-buildings-in-germany/

Breyer, C., Koskinen, O. and Blechinger, P. (2015) 'Profitable climate change mitigation: The case of greenhouse gas emission reduction benefits enabled by solar photovoltaic systems. *Renewable and Sustainable Energy Reviews*, 49, pp. 610-628.

Bridges, A., Felder, F.A., McKelvey, K., and Niyogi, I. (2015) 'Uncertainty in energy planning: Estimating the health impacts of air pollution from fossil fuel electricity generation', *Energy Research & Social Science*, 6, pp. 74-77.

Building Research Establishment, (2011), PASSIVHAUS, Outline Specifications, [Accessed on 4, Jun2, 2016], Available at: http://www.passivhaus.org.uk/standard.jsp?id=18

BPIE Buildings Performance Institute Europe, (2011), *Europe's buildings under the microscope. A country-by-country review of the energy performance of buildings*, Buildings Performance Institute Europe.

Cabeza, L.F., Castell, A., Medrano, M., Matorell, I., Perez, G. and Fernandez, I. (2010) ‘Experimental study on the performance of insulation materials in Mediterranean construction’, *Energy and Buildings,* 42(5), pp. 630-636.

Chan, A.L.S. (2012) ‘Effect of adjacent shading on the thermal performance of residential buildings in a subtropical region’, *Applied Energy,* 92, pp. 516–522.

Chan, H.-Y., Riffat, S.B. and Zhu, J. (2010) ‘Review of passive solar heating and cooling technologies’, *Renewable and Sustainable Energy Reviews,* 14(2), pp. 781-789.

Chan, W.W., Mak L.M., Chen, Y.M., Wang, Y.H., Xie, H.R., Hou, G.Q. and Li, D. (2008) ‘Energy saving and tourism sustainability: Solar control window film in hotel rooms’, *Journal of Sustainable Tourism,*16(5), p. 563.

Chen, H., Lee, W.L. and Wang, X. (2015) ‘Energy assessment of office buildings in China using China building energy codes and LEED 2.2’, *Energy and Buildings,* 86, pp. 514-524.

Chidiac, S.E., Catania, E.J.C., Morofsky, E. and Foo, S. (2011) ‘A screening methodology for implementing cost effective energy retrofit measures in Canadian office buildings’, *Energy and Buildings*, 43(2-3), pp. 614-620.

Chidiac, S.E., Catania, E.J.C., Morofsky, E. and Foo, S. (2011) ‘Effectiveness of single and multiple energy retrofit measures on the energy consumption of office buildings’, *Energy*, 36(8), pp. 5037-5052.

Cho, J., Yoo, C. and Kim, Y. (2014) ‘Viability of exterior shading devices for high-rise residential buildings: Case study for cooling energy saving and economic feasibility analysis’, *Energy and Buildings*, 82, pp. 771-785.

Chua, K.J., Chou, S.K., Yang, W.M. and Yan, J. (2013) ‘Achieving better energy-efficient air conditioning - A review of technologies and strategies’, *Applied Energy*, 104, pp. 87-104.

Clarke, K. (2016), 80% energy consumed by buildings, *Khaleej Times* [online], 4 February, 2016, [Accessed on 21 April, 2016], Available at: http://www.khaleejtimes.com/nation/abu-dhabi/80-energy-consumed-by-buildings

Crawley, D.B., Hand, J.W., Kummert, M. and Griffith, B.T. (2008) ‘Contrasting the capabilities of building energy performance simulation programs’, *Building and Environment*, 43(4), pp. 661-673

Cuce E. and Riffat, S.B. (2015) ‘A state-of-the-art review on innovative glazing technologies’, *Renewable and Sustainable Energy Reviews,* 41, pp. 695-714.

Cuce E., Young, C.-H. and Riffat, S.B. (2014) ‘Performance investigation of heat insulation solar glass for low-carbon buildings’, *Energy Conservation and Management*, 88, pp. 834-841.

Cuce, E., Young, C.H. and Riffat, S.B. (2015), 'Thermal performance investigation of heat insulation solar glass: A comparative experimental study', *Energy and Buildings*, 86, pp. 595-600.

CXE, Energy Code Analysis- Current Requirements & What is Coming, International Energy Conservation Code & ASHRAE Standard 90.1, GXE Group, [online], [Accessed on 4 May, 2016], Available at: http://cxegroup.com/wp-content/uploads/2015/11/Energy-Code-Analysis-by-CxE-150728.pdf

Darwish, Z.A., Kazem, H.A., Sopian, K., Al-Goul, M.A. and Alawadhi, H. (2015) 'Effect of dust pollutant type on photovoltaic performance', *Renewable and Sustainable Energy Reviews*, 41, pp. 735-744.

David, M., Donn, M., Garde, F. and Lenoir, A. (2011) 'Assessment of the thermal and Visual efficiency of solar shades*', Building and Environment*, 46(7), pp. 1489-1496.

Dawood, S., Crosbie, T., Dawood, N. and Lord, R. (2013) 'Designing low carbon buildings: A framework to reduce energy consumption and embed the use of renewables', *Sustainable Cities and Society*, 8, pp. 63-71.

DEWA, (2014), *CONNECTION GUIDLINES FOR RENEWABLE RESOURCES GENERATORS CONNECTED TO MEDUIM AND LOW VOLTAGE DISTRIBUTION NETWORK*, DRRG program, version 1.Goverment of Dubai.

Dirioz A. O., & Reimold, B. A. (2014), The Strategic Context of the UAE's Nuclear Project: A Model for the Region?, [online], vol. XXI(3), Middle East Policy Council (2016). Accessed 28 April, 2016], Available at: http://www.mepc.org/strategic-context-uaes-nuclear-project-model-region

Dubai Supreme Council of Energy, (2015), Demand Side Management, [online] [Accessed on March 2016], Available at: http://www.dubaisce.gov.ae/demand_strategic.aspx

EESI, Environmental and Energy Study Institute, (2002), Fact Sheet: Air Conditioner Efficiency Standards: SEER 13 vs. SEER 12, [Online], [Accessed on 22 Jun, 2016], Available at: http://www.eesi.org/papers/view/fact-sheet-air-conditioner-efficiency-standards-seer-13-vs.-seer-12

EGBC (2014), *Dubai Chamber of Commerce and Industry Headquarter Building Dubai , UAE, LEED FACTS*, [online] , [Accessed on January. 2015], Available at: http://emiratesgbc.org/wp-content/uploads/2014/08/case_study_dubai_chamber_leed.pdf

EGBC, (2015), Technical Guidelines, [online], [Accessed on 1 June ,2016] Available at: http://emiratesgbc.org/academy/emiratesgbc-technical-guidelines/

eia, (2015), *United Arab Emirates, International energy data and analysis* , U. S. Energy Information Administration, [online], [Accessed on April, 2016], Available at: http://www.eia.gov/beta/international/analysis_includes/countries_long/United_Arab_Emirates/uae.pdf

Eicker, U., Demir, E. and Gurlich, D. (2015) 'Strategies for cost efficient refurbishment and solar energy integration in European case study buildings', *Energy and Buildings*, 102, pp.237-249.

Eisenhower, B., O'Neil, Z., Fonoberov, V. A. and Mezic, I. (2012) 'Uncertainty and sensitivity decomposition of building energy models', *Journal of Building Performance Simulation,* 5(3), pp. 171-184.

EMS, Energy Management Services, (2016), Available at: www.ems-int.com

ENERGY STAR, (2016), ENERGY STAR Most Efficient 2016- Central Air Conditioners and Air Source Heat Pumps. [online], [Accessed on 22 Jun. 2016], Available at: https://www.energystar.gov/index.cfm?c=most_efficient.me_cac_ashp

Etihad ESCO, (2014), Ministry of Energy and Etihad Energy services Company (ESCO) Sign MOU to Develop Federal Energy Services Market in the UAE, [online]. [Accessed on September 2015], Available at: http://www.etihadesco.ae/pressreleases/ministry-of-energy-and-etihad-energy-service-company-esco-ign-mou-to-develop-federal-energy-services-market-in-the-uae/

Etihad ESCO, (2014a), 75% Measured and Verified Electricity Savings at DEWA Power Station, [online], [Accessed on 31 May, 2016], Available at: http://www.etihadesco.ae/pressreleases/75-measured-and-verified-electricity-savings-at-dewa-power-stations/

Etihad ESCO, (2014b), Welcome to Etihad ESCO, [online]. [Accessed on September 2015] , Available at: http://www.etihadesco.ae/

Etihad ESCO, (2015), DEWA Buildings Retrofit, [Online], [Accessed on Sep. 2015], Available at: www.etihadesco.ae/wp-content/uploads/2015/07/EtihadEsco_ProjectSheet_Dewa.

EWS-WWF, (2015), The Problem. [Online]. [Accessed 25 Jan 2015], Available at: http:/business.heroesoftheuae.ae/en/section/the-problem

Executive Affairs Authority. Demand-Side Management; Executive Affairs Authority: Abu Dhabi, UAE, 2009.

Fang, X. and Li, D. (2013) 'Solar photovoltaic and thermal technology and applications in China', *Renewable and Sustainable Energy Reviews*, 23, pp. 330–340.

Faraj, A.H., (2015), *The potential of integrating PV in the Heritage Sites, Case Study of Dubai Museum*. M.Sc. Thesis. British University in Dubai..

Firlag, S., Yazdanian, M., Curcija, C., Kohler, C., Vidanovic, S., Hart, R., and Czarnecki, S. (2015) 'Control algorithms for dynamic windows for residential buildings', *Energy and Buildings*, 109, pp. 157-173.

Flucher, C. , Maurer E. ,& Deshmukh, A. (2010). Achieving Radically Energy Efficient Retrofits: The Empire State Building Example. *ASHRAE Transactions,* vol. 116, part 2

Fong, J. and Alwan, Z. (2013) 'Modelling to predict future energy performance of solar thermal cooling systems for building applications in the north east of England', *Applied Thermal Engineering*, 57(1-2), pp. 81-89.

Fraunhofer Institute for Building Physics, (2011), Energy Efficient Measures for Government Buildings. [Accessed on 1 May 2016], Available at: http://www.annex46.de/index_e.html

Fraunhofer ISE , (2015), PHOTOVOLTAICS REPORT, Fraunhofer Institute for Solar Energy System, ISE & PSE AG, Freiburg, 17 November, 2015, [Online]. [Accessed on 26 February 2016], Available at: www.ise.fraunhofer.de

Fraunhofer ISE , (2016), PHOTOVOLTAICS REPORT, Fraunhofer Institute for Solar Energy System, ISE & PSE AG, Freiburg, 6 June, 2016, [Online]. [Accessed on 26 February 2016], Available at: https://www.ise.fraunhofer.de/de/downloads/pdf-files/aktuelles/photovoltaics-report-in-englischer-sprache.pdf

Friess, W.A., Rakhshan, K., Hendawi, T.A. and Tajerzadeh, S. (2012) 'Wall insulation measures for residential villas in Dubai: A case study in energy efficiency', *Energy and Buildings*, 44, pp. 26–32.

Garde F., Lenoir1 A. ,. Scognamiglio A., Aelenei D. , Waldren D. , Rostvik H. N., Ayoub6 J. , Aelenei7, M.Donn L. , Tardif M. & Cory S., (2013). How TO DESIGHN A NET ZERO ENERGY BUILDINGS? SOLUTION SETS AND CASE STUDIES: EXPERIENCE AND FEEDBACK OF THE IEA TASK 40/ANNEX52. [Accessed on 19 October 2015], Available at: http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/events/High-Performance-Buildings-June-2013/Papers/session4/41_pap_garde_hpb_2013_final.pdf

Gaur, A. and Tiwari, G.N. (2013) 'Performance of Photovoltaic modules of different solar cells', *Journal of Solar Energy*, 2013, pp. 1-13.

Gil-Lopez, T. and Gimenez-Molina, C. (2013) 'Environmental, economic and energy analysis of double glazing with a circulating water chamber in residential buildings, *Applied Energy*, 101, pp. 572–581.

Givoni, B. (1994). *Passive low energy cooling of buildings (architecture)*. United States: John Wiley & Sons.

Gohardani, N. and Bjork, F. (2012) 'Sustainable refurbishment in building technology', *Smart and Sustainable Built Environment,* 1(3), pp. 241-252.

Gong, X., Akashi, Y. and Sumiyoshi, D. (2012) 'Optimization of passive design measures for residential buildings in different Chinese areas', *Building and Environment,* 58, pp. 46-57.

Gowri, K., Winiarski, D., and Jarnagin, R.(2009), *Infiltration Modeling Guidelines for Commercial Building Energy Analysis.* Pacific Northwest National Laboratory, U.S. Department of Energy. USA

Graham, C. I. (2014), High performance HVAC, National Institute of Building sciences, [Accessed on 22 Jun, 2016], Available at: https://www.wbdg.org/resources/hvac.php

Graves, L., (2016), 2015 in review: Solar power was region's top alternative energy choice, TheNational BUSINESS, [online], [Accessed on 29 Jun, 2016], Available at: http://www.thenational.ae/business/energy/2015-in-review-solar-power-was-regions-top-alternative-energy-choice

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.

Harvey, L.D.D. (2010) Energy and the new reality 2: *Carbon - Free Energy Supply (energy & the new reality 2)*. London: Earthscan Publications.

Hee, W.J., Alghoul, M.A., Bakhtyar, B., Elayeb, O., Shameri, M.A., Alrubaih, M.S. and Sopian K. (2015) 'The role of window glazing on daylighting and energy savings in buildings', *Renewable and Sustainable Energy Reviews*, 42, pp. 323-343.

High Technology Lighting, (2016), what is the recommended level for offices?, [online], [Accessed on 11 July 2016], Available at: hightechnologylighting.com.

Hirsch, A., Pless, S., Guglielmetti, R., Torcellini, P., Okada, D. & Antia, P. (2011). The Role of Modeling When Designing for Absolute Energy Use Intensity Requirements in a Design-Build Framework. *ASHRAE Winter Conference*. National Renewable Energy Laboratory. 29 January-2 February. Las Vegas: Nevada.

Hoyt, T., Arens, E. and Zhang H. (2015) 'Extending air temperature setpoints: Simulated energy savings and design considerations for new and retrofit buildings', *Building and Environment*, 88, pp. 89-96.

HVAC HESS, Heating & Ventilation & Air-conditioning High Efficiency System strategy, (2013), Chiller Efficiency, Factsheet, [Online], [Accessed on 22Jun,2016], Available at: http://industry.gov.au/Energy/EnergyEfficiency/Documents/09_2013/hvac-fs-chiller-efficiency.pdf

Ibrahim, A. (2011) 'Effect of Shadow and Dust on the Performance of Silicon Solar Cell', *Journal of Basic and Applied Scientific Research*, 1(3), pp. 222-230.

IEA (2012), "*World Energy Outlook 2012*", Online report, [Accessed on 30 December, 2015], Available at; www.iea.org/publications/freepublications/publication/ English.pdf

IEA (2013), *World Energy Outlook 2013*, OECD/IEA, Paris

IEA , (2014), *Technology Roadmap, Solar Photovoltaic Energy. International Energy Agency*, OECD/IEA, 2014, Paris, France. Available at: www.iea.org

IEA PVPS, (2015), *Trends 2015 in photovoltaic applications, Survey Report of selected IEA Countries between 1992and 2014*, Report IEA-PVPS T1-27:2015

IEA PVPS, (2015), Trends 2015 in photovoltaic applications, Survey Report of selected IEA Countries between 1992and 2014, Report IEA-PVPS T1-27:2015

IEA-PVPS , (2009), Overcoming *PV grid issues in urban areas, International Energy agency*, Photovoltaic Power System Program. IEA PVPS Task 10, Activity 3.3,Report IEA-PVPST10-06:2009

IFC (2014), *Harnessing Energy from the sun: Empowering Rooftop Owners, White paper on Grid-Connected Rooftop Solar Photovoltaic Development Models*. International Finance Corporation. [Online report], [Accessed on 1 March 2014], Available at: http://www.ifc.org

Intergovernmental Panel on Climate Change. In Climate Change 2007: Mitigation; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2007.

Ioannou, A.K., Stefanakis, N.E. and Boudouvis, A.G. (2014) 'Design optimization of residential grid-connected photovoltaics on rooftops', *Energy and Buildings,* 76, pp. 588-596.

IPCC, (2011), *Renewable Energy Sources and Climate Change Mitigation, Summary for Policy Makers and Technical summary*, Special Report of the Intergovernmental Panel on Climate Change.

IRENA 2014, *REthinking Energy*: *Towards a new power system,* IRENA, 2014, Available at: www.irena.org

IRENA (2014a), REmap 2030: A Renewable Energy Roadmap, IRENA, Abu Dhabi. Available at: www.irena.org

IRENA (2015), RESOURCE: YOUR SOURCE FOR RENEWABLE ENERGY INFORMATION, [Accessed on January, 2016], Available at: http://resourceirena.irena.org/gateway/

IRENA (2015a), RENEWABLE ENERGY STSTISTICS, [online], available at: http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2015.pdf

IRENA, (2015b), *RENEWABLE ENERGY PROSPECTS: UNITED ARAB EMIRATES*, REmap 2030 analysis, Masdar Institute &I RENA, Abu Dhabi, available at: www.irena.org

Islam, M.D., Kubo, I., Ohadi, M. and Alili, A.A. (2009) 'Measurements of solar radiation in Abu Dhabi, UAE', *Applied energy*, 86(4), 511-515.

Itani, T., Ghaddar, N. and Ghali, K. (2013) 'Strategies for reducing energy consumption in existing office buildings', *International Journal of Sustainable Energy*, 32(4), pp. 259-275. DOI: 10.1080/14786451.2011.622765

Iwaro, J. and Mawasha, A. (2010) 'A review of building energy regulation and policy for energy conservation in developing countries', *Energy policy*, 38(12), pp.7744-7755.

Jalili, M., Clevenger, C. M., Ozbek, M. E., Abdullah. M. A. (2015), ENERGY STAR WINDOWS' PERFORMANCE AND ORIENTATION, *Proceeding 5th International/11th construction Specialty Conference*, 8-10 June,2015, Vancouver, British Colombia.

Jamil, M., Ahmad, F. and Jeon, Y.J. (2016) 'Renewable energy technologies adopted by the UAE: Prospects and challenges - A comprehensive overview', *Renewable and Sustainable Energy Review*, 55, pp. 1181-1194.

Janajreh, I., Su, L. and Alan, F. (2013) 'Wind energy assessment: Masdar City case study', *Renewable Energy*, 52, pp.8-15.

Jelle, B.P., Hynd, A., Gustavsen A., Arasteh, D., Goudey, H. and Hart, R. (2012) 'Fenestration of today and tomorrow: a state-of-the-art review and future research opportunities', *Solar Energy Materials and Solar Cells*, 96, pp. 1–28.

Jenkins, D.P., Ingram, V., Simpson, S.A. and Patidar, S. (2013) 'Methods for assessing domestic overheating for future building regulation compliance', *Energy Policy,* 56, pp. 684–692.

Juaidi, A., Montoya, F.G., Gazquez, J.A. and Manzano-Agugliaro, F. (2016) 'An overview of energy balance compared to sustainable energy in United Arab Emirates', *Renewable and Sustainable Energy Reviews,* 55, pp. 1195-1209.

Kaklauskas, A., Rute, J., Zavadskas, E.K., Daniunas, A., Pruskus, V., Bivainis, J., Gudauskas, R. and Plakys, V. (2012) 'Passive house model for quantitative and qualitative analyses and its intelligent system', *Energy and Buildings,* 50, pp. 7-18.

Katanbafnasab, M. (2013) 'Assessment of the energy impact of using building integrated Photovoltaic and Electrochromic glazing in office building in UAE', *Engineering,* 5(1), pp. 56-61.

Kaynakli, O. (2012) 'A review of the economical and optimum thermal insulation thickness for building applications', *Renewable and Sustainable Energy Reviews,* 16(1), pp. 415-425.

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.

Kim, G., Lim, H.S., Lim T.S., Schaefer, L. and Kim, J.T. (2012) 'Comparative advantage of an exterior shading device in thermal performance for residential buildings', *Energy and Buildings,* 46, pp. 105-111.

Kirimtat, A., Koyunbaba, B.K., Chatzikonstantinou, I. and Sariyildiz, S. (2016) 'Review of simulation modeling for shading devices in buildings', *Renewable and Sustainable Energy Reviews*, 53, pp. 23-49.

Kolaitis, D.I., Malliotakis, E., Kontogeorgos, D.A., Mandilaras, I., Katsourinis, D.I. and Founti, M.A. (2013) 'Comparative assessment of internal and external thermal insulation systems for energy efficient retrofitting of residential buildings', *Energy and Buildings,* 64, pp. 123–131.

Kumar, A. and Suman, B.M. (2013) 'Experimental evaluation of insulation materials for walls and roofs and their impact on indoor thermal comfort under composite climate, *Building and Environment,* 59, pp. 635-643.

Kung, Y., Qu, M. & Peng S.,(2014), An Integrated System of Vapor-Compression Chiller and Absorption Heat Pump for Efficiency Improvement: System Modeling and Performance Analysis, *ASHRAE Transaction*, 120, 11,21,31,41,51,61,71,81

Kwong, Q.J., Adam, N.M. and Sahari, B.B. (2014) 'Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review', *Energy and Buildings*, 68, pp. 547-557.

Kylili, A. and Fokaides, P. A. (2015) 'European smart cities: The role of zero energy buildings', *Sustainable Cities and Society*, 15, pp. 86-95.

Lacey, S. (2013), *5 technologies to make government buildings more efficient*, [online article], Accessed on 30 April, 2016], available at: http://www.greentechmedia.com/articles/read/Five-Technologies-to-Make-Government-Buildings-More-Efficient

Larsen, S.F., Filippin, C., Beascochea, A. and Lesino, G. (2008) 'An experience on integrating monitoring and simulation tools in the design of energy-saving buildings', *Energy and Buildings*, 40(6), pp. 987-997.

Leal, V.M.S., Granadeiro, V., Azevedo, I. and Boemi, S.-N. (2014) 'Energy and economic analysis of building retrofit and energy offset scenarios for net Zero energy buildings', *Advances in Building Energy Research*, 9 (1), pp. 120-139.

Lechner, N. (2008). *Heating, cooling, lighting: Sustainable design methods for architects*. 3rd edn. United Kingdom: Wiley, John & Sons.

Levine M., Feng W., Ke J., Hong T. & Zhou N., (2014), *A Retrofit Tool for Improving Energy Efficiency of Commercial Buildings.* ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY.

lfengspace Culture & Media Co., (2012). Architecture of Low Energy Consumption . Phoenix Publishing Limited, China

Li, D.H.W., Yang, L. and Lam, J.C. (2013) 'Zero energy buildings and sustainable development implications - A review', *Energy*, 54, pp. 1-10.

Li, R., Dai, Y.J. and Wang, R.Z. (2015) 'Experimental and theoretical analysis on thermal performance of solar thermal curtain wall in building envelope', *Energy and Buildings*, 87, pp. 324-334.

Lip Ahn B., Hun Kim J., Yong Jang C., Bok Leigh S. & Jeong H., (2015), Window retrofit strategy for energy saving in existing residences with different thermal characteristics and window sizes. *Building services Engineering Research & Technology*. The Charted Institution of Building services Engineering 2015. DOI: 10.1177/0143624415595904, available at: bse.sagepub.com

Liu, Y. and Guo, W. (2013) 'Effects of energy conservation and emission reduction on energy efficiency retrofit for existing residence: A case from China. *Energy and Buildings*, 61, pp. 61-72.

Ma, Z., Cooper, P., Daly, D. and Ledo, L. (2012) 'Existing building retrofits: Methodology and state-of-the-art', *Energy and Buildings*, 55, pp. 889–902.

Maceda, C. (2015), UAE electricity consumption to grow'more rapidly', GULF NEWS ENERGY, [online], [Accessed April 26, 2016], Available at: http://gulfnews.com/business/sectors/energy/uae-electricity-consumption-to-grow-more-rapidly-1.1569200

Machol, B. and Rizk, S. (2013), 'Economic value of U.S. Fossil fuel electricity health impacts', *Environment International*, 52, pp. 75-80.

Maehlum, M. A. (2016), Which Solar Panel Type is Best? Mono- vs. Polycrystalline vs. Thin Film. ENERGY INFORMATIVE, [online], Accessed on 29 Jun,2016, Available at: http://energyinformative.org/best-solar-panel-monocrystalline-polycrystalline-thin-film/

Mandalaki, M., Zervas, K., Tsoutsos, T. and Vazakas, A. (2012) 'Assessment of fixed shading devices with integrated PV for efficient energy use', *Solar Energy*, 86, pp. 2561–2575.

Maneewan, S., Hirunlabh, J., Khedari, J., Zeghmati, B. and Teekasap, S. (2005), Heat gain reduction by means of thermoelectric roof solar collector, *Solar Energy*, 78(4), pp. 495-503.

Manneh, A. (2013), *Assessing energy saving potential in existing buildings in Abu Dhabi through passive retrofitting strategies: Case study- office buildings*. M.Sc. Thesis. British University in Dubai..

Manneh, A., AlNaqabi, A., AlAwadi, W., Ayoub, K. & Abu-Hijleh, B. (2014). Economic Assessment of Refurbishment of Federal Public Housing in the UAE. *World Sustainable Building 14 Conference*. Barcelona 28-30th October, 2014.

Manzano-Agugliaro, F., Alcayde, A., Montoya, F.G., Zapata-Sierra, A. and Gil, C. (2013) 'Scientific production of renewable energies worldwide: An overview', *Renewable and Sustainable Energy Reviews*, 18, pp. 134–143.

Marino, C., Minichiello F. and Bahnflfeth, W. (2015) ‘The influence of surface finishes on the energy demand of HVAC systems for existing buildings’, *Energy and Buildings*, 95, pp. 70-79.

McGraw Hill Construction, (2013), *World Green Buildings Trends, Business Benefits Driving New and Retrofit Market Opportunities in Over 60 Countries*, SmartMarket Report, McGraw Hill Construction & United Technologies, Available at: www.construction.com

McKinsey& Company. (2009). “Unlocking Energy Efficiency in the U.S. Economy. McKinsey Global Energy and Materials. Available at: www.mckinsey.com/USenergyefficiency

Menassa, C. C. (2011) ‘Evaluating sustainable retrofits in existing buildings under uncertainty’, *Energy and Buildings*, 43(12), pp. 3576-3583.

Mingotti, N., Chenvidyakarn, T. and Woods, A.W. (2013) ‘Combined impacts of climate and wall insulation on the energy benefit on an extra layer of glazing in the facade’, *Energy and Buildings*, 58, pp. 237-249.

Minister of Foreign Affairs. (2010). *United Nations Framework Convention on Climatic Change* [online]. [Accessed on 1 May 2016]. Available at: http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/uaecphaccord.pdf

Ministry of Environment and Water, (2014), *UAE STATE OF GREEN ECONOMY*, United Arab Emirates: Ministry of Environment and Water.

Mirhassani, S., Ong, H.C., Chong, W.T. and Leong, K.Y. (2015) ‘Advances and challenges in grid tied photovoltaic systems’, *Renewable and Sustainable Energy Reviews*, 49, pp. 121-131.

Miyatake, M., Veerachary, M., Toriumi, F., Fujii, N. and Ko, H. (2011) ‘Maximum power point tracking of multiple photovoltaic arrays: A PSO approach’, *IEEE Trans Aerospace Electronic Systems*, 47, pp. 367–380.

Mokhatar, M., Ali, M.T., Brauniger, S., Afshari, A., Sgouridis, S., Armstrong, P. and Chiesa, M. (2010) ‘Systematic comprehensive techno-economic assessment of solar cooling technologies using location-specific climate data’, *Applied Energy*, 87(12), pp. 3766–3778.

Mokri, A., Aal Ali, M. and Emziane, M. (2013) ‘Solar energy in the United Arab Emirates: A review’, *Renewable and Sustainable Reviews*, 28, pp. 340-375.

Moran, F., Blight, T., Natarajan, S. and Shea, A. (2014) ‘The use of passive house planning package to reduce energy use and CO2 emissions in historic dwellings’, *Energy and Buildings*, 75, pp. 216-227.

Morelli, M., Ronby, L., Mikkelsen, S.E., Minzari, M.G., Kildemoes T. and Tommerup, H.M. (2012) 'Energy retrofitting of a typical old Danish multi-family building to a "nearly zero" energy building based on experiences from a test apartment', *Energy and Buildings*, 54, pp. 395-406.

Nagy, Z., Rossi, D., Hersberger, C., Irigoyen, S. D., Miller, C. and Schlueter, A. (2014) 'Balancing envelope and heating system parameters for zero emissions retrofit using building sensor data', *Applied Energy*, 131, pp. 56-66.

NATIONAL TRUST FOR HISTORIC PRESERVATION NTHP, (2012), *Saving Windows Saving Money: Evaluating the Energy Performance of Window Retrofit and Replacement*, National Trust for Historic Preservation, Preservation Green Lab.

NREL. (2011). "NREL Recommends Ways to cut Buildings Energy Costs in Half." National Renewable Energy Laboratory. NREL/FS-6A42-50991

Olgyay, V. & Seruto C., (2010). Whole-Building Retrofits: A Gateway to Climate Stabilization. *ASHREA Transactions,* vol.116, part2.

Orioli, A. and Di Gangi, A. (2013) 'Load mismatch of grid-connected photovoltaic systems: Review of the effects and analysis in an urban context', *Renewable and Sustainable Energy Reviews*, 21, pp. 13-28.

Ouarda, T.B.M.J., Charron, C., Shin, J., Marpu, P.R., Al-Mandoos, A.H., Al-Tamimi, M.H., Ghedira, H. and Al-Hosary, T.N. (2015) 'Probability distribution of wind speed in the UAE', *Energy Conversion and Management*, 93, pp. 414-434.

Pargana, N., Pinheiro, M. D., Silvestre, J.D. and de Brito J. (2014) 'Comparative environmental life cycle assessment of thermal insulation materials of buildings', *Energy and Buildings*, 82, pp. 466-481.

Patterson, M., Vaglio, J. and Noble, D. (2014) 'Incremental Facade Retrofits: Curtainwall technology as a strategy to step existing buildings toward Zero net energy', *Energy Procedia*, 57, pp. 3150-3159.

Petersdorff, C., Boermans, T., Stobbe, O., Joosen, S., Graus, W., Mikkers, E. & Harnisch, J. (2006). *Mitigation of CO2 Emissions from the Building Stock: Beyond the EU Directive on the Energy Performance of Buildings.* ECOFYS, Cologne Germany, 2010.

Pisello, A.L. and Asdrubali, F. (2014) 'Human-based energy retrofits in residential buildings: A cost-effective alternative to traditional physical strategies', *Applied Energy*, 133, pp. 224-235.

Prayas (2012), Solar Rooftop PV in India, Need to prioritize in-situ generation for self consumption with a net-metering approach. Prayas Energy Group, [Online], [Accessed on 1 March, 2016], Available at: http://www.indiaenvironmentportal.org.in/content/368705/solar-rooftop-pv-in-india-need-to-prioritize-in-situ-generation-for-self-consumption-with-a-net-metering-approach/

Radhi, H. (2010), 'On the Effect of Global Warming and the UAE Built Environment, Global Warming', *Stuart Arthur Harris (Ed)* -[Online]. [Accessed on 25 January 2015]. Available at: http://cdn.intechopen.com/pdfs/12173/

Radhi, H. (2009) 'Can envelope codes reduce electricity and CO2 emissions in different types of buildings in the hot climate of Bahrain?', *Energy*, 34(2), pp. 205-215.

Radhi, H. (2011) 'Viability of autoclaved aerated concrete walls for the residential sector in the United Arab Emirates', *Energy and Buildings*, 43(9), pp.2086-2092.

Ralegaonkar, R.V. and Gupta, R. (2010) 'Review of intelligent building construction: A passive solar architecture approach', *Renewable and Sustainable Energy Reviews,* 14(8), pp. 2238–2242

Rao, A., Pillai, R., Mani, M. and Ramamurthy, P. (2014) 'Influence of dust deposition on Photovoltaic panel performance', *Energy Procedia*, 54, pp. 690-700.

Rashid, F. , (2015). Demand Side management strategy 2030: Building retrofits program, The Dubai Supreme Council of Energy, RETROFITTECH conference, Dubai, 2015

Reddy R. & Kayal H. (2013), Performance evaluation of solar insulation in UAE conditions Proc. 17th international Passive House Conference , Frankfurt 19-20 April, 2013.

Rohani, G. and Nour, M. (2014) 'Techno-economical analysis of stand-alone hybrid renewable power system for Ras Musherib in United Arab Emirates', *Energy*, 64, pp. 828-841

Saches, M. (2016*), STATE OF ENERGY REPORT UAE 2015*, MOE, Ministry of Energy, UAE, available at: www.moenr.gov.ae

Sadineni, S.B., Attalah, F. and Boehm, R.F. (2012) 'Impact of roof integrated PV orientation on the residential electricity peak demand', *Applied Energy*, 92, pp. 204-210.

Sadineni, S.B., Madala, S. and Boehm, R.F. (2011) 'Passive building energy savings: A review of building envelope components', *Renewable and Sustainable Energy Reviews,* 15(8), pp. 3617-3631.

Saidur, R. (2009) ‘Energy consumption, energy savings, and emission analysis in Malaysian office buildings’, *Energy Policy*, 37(10), pp. 4104-4113.

Sallee, H., Quenard, D., Valenti, E. and Galan, M. (2014) ‘VIP as thermal breaker for internal insulation system’, *Energy and Buildings,* 85, pp. 631-637.

Salman,W., (2015), The UAE'S PATH TO CLEAN ENERGY, *UAE State of Energy Report 2015,* Ministry of Energy, UAE

Santamouris, M & Asimakopoulos D. (1996). *Passive Cooling Of Buildings.* London: James & James Ltd.

Schwartz, Y. and Raslan, R. (2013) ‘Variations in results of building energy simulation tools, and their impact on BREEAM and LEED rating: A case study’, Energy and Buildings, 62, pp. 350-359.

Sgouridis, S., Abdullah, A., Griffiths, S., Saygin, D., Wagner, N., Gielen, D., Reinisch, H. and McQueen, D. (2016) ‘RE-mapping the UAE's energy transition: An economy-wide assessment of renewable energy options and their policy implications’, *Renewable and Sustainable Energy Reviews,* 55, pp. 1166-1180.

Shameri, M.A., Alghoul, M.A., Elayeb, O., Zain, M.F.M., Alrubaih, M.S., Amir, H. and Sopian, K. (2013) ‘Daylighting characteristics of existing double-skin facade office buildings’, *Energy and Buildings,* 59, pp. 279–286.

Shawon, M.J., El Chaar, L. and Lamont, L.A. (2013) ‘Overview of wind energy and its cost in the Middle East’, *Sustainable Energy Technologies and Assessments,* 2, pp. 1-11.

Shonder, J. (2014), *Energy Savings from GSA's National Deep Energy Retrofit Program*. OAK RIDGE NATIONAL LABORATORY, US DOE.

Silva, P.C.P., Almeida, M., Braganca, L. and Mesquita, V. (2013) ‘Development of prefabricated retrofit module towards nearly zero energy buildings’, *Energy and Buildings,* 56, pp. 115-125.

Silva, S.M., Silva, P.P., Almeida, M. and Braganca, L. (2012) ‘Operative conditions evaluation for efficient building retrofit - A case study’, *Indoor and Built Environment,* 22(5), pp. 724-742.

SolarEdge, (2012), *Problem and Disadvantages in Current Residential & Commercial On-grid PV Systems,* SolarEdge Technologies, V. 01, Available at : www.solaredge.co.

Sozer, H. (2010) ‘Improving energy efficiency through the design of the building envelop’, *Building and Environment*, 45(12), pp. 2581-2593.

STAFFORD, A. , GORSE, C. and SHAO, L. (2007), ‘*The Retrofit Challenge: Delivering Low Carbon Buildings'*. Report. UK: The Centre of Low Carbon Future.

Stanton, C. (2009), Drilling deep for green energy, *The National* [online], Accessed 8 January 2016]. Available at: http://www.thenational.ae/business/energy/drilling-deep-for-green-energy

Stapleton, G., Neill, S. and Global Sustainable Energy Solutions Pty Ltd (2011) Grid-connected solar electric systems the Earthscan expert handbook for planning, design, and installation. Washington, DC: Earthscan..

STATE OF GREEN ECONOMY (2015). Your Roof. Our Power Plant, WORLD GREEN ECONOMIC SUMMIT. 2015

Stazi, F., Veglio, A., Di Perna, C. and Munafo, P. (2012) ‘Retrofitting using a dynamic envelope to ensure thermal comfort, energy savings and low environmental impact in Mediterranean climates’, *Energy and Buildings*, 54, pp. 350-362.

Stazi, F., Veglio, A., Di Perna, C. and Munafo, P. (2013) ‘Experimental comparison between 3 different traditional wall constructions and dynamic simulations to identify optimal thermal insulation strategies’, *Energy and Buildings*, 60, pp. 429-441.

STBA, (2015), What Are Measures? *The Sustainable Traditional Buildings Alliance,* [Online], [accessed on 11 August 2015], Available at: stbauk.org

Stevanović, S. (2013) ‘Optimization of passive solar design strategies: A review’, *Renewable and Sustainable Energy Reviews,* 25, pp. 177–196.

Stieb, I. and Dunkelberg, E. (2013), ‘Objectives, barriers and occasions for energy efficient refurbishment by private homeowners’, *Journal of Cleaner Production*, 48, pp. 250-259.

Taleb, H.M. (2014) ‘Using passive cooling strategies to improve thermal performance and reduce energy consumption of residential buildings in U.A.E. Buildings’, *Frontiers of Architectural Research*, 3(2), pp. 154-165.

Taleb**,** H.M. and Sharples, S. (2011) ‘Developing sustainable residential buildings in Saudi Arabia: A case study’, *Applied Energy,* 88(1), pp. 383–391.

Tanweer, 2016, Solar On-Grid, Go Green For a Green Future, [online image], [Accessed on 1 March 2016], available at: http://www.tanweercom.net

TAQAWORLD magazine, (2013), Waste -To-Energy, EXPLORING UNCHARTED TERRITORIES, online, issue 3, accessed on January 2016, available at: http://www.taqaglobal.com/media-centre/taqaworld-magazine/2013/taqaworld-issue-3/waste-to-energy?sc_lang=en

Tariq, T. (2015), THE NEW GUIDLINE FOR EXISTING BUILDING OWNERS, OPERATORS, AND END-USERS TO INCREASE OPERATIONAL EFFICIENCY, *UAE STSTE OF ENERGY REPORT 2016*, (PP.76-79). UNITED ARAB EMIRATES, MINISTRY OF ENRGY

Techato, K., Watts, D.J. and Chaiprapat, S. (2009) 'Life cycle of retrofitting with high energy efficiency air-conditioner and fluorescent lamp in existing buildings', *Energy Policy*, 37(1), pp. 318-325.

Teng, C.-C., Horng, J.-S., Hu, M.-L., Chien, L.-H. and Shen, Y.-C. (2012) 'Developing energy conservation and carbon reduction indicators for the hotel industry in Taiwan', *International Journal of Hospitality Management*, 31(1), pp. 199-208.

Tettey, U.Y.A., Dodoo, A. and Gustavsson, L. (2014) 'Effects of different insulation materials on primary energy and CO2 emission on a multi-story residential building', *Energy and Buildings*, 82, pp. 369-377.

THE AMERICAN INSTITUTE OF ARCHITECTS, (2016), Top Ten Projects, 2016 Winners, AIA Committee on the Environment Top Ten Project, [Accessed 30 April 2016], Available at: http://www.aiatopten.org

The ecoexperts, (2016), Which Solar Panels are More efficient? [online], Accessed on 29 Jun, 2016 , Available at: http://www.theecoexperts.co.uk/which-solar-panels-are-most-efficient

The ecoexperts, (2016), Which Solar Panels are More efficient? [online], [Accessed on 29 Jun, 2016] , Available at: http://www.theecoexperts.co.uk/which-solar-panels-are-most-efficient

the microscope. A country-by-country review of the energy performance of buildings. Buildings Performance Institute Europe, 2011.

THE ROCKEFELIER FOUNDATION. (2012). *United States Building Energy Efficiency Retrofits. Market Sizing and Financing Models*. [Online]. [Accessed on 5 January 2015]. Available at:.rockefellerfoundation.org.

Torcellin, P., Pless S., & Deru M., (2006). Zero Energy Buildings: A Critical Look at the Definition. *National Renewable Energy Laboratory* (NREL).

Treyer, K., Bauer, C. and Simons, A. (2014) 'Human health impacts in the life cycle of future European electricity generation', *Energy Policy,* 74(1), pp. S31-S44.

Tsagarakis, K.P., Karyotakis, K. and Zografakis, N. (2012) 'Implementation conditions for energy saving technologies and practices in office buildings: Part 2. Double glazing windows, heating and air-conditioning', *Renewable and Sustainable Energy Reviews,* 16(6), pp. 3986–3998.

Tsalikis, G. and Martinopoulos, G. (2015) 'Solar energy systems potential for nearly net zero energy residential buildings', *Solar Energy*, 115, pp. 743-756.

Tuohy, P.G. and Murphy, G.B. (2014) 'Closing the gap in building performance: Learning from BIM benchmark industries', *Architectural Science Review*, 58(1), pp. 47-56.

U.S. DOE, (2012), Federal Sector, Building Energy Data Book, U.S. Department of Energy, [online], [Accessed on 24 May, 2016], Available at: http://buildingsdatabook.eren.doe.gov/ChapterIntro4.aspx

UNC,(2014). *Literature Review Handout*. [Online]. The Writing Center at UNC Chapel Hill [Accessed on 4 Feb. 2015]. Available at: writing_center@unc.edu

UNEP, (2015). Why Buildings?, [online], United Nation Environment Programme and Sustainable Building and Climate Initiative [Accessed on 22 October 2015], Available at: www.unep.org/sbci/AboutSBCI/Background.asp

USGBC, (2016), Dubai Chamber of Commerce and Industry, U.S. Green Building Council. Ac

Utama, N.A., Ishihara, K.N., Tesuka, T., Gheewala, S.H., Zhang, Q., (2011). Indonesian Building Codes and Its Influence on Future Electricity Demand. *Sustainable Energy & Environment*, vol.2, pp.21-25

WAM, Emirates News Agency (2015), UAE ecological footprint dropped to 7.75 hectares per person in 2014: Environment and Water Ministry, [online news], [Accessed on May 2016], Available at: https://www.wam.ae/en/news/emirates/1395279019133.html

WAM, Emirates News Agency (2015a), Rising energy consumption calls for a more sustainable and integrated strategy in the UAE, says study, [online news], [Accessed on April 2016], Available at: https://www.wam.ae/en/news/economics/1395284500232.html

Wang, S., Yan, C. and Xiao, F. (2012) 'Quantitative energy performance assessment methods for existing buildings', *Energy and Buildings*, 55, pp. 873-888.

Wang, Z., Ding, Y., Geng, G. and Zhu, N. (2014) 'Analysis of energy efficiency retrofit schemes for heating, ventilating and air-conditioning systems in existing office buildings based on the modified bin methods', *Energy Conversion and Management*, 77, pp. 233-242.

WBDG, WHOLE BUILDING DESIGN GUIDE (2016), Photovoltaics, National Institute of Building Science, [Accessed on Jan. 2016], Available at: https://www.wbdg.org/resources/photovoltaics.php?r=buildingcomm

WHO (2014), "Household Air Pollution and Health", World Health Organization, [online Fact sheet N°292}, [Accessed 30 December 2015], available at: www.who.int/mediacentre/factsheets/fs292/en/

WHOLE BUILDING DESIGN GUIDE (WBDG). (2014). *Net Zero energy Buildings*. [Accessed 29 Oct. 2015], Available at: www.wbdg.org/resources/netzeroenergybuildings.php

Wiedmann, T. (2009) 'Editorial: Carbon footprint and input-output analysis: An introduction', *Economic Systems Research*, 21(3), pp.175–186.

World Bank (2014), World DataBank, [Accessed March 2015], Available at: http://databank.worldbank.org/data/views/reports/ tableview.aspx?isshared=true

Wouters, F. (2015), STATE OF CLEAN ENERGY IN THE UAE, STATE OF GREEN ECONOMY REPORT, pp.92-94, *WORLD GREEN ECONOMY SUMMIT*, Dubai , United Arab Emirates, 22-23 April 2015.

Yammahi, S. (2015), RETROFITTING UAE'S BUILDINGS, *UAE STSTE OF ENERGY REPORT 2016*, (PP.82-84). UNITED ARAB EMIRATES , MINISTRY OF ENRGY

Yao, J. (2014) 'An investigation into the impact of movable solar shades on energy, indoor thermal and visual comfort improvements', *Building and Environment*, 71, pp. 24-32.

Yasar, Y. and Kalfa, S.M. (2012) 'The effects of window alternatives on energy efficiency and building economy in high-rise residential buildings in moderate to humid climates', *Energy Conversion and Management,* 64, pp. 170–181.

Yin R., Xu, P. and Shen, P. (2012) 'Case study: Energy savings from solar window film in two commercial buildings in Shanghai', *Energy and Buildings*, 45, pp. 132-140.

Yin, R. K., 2003. *Case Study Research Design and Methods*. 3rd ed. California: Sage Publications, Inc.

Yu, F.W. and Chan, K.T. (2010) 'Simulation and electricity savings estimation of air-cooled centrifugal chiller system with mist pre-cooling', *Applied Energy*, 87(4), pp. 1198–1206.

Yu, F.W. and Chan, K.T. (2013) 'Improved energy management of chiller systems with data envelopment analysis', *Applied Thermal Engineering,* 50(1), pp. 309-317.

Yu, F.W., Chan, K.T., Yang, J. and Sit, R.K.Y. (2015) 'Comparative study on the energy performance of chiller system in an institutional building with stochastic frontier analysis', *Energy and Buildings*, 89, pp. 206-212.

Zafar, S. and Gadallah, M., (2013). Energy Production Through Wind Using Personal Use wind Turbines: A UAE case Study, *Proc. of ASME 2013 International Mechanical Engineering Congress and Exposition,* San Diego, California, USA, November 15-21, 2013

Zhai, Z., Johnson, M.-H. and Krarti, M. (2011) 'Assessment of natural and hybrid ventilation models in whole-building energy simulations', *Energy and Buildings,* 43 (9), pp. 2251–2261.

Zhang, H., Arens, E. and Zhai, Y. (2015) 'A review of the corrective power of personal comfort systems in non-neutral ambient environments', *Building and Environment*, 91, pp. 15-41.

Appendix A

Literature Review & Supporting Data

Tables A1-6: Comparison between 20 simulation software (Crawely et al. 2008)

X feature or capability available and in common use

P feature or capability partially implemented

O optional feature or capability

R optional feature or capability for research use

E feature or capability requires domain expertise

I feature or capability with difficult to obtain input

Table 1 ***Zone Loads*** (11 of the 21 rows from Table 2 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																				
▪ Dependent on temperature	X	X					P		X		X	X	X		X	X	X	X		X
▪ Dependent on air flow	X						X		P		X		X		X			X		E
▪ Dependent on surface heat coefficient from CFD									E		E		X							
▪ User-defined coefficients (constants, equations or correlations)		X	X	X	X				X		E	R	X		X	X	X	X		X
Internal thermal mass	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Automatic design day calculations for sizing																				
▪ Dry bulb temperature	X	X	X	X	X	X	X	X	X	X		X	X	X	X	P		X	X	
▪ Dew point temperature or relative humidity			X	X		X	X		X	X		X	X	X				X	X	
▪ User-specified minimum and maximum			X	X		X	X		X	X		X	X	X	X			X	X	
▪ User-specified steady-state, steady-periodic or fully dynamic design conditions			X									X	X	X				X	X	X

Table 2 ***Building Envelope, Daylighting and Solar*** (9 of the 52 rows from Table 3 in the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Outside surface convection algorithm																				
▪ BLAST/TARP	X								X										X	
▪ DOE-2				X					X	X									X	
▪ MoWiTT									X		X								X	
▪ ASHRAE simple	X					X		X	X				X		X			X	X	
▪ Ito, Kimura, and Oka correlation											X	X								
▪ User-selectable			X						X		X	X	X			X		X	X	X
Inside radiation view factors		X	X						X		X	X	X				P	X		
Radiation-to-air component separate from detailed convection (exterior)		X	X						X	X	X	X	X				X	X	P	X
Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		P			X				X		X		X			P				X

Table 4 ***Infiltration, Ventilation, Room Air and Multizone Airflow***	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X	P						P				X				X	X		
Natural ventilation (pressure, buoyancy driven)		X	P						X	P	X	X	X			X	X	X		O
Multizone airflow (via pressure network model)		X	P						X		X	X	X				X	X		O
Hybrid natural and mechanical ventilation		X	P			X					I	X	X			X		X		O
Control window opening based on zone or external conditions			X			X			X		X		X			P	X			O
Displacement ventilation									X		X	X	X					X		O
Mix of flow networks and CFD domains			X								E									
Contaminants, mycotoxins (mold growth)		P									R					P				

Table 5 ***HVAC Systems/Components & Renewable Energy Systems*** [summary from report Tables 5, 7 & 8 (9 pages)]	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Renewable Energy Systems (12 identified, X+O)	1	2	2	1	4	0	0	2	4	2	7	1	3	0	0	1	2	2	0	12
Idealized HVAC systems	X		X		X	X			X		X	X	X				X			X
User-configurable HVAC systems		X	X				P		X		X	X	X	X	X	X	R	X	X	X
Pre-configured systems (among 34 identified, X+O)	14	14	20	16	0	16	5	7	28	24	23	32	28	28	10	8	1	23	26	20
Discrete HVAC components (98 identified, X+O)	51	24	34	39	0	24	8	15	66	61	40	52	38	43	7	15	3	26	63	82

Table 6 ***Economic Evaluation*** (energy costs portion of Table 11 of the report)	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Simple energy and demand charges		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Complex energy tariffs including fixed charges, block charges, demand charges, ratchets		X	X	X			X		X	X			X	X	X	P			X	E
Scheduled variation in all rate components		X	X	X					X	X		X	X	X	X	P		X	X	X
User selectable billing dates				X					X	X					X	P			X	E

Table A7: NZEB Tools Matrix (Attia & De Herde, 2011)

NZEB Criteria	HEED	eQUEST	Energy 10	Vasari	Solar Shoebox	Openstudio	IES VE-Ware	ECOTECT	DesignBuilder	BeOpt
Metrics	•	•	•	•	•	•	•	•	•	•
Energy	•	•	•	•	•	•	•	•	•	•
Environmental (CO_2)	•	•	•				•		•	•
Economic	•	•	•						•	•
Embodied Energy										
Urban Scale NZEBs										
Comfort & Climate	•	•	•		•		•	•	•	•
Climate Analysis	•	•	•	•			•	•	•	
Static	•	•	•	•			•	•	•	•
Adaptive					•					
Comfort Visualisation					•			•	•	
Passive Solar	•	•	•	•	•	•	•	•	•	•
Geometry, Massing				•	•	•	•			•
Daylighting	•	•	•				•		•	
Natural Ventilation	•		•				•		•	•
WWR		•	•				•		•	•
Thermal Mass	•		•				•		•	•
Shading Devices	•	•	•			•	•	•	•	•
Energy Efficiency	•	•	•	•	•	•	•	•	•	•
Envelope Insulation	•	•	•	•	•	•	•	•	•	•
Glazing Performance	•	•	•	•	•		•	•	•	•
Envelope Air Tightness	•	•	•				•	•	•	•
Artificial lighting	•	•	•				•		•	•
Plug Loads	•	•	•				•		•	•
Infiltration rate	•	•	•		•				•	•
Mechanical Ventilation	•		•						•	•
Cooling System	•	•	•	•			•		•	•
Heating system	•	•	•	•			•		•	•
Renewable ES	•		•		•		•			•
Photovoltaic (PV)	•		•		•		•			•
Building Integrated PV										
Solar Therm. Collectors			•				•			•
Innovative Solution & Technologies					•		•			•
Mixed Mode Ventilat.					•					
Advanced Fenestration							•		•	
Green Roofs							•			
Cool Roofs	•									
Double Skin Facade									•	
Solar Tubes										
Phase change materials										

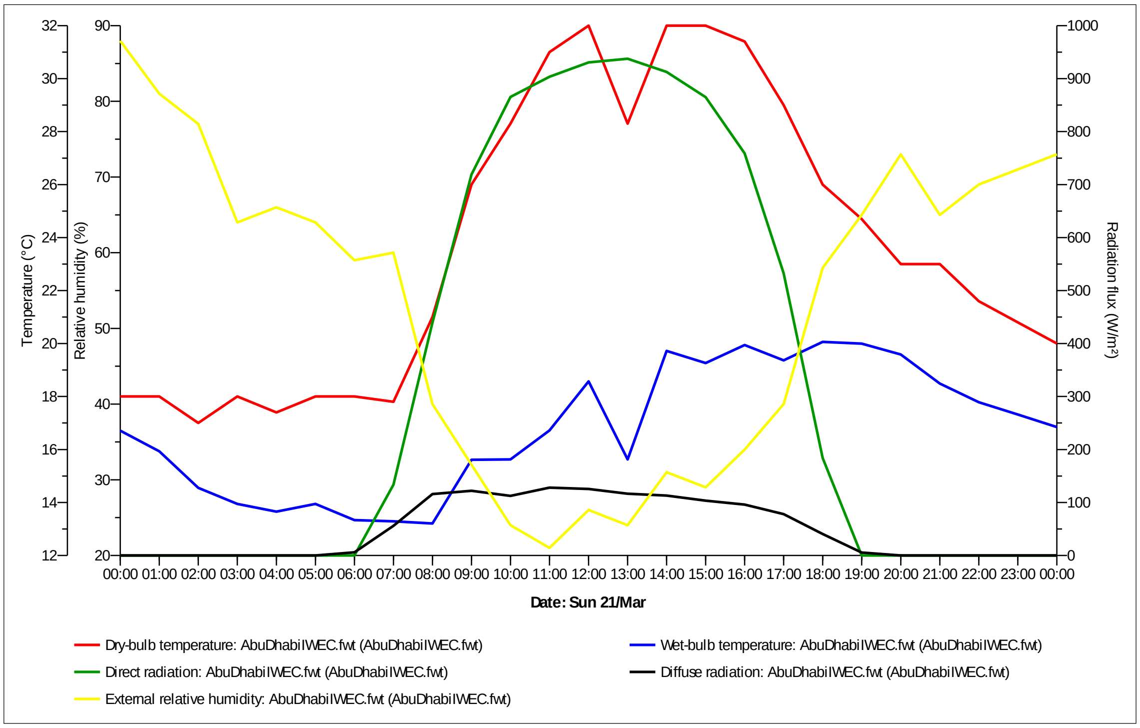


Figure A.1: Weather variables in March 21 (IES VE Weather database)

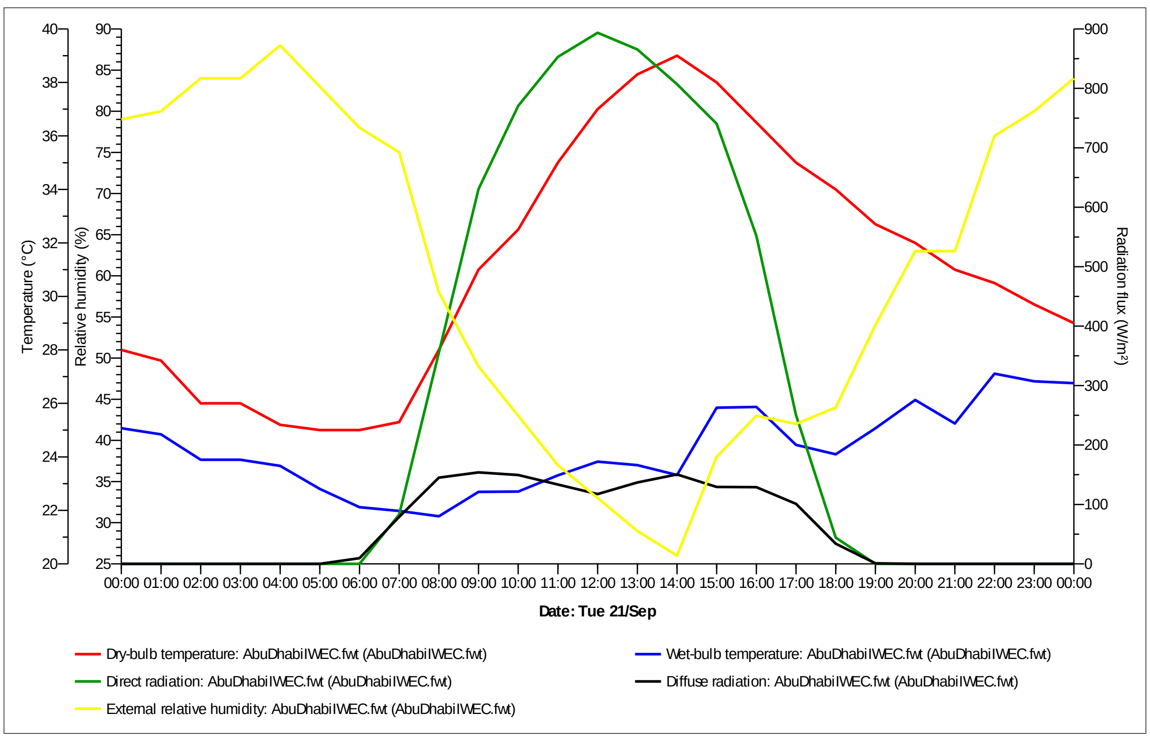


Figure A.2: Weather variables in September 21 (IES VE Database)

Appendix B

Base-case Electricity Bills for year 2015

الهيئة الاتحادية للكهرباء و الماء
Federal Electricity & Water Authority

United Arab Emirates

ملخص الحساب ملخص الفاتورة

ملخص الفاتورة

الفاتورة حتى 2015-01-31

اسم المالك	وزارة الاشغال العامة
اسم المستاجر	
رقم الحساب :*	238161115304
الفئة الاستهلاكية	وزارة الأشغال العامة والأسكان
مركز الخدمة	المدينة

المتاخرات (درهم)	المبلغ الحالي (درهم)	الرسوم الاخرى (درهم)	السداد (درهم)	المبلغ المستحق (درهم)
62811.20	9473.20		28119.20	44165.20

تفاصيل المبلغ الحالي

الخدمة	القراءة السابقة	القراءة الحالية	الاستهلاك	التعديلات (درهم)	الإعفاءات (درهم)	رسوم العداد (درهم)	رسوم	المبلغ المستحق (درهم)
كهرباء (ك.و.س)	15092	15241	23840			50.00	1192.00	8801.20
ماء (جالون)	10695	10875	18000			2.00		672.00
صرف صحي (جالون)								

الهيئة الاتحادية للكهرباء و الماء
Federal Electricity & Water Authority

United Arab Emirates

ملخص الحساب ملخص الفاتورة

ملخص الفاتورة

الفاتورة حتى 2015-04-30

اسم المالك	وزارة الاشغال العامة
اسم المستاجر	
رقم الحساب :*	238161115304
الفئة الاستهلاكية	وزارة الأشغال العامة والأسكان
مركز الخدمة	المدينة

المتاخرات (درهم)	المبلغ الحالي (درهم)	الرسوم الاخرى (درهم)	السداد (درهم)	المبلغ المستحق (درهم)
57697.80	15837.60		0.00	73535.40

تفاصيل المبلغ الحالي

الخدمة	القراءة السابقة	القراءة الحالية	الاستهلاك	التعديلات (درهم)	الإعفاءات (درهم)	رسوم العداد (درهم)	رسوم	المبلغ المستحق (درهم)
كهرباء (ك.و.س)	15592	15829	37920			50.00	1896.00	14855.60
ماء (جالون)	11330	11580	25000			2.00		982.00
صرف صحي (جالون)								

الهيئة الاتحادية للكهرباء والماء
Federal Electricity & Water Authority

United Arab Emirates

ملخص الحساب ملخص الفاتورة

ملخص الفاتورة

القاتورة حتى 31-05-2015

اسم المالك	وزارة الأشغال العامة
اسم المستأجر	
رقم الحساب :*	238161115304
الفئة الاستهلاكية	وزارة الأشغال العامة والأسكان
مركز الخدمة	المدينة

المتأخرات (درهم)	المبلغ الحالي (درهم)	الرسوم الاخرى (درهم)	السداد (درهم)	المبلغ المستحق (درهم)
73535.40	21965.40		27432.60	68068.20

تفاصيل المبلغ الحالي

الخدمة	القراءة السابقة	القراءة الحالية	الاستهلاك	التعديلات (درهم)	الإعفاءات (درهم)	رسوم العداد (درهم)	رسوم	المبلغ المستحق (درهم)
كهرباء (ك.و.س)	15829	16155	52160			50.00	2608.0000	20978.80
ماء (جالون)	11580	11831	25100			2.00		986.60
صرف صحي (جالون)								

الهيئة الاتحادية للكهرباء و الماء
Federal Electricity & Water Authority

ملخص الحساب ملخص الفاتورة

ملخص الفاتورة

الفاتورة حتى 30-06-2015

اسم المالك	وزارة الاشغال العامة
اسم المستاجر	
رقم الحساب :*	238161115304
الفئة الاستهلاكية	وزارة الأشغال العامة والأسكان
مركز الخدمة	المدينة

المتاخرات (درهم)	المبلغ الحالي (درهم)	الرسوم الاخرى (درهم)	السداد (درهم)	المبلغ المستحق (درهم)
68068.20	25763.40		0.00	93831.60

تفاصيل المبلغ الحالي

الخدمة	القراءة السابقة	القراءة الحالية	الاستهلاك	التعديلات (درهم)	الإعفاءات (درهم)	رسوم العداد (درهم)	رسوم	المبلغ المستحق (درهم)
كهرباء (ك.و.س)	16155	16535	60800			50.00	3040.0000	24694.00
ماء (جالون)	11831	12100	26900			2.00		1069.40
صرف صحي (جالون)								

United Arab Emirates

الهيئة الاتحادية للكهرباء و الماء
Federal Electricity & Water Authority

ملخص الحساب ◉ ملخص الفاتورة

ملخص الفاتورة

الفاتورة حتى **2015-03-31**

اسم المالك	وزارة الاشغال العامة
اسم المستاجر	
رقم الحساب :*	238161115304
الفئة الاستهلاكية	وزارة الأشغال العامة والأسكان
مركز الخدمة	المدينة

المتاخرات (درهم)	المبلغ الحالي (درهم)	الرسوم الاخرى (درهم)	السداد (درهم)	المبلغ المستحق (درهم)
46102.80	11595.00		0.00	57697.80

تفاصيل المبلغ الحالي

الخدمة	القراءة السابقة	القراءة الحالية	الاستهلاك	التعديلات (درهم)	الإعفاءات (درهم)	رسوم العداد (درهم)	رسوم	المبلغ المستحق (درهم)
كهرباء (ك.و.س)	15417	15592	28000			50.00	1400.00	10590.00
ماء (جالون)	11075	11330	25500			2.00		1005.00
صرف صحي (جالون)								

الهيئة الاتحادية للكهرباء و الماء
Federal Electricity & Water Authority

United Arab Emirates

ملخص الحساب ملخص الفاتورة

ملخص الفاتورة

الفاتورة حتى 2015-08-31

اسم المالك	وزارة الأشغال العامة
اسم المستاجر	
رقم الحساب :*	238161115304
الفئة الاستهلاكية	وزارة الأشغال العامة والأسكان
مركز الخدمة	المدينة

المتاخرات (درهم)	المبلغ الحالي (درهم)	الرسوم الاخرى (درهم)	السداد (درهم)	المبلغ المستحق (درهم)
77631.20	36519.40		0.00	114150.60

تفاصيل المبلغ الحالي

الخدمة	القراءة السابقة	القراءة الحالية	الاستهلاك	التعديلات (درهم)	الإعفاءات (درهم)	رسوم العداد (درهم)	رسوم	المبلغ المستحق (درهم)
كهرباء (ك.و.س)	17001	17536	85600			50.00	4280.0000	35358.00
ماء (جالون)	12336	12625	28900			2.00		1161.40
صرف صحي (جالون)								

Appendix C

Images and Construction Documents

Figure C1: Back view shows the employees entrance and the lack of any shading elements (Author,2016)

Figure C2: A view shows the main entrance with the shading overhang (Author,2016).

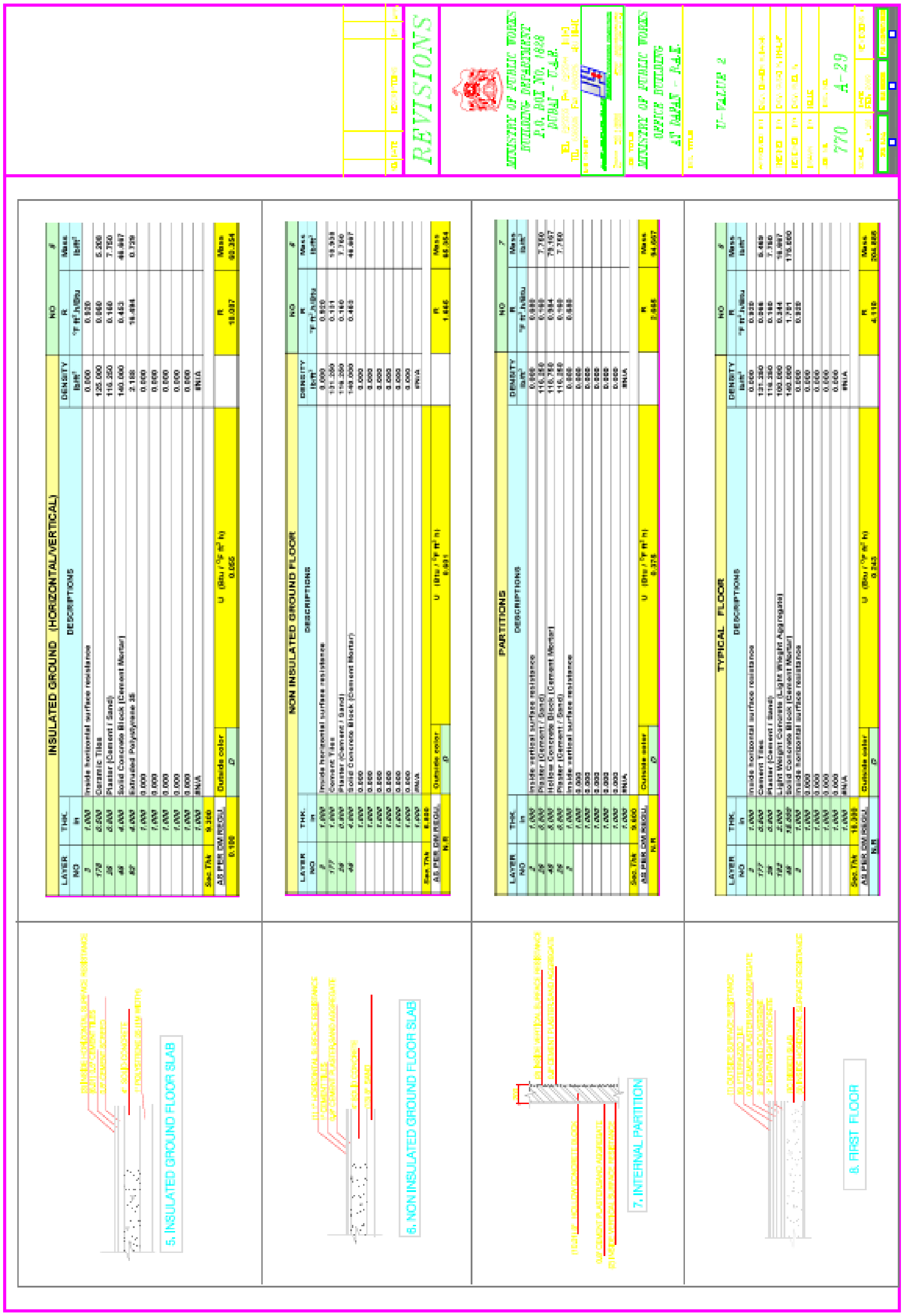


Figure C3: Buildings' elements U-values and construction details.

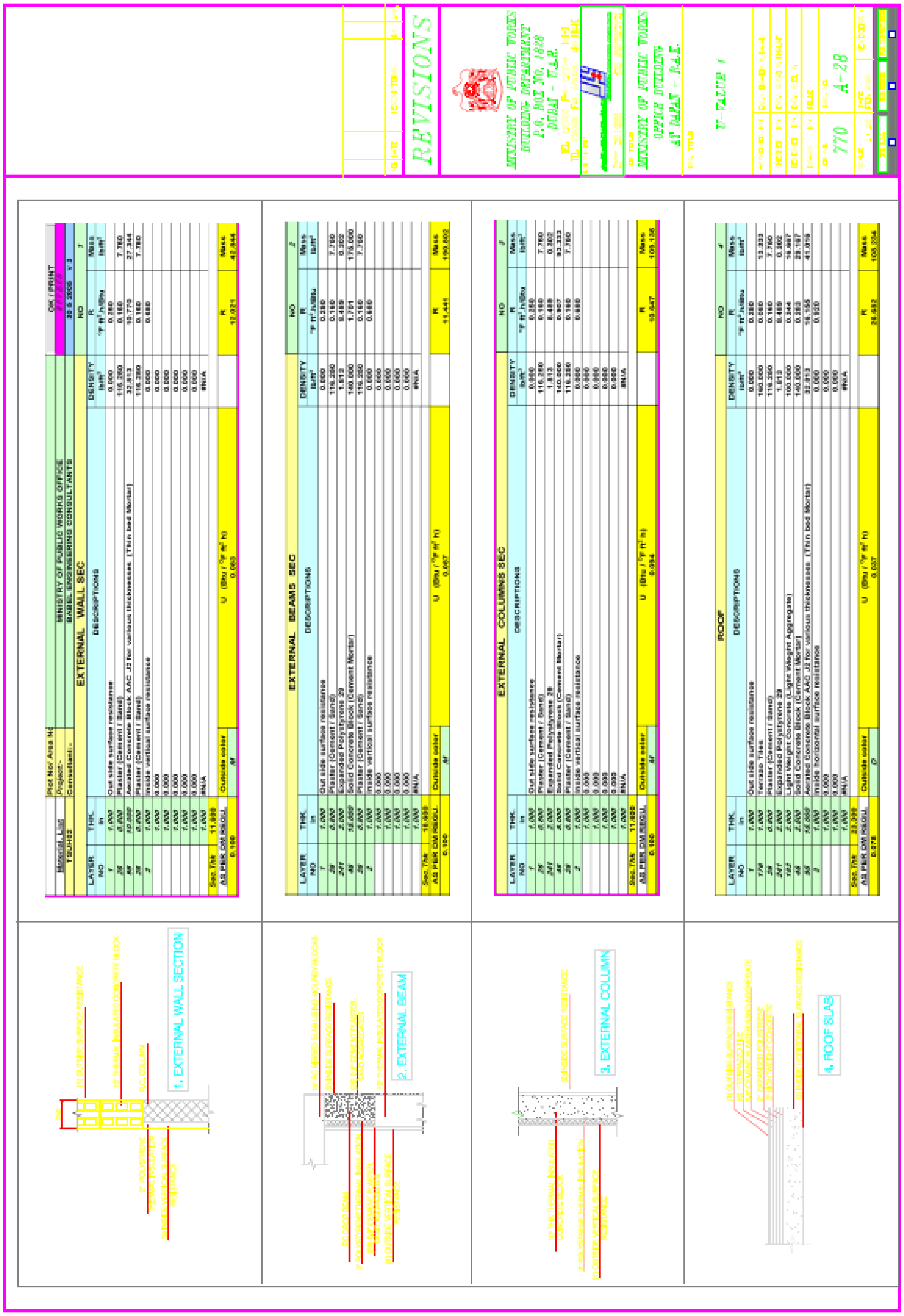


Figure C4: Buildings' elements U-values and construction details.

Appendix D

Construction Templates

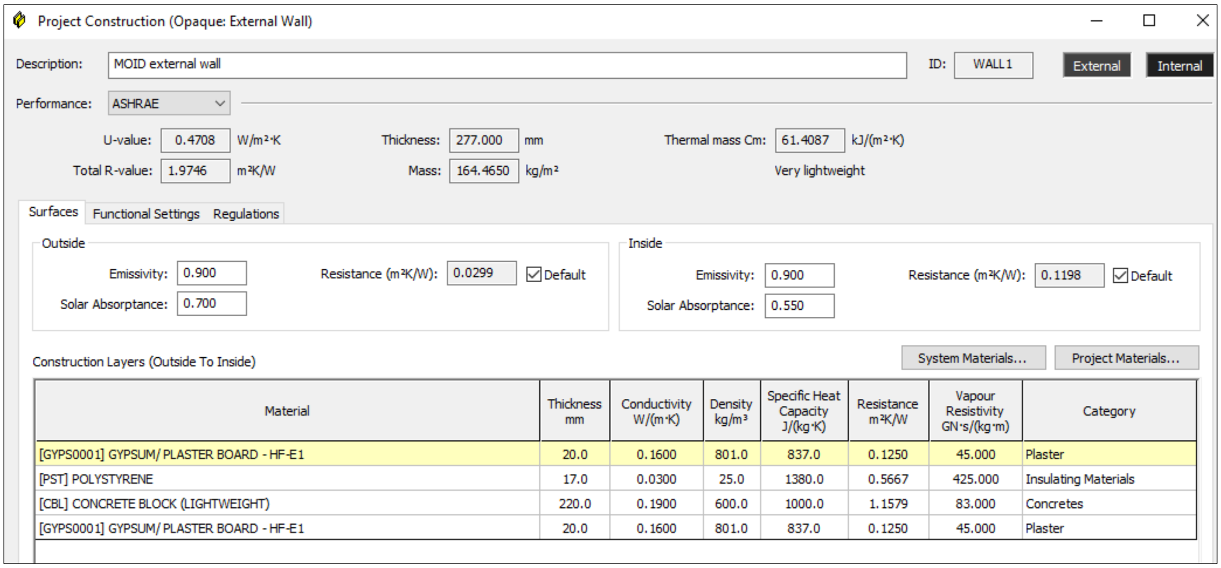


Figure D1: Baseline external wall construction template.

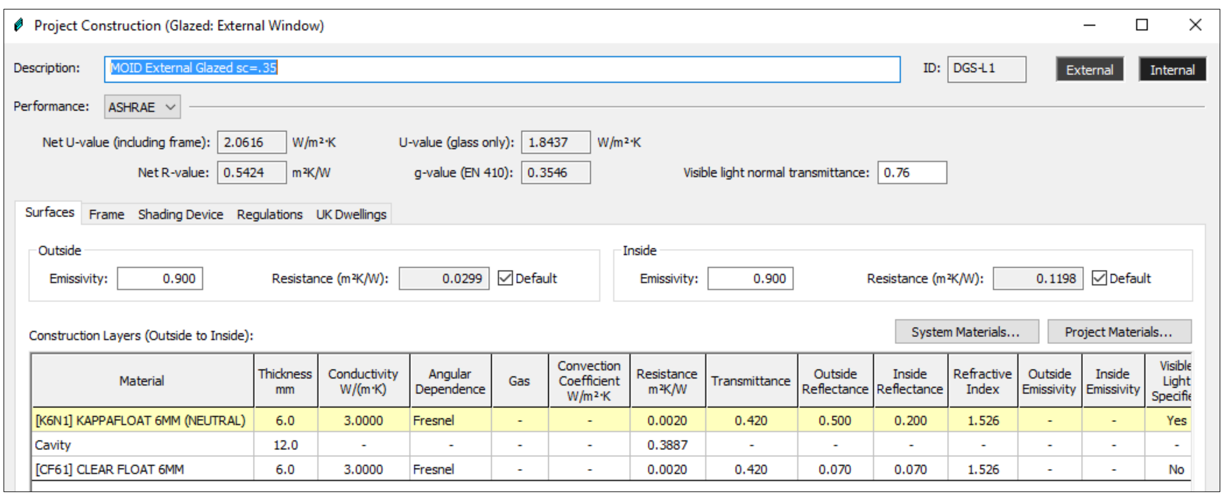


Figure D2 : Baseline external window construction template.

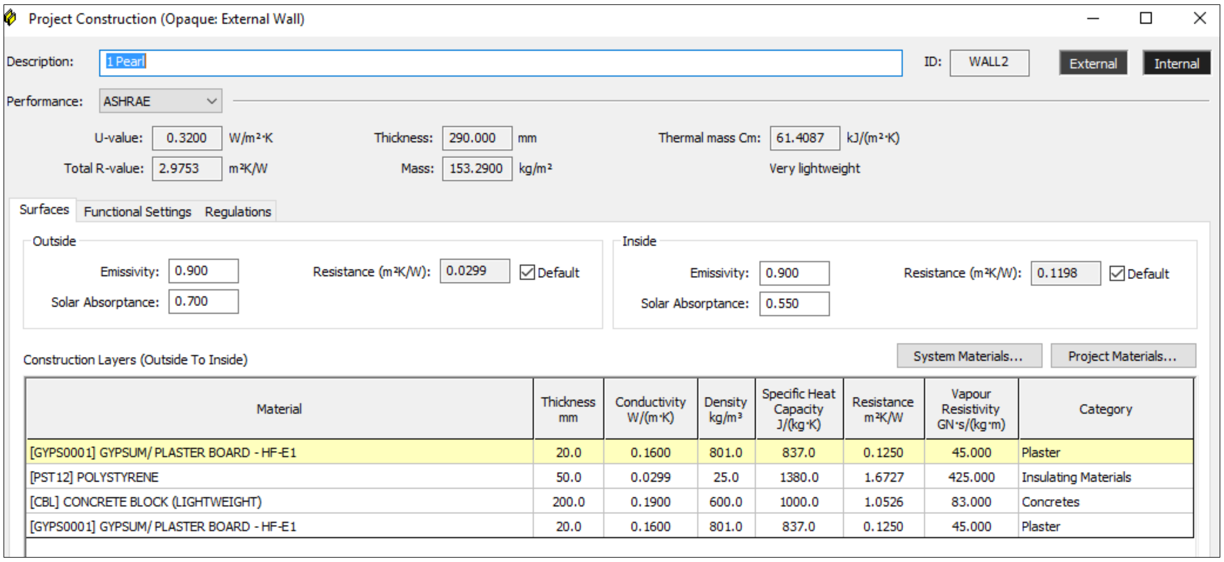


Figure D3 : 1 Pearl external wall construction template.

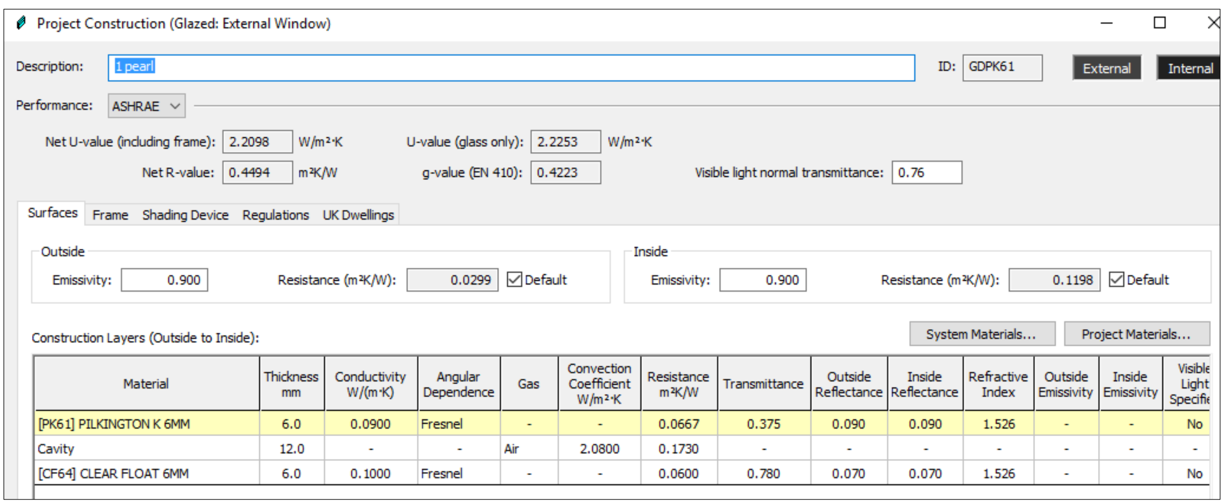


Figure D4 : 1 Pearl external window construction template.

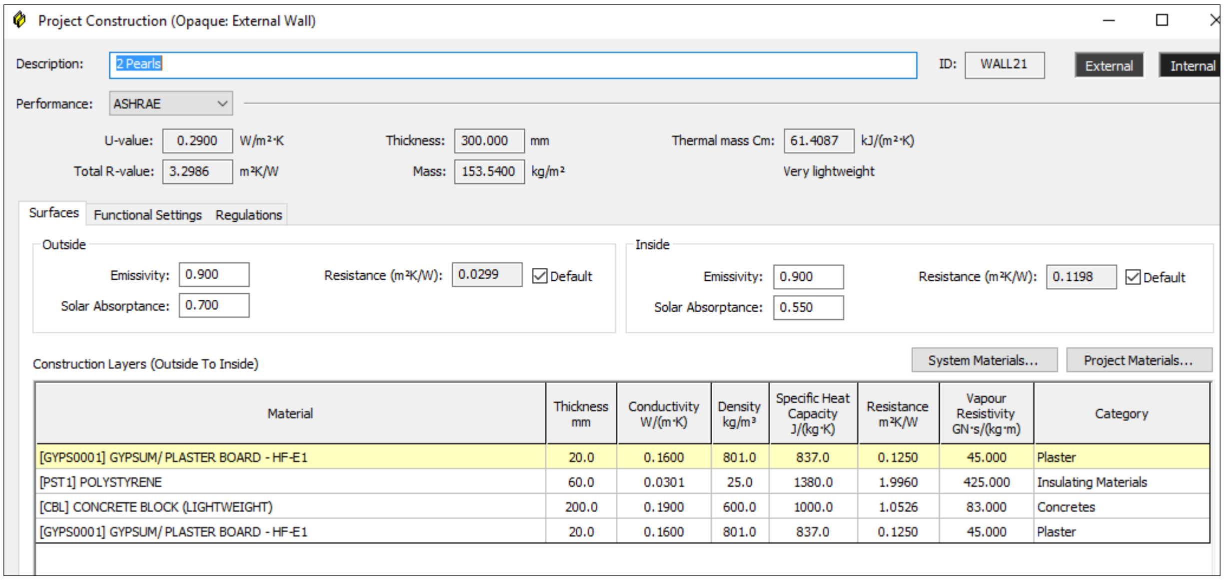


Figure D5 : 2 Pearls external wall construction template.

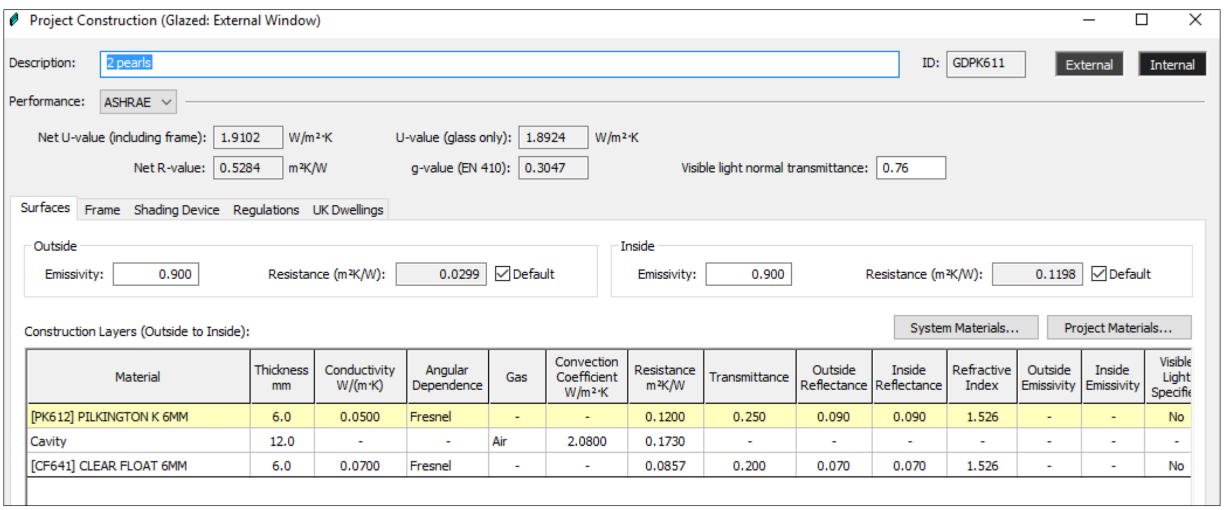
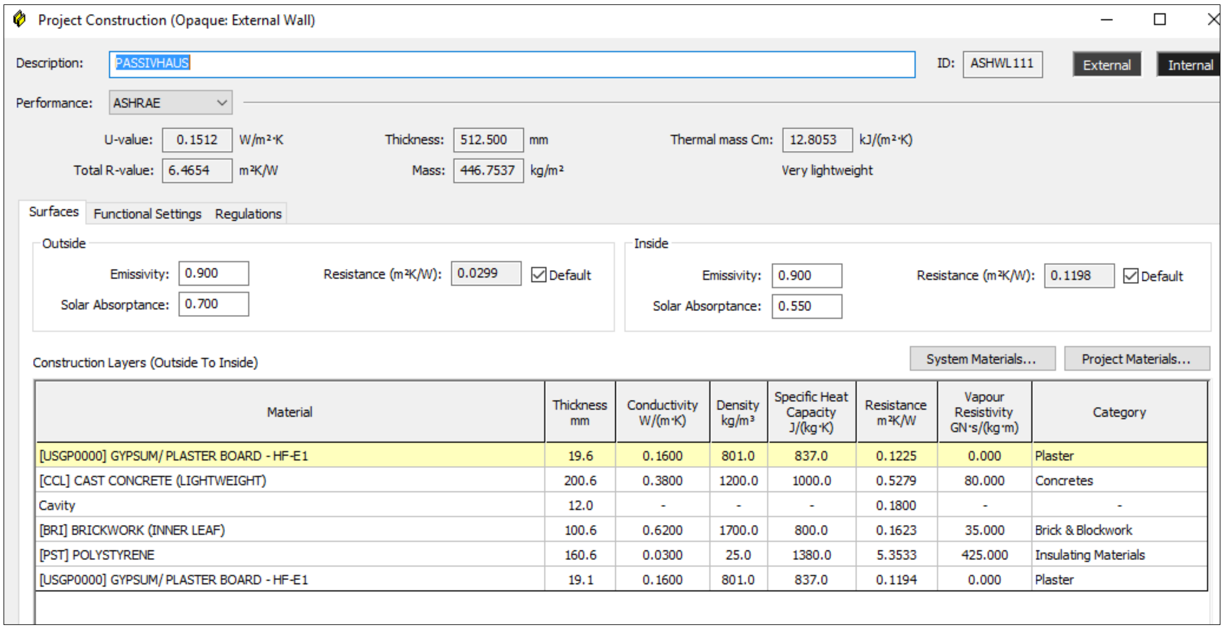


Figure D6 : 2 Pearls external window construction template



Project Construction (Opaque: External Wall)

Description: PASSIVHAUS ID: ASHWL111 External Internal

Performance: ASHRAE

U-value: 0.1512 W/m²·K Thickness: 512.500 mm Thermal mass Cm: 12.8053 kJ/(m²·K)

Total R-value: 6.4654 m²K/W Mass: 446.7537 kg/m² Very lightweight

Surfaces Functional Settings Regulations

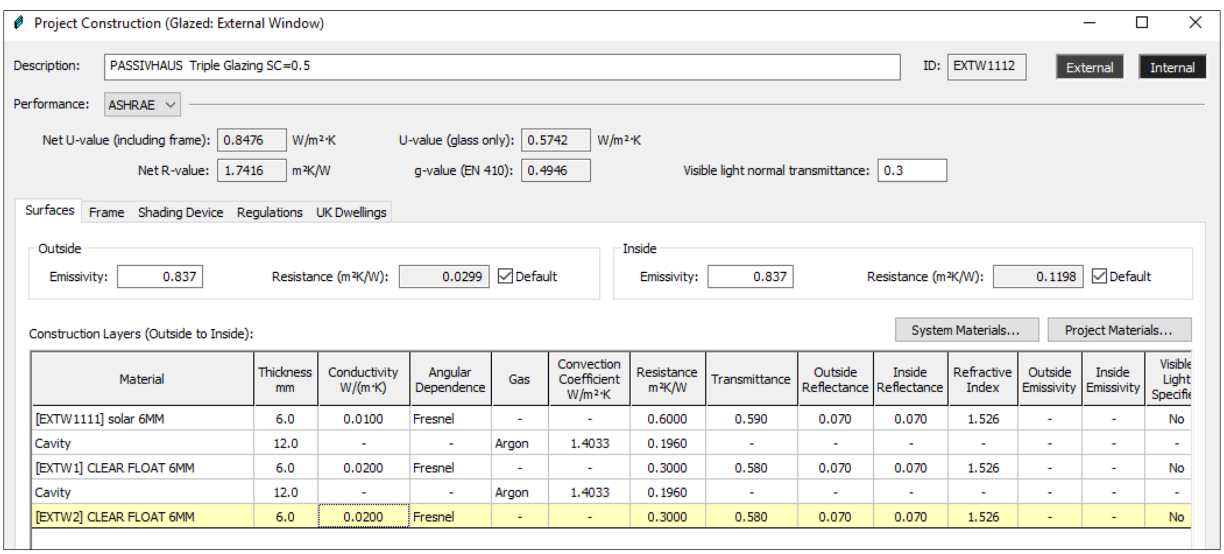
Outside — Emissivity: 0.900 Resistance (m²K/W): 0.0299 Default; Solar Absorptance: 0.700

Inside — Emissivity: 0.900 Resistance (m²K/W): 0.1198 Default; Solar Absorptance: 0.550

Construction Layers (Outside To Inside) System Materials... Project Materials...

Material	Thickness mm	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m)	Category
[USGP0000] GYPSUM/ PLASTER BOARD - HF-E1	19.6	0.1600	801.0	837.0	0.1225	0.000	Plaster
[CCL] CAST CONCRETE (LIGHTWEIGHT)	200.6	0.3800	1200.0	1000.0	0.5279	80.000	Concretes
Cavity	12.0	-	-	-	0.1800	-	-
[BRI] BRICKWORK (INNER LEAF)	100.6	0.6200	1700.0	800.0	0.1623	35.000	Brick & Blockwork
[PST] POLYSTYRENE	160.6	0.0300	25.0	1380.0	5.3533	425.000	Insulating Materials
[USGP0000] GYPSUM/ PLASTER BOARD - HF-E1	19.1	0.1600	801.0	837.0	0.1194	0.000	Plaster

Figure D7: Passivhaus external window construction template



Project Construction (Glazed: External Window)

Description: PASSIVHAUS Triple Glazing SC=0.5 ID: EXTW1112 External Internal

Performance: ASHRAE

Net U-value (including frame): 0.8476 W/m²·K U-value (glass only): 0.5742 W/m²·K

Net R-value: 1.7416 m²K/W g-value (EN 410): 0.4946 Visible light normal transmittance: 0.3

Surfaces Frame Shading Device Regulations UK Dwellings

Outside — Emissivity: 0.837 Resistance (m²K/W): 0.0299 Default

Inside — Emissivity: 0.837 Resistance (m²K/W): 0.1198 Default

Construction Layers (Outside to Inside): System Materials... Project Materials...

Material	Thickness mm	Conductivity W/(m·K)	Angular Dependence	Gas	Convection Coefficient W/m²·K	Resistance m²K/W	Transmittance	Outside Reflectance	Inside Reflectance	Refractive Index	Outside Emissivity	Inside Emissivity	Visible Light Specifie
[EXTW1111] solar 6MM	6.0	0.0100	Fresnel	-	-	0.6000	0.590	0.070	0.070	1.526	-	-	No
Cavity	12.0	-	-	Argon	1.4033	0.1960	-	-	-	-	-	-	-
[EXTW1] CLEAR FLOAT 6MM	6.0	0.0200	Fresnel	-	-	0.3000	0.580	0.070	0.070	1.526	-	-	No
Cavity	12.0	-	-	Argon	1.4033	0.1960	-	-	-	-	-	-	-
[EXTW2] CLEAR FLOAT 6MM	6.0	0.0200	Fresnel	-	-	0.3000	0.580	0.070	0.070	1.526	-	-	No

Figure D8 : Passivhaus external window construction template

Appendix E

Simulation Results Tables

Table E1: The impact of implementing different shading on reducing electricity consumption MWh

Date	Egg-crate	Cantilever	Vertical shading.aps	PV	optimal shading
Jan 01-31	11.8566	12.046	12.0418	12.1555	11.8387
Feb 01-28	13.2207	13.4884	13.5329	13.678	13.1946
Mar 01-31	28.6936	29.0009	29.0641	29.2129	28.6587
Apr 01-30	34.9236	35.1999	35.2785	35.4315	34.8929
May 01-31	50.4819	50.6801	50.7388	50.9018	50.4558
Jun 01-30	63.635	63.7873	63.8045	63.9486	63.6121
Jul 01-31	74.9835	75.1557	75.1889	75.3321	74.9549
Aug 01-31	76.608	76.8413	76.9482	77.0901	76.5763
Sep 01-30	69.6793	69.9748	70.1289	70.2576	69.6419
Oct 01-31	48.7607	49.113	49.2329	49.3906	48.7123
Nov 01-30	34.9636	35.3362	35.3258	35.5234	34.914
Dec 01-31	13.5963	13.8819	13.8373	14.01	13.5665
Summed total	521.4028	524.5053	525.1226	526.9323	521.0187

Table E2: The impact of implementing different building codes scenarios on reducing electricity consumption MWh

Date	Baseline	1 pearl	2 pearls	passivhaus.	Passivhaus Sc: 0.2	Passivhaus SC: 0.2 DG 2 pearls
Jan 01-31	12.161	12.2049	12.1716	13.3272	12.0565	11.9088
Feb 01-28	13.74	13.883	13.7079	15.1131	13.3576	13.1845
Mar 01-31	29.41	29.4069	28.3699	29.2303	26.9547	26.9131
Apr 01-30	35.66	35.4356	33.8908	34.2038	31.6273	31.8137
May 01-31	51.15	50.504	47.867	47.1601	44.1145	44.5689
Jun 01-30	64.2	63.1723	59.666	57.8777	54.9011	55.5022
Jul 01-31	75.6	74.2145	69.7704	66.8508	63.9043	64.6805
Aug 01-31	77.35	75.9441	71.5628	68.6713	65.7835	66.5899
Sep 01-30	70.51	69.2667	65.1831	62.5809	59.97	60.6282
Oct 01-31	49.64	49.0118	46.5115	45.716	43.3195	43.7146
Nov 01-30	35.75	35.5279	34.0566	34.2079	32.299	32.4033
Dec 01-31	14.08	14.1927	14.0676	15.3661	13.9198	13.7477
Total	529.29	522.7646	496.825	490.3051	462.2078	465.6552

Table E3: The impact of implementing window films on reducing electricity consumption MWh

Date	Baseline	Window Film SC=0.2	window Film SC=0.15
Jan 01-31	12.161	11.7551	11.603
Feb 01-28	13.74	13.0325	12.7789
Mar 01-31	29.41	28.3758	28.0276
Apr 01-30	35.66	34.47	34.072
May 01-31	51.15	49.7672	49.2996
Jun 01-30	64.2	62.8657	62.4171
Jul 01-31	75.6	74.2689	73.8225
Aug 01-31	77.35	76.0159	75.5645
Sep 01-30	70.51	69.2663	68.8487
Oct 01-31	49.64	48.4718	48.0813
Nov 01-30	35.75	34.8018	34.491
Dec 01-31	14.08	13.4987	13.2904
Summed total	529.29	516.5898	512.2966

Table E4: The impact of upgrading COP and changing the cooling set point on reducing electricity consumption MWh

Date	Optimal Active Scenario 25	Baseline Scenario 1
Jan 01-31	10.651	12.161
Feb 01-28	10.8563	13.7403
Mar 01-31	14.0681	29.4113
Apr 01-30	15.125	35.6644
May 01-31	17.9614	51.1585
Jun 01-30	20.7395	64.2022
Jul 01-31	20.3309	75.6033
Aug 01-31	23.9118	77.3579
Sep 01-30	18.6092	70.5146
Oct 01-31	16.9644	49.6488
Nov 01-30	14.4853	35.7527
Dec 01-31	11.3856	14.0813
Summed total	195.0884	529.2961

Table E5: Monthly electricity consumption MWh with an optimal retrofit scenario and with including AlAwadhi's (2014) previous result to form a holistic retrofit approach

Date	Baseline	Optimal retrofit (passive and active)	Electricity consumption after retrofitting lighting system
Jan 01-31	12.161	10.37	10.12
Feb 01-28	13.7403	10.4388	10.1888
Mar 01-31	29.4113	13.4913	13.2413
Apr 01-30	35.6644	14.4799	14.2266
May 01-31	51.1585	17.0136	16.7636
Jun 01-30	64.2022	19.7446	19.4946
Jul 01-31	75.6033	19.2928	19.0428
Aug 01-31	77.3579	22.8294	22.5794
Sep 01-30	70.5146	17.7245	17.4745
Oct 01-31	49.6488	16.2998	16.0498
Nov 01-30	35.7527	14.0425	13.7925
Dec 01-31	14.0813	11.0948	10.8448
Summed total	529.2961	186.8219	183.8187

Table 6: A 514 m2 PV electricity production with different technologies with the IES VE default efficiencies

Date	Thin Films	Amorphous	Poly C-Si	Mono C-Si
Jan 01-31	4.1847	3.0437	6.4204	7.5878
Feb 01-28	4.552	3.3324	6.9243	8.1833
Mar 01-31	4.8113	3.5266	7.3074	8.636
Apr 01-30	5.1196	3.7857	7.6852	9.0825
May 01-31	5.7842	4.3136	8.5835	10.1441
Jun 01-30	5.5588	4.1532	8.2284	9.7244
Jul 01-31	5.5432	4.147	8.1908	9.6801
Aug 01-31	5.6004	4.1974	8.2542	9.755
Sep 01-30	5.3214	3.9757	7.8773	9.3095
Oct 01-31	5.139	3.8136	7.6776	9.0735
Nov 01-30	4.3095	3.1653	6.5281	7.715
Dec 01-31	3.9701	2.892	6.0797	7.1851
Summed total	59.894	44.3462	89.7569	106.0763

Table E7: Monthly building's electricity demand and PV electricity production MWh with different technologies and scenarios

Date	Optimal Retrofit Electricity Demand	PV Scenario 27A	PV Scenario 28	PV Scenario 29	PV Scenario 30	PV Scenario 31	PV Scenario32	PV Scenario 33
Jan 01-31	9.3733	7.5878	12.549	3.7498	1.4317	14.9217	11.7985	16.0455
Feb 01-28	9.421	8.1833	13.5339	3.9467	1.6263	16.2288	12.8321	17.4123
Mar 01-31	12.3977	8.636	14.2827	4.0337	1.8895	17.4132	13.7686	18.6023
Apr 01-30	13.2204	9.0825	15.021	4.1075	2.0987	18.4978	14.6262	19.7098
May 01-31	15.5092	10.1441	16.7768	4.5359	2.4923	20.9053	16.5297	22.2075
Jun 01-30	17.9656	9.7244	16.0827	4.2909	2.4422	20.128	15.9152	21.3581
Jul 01-31	17.2697	9.6801	16.0093	4.3008	2.3947	19.976	15.795	21.213
Aug 01-31	20.6781	9.755	16.1332	4.4193	2.3208	19.9777	15.7963	21.2563
Sep 01-30	15.9302	9.3095	15.3965	4.3208	2.0788	18.8405	14.8971	20.1078
Oct 01-31	14.855	9.0735	15.0061	4.3245	1.867	18.0998	14.3115	19.39
Nov 01-30	12.8867	7.715	12.7595	3.7436	1.456	15.1724	11.9968	16.315
Dec 01-31	10.0994	7.1851	11.8831	3.5347	1.3143	14.0614	11.1183	15.1399
Total	169.6063	106.0763	175.4338	49.3082	23.4123	214.2226	169.3853	228.7575