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The Sustainability (Environmental and Economical) impact of upgrading Bahrain building regulations for affordable housing units: Case study in Bahrain

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التأثير البيئيي و الإقتصادي المستدام في ترقية قوانين البناء للمباني الإسكانية لذوي الدخل المحدود في البحرين

A dissertation submitted in partial fulfillment of the requirements for the degree of MSc. Sustainable Design of the Built Environment

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Abstract

According to World Population Review, Bahrain population is estimated to be around 1,336,250 people and it's expected to grow further till 2100. The rapid increase of population and continues growth of cities in Bahrain leads to significant pressure on the ministry of housing to expand their housing development projects to serve the present and future population needs. However, fast growth of cities and construction development will form a pressure on the energy demand and consequently on the environment and will contribute in the global warming due to the increase of carbon footprint. In addition to that, the Ministry of Electricity and Water states that Bahrain generates annually average of 3190 MWh and the consumption is estimated to be almost 266 MWh and for each standard household it almost 132 MWh that is 50 % of the overall electricity energy produced.

All the above facts as well as the climate classification of Bahrain as hot and arid region is considered to be kick off to move towards a sustainable and green development to reduce the negative impacts on the environment. Likewise, most of the GCC states are facing similar pressures that lead them to establish a sustainable building assessment certification to enhance their construction industry and the overall environment. For instance, the UAE generated the PRS - Pearl rating system, and the DGBR - Dubai Green building regulation. Also Qatar developed the QSAS – Qatar Sustainability Assessment System but not Bahrain. All the assessment systems are a combination of best practices extracted from international rating systems and customized to the unique conditions and requirements of its state of origin such as the local environment, culture and policies. Therefore, the research aims to explore the impact of upgrading the building envelope on reducing the consumption of annual energy, chiller energy and CO_2 emissions in a typical housing unit in Bahrain.

IES – VE simulation software was used to conduct number of evaluations to assess potential energy saving. The study covered 13 case scenarios upgrading the building envelop using specific U- values as recommended by selected regional sustainability assessments and also it tested upgrading each element of wall, roof and glazing separately to understand the impact of each on saving total energy consumption. Furthermore, it has proposed 3 new scenarios that is based on the available construction materials in the local Bahraini market. All the studied cases were an initial study to estimate the optimal case that can be integrated in the Ministry of Housing construction manual to save maximum percentage in the chiller energy, overall energy and the CO_2 emissions.

The collected results were compared to the current situation in Bahrain (Base Case) and it comes to the conclusion that upgrading the wall is the most beneficial building envelope element that can reduce the chiller energy, overall energy and the CO2 emissions more than the roof that is already insulated and the windows that are relatively having a low window to wall ratio. Moreover, the wall its considered as the largest surface area with poor current thermal properties and can achieve up to 21.6% reduction in chiller energy consumption and 10.8% in both overall energy consumption and CO2 emissions. This reduction was achieved by using the special dynamic wall recommended by QSAS and by using the external wall insulation system with plaster that was proposed by the author based on the available construction materials in the local Bahraini market. For that the best option will be insulating the walls externally because it's easier to be integrated to the Ministry of Housing construction manual and for sure it going to be cheaper that changing the entire wall data as recommended by QSAS.

ملخص

استناداً للتعداد السكاني العالمي، يقدر عدد سكان مملكة البحرين الى ١،٣٣٦،٢٥٠ نسمه على وجه التقريب. متوقعا زيادة وإرتفاع عدد النسمة إلى ٢١٠٠م. الزيادة السريعة للسكان والنمو المتسارع لإنشاء المدن في مملكة البحرين يؤدي إلى ضغط كبير على وزارة الإسكان لتوسعة التنمية الإسكانية المتزايدة لتلبية الطلبات الإسكانية الحالية والمستقبلية. وبتزايد النمو السريع في المشاريع الإسكانية سيشكل ضغط وزيادة استهلاك الطاقة الكهربائية مما يسهم في ظاهرة الإحتباس الحراري نتيجة لزيادة الإنبعاث الكربوني.
بالإضافة إلى ذلك، نصت وزارة الكهرباء والماء على ان اجمالي الطاقة الكهربائية المولدة بلغت ٣١٩٠ ميغاواط.ساعه ويقدر اجمالي الاستهلاك الى ما يقارب ٢٦٦ ميغاواط.ساعه بينما يقدر استهلاك الوحدة السكنية ب ١٣٢ ميغاواط.ساعه وهذا يعادل ٥٠٪ تقريبا من الطاقة الكهربائية الإجمالية المنتجة في مملكة البحرين.

جميع الحقائق المذكورة أعلاه وكذلك تصنيف مناخ البحرين الصحراوي الجاف يحتم التحرك السريع نحو التنمية المستدامة الخضراء للحد وتقليص الاثار السلبية على البيئة. وبالمثل دول مجلس التعاون الخليجي واجهت ضغوطاً مماثلة مما أدى بهم لصياغة إطار عمل متميز وبعيد المدى لقياس عامل الإستدامة بإسلوب يتجاوز مراحل التصميم والتخطيط العمراني التقليدي. وعلى سبيل المثال دولة الإمارات العربية المتحده، إمارة أبوظبي أطلقت (نظام التقييم بدرجات اللؤلؤ) (PRS)، وفي إمارة دبي (شروط ومواصفات المباني الخضراء)(DGBR)، وفي دولة قطر أطلقت نظام قطر لتقييم الإستدامة (QSAS). جميع نظم التقييم هي عبارة عن مزيج من أفضل الممارسات المستخلصة من أنظمة التصنيف العالمية لتتناسب مع الحالة المناخية والثقافيه لمنطقة الخليج. لذلك يهدف البحث لتقييم تأثير ترقية أساليب بناء الوحدات السكينية لذوي الدخل المحدود في البحرين لتقليل استهلاك الطاقة الكهربائية و بالخصوص الطاقة الكهربائية المستهلكة في اجهزة التكييف ، وكذلك تقليل انبعاثات غاز ثاني ثاني أكسيد الكربون.

خلال الدراسة تم استخدام برنامج IES - VE التحليل أداء كل الاستراتيجيات وتقييم مدى تأثريها على اجمالي استهلاك الطاقة الكهربائية و بالخصوص الطاقة الكهربائية المستهلكة في اجهزة التكيف وكذلك مقدار انبعاثات غاز ثاني أكسيد الكربون. لقد تضمنت الدراسة تقييم عدد من الحالات لتقييم الحالة الأمثل لكل متغير من اجل معرفة مدى جدواها في التقليل من استهلاك الطاقة. بلغ عدد الحالات التي تم تقييمها إلى ١٣ حالة مبنية على استخدام مقياس فقد الحرارة في عنصر البناء U-Value الموصى به من أنظمة ومعايير تقييم عامل الإستدامة التي أصدرتها الدول المجاورة. وعلاوة على ذلك فقد تم اقتراح ٣ استراتيجيات جديدة بناءا على مواد البناء المتوفرة في السوق البحريني المحلي. كل أقسام البحث تعتبر دراسة أولية لتقييم الاستراتيجيات الي يمكن دمجها في دليل وزارة الإسكان للإنشاء لتوفير أقصى نسبة توفير في الطاقة الإجمالية، طاقة التكييف و انبعاثات غاز ثاني أكسيد الكربون.

من خلال النتائج التي تم استنتاجها و جمعها و مقارنتها للوضع الحالي (case 1) تم استخلاص ان ترقية الجدران التي تفتقر لخصائص العزل الحراري في الوحدة الاسكانيه هو الحل الأمثل لتوفير الطاقة الإجمالية و طاقة التكييف و انبعثات غاز ثاني أكسيد الكربون، لأن المساحة السطحية للجدار تعتبر الأكبر عن مقارنتها بباقي الأسطح (السقف و النوافذ) وعلاوة على ذلك بلغ التوفير في الطاقة الكهربائية الإجمالية إلى ١٠،٨٪ و إلى ٦.٢١ ٪ في استهلاك الطاقة الكهربائية المستهلكة في التكييف. هذا التخفيض تم تحقيقه باستخدام الجدار المصنع الموصى به من نظام قطر لتقييم الإستدامة (QSAS) و كذلك باستخدام نظام العزل الحراري الخارجي المقترح في هذه الدراسة. في الختام تم استنتاج ان استخدام العزل الحراري الخارجي للجدران هو الأحل الأمثل و الأسهل و الأوفر لتكميل وترقية قانون الإنشاء المستخدم في وزارة الإسكان للوحدات الإسكانية لذوي الدخل المحدد.

Dedication

I dedicate this study to my beloved family, my parents, brother and sisters. I dedicate also to all those friends and relatives who wished me success and prosperity.

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First and foremost I should thank Allah the most Merciful for his blessing and I pray to Allah that this study offers beneficial for the kingdom of Bahrain economy.

Writing this dissertation has been one of the most significant academic challenges I have ever faced in my life. I would never have been able to finish my dissertation without the support, assistance, and patience of the following people who I owe my deepest gratitude.

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Chapter 1
Introduction

1.1. Overview

This chapter will briefly contain a general idea of the dissertation in order to highlight the climate change and global warming extreme stress. The effect of this major global problem is measured by high rates of energy demands and CO2 emissions. Hence, the sustainable and environmental building assessments have emerged to the international and regional market to mitigate the negative impacts of the built environment on the ecological environment and natural resources. The importance of sustainable and environmental assessments leads to the initiation of upgrading the local building codes to make it environmentally friendly. Further details regarding the need to the sustainable building assessments will be highlighted in this chapter, followed by the dissertation outline.

1.2. Global climate change and need of sustainability

Over the last decade the climate change has been increasing and this phenomena is a direct consequences of human activities and rapid growth population and economy. Therefore, climate change was considered as serious environmental problems that will lead to environmental catastrophes. According to Granados et al (2012), Carbon dioxide percentage indicates the global warming levels. In 1990(s), the CO2 emissions increased annually around 1.1% while it grows to 3% between 2000 and 2004. However, Shi et al (2010) found out that CO2 and CH4 levels are growing in parallel and known as greenhouse emissions. Once again all together is directly connected to the fast global population and economic growth. Same wise Meinshause (2009) stated that since the industrialization and plenty of energy and green house gases is running out of the atmosphere and there are no enough atmospheres to accumulate all that therefore he is fast action is needed to limit the global warming to 2 °C. Furthermore, NOAA (2010) conducted the longest record of CO2 emissions in the atmosphere was measured as a mole fraction in dry air at Mauna Loa, Hawaii Figure 1.1; the data shown is defined by the following equation:

Equation 1.1: Atmospheric CO2 calculation (Source: NOAA, 2010)

$$\frac{No.of\ molecules\ of\ Co2}{No.of\ molecules\ of\ dry\ air}\ x\ \ one\ million\ (ppm) \qquad (1.1)$$

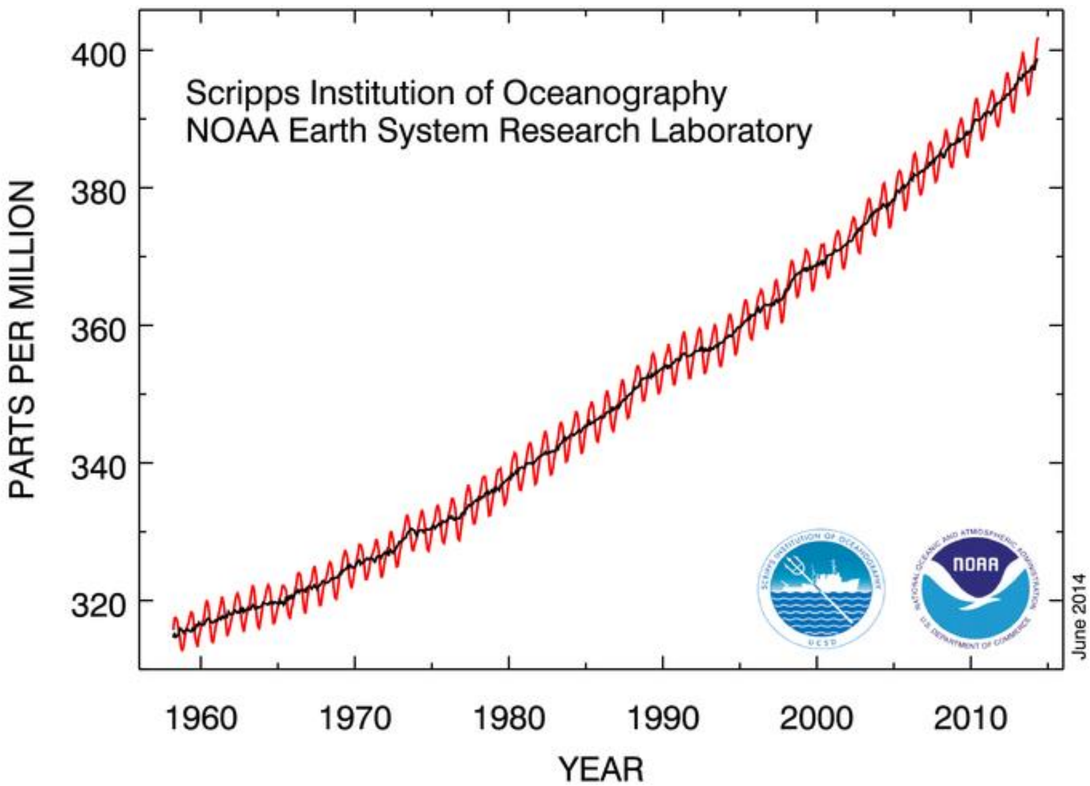


Figure 1.1: Monthly mean atmospheric carbon dioxide at Mauna Loa Observatory, Hawaii. Source: NOAA (2010)

According to (EPA) the United States Environmental Protection Agency (2014) Carbon dioxide concentration in the atmosphere has been increasing extensively due to human activities and manmade environment since the industrial revolution and has reached now to extreme danger levels. In other words, the climate change comes to happen by the common activities that involve the release of momentous amount of greenhouse emissions that allows the heat to be trapped in the atmosphere and consequently will cause environmental degradation. Houghoton (2009) also claimed that global energy emissions peak is expected to be on 2016, Figure 1.2 and urgent action is required to mitigate these emissions until 2050, for instance the UK set a low and a road map for this issue in 2008 to reduce the emissions from 1990 to 2050 by 80%. Therefore, sustainable movement is very important and involves wide understanding and implementation of lows and regulations to achieve the targeted goal.

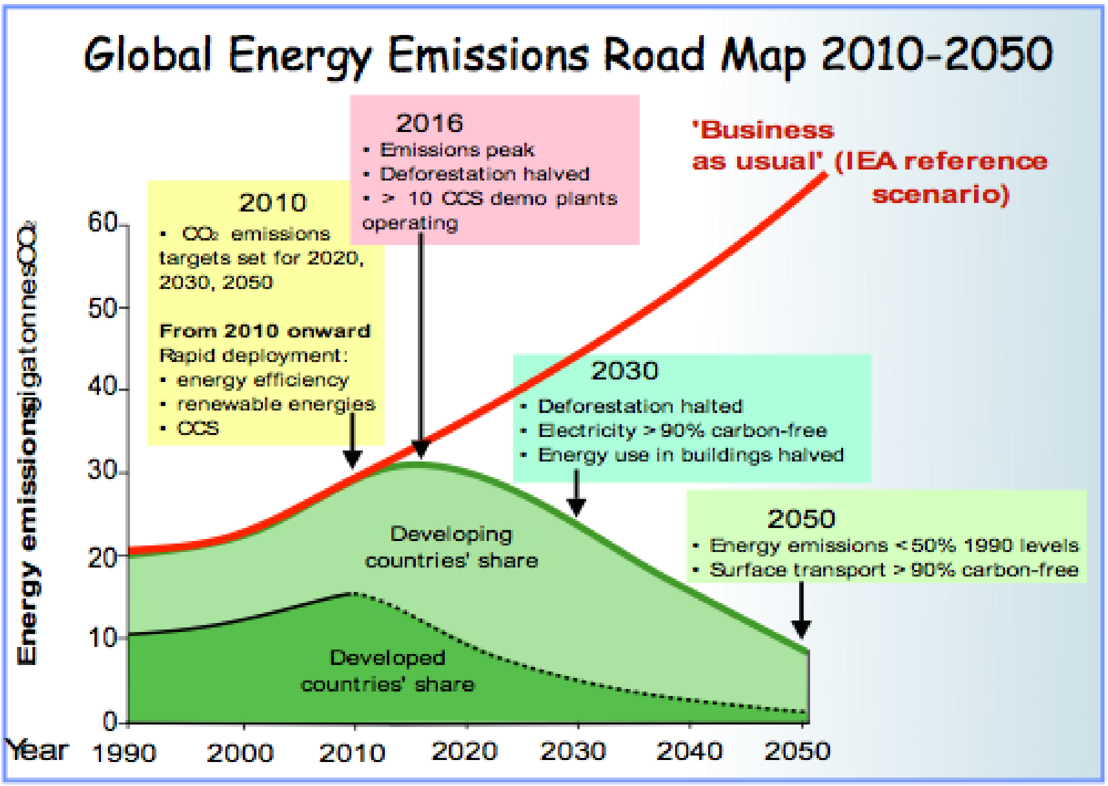


Figure 1.2: Global energy emissions road map from 1990 to 2050 showing International Energy Agency (IEA). Source: Houghoton (2009)

Moreover, the documentary movie (*An Inconvenient Truth: global warming* 2005) documentary movie directed by Guggenheim, has portrays global warming crises progress, presented some complex scientific facts and observations about the crises and its massive environmental impacts. Besides that, the director conveys a clear statement that the environment is important because it's the reason of human life and therefore its time to initiate some changes for better life. Same wise, many authors has highlighted that the primary cause of global warming is carbon dioxide that basically generated from burning fossil fuels such as oil, coal and gas for daily life activities such as cooking, transportation and for operating the buildings.

1.3. Global population and CO2 emissions.

Generally, economical development is double-edged sword, on one hand it's very important to raise the financial status of the country, but on the other hand it's expected that all the development together will have negative impacts on the environment due to the excess consumption of energy and water, as well as the carbon dioxide, Figure 1.3 shows that CO_2 emissions grew much faster than the population since 1960 as announced by the US Carbon Dioxide Information Analysis Canter (CDIAC)(2009). It also indicates that emissions were less than the population growth until 1950, which indicates that the CO_2 emission is related to the economic development and citizens life patterns. In other words, the level of CO_2 emissions is an indication of the efficiency level of population usage of the planet, which is directly, related to the local climate conditions, in addition to that, Hegger, (2008) the earth temperature rose 0.8 °C, and between 1995 – 2006 have been the hottest since the records began.

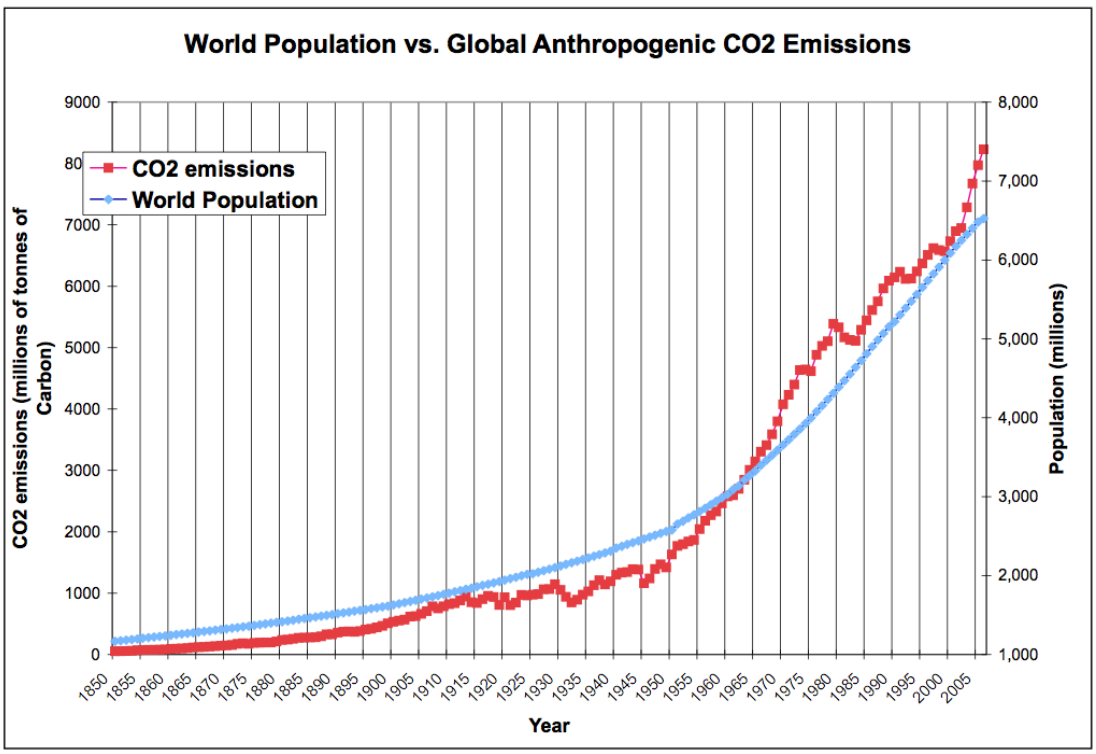


Figure 1.3: World Population Vs. Global CO_2 emissions. Source: CDIAC. (2009)

In addition to that, In May 2013, the level of CO_2 reached its peak at 400 ppm in city of Harbin in northeastern China and leads to closed down schools and suspension of public busses as affirmed by Schucking (2013). Furthermore, humans' contribution in greenhouse gases have raised dramatically from 75% to 350% higher than natural levels during the last 650,000 years as asserted by the famous American architect

Soellner (2013). Last but not least, the above text enforces the idea of upgrading the built environment urgently for better today and best tomorrow.

Elgendy (2014) asserted that Arab World is also affected by the negative impacts of fossil fuel consumption that badly affect the natural environment. The CO2 emission is directly connected to the countries own energy and ecological footprint and mainly due to rapid urbanization Figure 1.4.

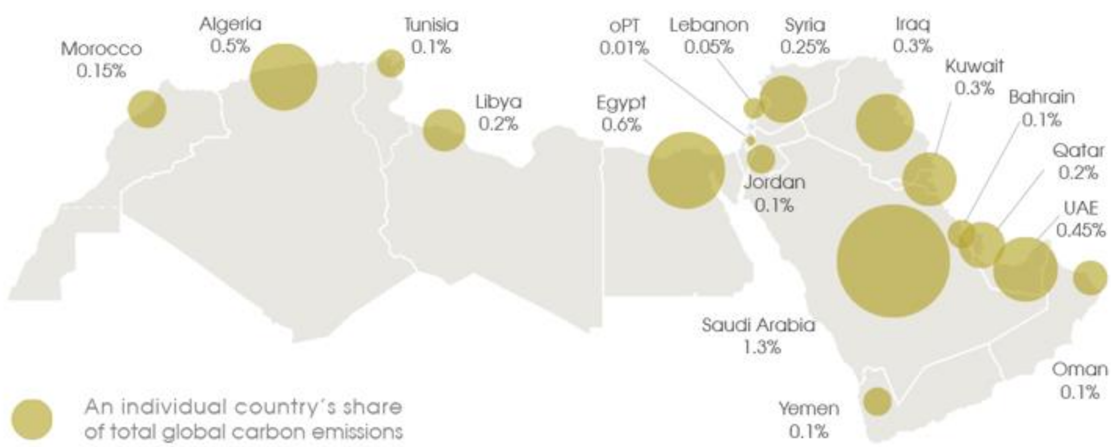


Figure 1.4: An individual country share of total global carbon emissions. Source: Elgendy. (2014)

1.4. Energy consumption in buildings and sustainability

Over the last few decades, building construction and land development had a major impact on the natural, social, economic and built environment. Therefore, electricity conservation has been the attention of researchers, economists, engineers and architects. Electricity energy is the main driving force of every aspect of modern life. Especially buildings, all heating, ventilation and air conditioning (HVAC) systems are depending on electricity and all these systems are responsible for the total energy consumption in buildings, which is relatively related to the carbon dioxide, other greenhouse emissions and the entire global warming. Chan, et al (2010) stated that building generally consumes 35.3% of the total energy of all HVAC systems. These systems are incorporated with controls and regulators for both the temperature and humidity ratios to provide the occupant with thermal comfort and indoor air quality. In addition to that, Retzlaff, (2008) found that buildings in the United States accounted for

39% of energy consumption, 68% of electricity consumption and 38% of CO_2 emissions in 2002 and its expected to increase in the future. In line with that, Mazria, (2003) has also investigated on this area in the United States and found out that the buildings role in damaging the environment is estimated to be 48% of the total US energy consumption and 46% of the total CO_2 emission.

Moreover, Hernandez, (2011) asserted that people generally spend between 80 & 90% of their time inside buildings of different typologies to do their activities, and might be even more when it comes to residential buildings, these remarks were eye opening for the architectural design and construction industry, concentrating on the role of buildings in our life style, usage of energy and the state of economy in any specified location due to the building responsibility towards the environment and the users comfort and wellbeing.

Improving the built environment is a shared responsibility between building and occupants, therefore upgrading the buildings to be more environmentally responsive is not the only goal but educating its users to smartly interact with the building will achieve the aim of enhancing buildings efficiency as claimed by Churchill, (1943): “We shape our buildings and our buildings shape us”. This statement inspires the author of how the building brings happiness and comfort to users. From that it’s worth understanding what are the negative impacts of buildings and what are the approaches to upgrade the buildings and the users to make them greener and more sustainable.

Therefore, the principles and lows of sustainability have been required to reduce the negative impacts of buildings on the environment and humanity. Figure 1.2 also indicates that there is a noticeable gap between the energy demand of the developed countries and developing countries, which reflects a gap between implementing the sustainable principles due to the country developing practices and citizen’s awareness and attitude. Therefore, it’s important to find suitable and affordable solutions for buildings to reduce the energy consumption and enhance the occupant’s comfort.

1.5. Green and sustainable building Design: Definition, motivation and commencement

Recently, the term of “sustainable life” or “green and sustainable” buildings has grown rapidly as philosophy, way of thinking or set of ethics and values aiming to live in a green, eco-friendly and healthy built environment. Therefore, it’s worth defining the green and sustainable building design in order to appreciate the reasons behind issuing such trend followed by some facts about its initiation.

1.5.1. Green and sustainable building design: Definition

Briefly, the green and sustainable building is an environmental friendly throughout the life cycle of the building from design, construction, operation and demolition to mitigate the negative environmental impacts as asserted by Bergman, (2012). Moreover, the U.S General Services Administration (2013) acknowledged that sustainable design aims to decrease the built environment negative impacts on the mother earth environment, also to improve the comfort and wellbeing of building occupants and consequently enhance buildings performance. Furthermore, Dear, (2014), described sustainable design architects and builders are responsible to create efficient and self-responsive buildings, which are able to meet the current environmental challenges.

The term of green building design and sustainable building design has been used integrally although they are not the same. For that, Kant, (2013) noted that the Green Design Education Initiative (2003) declared that green designed buildings involve design strategies that protect human health and wellbeing, also promotes comfort and enhance occupants productivity. While the sustainable designed buildings maintain the same goals but also protects environment and its resources for the future generations. In summary, the green buildings or sustainable buildings are responsible for being environmentally friendly and energy efficient via their building materials to reduce the environmental impacts, and also promotes external and internal healthy and comfortable environment through the building envelope thermal properties, as well as the indoor air quality. Therefore it’s considered as an intention, state of mind and life style.

1.5.2. The importance of green and sustainable design buildings

Sustainable buildings design is very important, because buildings are the main structures that serve human needs and requirements. It's known that there are several buildings typologies such as residential, commercial, social and industrial building; but every building typology has its special function and services. In addition to that, it has been noted by many recourses that standard and traditional building strategies are always aiming for short-term economic consideration. Due to the limited focus of buildings goals and objectives, it's expected that buildings will contribute in damaging the environment and increase the usage of energy and Carbon Dioxide emissions. Furthermore, Herzog, (2008), stated that buildings are major contributors to global warming, 40% of the greenhouse gases result from construction and usage of buildings. Therefore, the designers and architects should have responsible and contractual responsibility towards the buildings, users and environment. However, Bergman, (2012) suggested that the primary obligation of a designer and an architect is to provide private protection known as the creation of sustainable shelter and public safety known as the creation of sustainable community in both artistic and economical aspects and their positive integration to the environmental issues. Besides that, the responsibility of creating a sustainable environment and sustainable built environment is shared responsibility between the designer and architect, builder and also the user, because the design strategy, building mechanism and human activity will affect the world and definitely will lead to huge losses in resources and will also affect the quality of the atmosphere, that contains the human and other creatures basic needs, such as: air and water.

Section 1.4 briefly presented the building energy consumption and the urgent need of sustainability, in other words buildings are responsible for the fossil fuel energy consumption and greenhouse gas emissions. Moreover, Architecture 2030 organization (2011) has emphasized that the global warming problems are mainly caused by the building and they stated that according to U.S Energy Information Administration (EIA) buildings consume almost 75% of the total electricity produced in the United states, and specifically goes for the operation. Therefore it's highly important that green and sustainable design take a place to enhance the quality of buildings and occupants.

1.5.3. The beginning of green and sustainable design

The last section described the importance of sustainable design as a philosophical approach aims to maximize the quality of human life and built environment, but still eliminating the negative impact of the environment.

Lyle, J. (1994) states that:

> *"The development of ecological understanding is not simply another subject to be learnt but a fundamental change in the way we view the world".*

Generally, Sustainable design and green design terms are interchangeably because they all calls and aims and objectives. However, Bergman, (2012) claimed that the term was considerably evolved in 1960s capturing the phrase of "Reduce, reuse and recycle" and use it as a simple way of awareness. While McLennan, (2004) argued that sustainable design movement started early seventies as a direct reaction to the global oil crises starting a more responsive and concerned movement towards energy conservation and better life style. Both authors and some others researchers has wide-ranging consideration and reflections, but all of them are recognizing the unique role of human in creating a sustainable, comfortable and healthy built environment via the building envelop material and energy consumption. Therefore, awareness of sustainable development in building and construction industry has increased and leads to several rating systems to assess buildings sustainability level and other green building regulations and standards that enforce the designers and builders to improve the performance of buildings. However, the green building assessments is not equal to the green building standards and regulation. The next section will highlight the differences between each tem supported by examples.

1.6. Green Building Assessments and Green Building Regulations.

Green Building assessment systems allow designers, builders and owners to examine and evaluate the building sustainability level, such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental assessment Method (BREEAM), Green Star and other green building assessments schemes. These are voluntary rating and assessment systems based on performance and credit rating scheme, however they have major differences in the assessment method, scope and criteria regarding the energy performance rating.

On the other hand, the Green Building Standards and Regulations are not designed as a rating system, however it has similar topics and focuses same as the international voluntary rating systems. Green building regulations and standards addresses the mandatory need of sustainable building and built environment, it allow the designers and builders to improve the building performance via reducing the energy, water, materials consumption, in order to improve the public health and safety, building construction and operation.

Standards and regulations is directly targeting the orientation of glazed façade, the minimum envelope performance requirements (U- Value), the energy efficiency of the HVAC systems, illumination power density and water efficient systems. Many green building regulations are complementing voluntary rating systems; theses building regulations and codes are there to create a regulatory framework for existing buildings and new construction. Each country and/or region must have a specific policies and standards that suits the climatic weather conditions and the cultural or traditional activities and practices. Here with some of the current international and regional green building codes, Alaska Building Energy Efficiency Standard and Phoenix green building code as stated by (EPA) the United States Environmental Protection Agency (2014). In a similar way The Municipality of Emirate of Dubai has issued the Dubai Green Building Regulation and specification (2010), while Jordan is in the phase of developing Energy Efficient Building Code with respect to local citizens needs and the local climatic condition as affirmed Awadallah et al. (2008) through the official report of Sustainable

Energy Mix and Policy Framework for Jordan and they highlighted that the code of practice was issued in 2008 and waiting for government approval in order to be published.

All the green building assessments and green building regulations have a similar aims and goals, which are:

1- Reduce energy and water consumption
2- Minimize the environmental impacts
3- Reduce building materials and minimize waste
4- Provide a safety and healthy atmosphere.

Therefore, every country is able to adapt a local green building code based on architectural aspects, mechanical consideration and electrical principles as well as on the other regional green building regulations, and then officially publish it, examine it obligatory for all new buildings.

Similarly the Arabian gulf region is composed of six countries, the green building movement has emerged to the market to face the global warming challenges therefore, the United a Arab Emirates has issued the green building regulation in Dubai as mentioned above, while AbuDhabi initiated pearl rating system (ESTIDAMA), in Qatar they have also initiated QSAS rating system, and in the other countries its still under development.

The Kingdom of Bahrain is one of the smallest countries in area and resources when compared to the other six countries in the same region, however the it suffers from a high population growth pressure, limited available land, significant rose in the construction which leads to a magnificent increase in both energy consumption and greenhouse emissions. Therefore, Bahrain was chosen to be the case study to upgrade the building regulation to be greener for better tomorrow.

The following section will briefly present some information about Bahrain geographical location, climate and population.

1.7. Bahrain: Location, climate and population.

The kingdom of Bahrain archipelago is made up of 33 islands and the largest island is Bahrain that leads to name the entire country as " Bahrain", Figure 1.5. It is located in the Arabian Gulf between the Kingdome of Saudi Arabia and Qatar. The total area of Bahrain is equal to 780 Square meters as expressed by the official website of the Bahrain Ministry of Culture (2013).

Bahrain is classified as hot arid climate with relatively two seasons, extreme hot summer and mild winter and high rates of humidity. During the summer the temperature hits around 47°C combined with high humidity ratio that regularly reaches above 90% makes the summer season uncomfortable. Further details about the climatic weather conditions will be given in the following chapter.

Bahrain is a country with a very high population density. According to the World Population Review (2014) the current estimated population is 1,336,254 people; Figure 1.6 and its expected to grow further in the coming 86 years.

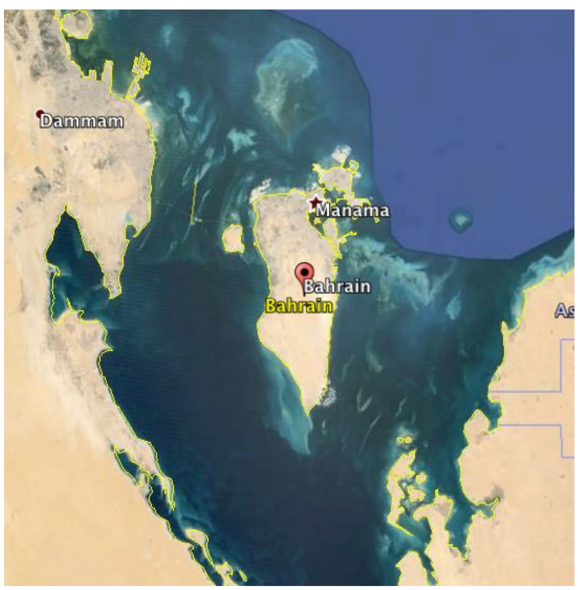


Figure 1.5: Bahrain Map (Source: Google Earth, 2014)

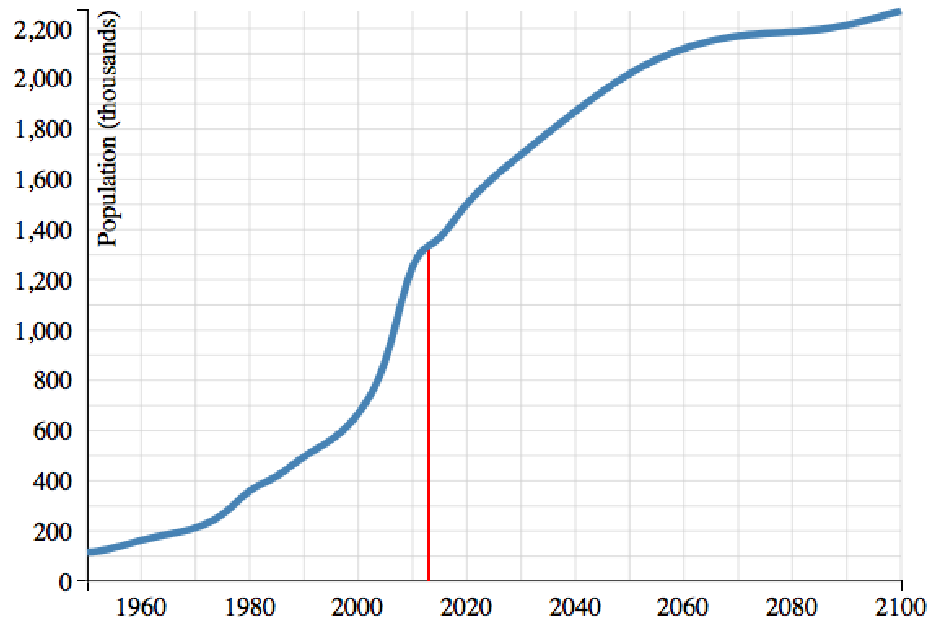


Figure 1.6: Bahrain Population (Source: World Population Review, 2014)

1.8. Bahrain construction industry and population growth

With reference to Figure 1.5 Bahrain has experienced rapid increase in population and a continuous growth of cities in which leads to a significant pressure on the overall construction industry, as well as on provision of social facilities to serve the current growth needs and secure the continuity of providing equal or better facilities for the future needs.

Similarly, Bahrain economy has developed and progressed rapidly over the past decades, this economic progress has been reflected on the citizen's living standards improvement via the condition of social, commercial and industrial services. However, the secret behind their rapid growth and development in Bahrain is their dependency on the oil wealth to create a strong economic status that is competitive to the international and global position.

Furthermore, Ahmed (2013) the head of waste disposal unit in the supreme council for environment in Bahrain has highlighted the construction is a progressing phenomenon due to the Economic revolution and the fast population growth all together leads to the initiate the green construction since the three past decades and was enforced by the depletion oil and environmental crises.

The prior was the base to the creation of ‘green construction’ rules and regulations. The following sections in the introduction chapter will briefly express the current efforts and challenges taken in Bahrain in this matter, and further facts about the green design initiation and importance.

Initiatives have been taken in Bahrain though the Economic Vision 2030 that has been launched in October 2030 by His Majesty King Hamad bin Isa Al-Khalifa (Bahrain Economic Board, 2014) presenting a comprehensive and ambitious vision focusing on shaping the government, society and economy around the bases of the three guiding principles: sustainability, fairness and competitiveness. The economic vision will provide the government of Bahrain with some standards to improve their economy in all dimensions but focusing on improving the citizens living standards to a worldwide levels.

Along with the economic vision 2030 and the progressive increase in the population, Bahrain has experienced a significant pressure on the construction and building market due to the need for buildings to accommodate different functions and facilities as required and mentioned earlier. However, the scarcity of quality available land for the extension of existing urban settlements, has lead Governmental Authorities to seek expansion through land reclamation to provide a sufficient land quality and area for the demanded development of new urban settlements and consequently provide the new cities with the basic infra-structure and several building that serves citizens over there. Though, any economic development requires provision of buildings such as, residential, commercial, recreational and industrial. Moreover, any local economic development, provide the government, the private sector, the non-profit sectors and the local community the chance to interact and work together as composite entity to improve the local economy Cooke, and Lazzeretti, (2008).

Nevertheless, there are number of factors that need to be considered to allow the country to enhance the local economy, the main factor is to reduce the negative impacts of the construction development on the environment and increase the user comfort and wellbeing. In other words, it's important to encourage sustainable growth and development in all its dimensions for a healthy community. Therefore, the author believes that to raise a country economy, its necessary to invest in buildings quality and specifically buildings regulations and lows.

Before introducing the outline, the dissertation title is clearly targeting the impacts of upgrading the construction properties and building regulations to be a more sustainable and eco-friendly. Therefore, number of evaluation will be conducted and then a list of recommendations will be proposed. Upgrading the construction properties in Bahrain is anticipated to enhance the buildings energy performance and thermal comfort. However, this dissertation will focus on affordable housing units only.

1.9. Dissertation outline

This dissertation will be divided into six chapters, which are as follows:

Chapter 1: will draw attention to general understanding of the environmental crises and global warming, followed by highlights and facts about sustainable and green building design importance and finally it presents some general information about the study geographical location to create an advanced building regulations and policies that will enhance performance and quality of the social housing sector in Bahrain.

Chapter 2: Will have an overview on the motivations behind the creation of green building assessments and importance in mitigating the building negative impacts followed by a critical literature review on the contents of some international and regional environmental building assessments compared to the current building regulations in the Kingdom of Bahrain. Also it will introduce some scientific point of view related to some examples of green building assessment applications and its advantages and disadvantages.

Chapter 3: Will describe different methodologies used in similar former studies and explain the preferred methodology for this research in order to evaluate the energy consumption and CO_2 emissions via using different building envelope scenarios in the same controlled climate conditions.

Chapter 4: will the case study physical characteristics and current construction database on Bahrain building regulations. Also it will explain and evaluate different scenarios recommended by other regional assessments. Test matrix will present the main parameters, which are the building envelope elements and will address the impact of each one on the energy consumption and CO_2 emissions.

Chapter 5: Will discuss the results and analyze the outcome data through critical comparison between all the cases and accordingly will highlight the most suitable one for Bahrain.

Chapter 6: The last part of the dissertation will represent the conclusion of the study and whether its feasible to upgrade the building regulations in the kingdom of Bahrain or no, and whether the results are fulfilling with the anticipated objectives of applying green building regulations.

Chapter 2
Literature Review

2.1. Overview

Over the past years, sustainable construction techniques and innovative buildings has been spread all over the world as a way to maximize occupants comfort while minimizing energy use and CO_2 emissions, which are the main causes for the global warming.

Therefore, This chapter is prepared to understand the negative impacts of buildings on environment and atmosphere, followed by a review for the current efforts towards sustainability in design and construction due to the negative impacts of conventional buildings on environment, occupants and construction cost. The literature review will also provide a general understanding of passive design strategies and its capabilities in saving energy. However, the main focus of this chapter is to introduce international and regional sustainable assessment and policies in order to understand their overlapped areas and to highlight the best and most suitable construction practices for Bahrain climatic weather and local conditions.

2.2. Building negative impacts on the environment

Generally, buildings role is beyond being a landmark or a shelter; it's a space that has a controlled and adaptable indoor environment to satisfy occupants' needs and help them to attain the proposed functions. For example, the gulf region is classified as hot arid climate but yet all the buildings are conditioned and can be flexible to the user desire. The argument here is the negative impacts of building construction or built environment on the environment. Furthermore, Ahmed (2013) asserted that construction activities have many acute environmental impacts and it extend to decades creating several types of pollutions that will consequently affect the life of many generations.

Moreover, the major impact of construction is usage of extreme energy, and therefore contributes in the global warming and climate change. In other words, buildings are recognized to be the most consumers of both energy and water that is directly linked to greenhouse emissions. According to Climate Tec book building review report (2009), the factors affecting the building negative impacts on the environment are: Embodied energy, building design, building envelope and general energy uses in the building. In the US, the residential buildings accounted for 21% of total energy and most energy is used for the HVAC systems as shown in Figures 2.1 and 2.2 as asserted in the Building energy data book (2008).

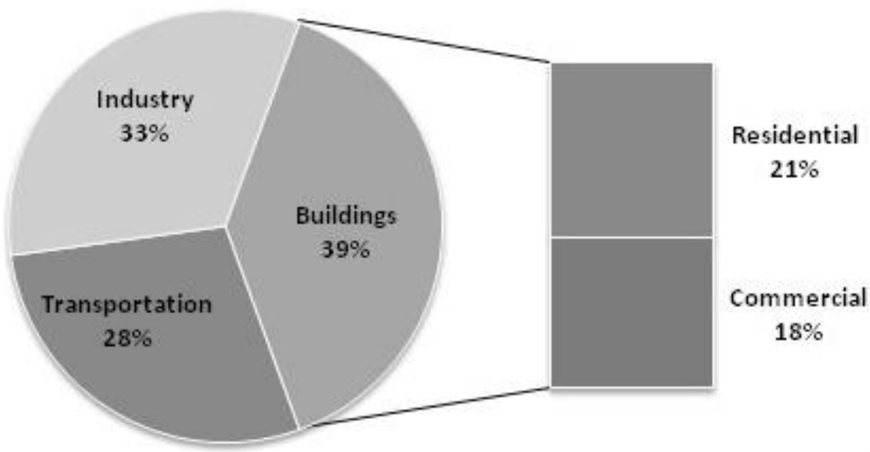


Figure 2.1: Building share of the primary energy consumption in the US 2006. (Source: Building energy data book, 2008)

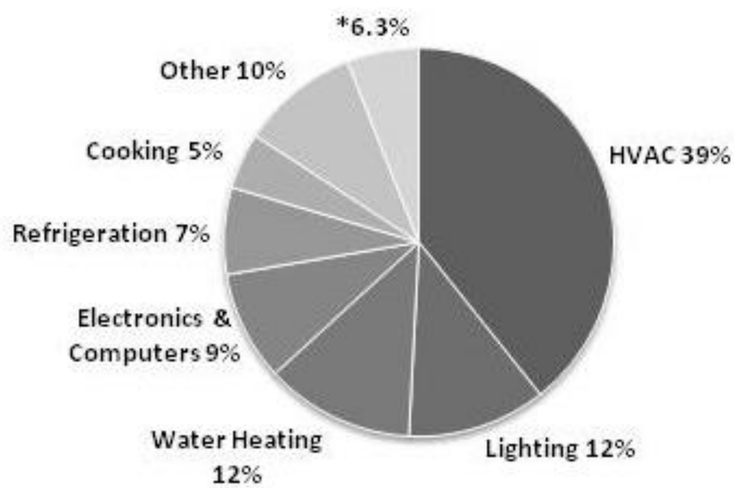


Figure 2.2: Building energy consumption division in the US 2006 (Source: Building energy data book, 2008)

Similarly, while Radhi (2009 a) in another study found that the residential sector in the UAE is again having the largest responsibility in both the energy consumption and CO_2 emissions as 45.9% Figure 2.3.

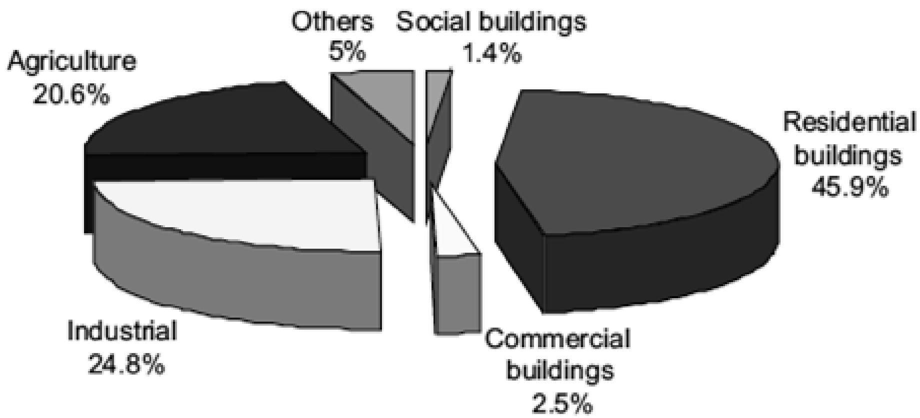


Figure 2.3: UAE Electricity consumption by sector (Source: Radhi, 2009 a)

While, Al-Rashed and Asif (2015), declared that the housing sector in Saudi Arabia is imposing a huge pressure on both energy and environment and its responsible of 52% of the total national electricity. However, Radhi (2009 b) asserted that residential buildings in Bahrain have the largest impact on the energy consumption and CO2 emissions reaching to 54% Figure 2.4 that is more than UAE and KSA, and consequently buildings are the largest contributors in the carbon dioxide and consequently to the climate change.

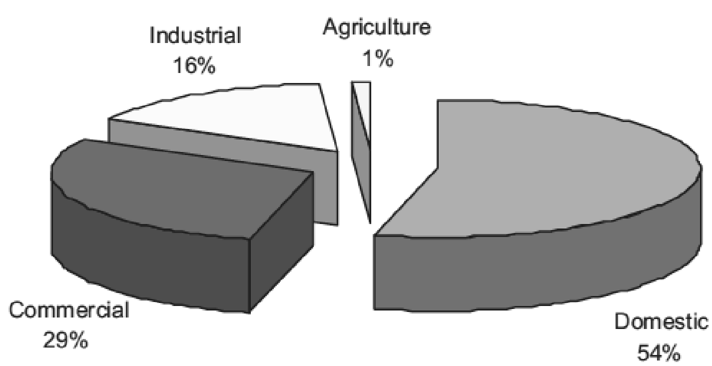


Figure 2.4: Bahrain Electricity consumption by sector (Source: Radhi, 2009 b)

Figures 2.1, 2.2, 2.3 and 2.4 illustrated that the residential sector has the largest impact on electricity consumption, which is logically related to the increase of the CO2 emissions. Therefore, the following section will introduce the efforts towards sustainable and eco-friendly development.

2.3. Towards Sustainable Design

Many industrial sectors and specially the construction industry are beginning to identify and recognize the negative impacts of their practices on the natural environment and to initiate significant changes to mitigate their harmful impacts. It's widely known that construction industry has taken the biggest responsibility towards the global climate change. Furthermore, Mahajan (2012) highlighted that buildings contribute about 1/3 of total global warming and greenhouse emissions due to excess use of fossil fuels through its life cycle and especially during the construction an operation phase.

Generally, buildings are one of the most important components in the city fabric because it has different typologies and holds several functions such as: residential, social, commercial and industrial functions. However, construction is processes that compose of assembling materials together to make durable structures for different mentioned functions and usages. Overall, construction use cement, sand, aggregate and concrete, steel, building services and finishes to create the best envelop for that specific function. Each building has a life cycle that improves human comfort and quality of life, while increasing the environmental negative impacts and decreasing the human wellbeing. Therefore, the building environmental assessment strategies and policies have emerged to the market as a design, operation and management tool that can be used as a guidance procedure for green and sustainable building design.

During the last few decades, the entire world has experienced a continuous population growth and excessive construction industry expansion that is anticipated to serve the population needs of residential, social, commercial and industrial purposes. Furthermore, the construction boom that hits the countries was magnificent, full of tall and advanced technological buildings that are anticipated to keep countries in a balanced economical status and a better quality of life style. However, the excessive and rapid construction industry left a huge negative impacts on the environment, human actions specially the spoiled life style that is leading to a horrible future and needs a fast and immediate action. Therefore, it's the time for international, regional and local integrated actions to enhance the natural and built environment statues via passive design and active design principles. However, this study will only focus on enhancing passive strategies with the presence of the conventional HVAC systems.

2.4. Passive design and built environment enhancements

Passive design strategies requires designing the building envelope in order to benefit from daylight, natural wind to control the solar heat gain through the windows that will reduce the need for electrical lighting and mechanical ventilation. In addition to that the main aim of passive design is to maintain the thermal comfort through out the year especially if I was implemented early design stage. Passive design techniques can be achieved by upgrading the building thermal performance of walls, roof and fenestration, using shading devices, natural ventilation and many other strategies that suits specific climatic conditions.

A study conducted by Ruiz & Romero (2011) in Spain, studied conventional residential buildings and found out that applying passive strategies can reduce the heating and cooling levels that and save 13% of energy when compared to the original design. The passive strategies were 350 mm lintel in window frames and additional 200 mm insulation on the building façade. While, Manioglu & Yilmaz (2007) claimed that responsive housing design is the future of the sustainable housing in hot dry climate in terms of the area, distance between building, orientation, building form and building envelope.

Al-Orrayedh (2014) has been interviewed in this regard and he asserted that the concept of sustainable construction incorporate and integrates different strategies during design, construction and operation, therefore the use of sustainable building strategy of sustainable materials will make the building environmentally responsible and promote and better living conditions for the occupants. Also is will have a durable life with reduced maintenance and replacement. Stevanovic (2013) and Ralegoankar and Gupta (2010) asserted that a dramatic reduction in cooling, heating and lighting energy consumption could be achieved by applying passive design strategies. The two studies concluded that applying passive design strategies reduced 2/3 of the discomfort in buildings. Ochoa and Capeluto (2008), found out that one of the most important elements in passive design in hot humid climates is the I intelligent and efficient building envelop, that controls the external solar and wind quality before entering the building as shown in Figure 2.5.

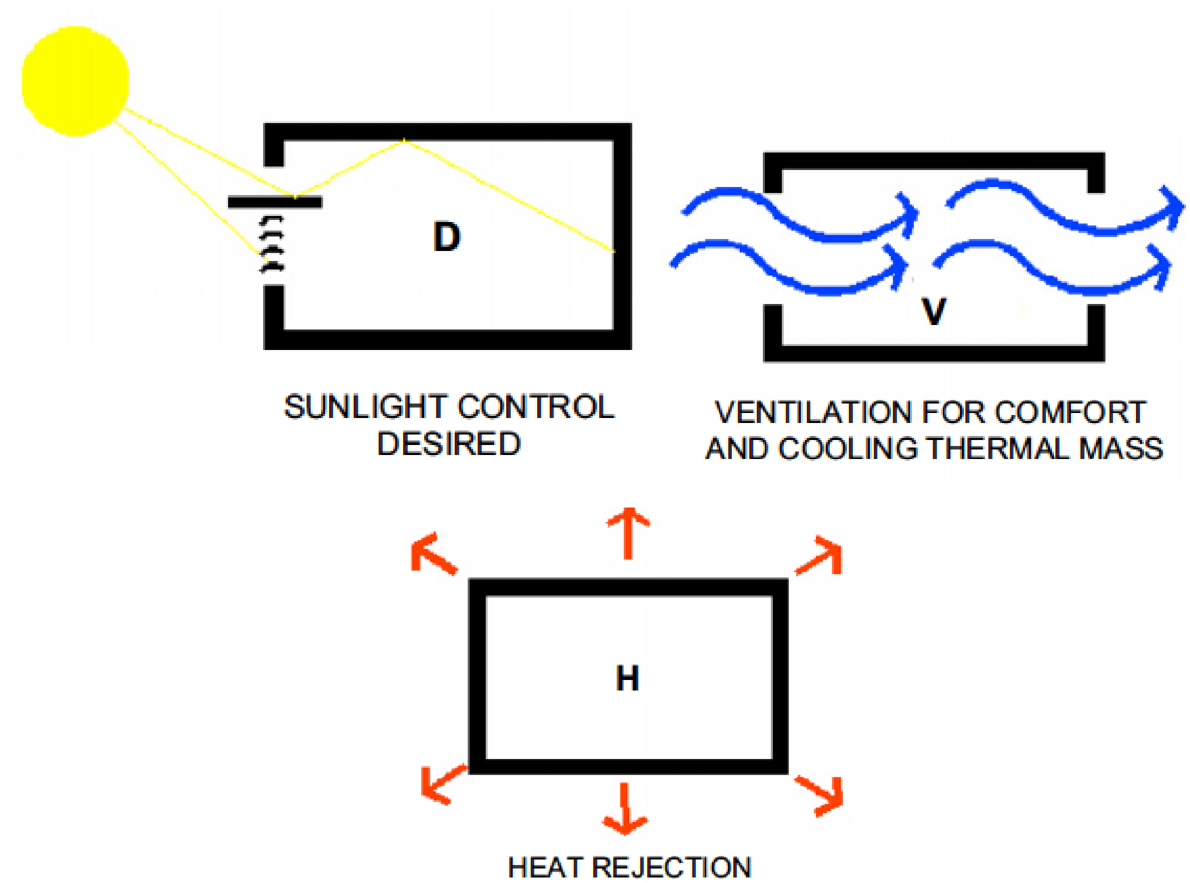


Figure 2.5: Some passive strategies for hot and humid climate (Source: Ochoa and Capeluto, 2008)

Now days, environmental crises is broadly known and many people start adapting their life style to be more sustainable, similarly many architects, designers and contractors start initiating some changes in the way of designing the built environment such as:

- Orienting the building to benefit or be protected from the natural resources such as sun and wind.
- Introducing roof and wall insulation to buildings.
- Sealing the building structure and ductwork by using a better craftsmanship.

In other words, its passive design strategies is a reflection that human beings are aware of green and sustainable buildings and its importance for the natural and the built environment. This awareness leads them to be concerned about the design and construction, as well as incorporating some advanced technology that will elevate the quality of the built environment and the quality of users life with minimum energy consumption and consequently show the way for green building assessments creation. All the above observations and studies conclude the importance of passive design strategies in enhancing the building thermal performance and reducing the energy consumption and CO2 emissions, the following section will provide a general understanding about the green building assessments and the green building codes and regulations and its integration to passive design strategies and principles.

2.5. Green and sustainable building assessment and building regulations

This section will be divided in to two parts, the first one focusing on green building assessment and ratting systems. While, the second part will focus on building codes and specifications.

2.5.1. Green and sustainable building assessment

Green building assessment has been recognized as a design or construction assessment system that evaluates the building durability, energy efficiency and comfort from a holistic perspective, covering the building site, design and the envelop materials that will meet the user goals for better a healthier life.

There are many international and regional green building-rating systems aiming to create a sustainable built environment that is expected to reduce the environmental damaging impacts. This can be achieved by developing a set of performance-based standards, which is geared towards unique needs of region or country and its environment. Moreover, these building assessments are flexible to be applied in different buildings typologies.

The green building assessment is the first part of the primary focus of this study; these rating systems were designed to assess the building construction industry in an integrated way with the social, economic and environmental aspects of sustainable balanced formula through an interchangeable and corporative approach between different stakeholders. Moreover, these rating systems challenges the architect, builder and user to develop and built a structure that satisfy the green building requirements and benchmarks such as energy and water conservation, usage of durable and eco friendly materials, products and appliances that aims for a healthy and comfort indoor environment.

2.5.2. Green and sustainable building assessment: commencement/ timeline

Worldwide, several assessment systems and programs have been developed targeting the environmental energy impacts of buildings. Generally, this paragraph will highlight the most known green building assessment, for example: The United Kingdom has initiated the first environmental certification system in 1990 called the Building Research Environmental Assessment Method (BREEAM), followed by Leadership in Energy and Environment Design (LEED) sustainable building rating system created in 1998 by the United States. However, in 2008, the United Arab Emirates has launched (ESTIDAMA) as a building design methodology program based on the goals of LEED and BREEAM rating systems with respect to the location and local climate conditions. Similarly, in 2010 Qatar has started the Qatar Sustainability Assessment System / Gulf Sustainability Assessment System (QSAS/GSAS). In line with the international and regional recognition to the importance of implementing green buildings assessment programs, this section will highlight that this dissertation will focus on the regional sustainability assessment, because it’s the closest implemented cases to the case study location: Bahrain, and more details about the building rating systems will be covered later. However, the green building specifications and code documented as mandatory regulation enforced by the policy and decision makers. Its main purpose to improve the building performance and help the builders to create structures based on special techniques and tools that aims a reduction of building impacts on human health and built environment throughout the building life cycle.

2.6. International and regional green building assessments: Background

This part of the paper will briefly explain BREEAM International new construction (NC) and LEED (V4) green building assessment as international systems and then followed by the regional rating programs PRS and QSAS. The main objective of this part is to understand the goals of every system, and track the international influences on the regional rating systems.

2.6.1. International green building assessment

There are number of international assessments such as the US LEED, the UK BREEAM, Green Star (GBCA) from Australia, GASBEE from Japan and other assessments, but this study will focus on LEED and BREEAM due to the strong influences on the regional environmental assessments.

BREEAM

Initially, BREEAM is the world leading sustainable and environmental assessment and rating system for buildings. In 1990, the UK established the BREEAM system by (UKGBC) or the UK Green Building Council and defined as the best practice in sustainable building design, construction and operation BREEAM (2014) and its considered the preferred scheme for number of national green building councils across Europe Figure 2.6 Alyami and Rezgui (2012) expresses that BREEAM utilizes a fixed scaling system, Table 2.1.

Figure 2.6: BREEAM is international building assessment (Source: BREEAM, 2014)

Table 2.1: BREEAM environmental weighting system (Source: Sev, A., 2011)

Category	Weightings %	Credits available
Management	12	10
Health and wellbeing	15	14
Energy	19	21
Transport	8	10
Water	6	6
Materials	12.5	12
Waste	7.5	7
Land use and ecology	10	10
Pollution	10	12
Innovation	10	10

Basically, BREEAM can be used to evaluate the environmental performance of wide typologies of buildings, new and existing anywhere in the world, Including: BREEAM new construction, BREEAM in Use, BREEAM communities and BREEAM eco homes. This assessment provides a number of stages that covers the entire life cycle of a building and aspects related to energy and water use, materials, waster, ecology and management process. Therefore, by following the rules and regulations of BREEAM with respect to the building typology and geographical location the building outcome will be way advance and higher quality than the standard practice.

This study will target the BREEAM International new construction (NC) issued in 2013 that was adaptation to BRE global version to cover buildings outside Europe with a new local and climatic constrains. BREEAM International (NC) provides set of ecological and environmental assessments method that wrap the entire stages of building life cycle aiming to encourage designers, builders, clients and others to improve the performance of buildings and understand the benefits of low carbon and low impact design on the environment. However, this scheme will not be applicable in countries that have its own local building assessment and their scheme must be used instead of BREEAM International as stated in their official website.

LEED

Leadership in Energy & Environmental Design or the famous name (LEED) is a green environmental assessment program that is recognized to be the best and most famous international practice in building strategies and practices. The US has developed the LEED rating system by (USGBC) or the United States Green Building Council. In 1998 LEED for new Construction and Major Renovations was developed but it has been updated several times the LEED, but this study will focus on LEED (V4) for building design and construction.

USGBC (2014) sees LEED as framework for identifying and measuring green building and community, construction, operation and maintenance. LEED provides building owners and operators with simple agenda for recognizing and executing practical and measurable ecological building design, construction, operation and maintenance solutions. This volunteer rating system is aiming to promote major changes in the construction industry through several strategies to achieve wide range of goals, and here are some of them:

- To control and hold back building contribution to global warming.
- To enhance the quality of life and wellbeing.
- To build a greener community.
- To minimize the energy and water consumption.

The above goals were selected among many other goals due to its relation to the focal point of this study, which is to upgrade the building regulations in Bahrain.

Furthermore, this system certification is based on number of collected points on many aspects such as location & transportation, materials and resources, water efficiency, energy and atmosphere, sustainable sites and other. All together is attempting to achieve a practical and measurable, healthy & quality, efficient and responsible built environment that will consequently improve the life quality.

Moreover, LEED is there to reduce the operating costs, reduce the waste, conserve both energy and water, provide a healthy and safe environment for the users and reduce the dangerous gas emissions. Same as BREEAM, LEED is very flexible and can be applied on wide range of building typologies, new and existing any where in the world with respect to local conditions. LEED has different rating system groups that express the unique requirements of building and project types towards the certification.

USGBC (2014) LEED has five rating systems that can be applied on different project types, which are: LEED building design and construction for new constructed buildings or the ones going through major renovation or refurbishment as: New construction, Core and shell, Schools, Health care, Retail, ….etc, LEED interior design for commercial interiors, hospitality and retail, LEED building operation and maintenance for all building typologies, while LEED neighborhood development is for communal projects that includes residential or non-residential or mix and finally there is LEED homes which deals directly with homes and multifamily homes. Ultimately, there are four levels of certification; the number of collected in the project will determine the level LEED certification that the project will receive, Figure 2.7.

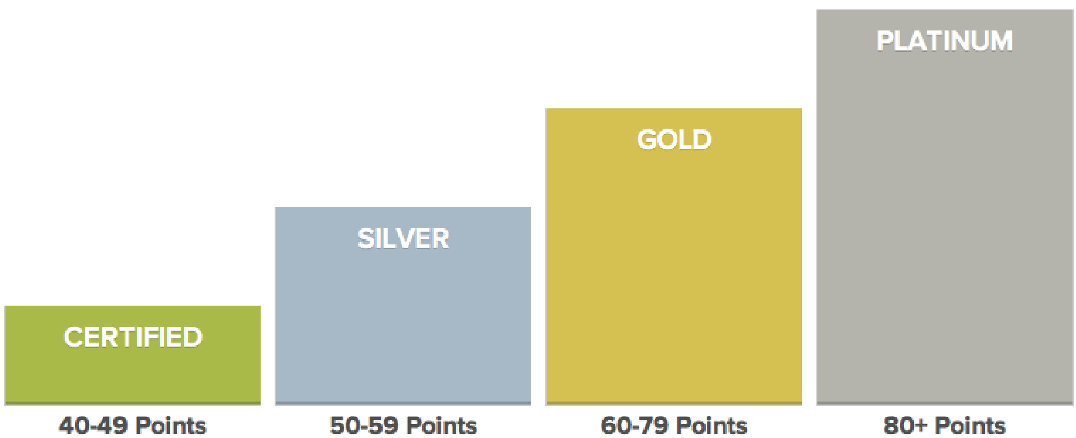


Figure 2.7: LEED certification levels based on points (Source: USGBC, 2014)

BREEAM and LEED sustainable, environmental building assessments are sharing the same objectives such are providing durable, affordable and environmental friendly practices, also mitigating the negative impacts of buildings on the occupants and the environment. All together will provide innovated and challengeable integrated design practices, provide market recognition, cost effective performance and low maintenance, promote the awareness among all the community members via expressing the benefits of green buildings and eco-friendly practices.

As mentioned earlier both schemes have their own categories, although a lot of the categories are overlapping and aiming to create sustainable strategies Table 2.2.

Table 2.2: Overlapping categories of LEED and BREEAM (Source: Author, 2014)

No.	LEED	BREEAM
1	Sustainable Sites	Management
2	Water Efficiency	Health & Well-being
3	Energy and atmosphere	Energy
4	Materials and resources	Transport
5	Indoor air quality	Water
6	Regional Priority	Materials
7	Innovation in Design	Waste
8		Land Use & Ecology
9		Pollution
10		Innovation

However, the international environmental assessments cannot be generalized and applied on all regions due to many reasons, such as: local conditions, cultural restrictions, the economic status, particular needs and requirements of each region, and the main one is the different climate and weather condition.

The following section will highlight the regional environmental assessments that are relatively used as regulations. The sustainable assessments in the Gulf region are PRS (Pearl rating system) by the UAE and QSAS by Qatar and both has its special principles and recommendations.

2.6.2. Regional green building assessment

With reference to the main aim of this study: is to develop a new set of building codes and regulation in the Kingdom of Bahrain, therefore this part of the study will focus on the regional environmental assessments that were launched from Abu Dhabi, UAE, from Doha, Qatar and later on will highlight some green building codes issued from Dubai, while in Jordan and Kuwait it's still under development. Both assessments PRS and QSAS are critically tailored for the climate and weather conditions in the Gulf region, as well as the cultural requirements over there.

ESTIDAMA (Pearl Rating System)

In line with the global sustainability growth and development the UAE, Abu Dhabi have established ESTIDAMA or (PRS) rating system in 2008 aiming to create a new model of sustainable cities that promote a balanced relationship between the four pillars of ESTIDAMA: environmental, economic, cultural and social, Figure 2.8.

Figure 2.8: The four pillars of ESTIDAMA (Source: Abu Dhabi Urban planning council, 2010)

The illustrated four pillars of sustainability are explained below:

1- Environment

- Control and reduce the demand for materials, energy and water consumption.
- Protect and preserve the region ecosystem.
- Control and reduce the air and water pollution.
- Develop smart and responsive structures that reduce the greenhouse emissions.

2- Economy

- Increase the investment returns for the certified developments.
- Reduce the maintenance and operation costs.
- Improve life quality and enhance users productivity.
- Promoting economy under the sustainability umbrella.

3- Society:

- Create sustainable communities that have all the basic daily life requirements.
- Stewardship and promoting awareness of sustainability benefits
- Provide education and training for all the community members.

4- Culture

- Preserve and sustain the unique identity of Abu Dhabi.

Abu Dhabi planning council (2010) asserted that ESTIDAMA or the Pearl rating system is the first program that is made exclusively for the Middle East region via influencing new sets of regulations for the buildings in its entire life cycle. Furthermore, the PRS program provides policies, design guidelines and detailed requirements that aim to enhance the building performance in relation to the four pillars.

Moreover, Sustainable development is the goal of the pearl rating system that is organized in to seven categories, which are:

- Integrated Development Process (IDP)
- Natural Systems (NS)
- Livable Villas (LV)
- Precious Water (PW)
- Resourceful Energy (RE)
- Stewarding Materials (SM)
- Innovating Practices (IP)

The government of the UAE is playing a special role to mitigate the harmful impacts of building through the new set of ESTIDAMA that aim to reduce the negative impacts of the building, energy and CO_2 emission reduction that is incorporated into the 2030 strategic development plan. Furthermore, Pearl Rating System has five levels starting from the mandatory level of 1 pearl heading to 5 pearls. In this study the regulation of 1 pearl, Table 2.3 will be chosen as the minimum acceptable thermal performance requirements for a sustainable villa in hot arid climate.

Table 2.3: Thermal performance requirements of 1 Pearl (Source: ESTIDAMA Villa products database, 2010)

Element	1 Pearl
Wall U-Value (W/m2. K)	0.32
Floor U-Value (W/m2. K)	0.15
Roof U-Value (W/m2. K)	0.14
Glazing U-Value (W/m2. K)	< 2.2

With reference to ESTIDAMA Villa Product Database, the official website of Abu Dhabi Urban Planning council (2010), has demonstrated some construction details proposals for nominated manufactures that proposed some details that meets the thermal performance requirements set in the 1 Pearl villa rating system. Table 2.4 will express some construction details to meet the given U- Values on Table - 2.3.

Table 2.4: Villa envelope based on 1 Pearl thermal performance requirements (Source: ESTIDAMA Villa products database, 2010)

Element	**Layers**	**U- Value**
Wall	16mm light weight plaster	**0.32 W/m2. K**
	300mm Thick ACICO wall (G2/04)	
	16mm light weight plaster	
Roof	30mm Tile, Roof Gravel	**0.14 W/m2. K**
	5 mm Concrete screed	
	150mm of Baymer insulation spray	
	4mm of Bitumen	
	80mm of aerated concrete	
	250mm of dense reinforced concrete	
Double Glazing	6mm Cool Light Lime Freeze KNT 440	**1.8 W/m2. K**
	12mm air gap	
	6mm Clear glass	

Figure 2.9 is illustrating one of the wall compositions that meet the 1 Pearl thermal performance. This wall is manufactured by Acico Industries Co, which is a company based on Dubai and approved by ESTIDAMA (Appendix A), while Figure 2.10 is illustrating one of the roof compositions that meets the 1 Pearl thermal performance. this roof is manufactured by Bayer Pearl Polyurethane systems LLC.

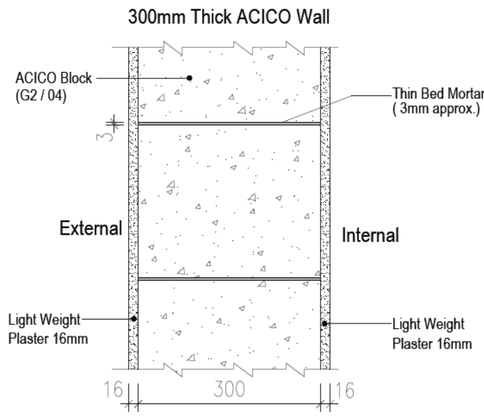


Figure 2.9: Wall section approved by ESTIDAMA (Source: Acico Industries Co, N.D)

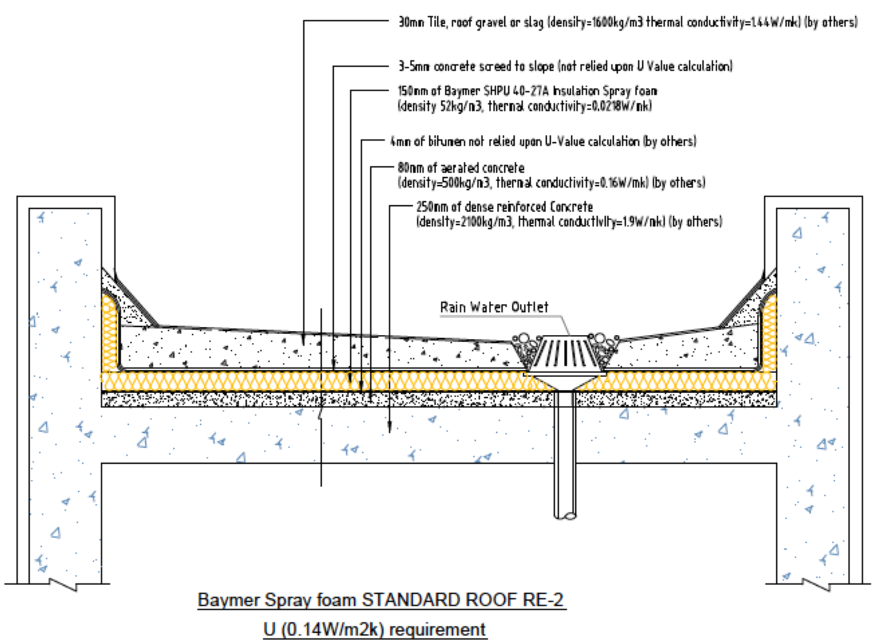


Figure 2.10: Roof section approved by ESTIDAMA (Source: Bayer Pearl Polyurethane System L.L.C, N.D)

Furthermore, the ESTIDAMA building regulation has included several energy saving methods that can reduce the cooling load energy in the UAE hot and harsh climate. Al-Awadi et al. (2013) showed that by applying the ESTIDAMA regulation there was a big reduction in cooling load and especially during the summer months when compared to the traditional model, Figure 2.11. However, the was not much difference between pearl 1 and pearl 2 model that means a notable reduction in energy load can be achieved by applying pearl 1 because applying pearl 2 will not create extra savings.

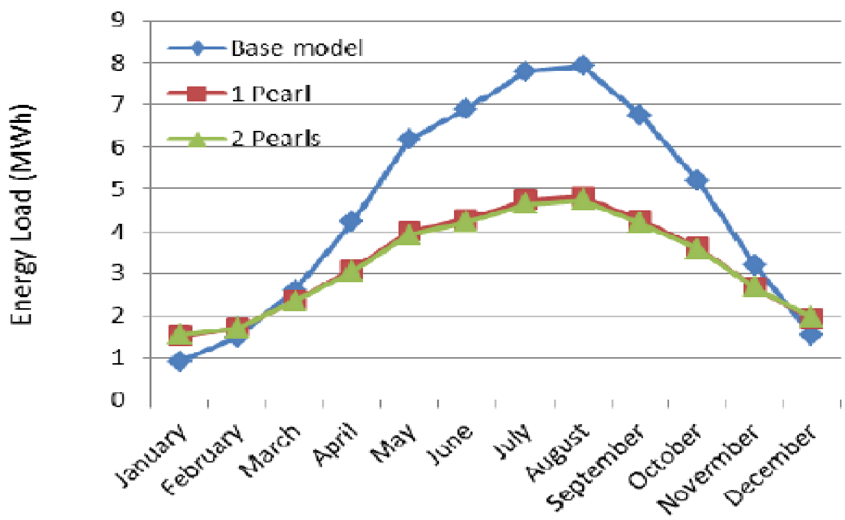


Figure 2.11: ESTIDAMA model monthly total energy consumption vs. traditional model monthly energy consumption (Source: Al-Awadhi et al. 2013)

Since that the climate and weather condition in the UAE is relatively similar to the weather condition in Bahrain, its anticipated that applying the ESTIDAMA building regulations on the typical social housed in Bahrain will record a huge reduction in the monthly cooling loads, and from this point a some modifications to the Bahrain building regulations and cods can be done for better building performance and efficiency. The following section will explain the QSAS rating system in the same way that ESTIDAMA rating system was explained, after that a critical comparison will take place to understand the similarities and overlapping between the two systems.

QSAS

In the same way Qatar have established "Qatar Sustainability Assessment System" or (QSAS) in 2010 which initially was developed by the Gulf Organization for Research and Development or (GORD). Shaka. (2013) Claimed that this rating system has developed through extensive study of all the former rating systems and with reference to BREEAM-Gulf to come with the best mix of methods and strategies filtered from the other rating systems and modified to meet Qatar main issues such as desertification, water scarcity and its wealthy cultural heritage.

During the design stage of QSAS the Gulf organization for R&D researchers considered the relationship between the environmental issues in the Gulf Region, Figure 2.12, the green building practices and the importance of green design in developing the QSAS sustainability rating system, Figure 2.13.

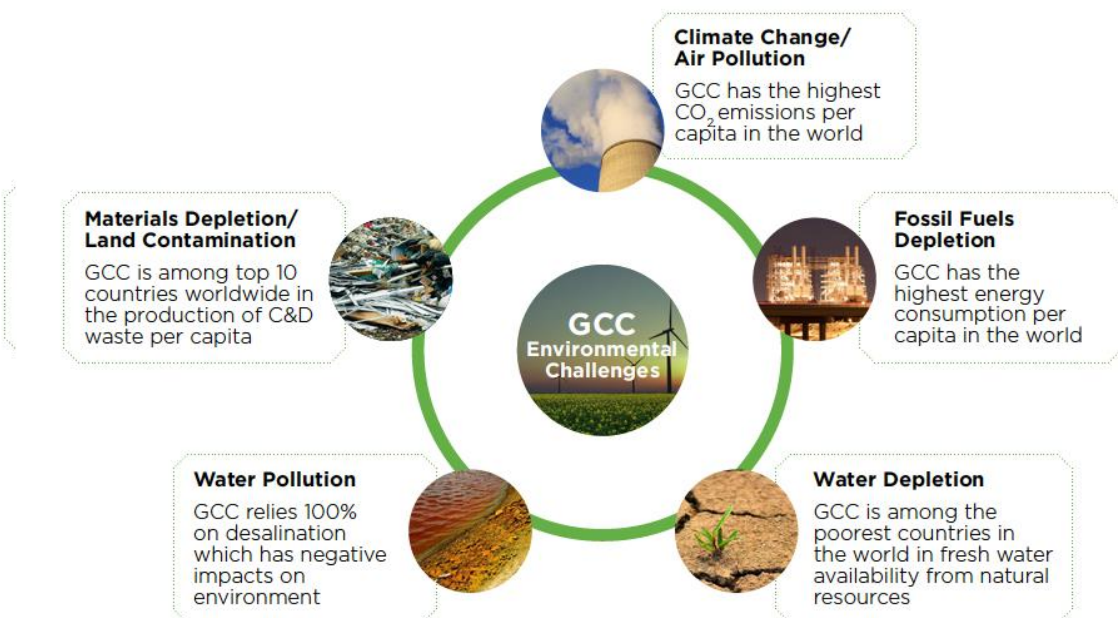


Figure 2.12: GCC Environmental Challenges (Source: GSAS overview, 2014)

The main objective of the QSAS rating system is to create a sustainable and eco-friendly built environment via reducing the ecological impacts and increase the buildings efficiency through set of standards through the entire project life cycle including the design, construction and operations, the regulations and standards addresses specific regional and cultural requirements of Qatar.

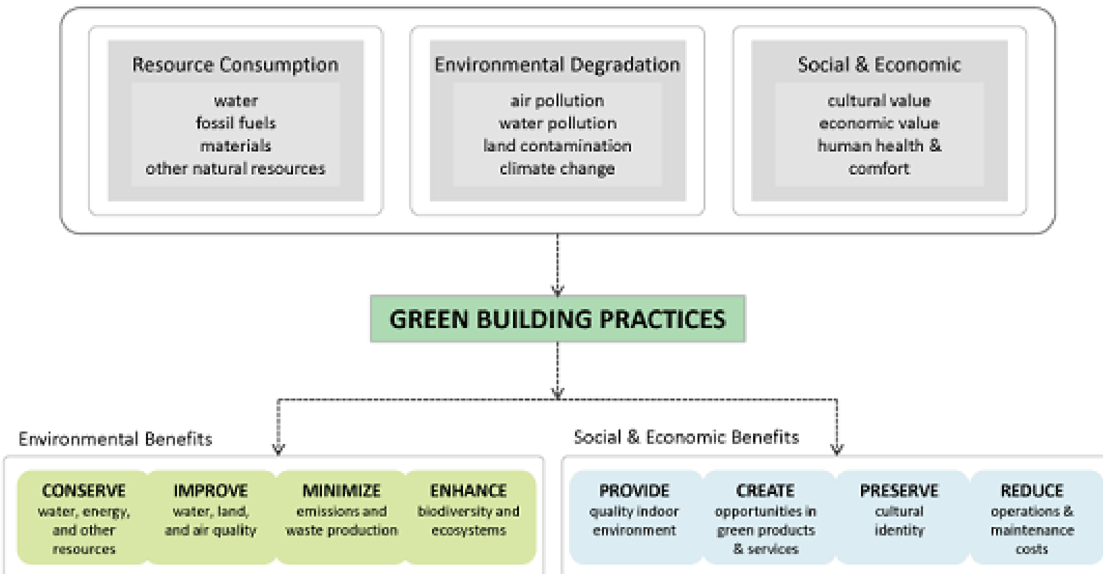


Figure 2.13: Green building practices and their importance (Source: GSAS overview, 2014)

The GSAS asserted that the QSAS system is the first kind of performance- based sustainability rating system in the MENA region that addresses all the related aspects of sustainability, green building design consideration and ecological impacts developed exclusively to support Qatar building energy rating.

QSAS/GSAS is divided into eight categories that are: 1) Energy, 2) Water, 3) Indoor Environment, 4) Cultural & Economic Value, 5) Site, 6) Urban Connectivity, 7) Material, and 8) Management/ operations. Each category has different weighing system that is directly connected to the environmental stress as illustrated in Figure 2.14.

QSAS highlighted a clear set of benefits and advantages of its own program that are:

- Ground up approach: integration between Qatar specific requirements and the sustainability goals.

- Best mix: it combines the best methods of the former environmental assessments and result a customized system for the specific needs of Qatar.
- Performance based: Same as ESTIDAMA and LEED
- Flexible
- Control: Complete control over the project at its current stage as well as for any future modification or expansions.

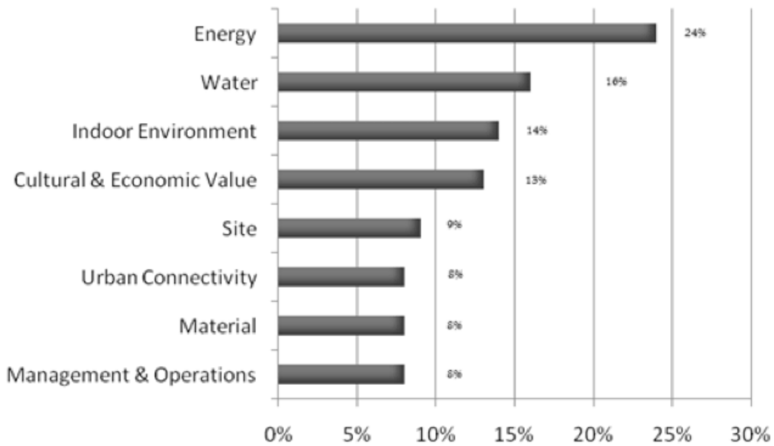


Figure 2.14: QSAS/GSAS categories and weighing system (Source: GORD, 2013)

Furthermore, El-Sarrag and Al-Horr (2012) affirmed that QSAS/GSAS is promoting an innovative passive design and construction technologies that aims to reduce the cooling energy demands and CO2 emissions in hot humid climate. This result can be achieved by introducing dynamic insulation, which is recommended by QSAS minimum level of performance as shown in Table 2.5, and is anticipated to record magnificent reduction in both energy consumption and CO2 emissions. Figurer 2.15 is presenting the differences between static and dynamic insulation and Figure 2.16 is presenting the wall construction layers as per QSAS regulation. The same authors stated that this wall is constructed to reduce the building heat gain without the use of massive thermal insulation. This scenario can be achieved via recycling the heat preformed through the fabric or reducing the temperature flow across the wall section via suitable heat transport fluid.

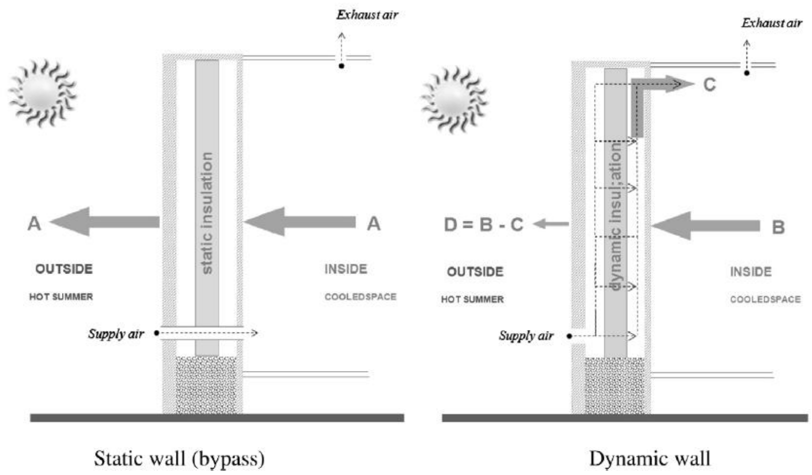


Figure 2.15: Wall construction schemes (Source: El-Sarrag, and Al-Horr , 2012)

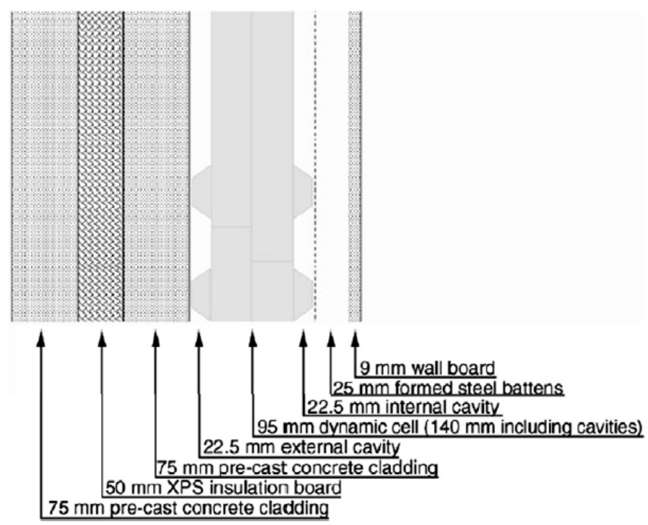


Figure 2.16: QSAS wall construction layers (Source: El-Sarrag, and Al-Horr , 2012)

Table 2.5: Thermal performance requirements of QSAS (Source: Elsarrag, and Alhorr, Y., 2012)

Element	**U- Value**
Wall	0.125 W/m2.K
Roof	0.25 W/m2.K
Glazing	2.2 W/m2.K

Attia (2009) has investigated the similarities between different sustainable building assessment systems in the Middle East. Table 2.6 presenting that the assessment criteria in LEED, BREEAM, PBRS and QSAS is all aiming to reduce the ecological footprint, however the Materials and Water efficiency is taking the maximum attention as well as each system is focusing on certain aspect more that other due to the country local condition.

Table 2.6: Comparison between different assessment criteria (Source: Attia, 2009)

Items of comparison	Green building rating system					
	GPRS	SI 5281	QSAS	PBRS	LEED	BREEAM
Site Selection	15	22	51	12	26	28
Energy Efficiency	25	40	72	44	10	19
Water Efficiency	30	6	48	43	35	6
Materials	10	5	24	28	14	20
IEQ	10	18	42	37	15	15
Management	10	1	24	13	-	12
Waste	-	2	-	-	-	-

While Reiche (2010) believes that reducing the ecological footprint can be achieved by governmental policies and regulations. This paper is highly recommending the GCC countries to reduce their energy consumption due to the climate change and was supported by a survey conducted by Arab Forum For Environment and Development (AFED) in 2009, the majority agreed that a fast action must be taken by the government and the society, while 35% believes that government generally can do more to enhance the residents life quality, reduce the energy consumption and the CO2 emissions. Al-Hajeri (2013) agreed that green building assessments systems such as LEED, BREEAM, GREEN STAR and QSAS has a great impact in energy saving and conservation via enhancing the building envelop.

2.6.3. Green building codes and specifications:

As mentioned earlier, the green building codes and specification are not equal or similar to the green building assessments because the first one is a mandatory regulation forced by the local government for the public health being and conservation of resources, while the second is a voluntary rating system mainly conducted to assess and evaluate the building level of sustainability and usually deals with number of points, its generally categorized as certified, silver, gold and platinum as illustrated in Figure 2.7. Since that the main goal of this dissertation is to upgrade the building regulation in Bahrain, the following part will focus on the current regional regulations and the ones under development in order to extract and develop the best set of regulations for Bahrain.

Dubai green building codes

In line with the strategic plan of Dubai 2015 and global warming crises, the Emirates of Dubai means the Government of Dubai, DEWA and Dubai Municipality has issued the green building regulations and specifications with aiming to improve the performance of buildings in Dubai via reducing its consumed resources such as energy, water and materials in order to enhance the built environment and residents life style.

Dubai Green Regulations & Specification (2008) claimed that the minimum envelope performance for air conditioned buildings must have average thermal transmittance (U-Value) that not exceeds 0.3 W/m2K for the roof and 0.57 W/m2K for external walls, while for the glazing; it should be 40% or less of the total external wall and U-Value not exceeds 2.1 W/m2K, Table 2.7.

Table 2.7: Minimum envelope performance requirements (Source: Dubai Green Regulations & Specification, 2003).

Thermal Transmittance (Summer U value)	U= 2.1 W/m²K (max)
Shading Coefficient (SC)	0.4 (max)
Light Transmittance	0.25 (min)
Roof	U= 0.3 W/m²K
External Wall	U= 0.57 W/m²K

Green building codes: Under development

Among many countries in the region, Kuwait and Jordan has been chosen as samples of countries that is in process of developing their own green building codes and regulation that matches their local conditions.

Kuwait

Through the green building forum, the national committee of building codes in Kuwait (2012) announced the need of sustainable construction codes in Kuwait after analyzing the their local construction industry and they found out many deficiencies in their current practices such as: low health and safety standards, poor construction and waste management and the main reason behind their announcement is that all American and British imported standards are not suitable to this region and there is no complete standards specified for this region needs and requirements.

According to the GCC construction industry (2012), 67% of the GCC construction projects are buildings, while the other 33% is divided between industry and energy, therefore initiating a green building code is very important to mitigate the environmental impacts of buildings such as: high energy & water consumption, CO2 emissions, materials exhaustion, waste production, natural site disturbance and human health due to sick building syndrome and VOC's emissions.

Al-Sayegh (2012), chair of green buildings technical team and number of specialists in this area published a report under the title of "Fundamentals for establishment of sustainable design standards and codes in the construction field of Kuwait. They found out that all green building assessments and rating systems share the same goals and objectives, however they vary in their background, methodologies, standards and rating methods. On the other hand, they concluded their report with a strong recommendation that the new proposed Kuwaiti green building codes should be based two systems that are: primary QSAS system and the reference system BREEAM- Gulf.

Jordan

Similarly Jordan has faced number of environmental and construction challenges and prepared a national agenda toward a green and sustainable development and mainly focus on their traditional culture and customs, climate concerns, material resources, efficient use of water and energy and avoid site disturbance to reduce the negative environmental impacts. The Jordanian government and ministry of public works created the National Green Building Council as well as the Jordanian green building council (J.G.B.C) in order to develop the a green buildings codes and regulations as presented in their local Jo-Green competition about understanding the green building construction (2013).

Awadalla, et al. (2009) claimed that green code of construction practice has been issued in 2008 but still waiting for the ministries council approval to be published and used in all Jordanian buildings. However, it contained the recommended minimum envelope performance requirements, for walls Table – 2.8, for exposed roofs and floors Table 2.9 and for windows types Table 2.10.

Table 2.8: Minimum wall performance requirements (Source: Awadalla, et al. 2008).

Walls	**U- value W/m2.K**
Opaque walls	0.6
Total wall including percentage of openings	1.6
Divider walls between 2 different energy source provider for 2 buildings spaces	2.0
Divider walls between 2parts of the building one of them is heated / air conditioned and the other not	2.0

Table 2.9: Minimum roof and floor performance requirements (Source: Awadalla, et al. 2008).

<table>
<tr><th colspan="2">Exposed Floors andd roofs</th><th>U- value W/m2.K</th></tr>
<tr><td rowspan="2">Exposed for outdoor air</td><td>Heat transfer towards the top</td><td>(1.2) 0.55</td></tr>
<tr><td>Heat transfer towards the bottom</td><td>0.8</td></tr>
<tr><td colspan="2">Floors / Roofs dividing to floors with different energy source provider</td><td>1.2</td></tr>
<tr><td colspan="2">Floors located above un heated / air conditioned basements or spaces</td><td>1.2</td></tr>
</table>

Table 2.10: Minimum windows performance requirements (Source: Awadalla, et al. 2008).

Window Type	U- value W/m2.K	Allowed Ratio of Wall to Window
Aluminum / Steel frame, single glazing	5.7	20.1%
Aluminum / Steel frame, double glazing	3.4	32.9%
Wooden / plastic frame, single glazing	4.8	24.3%
Wooden / plastic frame, double glazing	3.1	40.7%

It's clear that the U-Value of external walls is 0.57 W/m2K for both Dubai and Jordan, however in Dubai the thermal performance is to heat gain reduction, while in Jordan to increase gain to reduce the cooling loads and minimum wall performance is shown in Table 2.7 & 2.8. However, the other building parameters vary in the both cases due to local climate conditions. Moreover, the national committee of building codes in Kuwait recommended that the proposed Kuwaiti green building codes should be based two systems that are: primary QSAS system and the reference system BREEAM- Gulf, which means that the countries in the region should benefit from the available international and regional building codes and build on it. Similarly, Bahrain should build its own green and sustainable building regulation based on the GCC region countries developed green regulations.

2.7. Advantages and disadvantages of sustainable building assessments

Generally, sustainable building assessment and regulations is designed to assess the buildings from a holistic perspective covering the sustainability three bottom line that are: social, economic and environmental via a balanced relationship between the three factors and proper communication between the architect, the builder and the owner of that particular building.

The main advantage of the sustainable building assessment is its influence in guiding the building stakeholders via set of standards and regulations such as: energy and water, indoor environment, environmental friendly building envelope and more. Applying these regulations will make building healthier and comfortable, durable, very efficient and economical that saves the owner money. In addition to that, Akbari (2013) concluded that the benefits for constructors will contain efficient use of material and recourses, minimization of maintenance and repair tasks, reduced work force, while for the country, it will reduce the dependency on the fossil flues and reduce the greenhouse gas emissions and furthermore, provide the citizens more affordable homes and healthier living conditions. However, the building assessment still has some disadvantages such as: the high initial cost of the building from both the special intelligent design that deals with list of considerations and the increased cost due to the installation of the high performance fixtures and equipment's.

2.8. Bahrain: Energy consumption overview

After the discovery of oil in Bahrain in 1932, and the rapid development in all sectors over's the past few decades, the energy consumption increased dramatically which is mainly due to the fast growth of population as indicated earlier in section 1.3.2. According to The International Energy Agency (IEA)(2014), Bahrain has recorded a significant increase in energy consumption and CO_2 emissions 59.3% and 39.4% from 2004 to 2010, Table 2.11, and its anticipated that it will increase more with the current growth of population and progressive demand.

Table 2.11: Energy in Bahrain indicators (Source: IEA and author, 2014)

	Capita	Prim. Energy	Production	Electricity	CO2 - emissions
	Million	TWh	TWh	TWh	Mt
2004	0.72	87	184	7.77	16.95
2007	0.75	102	198	10.75	21.26
2008	0.77	107	203	10.19	22.30
2009	0.79	110	204	10.78	22.82
2010	1.26	114	206	12.38	23.62
Change 2004 -2010	75.0%	30.6%	11.9%	59.3%	39.4%
Mtoe = 11.63 TWh, Prim. Energy includes energy losses Mtoe: Million Tones of Oil Equivalent					

However, Bahrain share of the total global CO2 emissions is 0.1% as shown in Figure – 1.4 in chapter 1, and equal to Jordan is in process of developing a green building code.
Moreover, the Electricity and water authorities in Bahrain (EWA), (2014) has shown in their official website that the to total availability of electricity in December 2014 is 2973 MW, while the total demand is 1373 MW, which means that the government of Bahrain is keen to meet the severe increasing demands of the electricity and to ensure delivering a consistent service to the demanders. On the other hand, the more electricity is used the more CO2 emissions is released to the atmosphere therefore a fast action need to be taken in promoting public awareness for electricity conservation and to find smarter ways for providing and consuming electricity.

With reference to the core study targeting the typical housing unit provided from the ministry of housing, Engineer AlOrrayedh (2013) has affirmed that the electrical energy is expensive to produce and the resources to generate electricity is not easily available and will not last forever. Since that the ministry of housing is the largest and single producer for housing units in Bahrain, he drew the attention that the current housing units consumes huge amount of the country electricity production for space cooling and the current construction techniques as shown in Figure 2.3 that 54% of the total energy consumption in Bahrain goes for domestic and residential purposes Radhi (2009).

Therefore, the ministry should enhance the construction system to be more energy efficient, which consequently will reduce the electricity consumption and from this reduction in energy consumption the ministry could utilize the saved funds in building more required housing units.

2.9. Bahrain social housing energy demands: current and future

Bahrain Economic Development board, EDB (2011) announced in their Economic Quarterly report that “Bahrain needs to build 225,000 housing units by 2030”, the report also indicated that total Bahraini housing demand is predictable to grow from 145,181 housing units in 2010 to 263,536 in 2020 and to 346,718 in 2030, which means a huge pressure on the ministry of housing. Those houses are mainly for citizens with limited and low income, therefore the main objective of the ministry to ensure a high quality services and enhance the resident’s quality of life.

The GCC construction industry report (2012) affirmed that the government is planning to build three new cities in East Hidd, East Sitra and Northern Town that is anticipated the provision of 23,000 units by the end of 2016. They also stated that the best solution for Bahrain residential projects pressure is addressing the issue of affordable housing units, which strongly supports the study argument. In addition to that, construction is highly technical practice and extremely complex industry where it can tackle and only accept low percentages in risks or financial capital loss for lake of quality of material or the workmanship. According to the GCC construction industry report (2012), the building material accounts 33% of the total construction cost. Moreover, construction practices are responsible to achieve an efficient building that conserves energy and provide the owner with a comfortable and healthy indoor environment. Therefore, the following will briefly present the current construction practices in Bahrain based on the ministry of housing standard specification for housing projects (2010) and the suggested construction practices and will be followed by some suggested practices that will enhance the housing construction in Bahrain.

Current

Based on Bahrain Ministry of housing standard specifications (2010), it has been noticed that the construction of the residential typologies in Bahrain has different ways of construction, the single housing units are built up their walls with standard 200 mm concrete blocks and two external and internal plaster layers as shown in the ministry of housing drawings and Bahrain Electricity and water documents Figure 2.17, while the apartments buildings is treated differently, Figure 2.18 the walls are built using concrete blocks with 35 mm polystyrene boards inserted in the blocks which makes the wall have a total U-Value for the insulation system including the internal and external finishes should not exceed the 0.75 W/m2C when calculated in accordance with the ISO 6946.

AlOrraydeh (2013) affirmed that this system has a lot of disadvantages such as thermal bridging, corners and openings could not be filled with concrete, as well as beams and columns are not insulated. Also, the same information has been told some professionals in this field that has been interviewed casually. Furthermore, it has been asserted by engineer Khalil (2014) that the glazing system for the windows transfers approximately 30% of the thermal heat gain from outside to the inside of the housing unit, however the ministry of housing units are fixed with tinted double glazing windows that reduce the heat gain and an air gap of 8 mm that helps to reduce the heat transfer, while the roof is thermally insulated by using 50mm of CFC free polyurethane sprayed layer and average of 50 mm thick concrete screed Figure 2.19, it provide the roof with 0.5 W/(M2.K) and consequently saves 80% in construction period over the conventional systems.

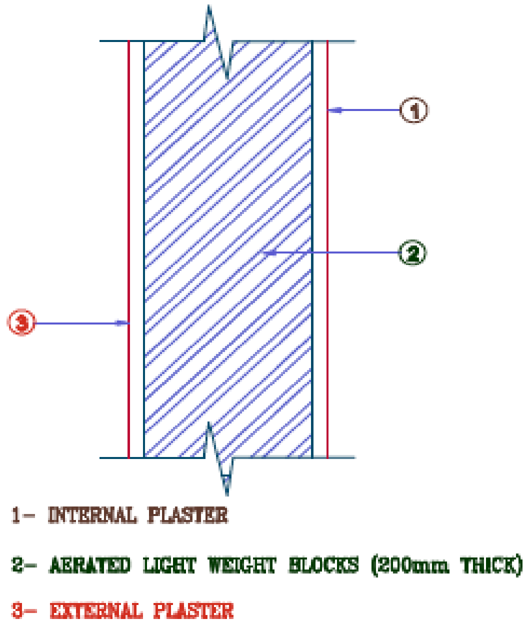


Figure 2.17: Bahrain current wall construction detail in housing units (Source: Bahrain Electricity and Water Authorities, 2014)

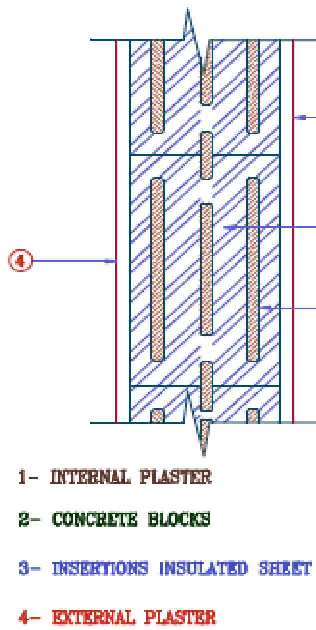
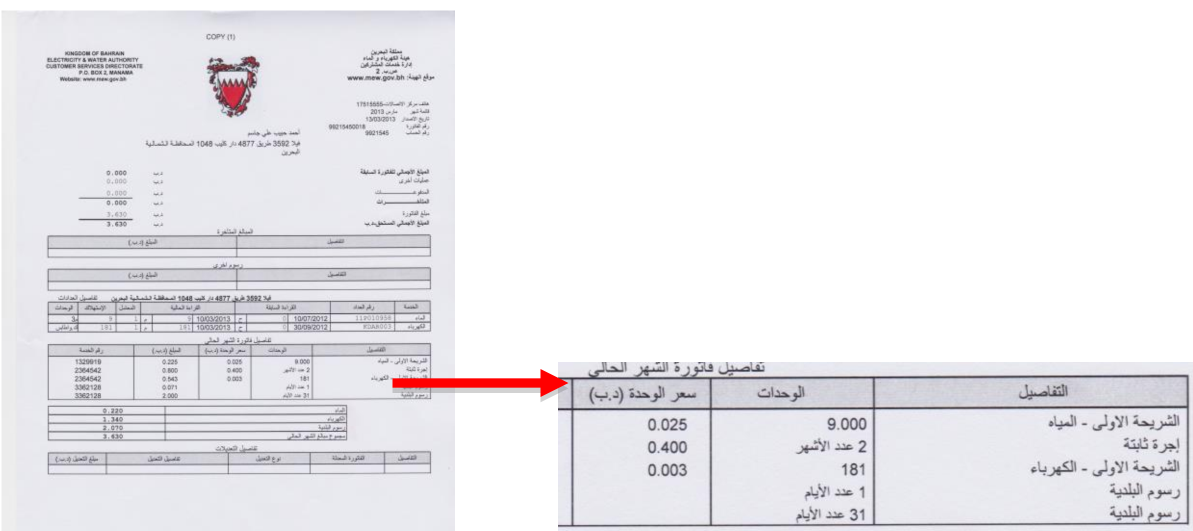


Figure 2.18 Bahrain current wall construction detail in apartment buildings (Source: Bahrain Electricity and Water Authorities, 2014)

Figure 2.19: Bahrain current roof construction in housing units (Source: Khalil , 2014)

Between the present and the future

Electricity conversation has been the most important topic in Bahrain for the last decade; however it’s the core attention of electricity and water and the ministry of housing to provide a cost economical and energy efficient housing units. However, the efforts in this field was limited because of the plentiful oil resources, there was no need for this kind of efforts since that the energy rates is very low at three Fills / units (electricity) as seen in official electricity bills issued from EWA Bahrain Figure 2.20.



COPY (1)

KINGDOM OF BAHRAIN
ELECTRICITY & WATER AUTHORITY
CUSTOMER SERVICES DIRECTORATE
P.O. BOX 2, MANAMA

تفاصيل فاتورة الشهر الحالي

التفاصيل	الوحدات	سعر الوحدة (د.ب)
الشريحة الاولى - المياه	9.000	0.025
إجرة ثابتة	2 عدد الأشهر	0.400
الشريحة الاولى - الكهرباء	181	0.003
رسوم البلدية	1 عدد الأيام	
رسوم البلدية	31 عدد الأيام	

Figure 2.20: Sample of monthly Energy bill of a typical housing unit in Bahrain, presenting the rate /electricity unit (Source: EWA Bahrain, 2014)

According to the (EWA) Elerctrisity and Water Authorities, Bahrain is currently having five production stations concentrated on the north and north east part of the island as shown in Figure 2.21 and they have achieved a magnificent growth in this field as their generation in more that the demand Figure 2.22 with minor recorded interruptions.

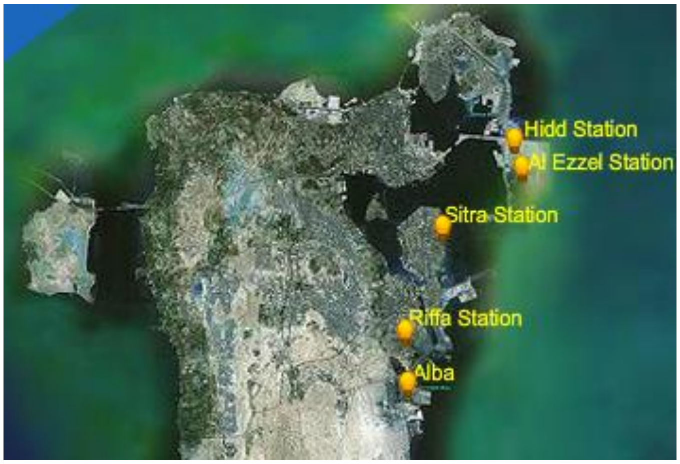


Figure 2.21: Bahrain electricity production stations concentrated in the north and north east part of the island. (Source: EWA, 2014).

Figure 2.22: Bahrain generation availability and peak load 2013. (Source: EWA, 2014).

The graph presented in Figure 2.22 showed that the overall energy demand is very high specially in the summer months. The electricity consumption in Bharin has been gowing dramatically from 1998 until 2007 as stated by Radhi (2009 b) and expected to be worse in the present and the future as shown in Figure 2.23.

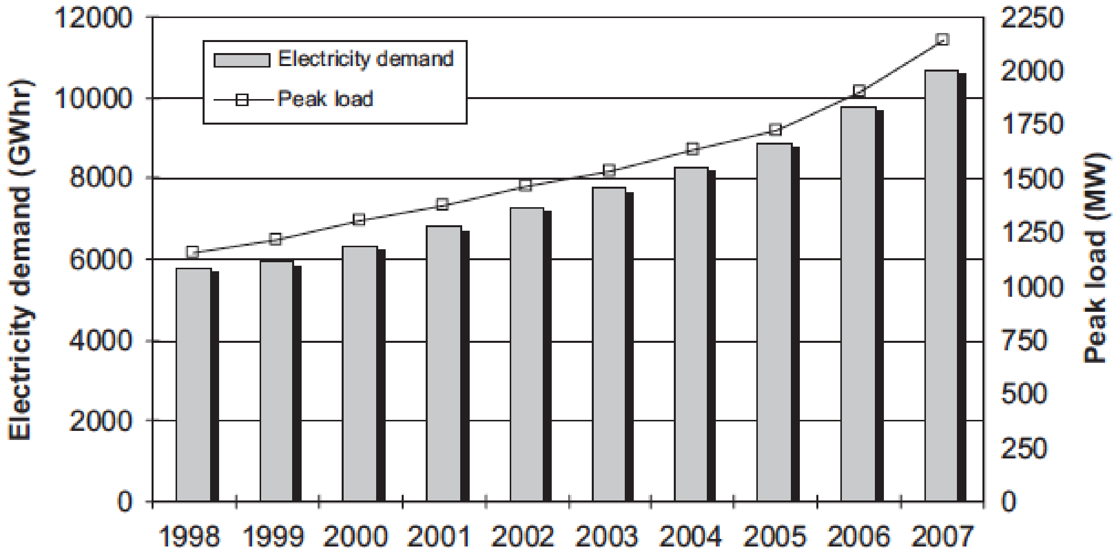


Figure 2.23: Growth of Electricity consumption in Bahrain (Source: Radhi (2009 b))

However, the generation and the demand rate is currently stable with the current population and urban developmnet growth. This stable situation will not last for ever due to many reasons such as : the rapid population growth, construction developments and specially the residential buildings and units and here with additional critical reason, that electricity in Bahrain as most of the GCC countries is subsidized which leads to increase the cooling energy demand specially in July, August and September when the temperature reaches its max.

In line with that, Radhi, (2009 b) declared that EWA in Bahrain has set a target to reduce energy consumption and CO2 emissions by 40% via using efficient thermal envelope and insulations codes. The paper concluded that envelope codes in commercial buildings can literally reduce energy use by 25%. Therefore its anticipated that a similar result can be achieved in the residential units. In addition to that, Al-Naser and Flangan (2007) and Al-Naser *(2008) asserted that 60 to 70 % of total energy consumption in Bahrain is for buildings and construction. In spite of this, they believe that buildings should have less reliance on conventional energy and construct buildings integrated with renwable energy resourses and they concluded that the best option for

Bahrain is the building integrated with photovoltaic (BIPV) due to the high solar intensity.

However, the author believes that green buildings codes and regulations is the most feasible solution in Bahrain, because installing renewable resources equipments will always increase the initial cost, furthermore, Al-Naser and Flangan (2007) stated that installing active systems equipments is not profitable because the cost of (tariff) in Bahrain is only US cent 1 which is equal to Fills 0.003 as shown in Figure 2.20. In addition to that, the biggest barrier of implementing sustainable active systems the lake of incentives from the Bahraini government, therefore implementing achieve systems will be profitable when the tariff raised up or a strict building regulations are imposed in energy conservation.

Housing units energy demand

Since that this study is targeting affordable housing units provided from the ministry of housing in Bahrain, and there is different housing typologies in area, design and facilaties, however, the most famous and widly spread one is T3M, therfore a field trip was conduted in 2014 to some of this housing typology and group of those units were selected based on housing typology (T3M), area, design and conventional construction strategy as shown in Figure 2.24.

Figure 2.24: Sample of the houses chosen for the energy consumption analysis (Source: Author ,2014).

According to the field trip conducted in (2014) and the official electricity bills given from (EWA) Electricity and Water Authorities. The three selected houses were the houses built by the typical construction system using the typical wall shown in Figure 2.17 and the roof system shown in Figure 2.19.

Table 2.12 and Figure 2.25 are presenting the first group monthly energy consumptions. Its clear that all the houses varies in energy consumption which can be directly linked to the user behavior and life style, it may also be connected number of users in the housing unit.

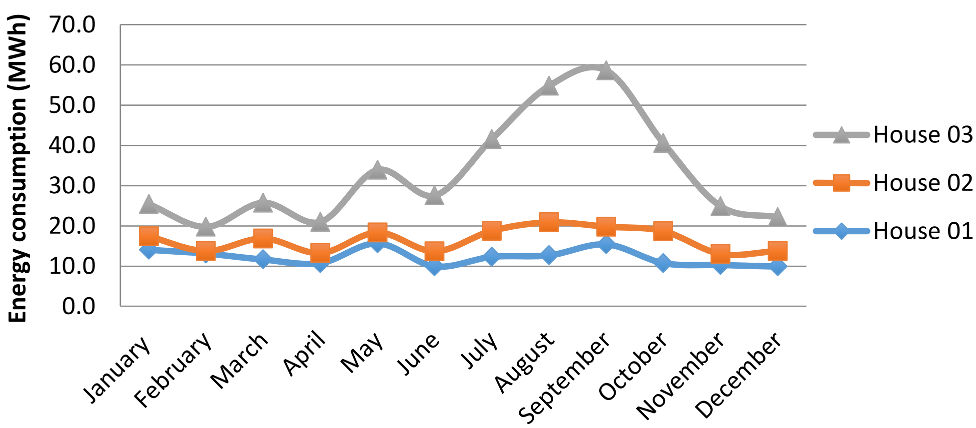


Figure 2.25: Average energy consumption of three houses (typical construction).(Source: Author ,2014).

Since that the existing data indicates high-energy consumption from housing units in the kingdom of Bahrain, and with reference to the international and regional efforts towards energy efficient buildings and better life quality. The following section will highlight the proposed improvements for the future.

Proposed improvements for the future

The kingdom of Bahrain has been classified as one of the successful countries in the gulf in meeting the fast population growth and urban development, especially residential projects. Consequently the energy generation should be increased to satisfy the growing demand that initially requires costly investment as stated by Al-Irani. (2004).

With reference to the goals and objectives of ministry of housing in enhancing the housing units construction techniques via insuring a healthy and comfortable indoor environment, energy conservation and reduction of external heat transfer to the indoor spaces. Therefore, the improvement in the housing units quality is anticipated to cover the whole building envelope that means: the roof, walls and windows.

Concisely, the ministry of housing units are currently has thermally insulated roof but the walls and glazing still needs to be enhanced to act smartly in preventing the heat entry to the indoor spaces. For that, AlOrraydeh (2013), highlighted that the roof insulation system has been used in the ministry of housing projects for long time and is described by being very effective, but still can be improved by increasing the thickness or adding a layer of water membrane layer on the top, Figure 2.26.

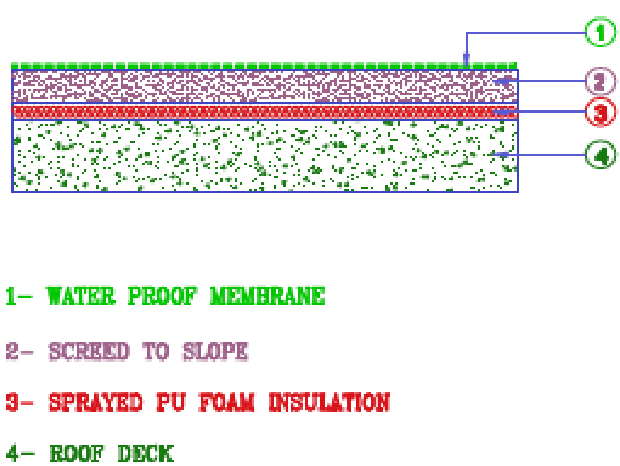


Figure 2.26: The recommended roof insulation detail in housing units (Source: Bahrain Electricity and Water Authorities, 2014)

On the other hand, he highlighted that the wall insulation system should be economical, durable, maintainable and eco-friendly for both the external and internal environment that consequently will affect the human health. Therefore, he suggested that the suitable system is external insulation for the wall that has been already used twelve years ago on 3 houses and has been inspected recently and the study results are shown in (Appendix B).

Furthermore, the windows and glazing system can also improve via using Low E Glass, coated with microscopically thin layer of metal oxide charged to further heat gain reduction by using insulated aluminum frames with thermal break. In addition to that, windows and glazing areas orientation may reduce the heat gain as well as the usage of external and internal shading devices. Appendix B briefly presenting the results of the study conducted by AlOrraydeh (2013) (Appendix B) shows that 31% saving in electrical consumption can be achieved by using insulation materials for both walls and roof in inspected housing units. Moreover, the ministry of housing construction department had installed the insulation system in few housing units in different area in Bahrain in order to investigate the feasibility of such systems and their impact on energy consumption and construction cost as declared by Al-Orraydeh (2013). For that, the author (2014) conducted a field trip to some of the houses that have installed the insulation system but still not occupied and other chosen as housing unit using the typical construction system.

The field trip was extended to the construction site of the same housing typology, hence its widely spared all over the country Figure 2.27 and Figure 2.28. Moreover some of the houses are single Figure 2.29 and some of them are semidetached, Figure 2.30 depends on the plot size and location.

Figure 2.27: Housing unit T3M under construction (Source: Author, 2014).

Figure 2.28: Construction method only block work (without insulation) (Source: Author, 2014).

Figure 2.29: Single housing unit (Source: Author, 2014).

Figure 2.30: Semi detached housing units (Source: Author, 2014).

This house is classified as T3M that is 2 storey housing with four bed rooms, Figure 2.31 is presenting the plan that provides the minimum and standard required area for a typical Bahraini family that is equal to 209 Sq.m and Figure 2.34 is presenting one sample of the T3M suggested elevations.

Figure 2.31: Housing unit T3M plan, Ground floor (left), First floor (right), (Source: Ministry of Housing, 2012).

Based on the literature review and background research presented earlier, the identification of research problem, as well as the aims and objectives have been developed. The following section will present the problem statement followed by the aims and objectives.

2.10. Problem statement

The core of this research is to evaluate the current construction status and then propose an advanced construction properties that is anticipated to enhance performance and quality of the social housing sector in Bahrain. The challenge is to combine different aspects extracted from green building assessments and regulations to recommend a new green building properties tailored for Bahrain climate conditions and cultural requirements.

Overall, the research has portrayed some international and regional green or environmental building assessments/regulations and focuses on the thermal performance of the building envelop elements that are wall, roof and windows.

The main focus of literature and several data analysis on the field of green building assessment/regulations is based on energy consumption and CO2 emissions. However, there were number of researchers have initiated different solutions to reduce both the energy consumption and the CO2 emissions but the lack of verification to the resulted numbers is almost missing, therefore this dissertation is intent to is to validate the results via computer simulation software and to investigate the impact of changing each building envelop. Furthermore, the efforts of Bahrain electricity and water authorities and the ministry of housing is lacking the presence of green building codes and regulation as in other counterparts countries in the GCC. Therefore, developing an energy efficient regulations and enforced by the private and public sector will achieve a significant reduction in energy consumption and CO2 emissions.

2.11. Aims and objectives

Based on the author observations and the presented literature review regarding the current construction methodologies and its relation to the electricity demand in Bahrain and the regional and international green and sustainable building assessments.

This disseratation is aimed and anticipated to give solutions and recommendations to the the Ministry of housing to modify the construction properties of the building enevlop elements to reduce the overall enegy demands in the residential housing.

While the objectives are:

1- Examin the effect of different U-Values of roof and walls cbased on various building envelop scenarios suggested by the local and regional green building regulations.
2- Examin different values of Glazing Solar Heat Gain Coefficient (SHGC) and its impacts on energy consumption and CO_2 emissions.
3- Evaluate the overall energy consumption, chillier load and CO_2 emissions for each scenario
4- Estimate and propose an appropriate wall and roof thermal transmittance sutible for Bahrain conditions.
5- Provide some recommendations according to the simulation results.

Chapter 3
Methodology

3.1. Overview

This chapter will present different methodologies that have been used to assess and evaluate the performance and workability of green and sustainable buildings regulations. However, every methodology has its own pros and cons and both will be evaluated in order to justify the selected methodology for this research. Extensive research has been conducted in evaluating the performance and effectiveness of green buildings in the western world but limited research in the same field was conducted in the gulf region and particularly Bahrain. Therefore, this chapter will cover some of the papers that studied Gulf region as well as in other regions that have similar conditions in order to understand the influence of green building envelope regulations in hot arid climate and its impacts in the energy consumption via different methodologies.

However, Selection of the suitable research method is very important to enable the existence of this study. Before initialling the study it’s important to have a full understanding of the appropriate research method used to assess the energy conservation and CO2 emissions reduction in residential housing units in order to achieve the main goal of this dissertation. In addition to that, a comprehensive understanding of the limitation of the preferred methodology is required to be evaluated within the research time line. Methodology limitation includes research resources, time, applicability to the research problem and validation of the research method.

Furthermore, it will show different ways of describing the findings in Qualitative measures that allow the researcher to give the reader a mental image of what is he or she observing and doesn’t depend on static data but objects and individuals to be observed, while the Quantitative measure is the one that deals with numerical figures to test and prove a hypotheses and usually presented by figures, charts and tables or mixed methods that will combine some quantitative and qualitative findings either to support the findings of each other or to validate the observations with the founded numbers.

3.2. Defining research parameters

This research will investigate the potential reduction of energy consumption and CO2 emissions of standard residential unit in Bahrain via adopting several scenarios of building envelop layers learned from the green building regulations in the region and some recommendations from the international sustainable building assessments. Therefore, overall energy and chillers energy consumption as well as the CO2 emissions will be the major output results covered in this study. As mentioned earlier a typical housing unit in Bahrain will be created to examine the different discussed building envelope scenarios that are the wall and roof configuration, as well as the glazing area in the residential unit. These factors are classified as passive strategies that deals with U- Value of construction element (Rood and Wall), as well as the glazing solar heat gain coefficient (SHGC) that is related to the surface area and orientation. As highlighted earlier different scenarios will be extracted from different regional green building assessments and will be assessed to find out which scenario is most suitable one to Bahrain to reduce the energy consumption and CO2 emissions.

3.3. Comparison of research methods applicable to this research

Extensive research has been conducted to examine and inspect the effect of passive strategies in building envelop in hot arid climate via applying different construction strategies. Each paper has determined number of parameters that can be applied in residential projects according to the methodology used and the element that has been inspected. However, all the papers are having similar outputs and finding no matter what is the methodology used, which help the author to achieve the aims and objectives of this study. The different methodologies are: Literature review, experimental approach & field measurement, and simulation approach & computer modelling.

3.3.1 Literature review approach

Literature review is built up content from previous studies, observations and qualitative surveys that varies due to local condition of the observed place and to the personal human sensibility. It’s also a helpful tool to familiarize the researcher with other studied situations in the same field to understand the advantages and disadvantages of certain methodology and consequently help him/her to select the most appropriate method for data collection.

Roodgar et al (2011) generates a detailed comparison between modern and traditional housing in Kashan, Iran to understand the potentials of both in saving energy. The study was based several previous studies in this field as well direct monitoring to the selected case study. The paper highlighted that the new housing units should be based on the past vernacular Iranian architecture and directly deals with passive strategies such as form and orientation, thermal insulation, cross ventilation, windows size and solar gains ... etc. Figure 3.1 presents different passive solutions that could be incorporated in contemporary designed houses.

When designing new houses in order to improve the energy performance of building, follow the fundamental laws of climate-responsive design, as well as vernacular materials.
In order to achieving both low U-value and high thermal inertia of construction, use sufficient insulations with good properties in wall and roofs.
Use energy-efficient appliances and lighting equipment (e.g. use of fluorescent lights instead of incandescent lamps).Based on this study's findings, it is recommended that at least 70% of the building's lighting should be of the fluorescent type.
Not only there is high level of solar irradiation in Kashan but also the largely amount of available inutile area on the roof of the building, to use solar PV panels could be fitted in order to supply amount of household electricity and heating.
Not only using the rough and translucent surfaces to prevent reflection of irradiation on external walls but also using dark colors to absorbing thermal energy of the environment during the days and releasing it during the nigts which it has beneficial effect on practical design.
By recognizing the useful winds through the environment which can be used in optimum usage on formation and direction of a building.
Using double glazed windows and fit external shading devices in order to shade building and environment. Position of these devices not only is important to reduce solar gain but also put to use natural light.
The use of free cooling to reduce electric load of air conditioning system by the aim of wind-fans in Badgirs and integrate with other zero-carbon technology such as pumping.
To speed the wind input this can be simply created track in through the Badgir channel, that it make happens turning wind rapidly and better quality in whole of rooms.

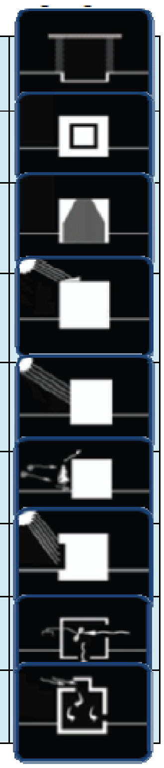


Figure 3.1: Design recommendations for new domestic units based on the vernacular notions (Source: Roodgar et al (2011)

Roufechaei et al (2013) evaluated the possible design solutions for energy efficient sustainable housing unit. The study was conducted based on a combination of literature review, existing research reports and a questionnaire survey. The data collected from the survey was evaluated, analysed and ranked via the use of relevant statics methods such as descriptive and regression analysis against the data found in previous studies as shown in Table 3.1. Based on the results, it has been concluded that the best energy efficiency parameters to achieve a sustainable housing development is to insulate the entire building envelope (roofs, windows, walls and floors).

Table 3.1: The relative significance of energy efficiency parameters for sustainable housing development. (Source: Roufechaei et al (2013)

Energy efficiency parameters	Mean	Rank
Insulation (roofs, windows, floors, walls and exterior doors)	4.52	1
Application of lighting choices to save energy	4.26	2
Application of passive solar (take advantage of climate conditions)	3.98	3
Application of natural ventilation	3.72	4
Making clean electricity	3.51	5
Cooling and heating system (environmental friendly materials for HVAC system)	3.45	6
Integrative use of natural lighting (day lighting) with electric lighting system	3.39	7
Optimization building orientation and configuration	3.32	8
Optimization building envelope thermal performance	3.18	9
Use energy efficiency and renewable energy sources	3.04	10
Ample ventilation for pollutant and thermal control	2.98	11
Application of efficient water heating	2.94	12
Application of solar water heater	2.92	13
Application of green roof technology	2.85	14
Use of efficient type of lighting (lighting output and color)	2.76	15
Application of lighting product	2.71	16
Application of thermostats, ducts and metres	2.63	17
Application of artificial lighting	2.58	18
Insulation tank and pipes	2.46	19
Application of ground source heat pump	2.41	20
Demand tank less water heater	2.39	21
Use wooden logs to provide structure and insulation	2.33	22

Furthermore, Kalili and Amindeldar (2014) asserted that indigenous constructional patterns or passive design strategies based on the climatic consideration such as basements, courtyards, wind catchers, domical ceiling and porches. The paper has compared the indigenous housing to the modern housing units and it declares that low carbon and energy efficient construction could be achieved based on traditional elements. Table 3.2 will present a comparison of architectural concepts and patterns of indigenous and modern housing design in Iran.

Table 3.2: Comparison between indigenous and modern housing design. (Source: Khalil and Amindeldar (2014)

Indigenous houses	Contemporary houses
Spatial organization of indigenous houses, itself, undertook the comfort supply by considering the use of open, semi-open and closed spaces and flowing air in all components of the rooms, and developing shadows and putting ponds for surface evaporation and observing energy saving elements.	The responsibility and plan for comfort supply of houses are not included in spatial organization of contemporary houses. Amount of participation of spatial organization in providing cold, heat and ventilation seems little.
Existence of three type of spaces; open, semi-open and closed, with specific ratios for these three spaces proportionate to the climate.	Change in amount of utilizing semi-open and mediating spaces (porch, etc.) leading to decrease and omit them as well as change in the ratio of these spaces.
Space flexibility for life style dynamism, human behaviors and status and allocating no space for special operation	Domination of objects on house special organization, transformation of space into a rigid material resulting from space inflexibility
Comfort providing elements such as wind-catcher, basement, shades, pond and courtyard in a uniform pattern were integrated inside the spatial organization and appeared in architectural displays	Architecture does not have any role in installing of factory packages (cooling and heating devices) in internal spatial organization. These devices are attached to the building as an accessory part.
In indigenous house, there was a convergence between residents' needs and demands with environment.	In the spatial organization of contemporary houses, there is no spatial response for achieving adaptation to environment and its changes and space response is replaced by technology in a divergent way.
House was not separated from nature, and existence of some natural representatives was mandatory in internal spatial organization of a house.	The spatial organization of a house does not consider the nature. Its facilities have not been used for providing residents' comfort, and relation of construction with nature in contemporary houses has been minimized to consumption of environment and weakening it.
House took advantage from wind flow, sun radiation, water, seasonal order etc. for providing comfort and integrates them inside itself by offering description of architectural elements.	Existence of nature in contemporary houses is limited and marginal. Nature in indigenous houses which was a courtyard, changed into a small flower pots in modern houses or into a small and limited skylight. In most cases, plants are transported in vases into the houses and have a secondary role among the mass of objects.
In semi-open spaces (such as porches), there was a direct connection with nature, and these spaces not only played important role in indoor temperature adjustment, but were also a reflection of comfort besides the concept of outlook.	Change in the area of open and closed spaces to minimize the mediating semi-open space.
There was a wide range of open spaces from yard surface to the roof such as: Soffeh, Mahtabi, terrace and roof which had a seasonal role in providing comfort facility.	Avoiding usage of roofs and lack of open spaces in spatial organization of houses reduces the relation with nature and use of comfort facilities of the environment.
All the environmental potentials such as stable temperature of the earth were used for cooling in the hottest hours of summer.	Reducing the use of basement and trend toward omission of using passive heating and cooling energies by soil, can be observed in modern houses.

The previous papers have used the literature review methodology in conduction the study. However, in the beginning of this section it was clearly mentioned that literature review is based in qualitative surveys that may vary due to the local conditions. The aim of this paper to achieve a noticeable reduction in both energy and CO2 emissions of the research case study, that means a numerical data and analysis that cannot be obtained from using the literature review method. Therefore, this method not preferred for this study and can only be useful when combined with another quantitative methodology in order to be reliable.

3.3.2 Experimental approach and field measurements

The experimental approach preformed best for evaluating thermal comfort in existing buildings via discussing the comfort parameters such as: dry bulb temperature, humidity levels and day lighting. However, most of the papers discussed indicative solutions to reduce energy consumption of cooling loads and CO2 emissions in buildings. The experimental method is applicable only when the study is targeting certain parameters and the time frame is not limited. Furthermore, this approach is relatively expensive because it requires special equipment. Ross and Morrison (2012) asserted that "Laboratory approach" is as experimental type of research methodology. It requires a controlled environment in a physical laboratory, where all variables are consistent to create a baseline model conditions and allow the researcher to investigate the affect of each variables throughout the study, after that the outcome of the study will be evaluated independently to the baseline. Generally, researchers in this field rarely apply this method due to its limitations such as the high cost, time and effort consuming to create the required physical structure and controlled environment. Therefore, this method is not the best one for this research.

Guo et al (2013) used the experimental method to test three apertures as shown in Figure 3.2 and actual two test rooms as shown in Figure 3.3; with and without reflective insulation to evaluate the possible energy saving effects of heat-reflective insulation on exterior envelope walls in both hot summer and cold winter. The study focused on monitoring the wall temperature changes in both test rooms and indicated that the heat reflected insulation coating could reduce temperature about 8 – 10 degrees as well as the annual air conditioning electricity saving about 5.8 Kwh / (square meter month).

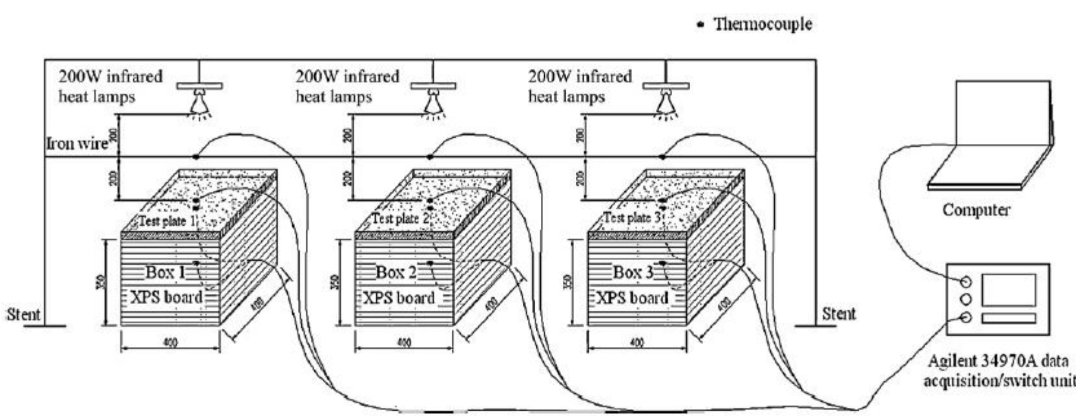


Figure 3.2: Schematic of the experimental apparatus (Source: Guo et al (2012)

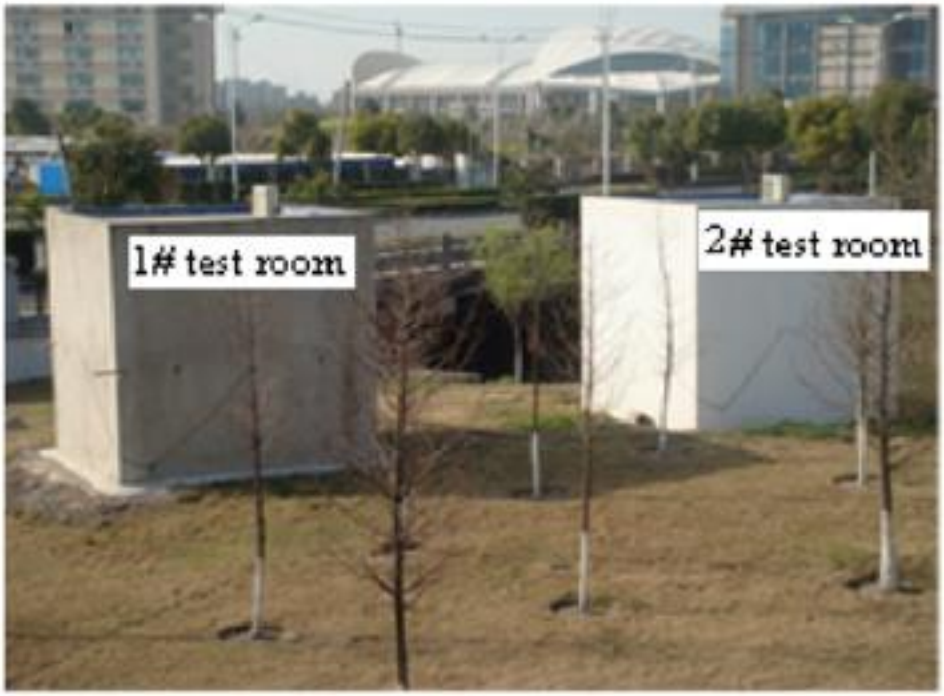


Figure 3.3: Schematic of the experimental test rooms (Source: Guo et al (2012)

Fang et al (2014) conducted two types of experimental constructed chambers to investigate the effect of external wall insulation on the total household energy consumption and the indoor temperature. One of the models was constructed using thermal insulation systems and the other one was designed as the conventional housing dated from 1980 as shown in Figure 3.4.

Figure 3.4: Photograph of the two experimental chambers (Source: Fang et al (2014)

The results showed that the insulated model recorded saving up to 23.5% during the summer season and maintain comfortable indoor environment when compared to the conventional base model. The study concluded that external insulation system would improve the building energy efficiency.

Furthermore, Castell et al (2010) studied the PCM – phase changing materials – as thermal insulation and compare it directly to other types of insulation materials in two different seasons. The study experimented several demonstration cubical as shown in Figure 3.5. The study showed that 15% of reduction in total energy could be achieved by placing the PCM insulation material closer to the inner wall. However, it performs better in cold season than hot season.

Figure 3.5: Photograph of cubicles built as typical Mediterranean building strategies tested different insulation materials (Source: Castell et al (2014)

It must be noted that none of the discussed papers had used the field measurement method as independent research method but its usually complementary to another research method such as questionnaire, field observation and/or results obtained through simulation and computer modelling tools.

In addition, field monitoring and measurement methodology is a type of observational research method. Generally, the study is directly related to an actual environment where the different variables measured via different instruments followed by extracting the data for analysis and comparison. Field measurement approach could perfectly be applied in this study to monitor the affect of every variable on the energy bills, those different variables such as thermal heat gain of building envelop, illumination levels and other variable needed for this study. Those variables can be measured by using special equipments and tools.

Furthermore, this method is considered as the only method that allow the researcher to get tangible findings that will lead to cause and effect conclusion, it might be in an existing building or it might be necessarily to build a mock-up under real condition. Moreover, this method requires some special equipment such as: human resources, sensors, data logging system and other tools in order to monitor and calculate the data followed by transferring them to the computer. Field monitoring method is very powerful, for instance by changing the orientation of the room the observer can feel the variations in comfort levels in both temperature and solar radiation, or by changing the construction methodology the monthly energy bills will reflect the impact of the materials on the building it self. However, that results cannot be generalized to all life situations especially when it deals with location and weather data, so there is a limitation in results considerations. This method has been used by several researches and they all agreed that its very powerful tool but time consuming and expensive due to the special required tools.

Morrissey et al (2011) conducted an experiment in residential buildings orientation to understand the best strategy that may reduce the total demanded energy as shown in Figure 3.6. The study resulted that the most energy efficient and economical solution is the building orientation. In other words, the passive solar design is the easiest design concept that could be applied in early design stages and consequently will reduce the overall energy consumption and improve the indoor environment quality.

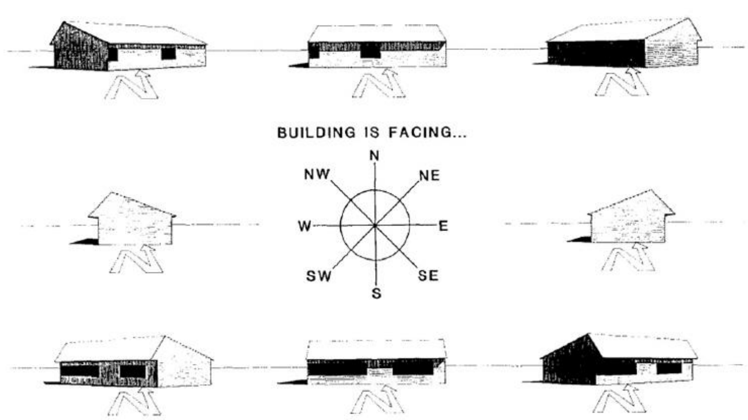


Figure 3.6: Schematic showing different orientations for a housing unit (Source: Morrissey et al (2014)

Tong et al (2014) carried out a felid measurement on two full-scale roofs to understand impacts of rooftop surface reflectivity and thermal resistance on thermal performance of two types of concrete based roofs. They found out that increasing the solar reflectivity by 0.1 reduces the daily heat gain by 11% and they also asserted that applying passive design techniques could reduce 42-84% of the daily heat gains, which will consequently reduce the energy consumption.

While Tenpierik, and Hasselaar, (2013) claimed that reflective multi-foil insulations is very effective material for roof insulation and can reduce the energy and has a very high thermal resistance up to 6 m2K/W, however it was discovered that it has a lower thermal resistance via field measurements using a hot box and hot plate measurements in laboratories.

Celik, (2011) studied the properties of thermal insulation of 12 different green roofs systems involving four types of growth media and sedum systems. The temperature readings was carried out over continuous 3 years every 15 minutes, Figure 3.7 and after the study they concluded the best configuration of green roof system that can yield a significant reduction air conditioning energy.

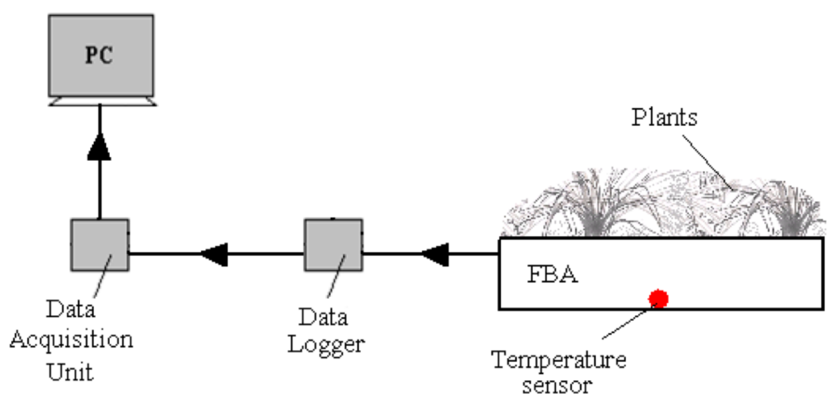


Figure 3.7: Schematic of the experimental setup (Source: Celik, S. (2011)

Recently, Energy modelling and building simulation has become a popular and reliable assessment tool used in both commercial and academic scales. Architects and designers have a tendency to use such tools before building construction to guarantee the building performance with minimum.

3.3.3 Simulation and computer modelling approach

Recently, Energy modelling and building simulation has become a popular and reliable assessment tool used in both commercial and academic scales. Architects and designers have a tendency to use such tools before building construction to guarantee the building performance with minimum human and financial resources. There is variety of simulation programs such as Energy Plus, ECOTECT, IES VE and other programs that is capable to assess energy consumption and human thermal comfort. In addition to that, building simulation programs has the ability to produce CFD analysis, thermal modelling, and energy and daylight analysis.

Radhi et al (2009 b) have studied the relationship between building envelope elements and the human comfort in Bahrain, they examined the thermal performance of residential buildings by using simulation model, as the kingdom is suffering from rapid population growth and consequently a huge demands on electricity specially for cooling purposes due to the poorly designed buildings. This paper is promoting green buildings regulation for to enhance the residential building envelope and they found out that thermal comfort could be achieved by lowering the U-value of the glazing to 1.6 W/m2K for double glazing with air gap and providing shading devices more than applying thermal insulation that will result a reduction in total energy consumption.

Similarly Friess et al (2012) have studied energy consumption patterns in Dubai city that has a similar local and climatic conditions to Bahrain, they investigated the impact of thermal bridging on increasing the energy consumption resulted from improper insulation system by using simulation model prepared by Design Builder / Energy Plus. They also highlighted the importance of local authorities on driving building legislations that prescribes minimum insulation levels for external walls and roof. The simulation results showed that wall configuration of U-Value equal to 0.169 W/m2K as shown in Table 3.2 is providing 23% of energy saving over that as built scenario Figure 3.8, however the best saving can be achieved by controlling the solar heat gains via using appropriate external shading devices.

Table 3.3: Wall insulation alternatives studied (Source: Friess et al, (2012)

Wall insulation alternatives studied.

Parameters	Villa	Wall *U* value (W/m² K)	RC frame *U* value (W/m² K)
A – as built	20 mm mortar (outer surface) Precast insulated block (200 mm) 15 mm gypsum plastering	0.523	2.398
B – as built + 50 mm EPS on Thermal bridge only	20 mm mortar (outer surface) 50 mm EPS expanded polystyrene on recessed RC structure only Precast insulated block (200 mm) 15 mm gypsum plastering	0.523	0.600
C – as built + 50 mm EPS	20 mm mortar (outer surface) 50 mm EPS expanded polystyrene Precast insulated block (200 mm) 15 mm gypsum	0.316	0.600
D – as built + 160 mm EPS	20 mm mortar (outer surface) 160 mm EPS expanded polystyrene Precast insulated block (200 mm) 15 mm gypsum	0.169	0.226
E – non-insulated block	20 mm mortar (outer surface) 200 mm concrete block 15 mm gypsum	2.383	2.398
F – non-insulated block + 50 mm EPS	20 mm mortar (outer surface) 50 mm EPS expanded polystyrene 200 mm concrete block 15 mm gypsum	0.600	0.600
G – non-insulated block + 160 mm EPS	20 mm mortar (outer surface) 160 mm EPS expanded polystyrene 200 mm concrete block 15 mm gypsum	0.226	0.226

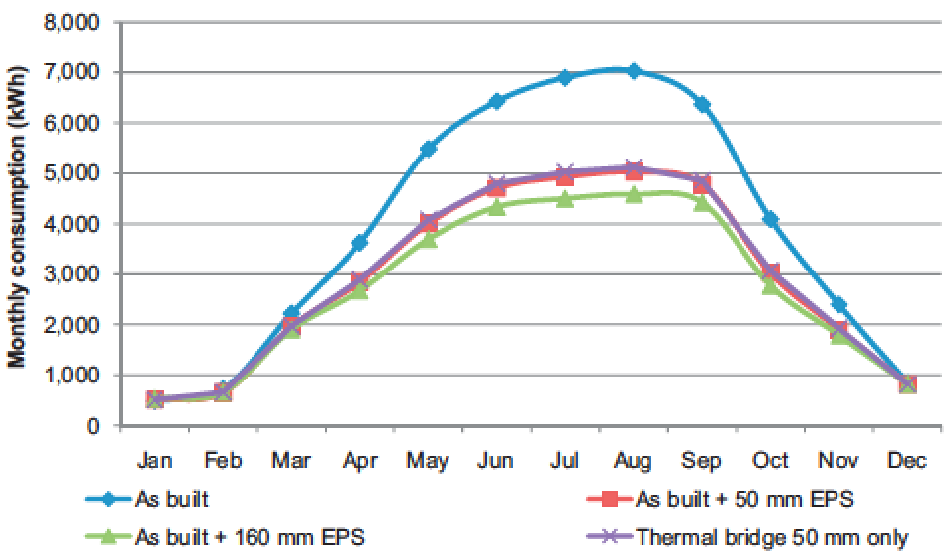


Figure 3.8: Seasonal variation of monthly energy consumption for retrofit (Source: Friess et al, (2012)

Taleb and Sharples (2011) have conducted a similar study in Saudi Arabia aiming to establish sustainable construction guidelines for residential buildings in a hot arid climate. Both believed that improper designed house in Saudi Arabia as well as the entire GCC leads to high-energy consumption and they found that 80% of the produced electricity is used for air conditioning and refrigeration. In order to assess the current construction condition and the potential improvement simulation modelling was conducted and they found out that enhancing the insulation of external wall and roof as well as using double glazed windows with appropriate shading devices can achieve 32.4% reduction in annual household electricity.

Most of the simulation and building energy software's have the ability to evaluate thermal comfort under the a same conventional conditions. This methodology main advantage is its flexibility in providing the climatic conditions data of the case study, the type of construction and the occupancy percentage and schedule of space …ect at any time of the year and it can have a high level of details and will give results that are not even being able to be measured through field measurements via using the available technologies.

Its flexibility will allow researchers to study different scenarios of the same case study by changing selected parameters to understand its effect on the overall study. In the case of this research most of the papers used the simulation methodology because it saves time, cost and space rather than designing, building, testing then redesigning and after that changing and so on, which is just time consuming and very expensive. The computer modelling and simulation methodology allows the researcher to do the same study several times at the same place and in the same model. In the other hand, the simulation method has a huge disadvantages which are simulation errors, and any incorrect input from the researcher will result giving a inaccurate results, also the simulation program still has the validation issue and inaccuracy some times when changing the weather data or the construction methodology, which will consequently give some doubts in the results that will lead to in accuracy in the produced results, and according to Zahi et al (2011) the inherent doubts in the program can affect the results of the research and also some parameters that cannot be controlled through the simulation modelling. Therefore, it's important to take some experimental or real life results and validate them via the program in order to accept the results. Furthermore, some conditions cannot be controlled or added to the software such as people behaviour or lighting levels and much more.

3.4. Methodology selection

Having concisely discussed alternative research methodologies earlier, as well as further understanding of the pros and cons of each method, the preference to the best research approach has been given to the modelling and simulation approach conducted particularly for this study.

According to many researchers, simulation modelling programs have best the best assessment tool in order to investigate different strategies to enhance building performance and energy saving. However, the selection of the method was also constrained by several factors such as the limitation of human resources, research time frame, the instruments and tools required to conduct this study as well as the financial aspects.

Therefore, computer modelling and simulation is the most appropriate method that will allow the researcher to study multiple factors to achieve the research main objective that is evaluation different building construction configurations aiming to reduce energy consumption and CO_2 emissions with respect to specific context, geographical location and climatic conditions within the limited time available unlike the field measurement methodology.

Following is a brief about the different modelling and simulation programs in order to choose the best program that will be used in this study.

3.5. Selection of computer modelling and simulation program.

Having concisely discussed alternative research methodologies earlier, as well as further understanding of the pros and cons of each method, the preference to the best research approach has been given to the modelling and simulation approach conducted particularly for this study.

Wide range of simulation programs has been developed to simulate different building envelope configurations with respect to local and climatic conditions as well as quantified energy consumption and CO_2 emissions, and most of them could be employed for this study. Hirsch (2011) asserted that computer modelling played a significant role in evaluating energy impacts on buildings and environment and helped engineers and designers in decision making. In the same paper he also asserted that simulation programs falls in to two categories, the first one is compute the whole building energy while the other ones are designed to give more details about day lighting, natural ventilation, thermal bridging and data related to implementation of renewable energy such as photovoltaic. However, the validation of these software's will always be an issue, therefore most of the studies done claimed that simulation results are correct when compare to field and experimental data collection.

Crawley et al (2005) provided a comparison between twenty energy simulation programs and concluded that IES VE is a very powerful tool that assess engineers, architects and researchers to optimize comfort criteria and energy consumption in buildings based on thermal insulation type and placement, building dynamics and thermal mass of different construction configurations, as well as environmental CO2 emissions, Table 3.4 and other capabilities with respect to local and climatic. The compared simulation programs included BLAST, BSim, DeST, DOE-2.IE, ECOTECT, Ener- Win, Energy Express, Energy -10, EnergyPlus, eQUIEST, ESP-r, HAP, HEED, IDA ICE, IES <VE>, PowerDomuns, SUNREL, Tas, TRACE, and TRNSYS.

Table 3.4: comparison of 20 software programs based on environmental emission (Source: Crawley et al (2005)

Table 9 Environmental Emissions	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Power plant energy emissions	X		P	X	[3]	X		X	X	X	X	X	X		X			X	X	I
On-site energy emissions	X	X	P	X	X	X		X	X	X	X	X	X		X			X	X	I
Major greenhouse gases (CO_2, CO, CH_4, NO_x)	X	P	P	X	[3]	X		X	X	X	X	X[204]	X		X			X		
Carbon equivalent of greenhouse gases	X			X	[3]				X						X			X		I
Criteria pollutants (CO, NO_x, SO_2, PM, Pb)					[3]				X			X[205]			X					
Ozone precursors (CH_4, NMVOC, NH_3)					[3]				X											
Hazardous pollutants (Pb, Hg)					[3]				X											
Water use in power generation					[3]				X											X
High- and low-level nuclear waste					[3]				X											
Pollutant emissions factors[206]					[3]				X				X							

The study shows the pros and cons of each simulation program and it highlighted that IES <VE>, EnergyPlus and TRANSYS are the best tools capable of evaluating the solar and construction configuration.

For this study building envelop calculation is very important, the study also highlighted that IES <VE> is based on ASHRAE requirements for calculating the outside surface conduction. Also it pointed out that IES <VE> is the only software that is able to evaluate general building envelop assessments with reference inside radiation, radiation to air component separate from the exterior convection and air emissivity/radiation coupling.

IES VE simulation software was ranked the best of ten software simulation and modelling programs and has 85% accountability which shows the strength and capabilities of the program in being a user friendly program that can offer the user to create templates of occupancy, activity and general thermal performance of space Figure 3.9. All the mentioned elements can assess the designer to anticipate the building energy performance in early design stages.

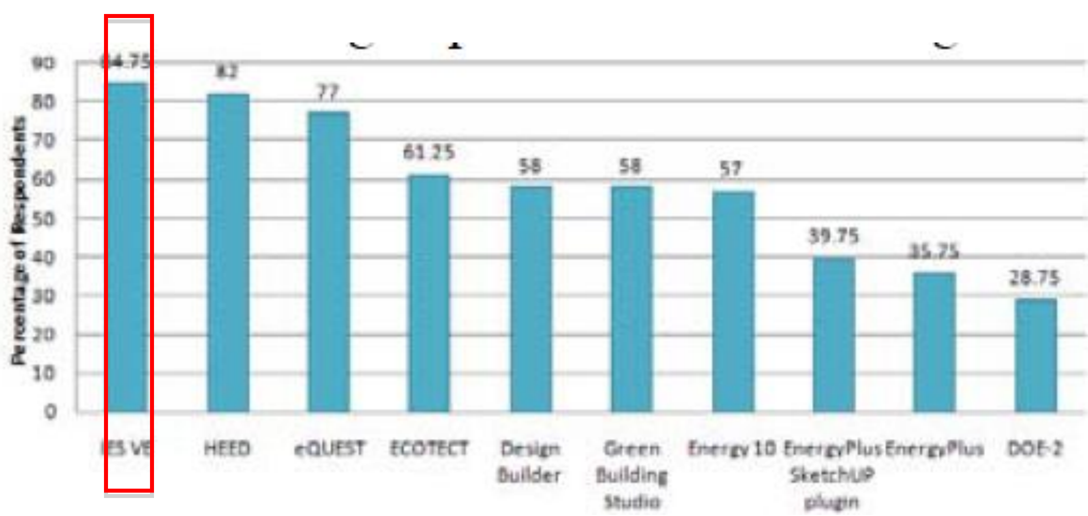


Figure 3.9: IES ranked the best of 10 modeling and simulation programs (Source: Attia, (2009).

Therefore, IES <VE> will be the selected energy modelling and simulation program for this study in order to assess the reduction in both the energy consumption in cooling loads for the standard housing unit in Bahrain and the related CO_2 emissions.

3.6. IES virtual Environment Software Validation.

With reference to the presented studies, it's obvious that many researchers have been using IES <VE> for energy simulation and thermal analytical modelling. This software has been compared to many other simulation and energy modelling software's as shown in the previous section but its proven that it's the best capable and reliable program to assess the impact of building envelope configuration on the energy consumption patterns on the selected standard housing unit in Bahrain. Furthermore, this simulation software has been compared to several field measurements and proven minor variations that validate the capabilities of IES <VE>.

The following lines will present some studies that apply both field measurements and IES <VE> simulation and modelling programs. Manneh, et al (2013) highlighted a study conducted by AlNaqabi, at al (2013) in investigating energy savings due to implementing green roof on existing residential building in UAE. AlNaqabi, et al (2013) found out that energy consumption evaluation done by simulation modelling program (IES <VE>) has 6% deviation of the actual annual energy consumption Table 3.5 and Figure 3.10.

Table 3.5: Validation model results. (Source: AlNaqabi, et al (2013)

Month	Actual Energy Consumption (MWh)	Simulated Energy Consumption (MWh)
January	4.29	2.63
February	4.22	4.10
March	6.74	6.33
April	7.24	10.07
May	12.56	14.78
June	11.82	16.67
July	18.34	18.97
August	14.71	19.28
September	16.74	16.70
October	12.49	12.92
November	9.80	7.99
December	7.22	3.93

Another study conducted by Nikpour, et al (2013) has showed the capability and accuracy of simulation and modelling software via carrying out an imperial validation of the simulation and modelling software when compared to experimental measurements of self shading room in term of heat gain at same date, time and local condition shows a 10% difference between the simulation and experimental results can be ignored and therefore the IES program can be used for developing pre-design studies for buildings performance.

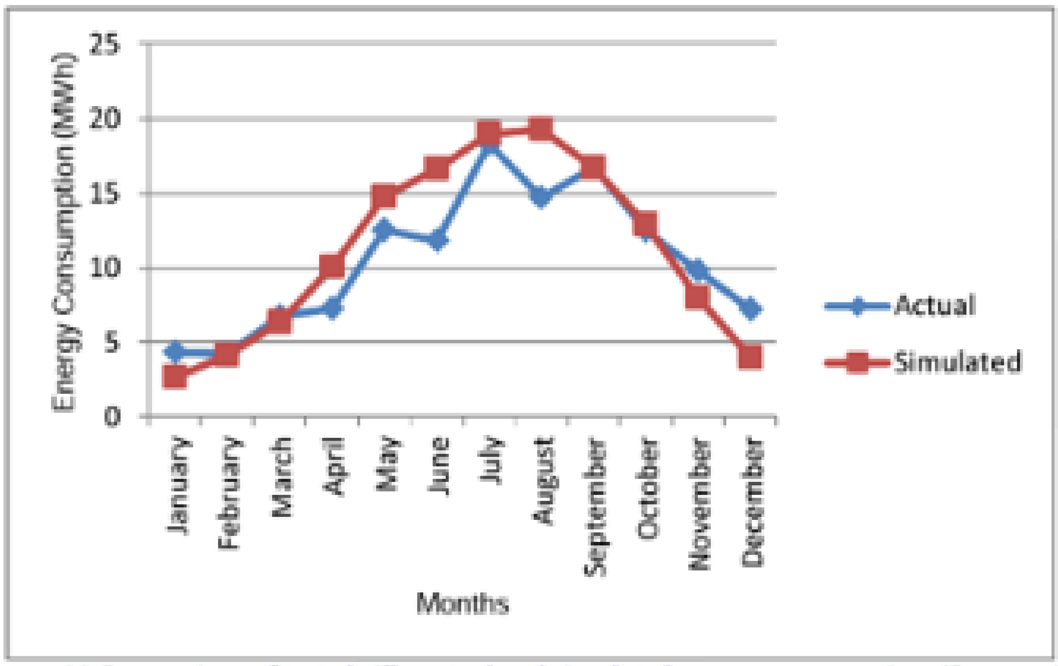


Figure 3.10: Comparison of tested villa showing the actual and simulated energy consumption. (Source: AlNaqabi, et al (2013).

3.7. Research methodology summary

The research methodology is going to be based on data collection from the existing condition as a base case and the recommended alterations learned from the other regional green building assessments. In addition to that some personal observation will be undertaken during site visits as well as some interviews with the concerned people in this subject. After that all the data will be analysed and evaluated via quantitative, qualitative and graphical quantities analysis. However, it's worth understanding the climate of Bahrain before the modelling and simulation stage.

3.8. Building modelling and simulation objectives

The study will conduct three sets of building simulation using IES <VE> software:

- The first scenario will model and analyse the existing building as built.
- The following three scenarios will mainly investigate the different construction configuration that has an impact on the energy consumption, which are:
  1- External walls thermal insulation.
  2- Roof thermal insulation.
  3- Glazing materials.

  Based on the studied configurations that are: ESTIDAMA (PRS 1), QSAS rating system and Dubai Green Building Regulations (DGBR).

- The following scenario will analyse the same building but by using the construction configuration recommended by ESTIDAMA (PRS 1) rating system.
- The following scenario will analyse the same building but by using the construction configuration recommended by QSAS rating system.

  The following scenario will analyse the same building but by using the construction configuration recommended by Dubai Green Building Regulations (DGBR).

Moreover, the following parameters will be evaluated using the software:

- Total energy consumption
- Total chillier and cooling load.
- Total carbon emissions

The details of the simulation will be presented and discussed in the following chapter.

Chapter 4
Simulation Models

4.1. Overview

This chapter will briefly introduce the case study through computer modelling and simulation program. However, before starting the modelling it's important to consider many aspects such as: geographical location, building orientation, number of occupants and their occupancy patterns or schedule as well as specific weather data and site consideration. Generally these aspects need to be considered during the design stage and before the construction phase to guarantee the building performance.

Based on the literature review and the collected data presented in chapter 2, the research aims to conduct several energy simulations for the selected housing unit based on the current construction situation in Bahrain as (Base Case), followed by 12 different scenarios. The first section will explain the case study parameters and location information, followed by brief explanation of the general input data for the baseline model. Then it will also present the simulation inputs variables of all the other simulation models. Finally, the study will presents a summary of all the models that will be assessed through the computer modelling and simulation for the 4 scenarios including the base case.

4.2. Case Study Description

Late in1984 Madinat Hamad Figure 4.1 was set up in northern Bahrain as a new affordable housing city for those residents who cannot afford to own a house in the city centre. This city is having a high percentage of social housing when compared to the private housing units in the city and expected to grow more and more with the current progressive developments.

Therefore a typical housing unit located in Madianat Hamad and specifically block 155 Figure 4.2 that show new development of 48 standard housing units over a total plot area of 2.5 hectares has been selected as a case study for this research.

Figure 4.1: Madinat Hamad (Source: Google Earth, 2014)

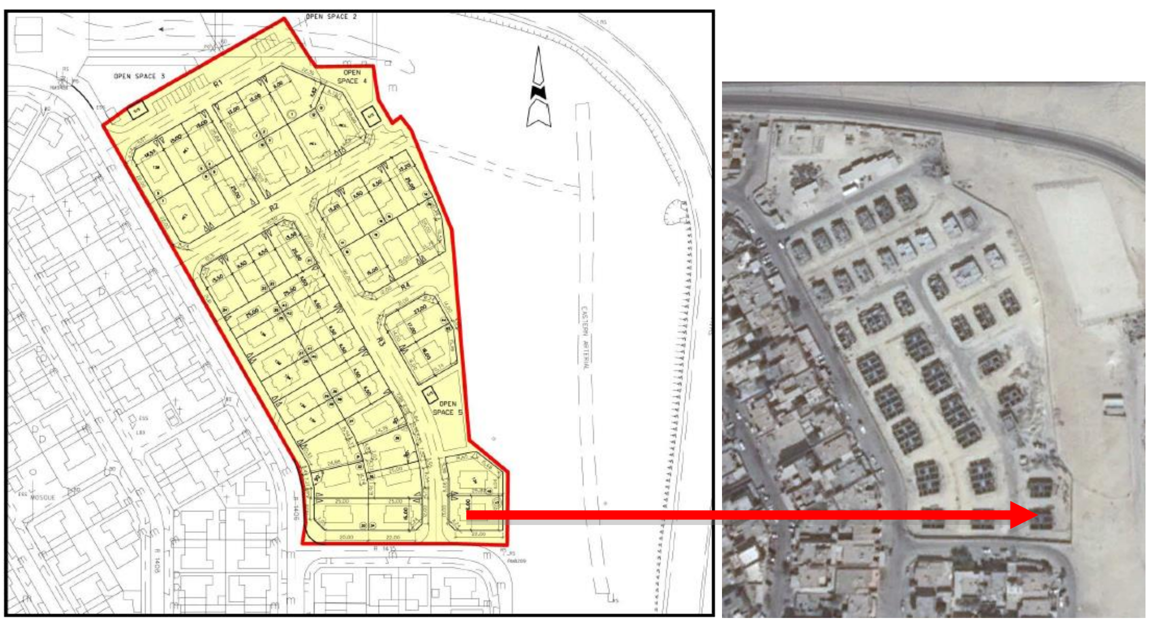


Figure 4.2: Madinat Hamad, Block 155 official layout (Left) and Satellite image (right) (Source: Ministry of Housing and Google Earth, 2013)

From the plan above it's shown that some of the typical housing units are single housing units and some and semi-detached housing. However, the plot sizes have a minor variation between both configurations and vary between 280 and 320 Sq. M. The red arrow in the above figure is indicating the exact location of the chosen case study.

The housing unit represents one of the most famous models in Bahrain dated from the 90's with a basic building construction technique as explained in Figure 2.16 in chapter 2. However, the total built up area of the selected housing unit is 209 Sq.m that spreads over 2 floors. This unit has 2 bedrooms and a 2 master bedroom, living room, family living, kitchen and two bathrooms, in addition to the garage and small garden as shown in Table 4.1.

Table 4.1: Case Study Description (Source: Ministry of Housing, 2014)

Parameters	Standard Housing Unit (T3M)
No. of floor	2
Total area	209 m2
Floor height	3.17 m
Raised from ground	0.45 m
Total external wall area	421.6 m2
Total opening area	104.03 m2
Window to wall ratio	24.67%

The base case represents the common practices of construction in Bahrain during the past decade. The IES software has the ability to consider the exact type of construction, insulation and finishing material, as well as glazing performance. The following section will explain the case study model and then will be compared to other cases as per the recommendations of Pearl rating system, QSAS rating system and Dubai green buildings regulation.

4.3. Modelling

With reference to Figure 2.29 that present the layout of both the ground and first floor of the chosen case study, Figure 4.3 is extracted from the simulation model of the standard housing unit.

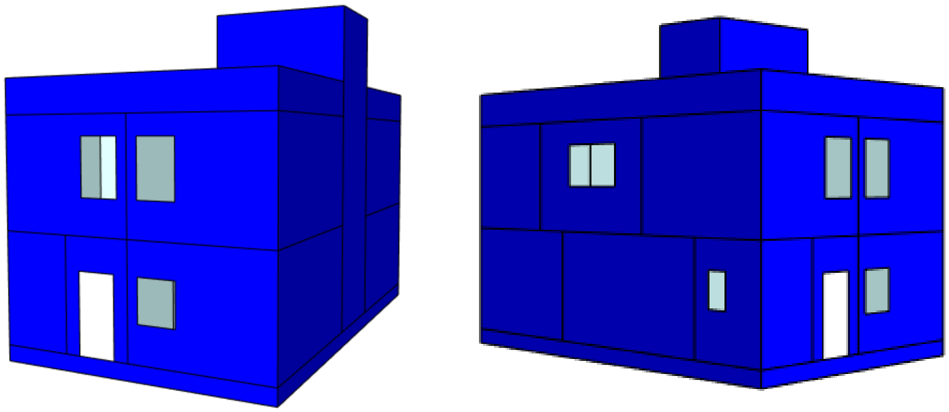


Figure 4.3: 3D shoots of the IES- VE model (Source: Author, 2014)

4.4. Base model input

Based on Civil Aviation- Bahrain Metrological Service (2014), Bahrain is classified as hot arid country with a very small annual rainfall (70.8mm). Generally the year in Bahrain is divided in to two climatic seasons, the summer from June to September that is described with its clear sky, cool moist overlaid by hot dry air. While the winter spans from December to March that is described with its changeable weather and surface winds alternate between south east and North West direction. However, the overall year climatic periods is separated by two transitional periods known as “Sarrayat” between April and May / October and November, where it’s characterized by incursions of cold breeze from the North West. Further climatic information will be presented below with the assistance of the IES-VE software (Appendix C).

4.4.1. Geographical and location data

As mentioned earlier the case study building is located in Madinat Hamad, Bahrain. The building is oriented approximately 90 degrees east. In order to get accurate geografical and weather data, the computer model used IES – VE APLocate tool. Via this tool, the identified location data was linked to the Bahrain international arirort, Bahrain Figure 4.4. Further site and location data that has been used is listed below, While the day light adjustmendt were set to zero.

Location Data:

- Latitude: 26.27 ° N
- Longitude: 50.65 ° E
- Altitude: 2.00 m
- Time zone: 3 hours (hours ahead GMT)

Site Data:

- Ground reflectence: 0.20
- Terrain type: City
- Wind expodure: Normal (CIBSE heating loads)

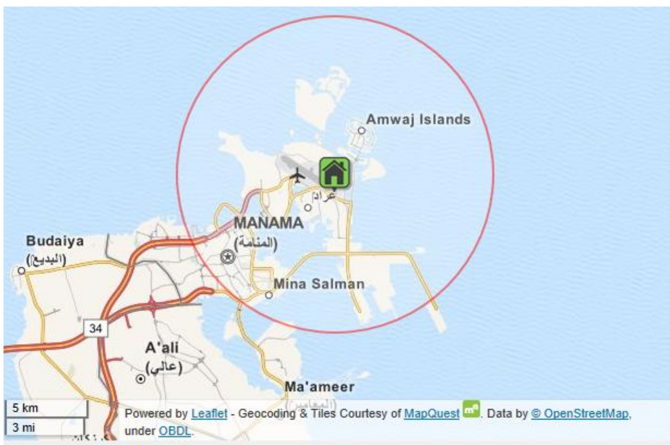


Figure 4.4: IES – VE Location and site data source (Source: IES - VE, 2014)

4.4.2. Weather data

With reference to section 3.8 that presnts Bahrain climate, it has been highlighted that Bahrain has no IES – VE weather file, therfore Kuwait weather file was considered because it's the nearest weather measurments can be applied for this study.

The wether data file for each city includes hourly data of dry buld, wet bulb temprature, wind speed and direction, cloude cover, direct and difused slar radiation, azmimuth and solar altitude, as well as the sun path diagram Figure 4.5.

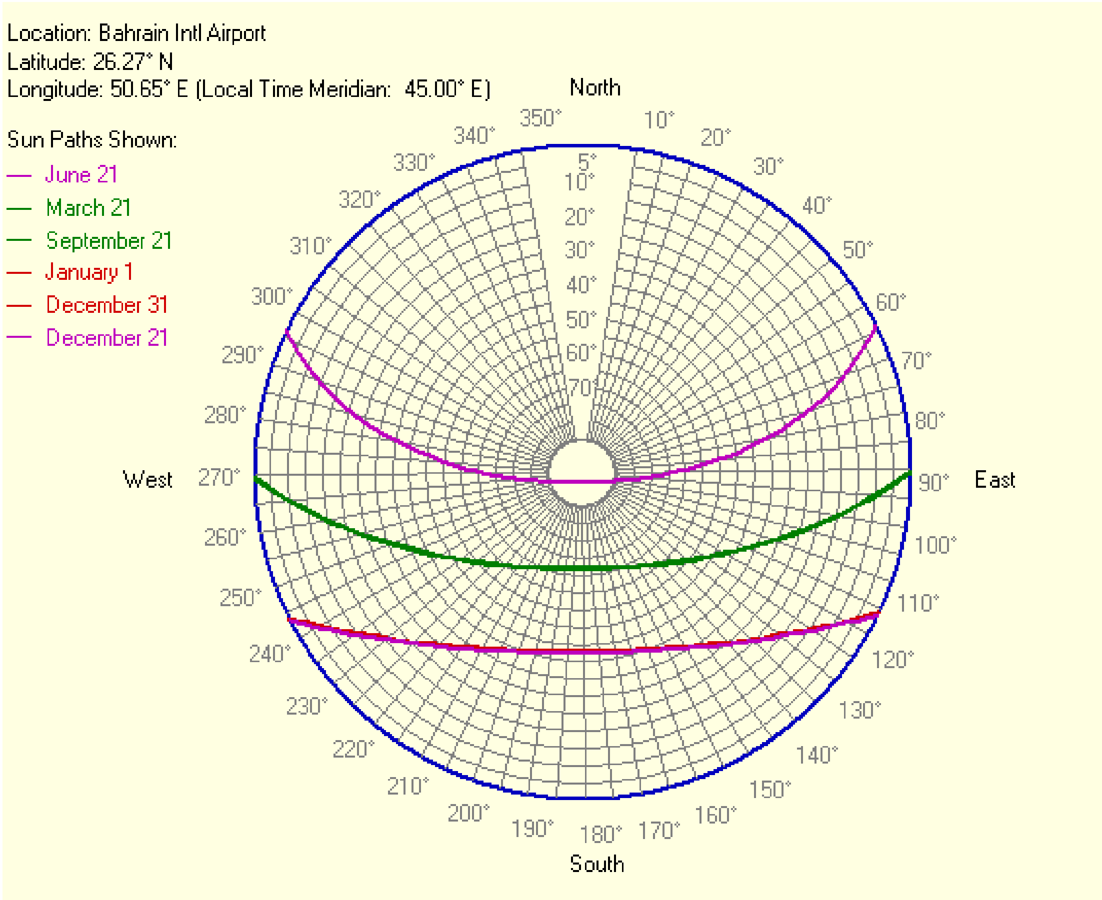


Figure 4.5: Bahrain sun path diagram (Source: IES - VE, 2014)

4.4.3. Peak simulation time

In the liteture review chapter, it was presented that many reserchers has asserted that energy consumption varies as per the season or the user pattern of usage, it was also clearly shown in section 2.11 that threetypical housing units were studies and the variation was determined from their monthly energy bills Figure 2.23. Therefore, its important to briefly understand the peak months for the dry bulb and wet bulb temprature, as well as direct and diffused radiation.

On the other hand, the maximum direct radiation was in 28th January as shown in Figure 4.6, although it's one of the winter months, the direct radiation is still high reaches to 1200 (W/m2) when the maximum temrature is 15°C. In additon to that the maximum diffused radition was in 20th October where the maximum temrature is 30°C Figure 4.7.

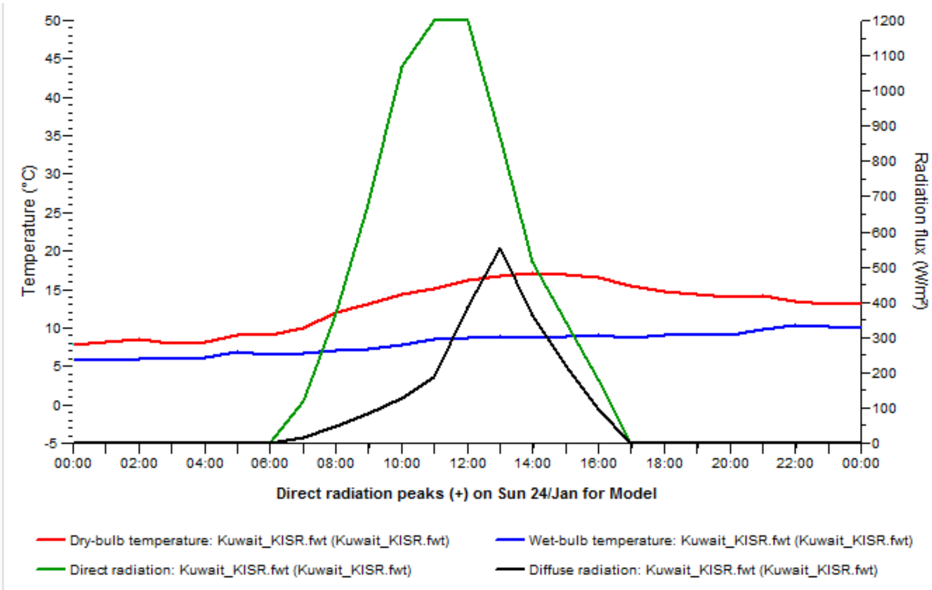


Figure 4.6: Bahrain weather data in 24th January (Source: IES - VE, 2014)

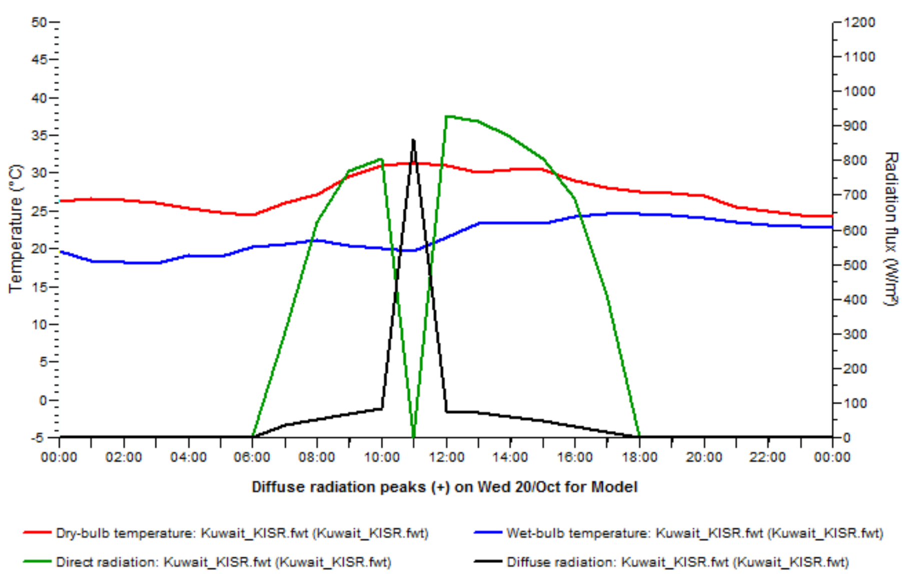


Figure 4.7: Bahrain weather data in 20th October (Source: IES - VE, 2014)

All the above figures are strong evidence that the building envelop is exposed to high temperature and solar diffusions all over the year, therefore its important to enhance the building envelope to reduce the energy consumption, chillier load and CO2 emissions as well as to increase the overall human comfort in indoor spaces.

4.5. Thermal conditions

This section is designated to explain the simulation input used to generate the base model. The IES – VE software offers the ability to create different types of profile for the same project. It's usually based on simulation profiles/ occupancy schedule, room conditions, system, internal gains and air exchange.

4.5.1. Simulation profiles

The daily profile is created to represent a typical Bahraini family life style. The profile is directly related to the occupancy schedule and the HVAC cooling system.

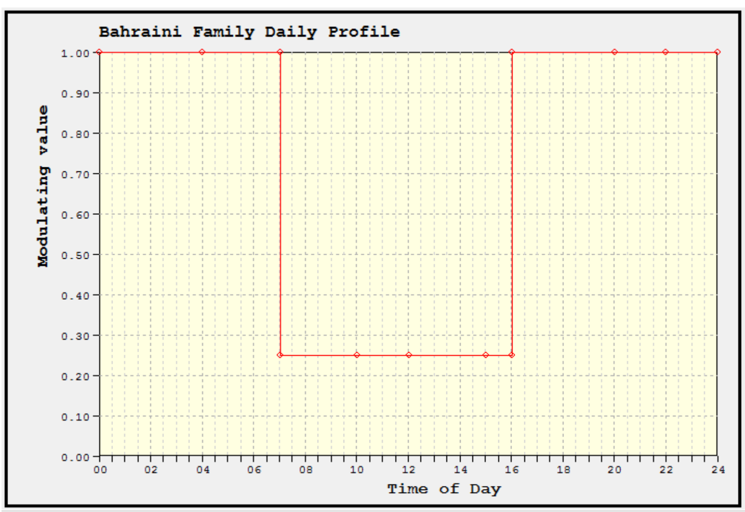


Figure 4.8: Typical Bahraini family daily profile and HVAC load (Source: IES - VE, 2014)

The profile illustrated in Figure 4.8 assumes that from 8 am to 4 pm, parents will be out for work and the kids will be out for education, while the housemaid will be home. Therefore, the internal occupancy load will be 20% during family absence and 100% during their presence and similarly it will be 100% during the weekend. Relatively the use of HVAC is linked to the occupancy profile as shown in Figure 4.9 because its there to provide thermal comfort and acceptable indoor air quality.

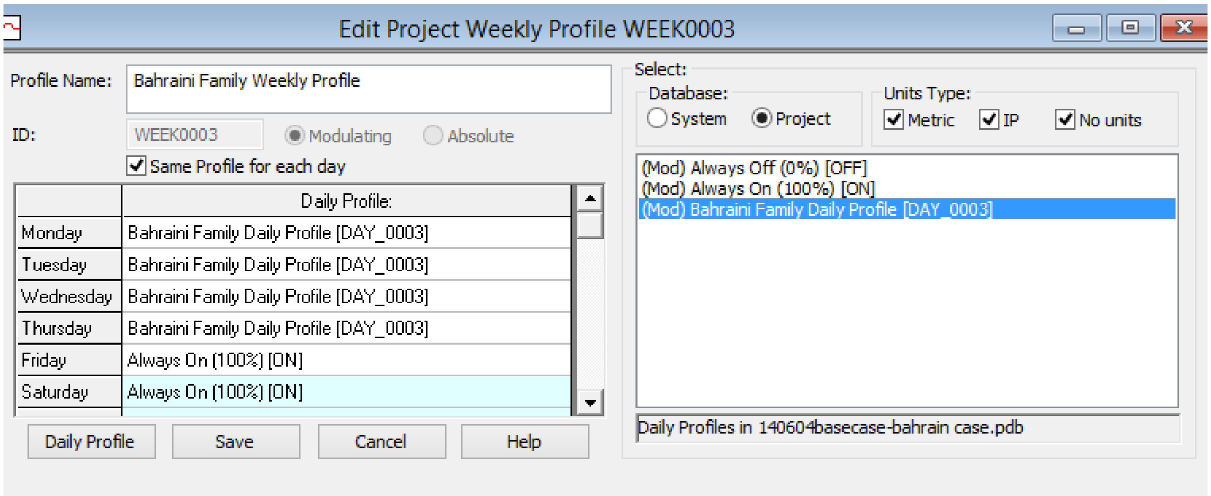


Figure 4.9: Typical Bahraini family weekly profile and HVAC load (Source: IES - VE, 2014)

4.5.2. Room conditions

All rooms are set to the same profile as shown below:

- Heating: Heating profile is set off continuously
- District Hot Water System (DHW): is set to zero consumption
- Cooling: Cooling profile is linked to the space occupancy profile
- Plant Auxiliary system: The auxiliary system is set to cooling profile and linked to the space occupancy profile.
- Model setting: Model setting is set to default with 0.05 solar reflected fraction and 1.00 for furniture mass factor
- Humidity control: humidity is set between 30% to 70% saturation based on thermal comfort guidelines of ASHRAE.

4.5.3. System

The main system is operated to cooling only system

4.5.4. Internal gains

Any residential unit may have the following internal gains:

- Florescent lighting
- People (5) (Parents, 2 kids and the maid)

- Computers
- Cooking and miscellaneous

4.5.5. Air exchanges

All rooms are set to an infiltration rate of 0.25-air change per hour based on ASHRE Journal’s official product & show guide (2004), the whole house mechanical ventilation requires infiltration rate is about 50 CFM (25 L/s) and as per the equation 4.1 stated by Thomas (2003) as shown below:

Equitation 4.1: Mechanical ventilation infiltration rate

$$CFM = \frac{NxV}{60} \qquad N = CFM\,x\,\frac{60}{V}$$
$$CFM = cubic\ feet\ per\ \min.of\ air$$
$$V = Room\ volume\ (cubic\ feet\ of\ ft^3) \tag{4.1}$$
$$N = Number\ of\ Air\ Changes\ per\ Hour$$

Therefore the total volume is approximately 1325 m3 via applying the following mathematical equation (4.1).

50 = N x 1325/60 and N = 50 / 220.8 = 0.23 – air change per hour.

However, the infiltration rate will be set to 0.25 as set from the IES system and has been used in many previous studies such as Al-Badri and Abuhijlleh (2013).

4.6. Construction templates

The IES-VE software provides the ability to evaluate and test different building envelope configurations. This template will consider the thermal properties of each element such as: External wall, Internal partition Roof, Exposed floor and windows that will be applied to the case study. The construction templates enable the researcher to assess these materials and evaluate their impact of the energy consumption and CO_2 emissions.

The base case has the common materials that are used for construction in Bahrain and specifically for the social housing units provided from the Ministry of Housing as shown in Table 4.2.

Table 4.2: Building envelop configuration used for base case (Case 1) (Source: Ministry of Housing, 2014)

External wall	12 mm mortar (outer surface)	2.746 W/m2K
	200 mm concrete blocks	
	20 mm gypsum rendering	

Roof	70 mm Screed	0.53 W/m2K
	2 mm bitumen, felt/sheet	
	50 mm EPS expanded polystyrene	
	200 mm reinforced concrete slab	

Window to wall ratio	40.50%

Glazing	Double coated 6/8/6 (SHGC 0.31)	3.26 W/m2K

The descriptions of each material determined by thickness and total U-Value for wall and roof building elements to be examined through the simulations. However, the glazing has SHGC equal to 0.31 that refers to the solar energy permeability of glazing.

Since that Bahrain, Qatar and UAE are in the same region and sharing a similar climate conditions. PRS1, QSAS and DGBR green building assessments were created in a way to suit this particular climate. Therefore, this paper will evaluate all the cases and compare them to the base case shown above followed by some combined scenarios to achieve maximum reductions in energy consumption, chillier load and CO_2 emissions.

4.7. Simulation scenarios

Different simulation scenarios have been created to examine and evaluate the thermal parameters of the building envelope, and the impact of upgrade for the external wall, roof and glazing. This study will use the minimum thermal properties requirements (U-Values) of QSAS, Pearl 1 and Dubai green building regulations against the base case (Bahrain). Through the construction database, the author will be able to recognise the impact different scenarios on the energy consumption and CO2 emissions.

Here with the different scenarios that is proposed to be studied and evaluated in this paper.

- Case 1: As built in Bahrain
- Case 2 has three scenarios:
  - (a) As built in Bahrain with thermal insulation upgrades for external walls as advised by QSAS (U-Value = 0.125 W/m2. K).
  - (b) As built in Bahrain with thermal insulation upgrades for external walls as advised by ESTIDAMA – 1 Pearl (U-Value = 0.140 W/m2. K).
  - (c) As built in Bahrain with thermal insulation upgrades for external walls as advised by Dubai Green buildings regulation (U-Value = 0.57 W/m2. K).
- Case 3 has three scenarios:

(a) As built in Bahrain with thermal insulation upgrades for Roofs as advised by QSAS (U-Value = 0.250 W/m2. K).

(b) As built in Bahrain with thermal insulation upgrades for Roofs as advised by ESTIDAMA – 1 Pearl (U-Value = 0.150 W/m2. K).

(c) As built in Bahrain with thermal insulation upgrades for Roofs as advised by Dubai Green buildings regulation (U-Value = 0.300 W/m2. K).

- Case 4 has three scenarios:

(a) As built in Bahrain with thermal insulation upgrades for Glazing as advised by QSAS (U-Value = 1.700 W/m2. K) and SHGC 50%.

(b) As built in Bahrain with thermal insulation upgrades for Glazing as advised by ESTIDAMA – 1 Pearl (U-Value = 2.200 W/m2. K) and SHGC 40%.

(c) As built in Bahrain with thermal insulation upgrades for Glazing as advised by Dubai Green buildings regulation (U-Value = 2.100 W/m2. K) and SHGC 40%.

- Case 5: Implementing ESTIDAMA – 1 Pearl building envelop thermal properties. However there are different scenarios in ESTIDAMA from 1 to 5 pearls. With reference to Abeer, et al. (2013) found out that the most cost effective solution is pearl 1 when compared to the other pearls as well as the energy saving has minor changes therefore 1 pearl scenario is going to be evaluated only as it's the mandatory level that should be achieved in the Abu Dhabi.
- Case 6: Implementing QSAS building envelop thermal properties
- Case 7: Implementing Dubai green building regulations, building envelope thermal properties.

Table 4.3 provides a summary of the minimum thermal requirements in compliance with PRS (1), QSAS and Dubai Green building regulations as well as the current condition in Bahrain (Case 1).

Table 4.3: Summary of thermal performance requirements in compliance with QSAS, 1 Pearl and Dubai Green Building Regulation (Source: et al, 2014)

Element	**Baseline**	**1 Pearl**	**QSAS**	**Dubai G.B**
	Actual	*Target Value*	*Target Value*	*Target Value*
Wall (U Value)	2.746 W/m2. K	0.320 W/m2. K	0.125 W/m2. K	0.570 W/m2. K
Roof (U Value)	0.530 W/m2. K	0.150 W/m2. K	0.250 W/m2. K	0.300 W/m2. K
Glazing (U-Value)	3.26 W/m2. K	2.200 W/m2. K	1.700 W/m2. K	2.100 W/m2. K
Gazing (SHGC)	31%	40%	50%	40%

In the following page Table 4.4 summarizes all the scenarios based on different simulation input variables that were used for the case study. In order to make the comparison easier Table 4.4 uses different symbols for the baseline and for each rating system to show the modified parameter. The symbol O is used for baseline, X for 1 Pearl, XX for QSAS and XXX for Dubai Green buildings regulations.

After the following list of scenarios another three scenarios will be proposed based on the available materials on the Bahraini market.

Table 4.4: Summary of IES model simulation input variables (Source: Author, 2014)

Scenario			**Case 1**	**Case 5**	**Case 5**	**Case 5**	**Case 6**	**Case 6**	**Case 6**	**Case 7**	**Case 7**	**Case 7**	**Case 2**	**Case 3**	**Case 4**
			Baseline	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**PRS**	**QSAS**	**DGBR**
			Model	Model	Model	Model	Model	Model	Model	Model	Model	Model	Model	Model	Model
Variables	U- value (W/m2.k)	SHGC (%)													
Wall	Baseline		**O**	_	_	_	**O**	**O**	**O**	**O**	**O**	**O**	_	_	_
	0.320	n.a.	_	X	_	_	_	_	_	_	_	_	X	_	_
	0.125	n.a.	_	_	XX	_	_	_	_	_	_	_	_	XX	_
	0.570	n.a.	_	_	_	XXX	_	_	_	_	_	_	_	_	XXX
Roof	Baseline		**O**	**O**	**O**	**O**	_	_	_	**O**	**O**	**O**	_	_	_
	0.150	n.a.	_	_	_	_	X	_	_	_	_	_	X	_	_
	0.180	n.a.	_	_	_	_	_	XX	_	_	_	_	_	XX	_
	0.300	n.a.	_	_	_	_	_	_	XXX	_	_	_	_	_	XXX
Glazing	Baseline		**O**	**O**	**O**	**O**	**O**	**O**	**O**	_	_	_	_	_	_
	2.200	0.5	_	_	_	_	_	_	_	X	_	_	X	_	_
	1.700	0.4	_	_	_	_	_	_	_	_	XX	_	_	XX	_
	2.100	0.4	_	_	_	_	_	_	_	_	_	XXX	_	_	XXX

4.8. Simulation process

The 209 m2 housing unit is relatively small and consist of ground and first floor. Therefore, the simulation processing through IES-VE is expected to be simple and easy to study the model as whole in each simulation scenarios. With reference to Table 4.4, thirteen simulations are going to be conducted and generated separately; also another three proposed scenarios would be simulated and evaluated as mentioned earlier on the end of section 4.7.

All results will be presented statically and imported into table from using MS Office Excel programs. The results from each configuration will be presented independently and then followed by a final summary showing the overall results and highlight the best configuration that could upgrade the building regulation in Bahrain. Further details will be presented in the following sections of this paper.

Chapter 5
Results and Discussion

5.1. Overview

This chapter will include the results of this research and disuses the reduction and saving in overall energy consumption that is equal to air conditioning, lighting and other equipments), chiller load and CO_2 emissions that are achieved through different building configurations via upgrading their thermal performance. A comprehensive analysis of all results is required to understand the potential of energy saving by upgrading building envelope thermal performance.

The results will be presented of the targeted factors (total energy, chiller load and CO_2 emissions) is a direct reflection of both electricity consumption and possible ways to conserve energy under Bahrain climatic conditions. Furthermore, room-cooling planet sensible and latent loads will be highlighted, while total lighting energy and total equipment energy will be constant in all cases. It's also important to understand the sensible heat that includes the conduction gain in the outer building envelope elements, which are wall, roof and glazing elements. Moreover, the previous studies presented and analyzed in chapter 2 have noted that upgrading building envelope in hot arid climate has achieved noticeable reduction in both energy consumption and CO_2 emissions. In more details this chapter will present a summary of the possible upgrading solutions learned from other countries green building regulations and other combined upgrading solutions proposed by the author. The discussion will directly target the building envelop performance through understanding the solar gain and the external condition gain annually.

In the conclusion all the scenarios will be presented to understand the impact of upgrading each element of building envelope separately based on the studied regional green building assessments and regulations and will be presented on cases 2,3 and 4 (A, B & C). Followed by an overall upgrade based the studied assessments an regulation and will be presented on case 5, 6 and 7 as shown in Table – 4.4 in section 4.7 in the previous chapter. The finding of each scenario will be compared to base case in order to understand the potential savings possibilities in both energy consumption and CO_2 emissions.

Here with more details about each scenario:

5.2. Basic case (Case 1): Bahrain as built

The simulation results indicate that main energy consumption resulted by cooling loads. The total energy consumption of case 1 is (178.4 MWh), while the total system energy is (109.3 MWh) divided between air conditioning energy and other energy consumption. 61 % of the total system energy is taken by the air-conditioning use while it 39 % taken for other purposes. However, the total energy consumption is a summation of total system energy as 109.3 MWh as well as the constant total light energy as 24.4 MWh and total equipment energy as 44.6 MWh as shown in Table 5.1.

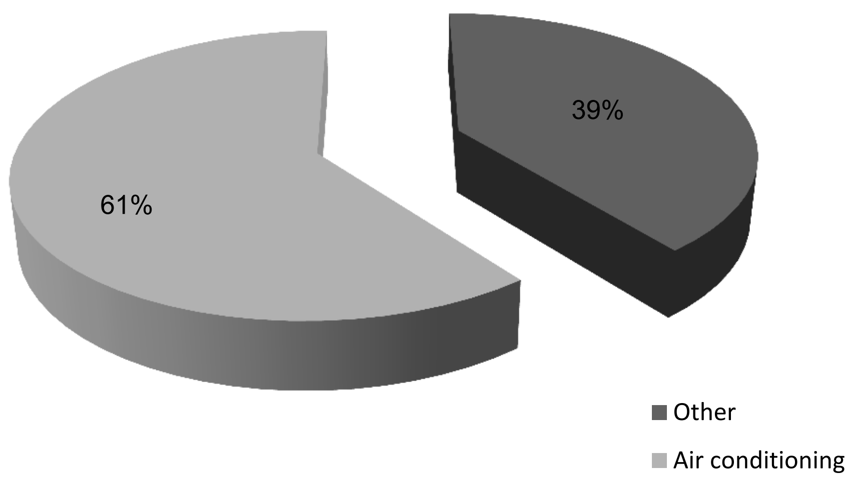


Figure 5.1: Case 1- Energy consumption is mainly caused by air conditioning usage (Source: Author, 2014)

It has been noted in chapter 4 that Bahrain traditional construction methods lead to low building envelope thermal insulation properties as shown in Table 4.2. Moreover, it in chapter 2 that maximum energy consumption is happening during the summer which is clearly reflected in Figure 2.22 where the maximum energy consumption accurse during the summer season and especially in both July and August. However, the total energy during the winter months indicates that total energy in December and January is more that it in February and this is a clear reflection of the weather data extracted from IES –

VE shown in Figure 4.8, where the maximum radiation appears in January, 24th even when the maximum temperature doesn't exceed 15°C.

Table 5.1: Case 1- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.7199	2.1124	3.8336	10.666
Feb 01-28	4.0173	1.8755	3.4183	9.3111
Mar 01-31	5.8884	2.0495	3.7477	11.6856
Apr 01-30	8.0579	2.023	3.6809	13.7617
May 01-31	11.6636	2.081	3.7907	17.5353
Jun 01-30	12.9954	1.9915	3.6379	18.6249
Jul 01-31	14.2165	2.1124	3.8336	20.1626
Aug 01-31	13.9265	2.0495	3.7477	19.7237
Sep 01-30	11.7824	1.9915	3.6379	17.4119
Oct 01-31	10.7349	2.1124	3.8336	16.6809
Nov 01-30	6.3409	1.9915	3.6379	11.9704
Dec 01-31	4.9588	2.081	3.7907	10.8304
Summed total	**109.3025**	24.4711	44.5905	**178.3644**

* Total System Energy includes: Air Conditioning System Energy (66.3 MW) and other cooling equipments energy consumption

Generally, energy consumption is always associated to the CO2 emissions because the more combusted fuel to generate energy the more CO2 emissions is accounted. Therefore, the energy consumption and CO2 emissions is reflection of each other. Moreover, case 1 – Bahrain case, has total CO2 emissions of 92568 (KgCO2) and it hits its peak at 24.4 KgCO2/h in August 4th at 4:30 Pm.

The above results is a straight forward indication that the total energy consumption and the CO2 emissions is way high when compared to cases that has applied green building regulation. Manneh, et al (2013) has highlighted that potential saving in energy consumption and reduction in CO_2 emission could be achieved by upgrading the building traditional construction, which is more or less similar to Bahrain construction to fulfil with the Pearl Rating system promoted by the UAE.

Since that any building envelope consist from wall, roof and glazing it will be very important to evaluate the upgrade of each element separately to highlight the possible savings with minor changes in the current construction scenario as recommended by the studied building assessments and regulations. The first group of scenarios will address the wall upgrading A) as recommended by PRS 1, B) as recommended by QSAS and C) as recommended by DGBR.

5.3. Upgrading walls only as per case 2A as per PRS 1, 2B as per QSAS and 2C as per DGBR

It has been noticed in many papers that upgrading wall is the main building envelope to achieve noticeable percentage will be achieved in both energy consumption, cooling load energy and CO_2 emissions. It's anticipated that a noticeable percentage will be achieved in both energy consumption, cooling load energy and CO_2 emissions.

Therefore this section will implement the PRS 1 wall upgrade in case 2A followed by implementation of QSAS and then implementation of DGBR with the current roof and glazing system in Bahrain. Each case will be studied separately and compared to the base case. Finally, will present all the results in one table to summarize the possible reduction in overall energy and chillier energy.

5.3.1. (Case 2A): Base case + Wall upgrading only as recommended by Pearl Rating System.

This section will examine the exact base case size, orientation and weather data as well as construction data but will but will only upgrade the external wall data as promoted by PRS, its advised to have a maximum U-Value of walls as 0.320 W/m^2. K, while the roof and glazing as 0.530 W/m^2. K and 3.26 W/m^2. K. The total energy consumption and CO_2 emissions are expected to achieve extreme changes because the wall U-Value has been reduced approximately 88 % from 2.746 W/m^2. K to 0.320 W/m^2. K.

The simulation of case 4A shows that the total energy consumption is (160.5 MWh) which is lesser than the total energy consumption in case 1 by almost 17.8 MWh that is 10 %. Similarly the total system energy is equal to 91.4 that are divided between 58 % for cooling consumption and 42% other consumptions. Moreover, the total energy is a summation of total system energy equal to 91.4 MWh, total light energy and total equipment energy equal to as shown in Table 5.2.

Table 5.2: Case 2A- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	5.7549	2.1124	3.8336	11.701
Feb 01-28	4.9574	1.8755	3.4183	10.2513
Mar 01-31	6.429	2.0495	3.7477	12.2263
Apr 01-30	7.3583	2.023	3.6809	13.0621
May 01-31	8.8654	2.081	3.7907	14.737
Jun 01-30	9.0086	1.9915	3.6379	14.638
Jul 01-31	9.6707	2.1124	3.8336	15.6168
Aug 01-31	9.4312	2.0495	3.7477	15.2285
Sep 01-30	8.5765	1.9915	3.6379	14.2059
Oct 01-31	8.8414	2.1124	3.8336	14.7875
Nov 01-30	6.5778	1.9915	3.6379	12.2072
Dec 01-31	5.9533	2.081	3.7907	11.8249
Summed total	91.4245	24.4711	44.5905	**160.4863**

The energy has reduced in case 2A and the CO2 emissions have recorded about 10% when compared to case 1. In addition to that it the chillier energy was reduced by 20 % as shown in Figure 5.2 but it was noticed that there is increase in the chillier energy during the winter season in December, January and February. This result leads to the logical reason that upgrading the wall properties will increase the thermal storage of the wall and consequently will increase the energy in winter and will reduce it during the summer season.

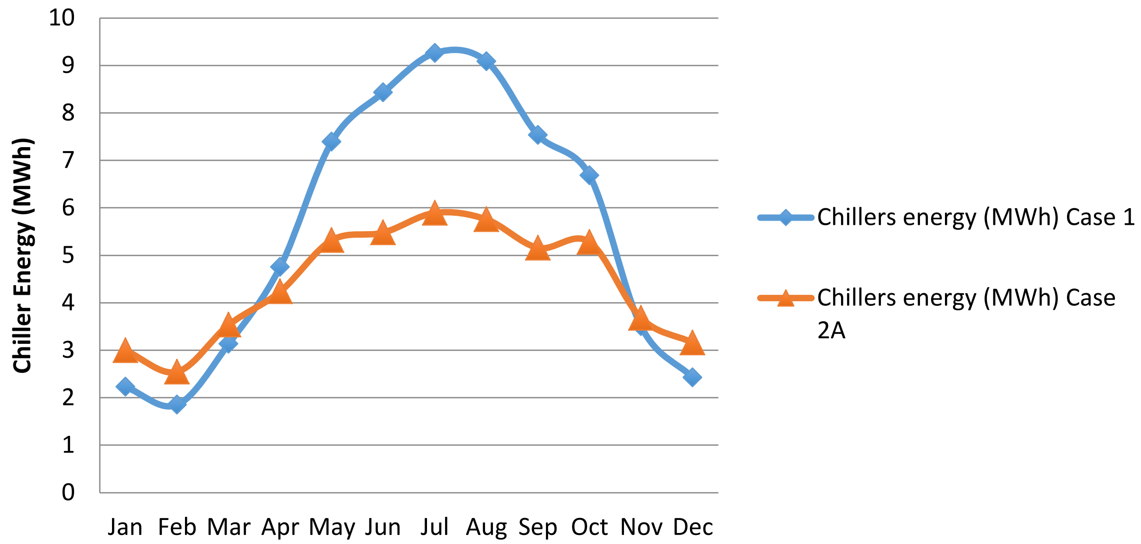


Figure 5.2: comparison between Case 2A and Base case chiller energy via upgrading the walls only (Source: Author, 2014)

5.3.2. (Case 2B): Base case + Wall upgrading only as recommended by QSAS.

This section will examine the exact base case but will upgrade the external wall data as promoted by QSAS. It's advised to have a maximum U-Value of walls as 0.125 W/m2. K, while the roofs and glazing as 0.530 W/m2. K and 3.260 W/m2. K. The total energy consumption and CO2 emissions is expected to achieve similar changes as case 2A because the wall U-Value has been reduced approximately 61 % from case 2A and reduced 95 % from case 1.

The simulation of case 2B shows that the total energy consumption is (159.1 MWh) which is lesser than the total energy consumption in case 1 by 10.8 %. Similarly the total system energy is equal to 90 MWh that is divided between 57.8 % cooling consumption and 42.2 % other consumptions. It's clear that chillier energy in Case 2B is almost equal to it in Case 2A, but lesser than Case 1 by 21.5 %. The result indicate that implementing QSAS wall along with the current roof and glazing system in Bahrain can reduce the chillier load more than the reduction achieved by PRS recommended walls as shown in case 2A but yet its not worth it due to the increased associated costs.

Moreover, the total energy is a summation of total system energy equal to 90 MWh, total light energy and total equipment energy equal to as shown in Table 5.3.

Table 5.3: Case 2B- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	5.9504	2.1124	3.8336	11.8964
Feb 01-28	5.1256	1.8755	3.4183	10.4194
Mar 01-31	6.5055	2.0495	3.7477	12.3028
Apr 01-30	7.3202	2.023	3.6809	13.024
May 01-31	8.6222	2.081	3.7907	14.4938
Jun 01-30	8.6454	1.9915	3.6379	14.2749
Jul 01-31	9.2448	2.1124	3.8336	15.1908
Aug 01-31	9.0149	2.0495	3.7477	14.8121
Sep 01-30	8.2681	1.9915	3.6379	13.8976
Oct 01-31	8.655	2.1124	3.8336	14.6011
Nov 01-30	6.6009	1.9915	3.6379	12.2303
Dec 01-31	6.135	2.081	3.7907	12.0067
Summed total	90.0881	24.4711	44.5905	159.1499

The reduction in energy consumption in case 2B is slightly greater than case 2A, which reflects that upgrading the wall, could achieve a maximum reduction in energy and CO2 emission.

Furthermore, the CO2 emissions were recorded as 82595 KgCO2 lesser that case 1 by 10.8 %. Similarly the total energy consumption is 231.8 MWh and closest to case 3 that is equal to 10.8 % that is equal to the reduction in the CO2 emissions because those two elements are reflecting each other.

5.3.3. (Case 2C): Base case + Wall upgrading only as recommended by Dubai Green Building Regulations.

This section will examine the exact base case but will upgrade the external wall data as promoted by DGBR. It's advised to have a maximum U-Value of walls as 0.570 W/m2. K, while the roofs and glazing as 0.530 W/m2. K and 3.260 W/m2. K. The total energy consumption and CO_2 emissions are expected to achieve greater value than case 2A and 2B because the wall U-Value has been increased approximately 43.8 % and 78.0 %.

The simulation of case 2C shows that the total energy consumption is (162.3 MWh) which is lesser than the total energy consumption in case 1 by 9 %. Similarly the total system energy is equal to 93.3 MWh that is divided between 58.3 % cooling consumption and 41.7 % other consumptions. It's clear that there is no reduction in the cooling consumption that is an indication that DGBR recommended walls cannot reduce the chillier load more than the reduction achieved by PRS and QSAS recommended walls as shown in case 2A and 2B. Moreover, the total energy is a summation of total system energy equal to 93.2 MWh, total light energy and total equipment energy as shown in Table – 5.4.

Furthermore, the CO_2 emissions were recorded as 84257 $KgCO_2$ lesser that case 1 by 8.9 %. The CO_2 emissions are more than case 2A and 2B as shown in Figure 5.3. Similarly the total energy consumption is 162.4 MWh and more than the other former cases 2A and 2B.

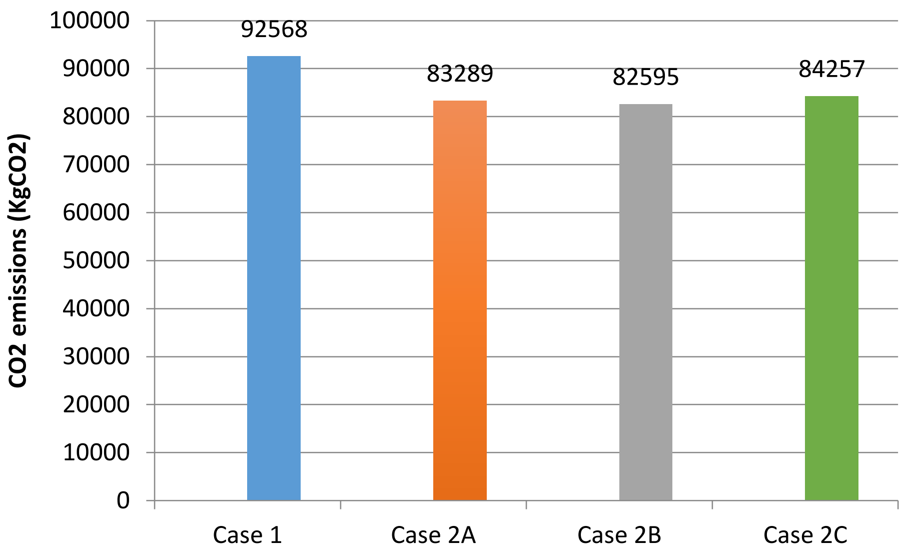


Figure 5.3: comparison between Case 2A, 2B, 2C and Case 1 and Base case CO2 emissions via upgrading the walls only (Source: Author, 2014)

Table 5.4: Case 2C- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	5.5356	2.1124	3.8336	11.4817
Feb 01-28	4.7911	1.8755	3.4183	10.0849
Mar 01-31	6.3572	2.0495	3.7477	12.1545
Apr 01-30	7.446	2.023	3.6809	13.1499
May 01-31	9.2044	2.081	3.7907	15.0761
Jun 01-30	9.4815	1.9915	3.6379	15.1109
Jul 01-31	10.2059	2.1124	3.8336	16.152
Aug 01-31	9.9616	2.0495	3.7477	15.7589
Sep 01-30	8.9567	1.9915	3.6379	14.5861
Oct 01-31	9.0663	2.1124	3.8336	15.0123
Nov 01-30	6.5442	1.9915	3.6379	12.1736
Dec 01-31	5.7395	2.081	3.7907	11.6112
Summed total	93.2902	24.4711	44.5905	162.3521

5.3.4. Comparison between case 2A, 2B and 2C against case 1

This section will discuss a straightforward comparison between the base case and the other cases upgrading the wall. It has been noticed that the lowest annual energy can be achieved in case 2B as recommended by QSAS, the recorded energy consumption 10.8 % lesser than case 1 as well as the CO2 emissions as shown in Figure 5.4.

However upgrading the walls in all the cases increase the chillier energy consumption during the cold months as highlighted in Figure 5.5 that means that adding insulation material to the wall has a positive effect in the summer but not the winter season due to the thermal storage properties.

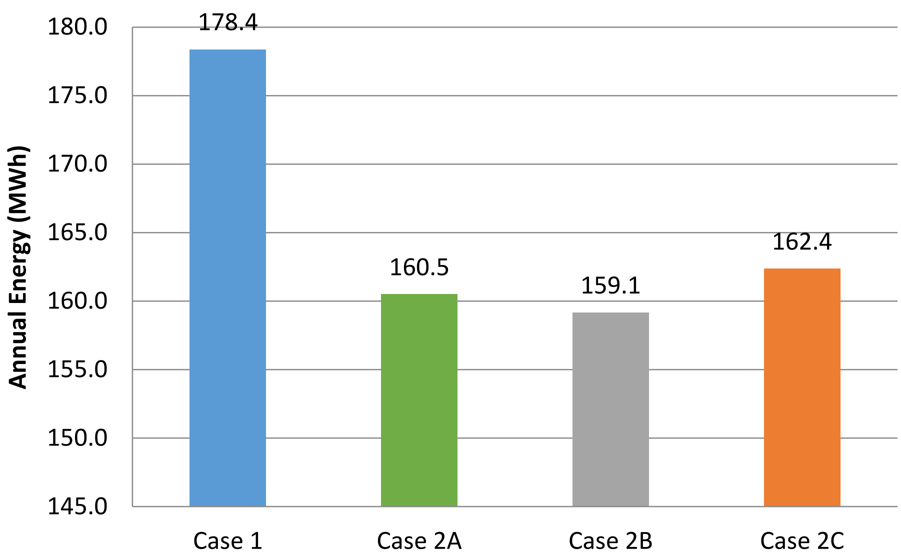


Figure 5.4: Compression between case 2A, case 2B, case 2C and case 1 annual energy consumption (Source: IES <VE> & Author, 2014).

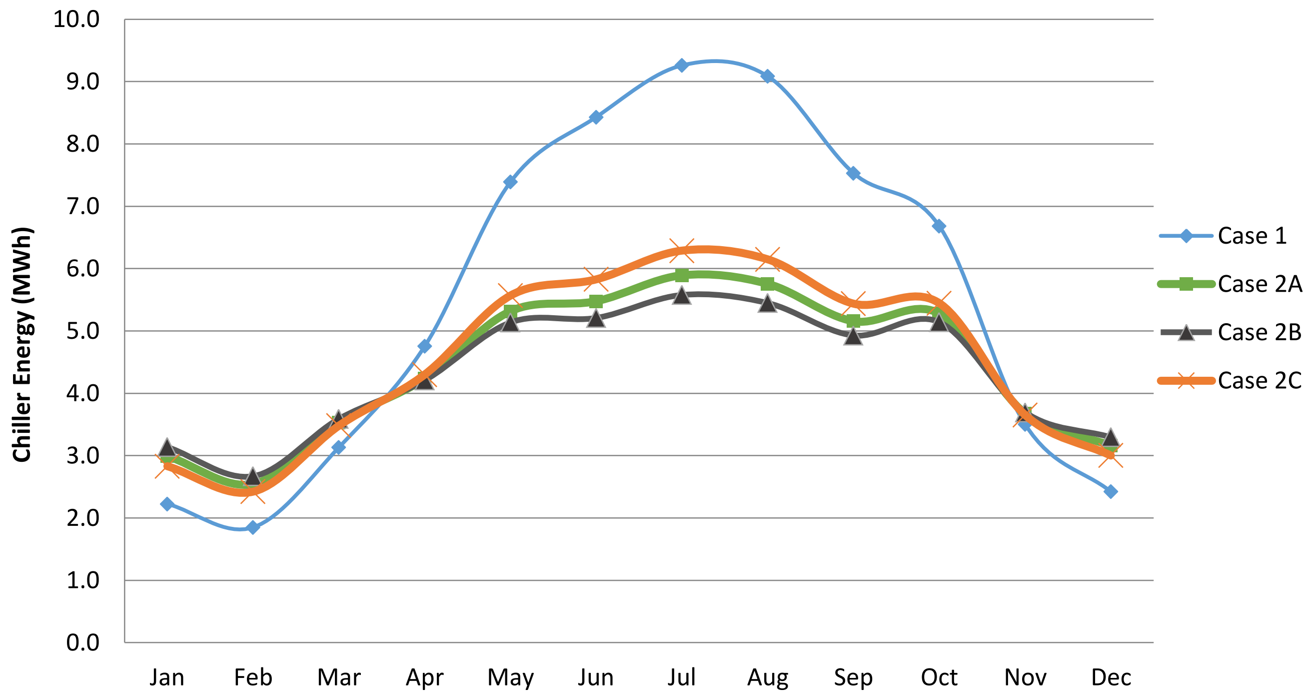


Figure 5.5: Compression between case 2A, case 2B, case 3C and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

Furthermore, case 2B has the highest energy consumption in cold months as shown in grey, while case 2C is having the highest energy consumption during the hot months as highlighted in orange. The overall results indicates that case 2C is not suitable to Bahrain due to the wall thermal properties and the additional energy consumption comparing to the 2A and 2B specially during the summer season where the maximum protection from external environment is needed. Furthermore, the chillier energy has maximum reduction of 20 % from the total energy consumption in case 2A, while it is 21.5 % in case 2B and 17.9 % in case 2C. Moreover, the total energy has maximum reduction of 10.8 % from the total energy consumption in case 2A, while it is 10 % in case 2B and the lowest energy 9 % in case 2C. The reduction is varies between the three cases because every case has a different insulation configuration.

Table 5.5: Compression between case 2A, case 2B, case 2C and case 1 total energy and chiller energy achieved saving (Source: IES <VE> & Author, 2014).

Total Energy Reduction			
Case 1	Case 5A	Case 5B	Case 5C
0.0	10.0	10.8	9.0
Chiller Energy Reduction			
Case 1	Case 2A	Case 2B	Case 2C
0.0	20.0	21.5	17.9

The following sections will examine case one with replacement of both roof and windows separately as recommended by PRS, QSAS and DGBR.

5.4. Upgrading Roof only as per case 3A as per PRS 1, 3B as per QSAS and 3C as per DGBR

While studying the current case of Bahrain it has been noted from Eng. Al –Orrayedh (2014) that Ministry of Housing has already applied roof insulation in their development because they believe that insulating the roof in their provided social houses will reduce the overall energy consumption and chillier energy, as well as it will enhance the comfort of the tenants and consequently will reduce the CO2 emissions to the environment.

Therefore this section will implement the PRS 1 roof upgrade in case 3A followed by implementation of QSAS and then implementation of DGBR with the current roof and glazing system in Bahrain. Each case will be studied separately and compared to the base case. Finally, will present all the results in one table to summarize the possible reduction in overall energy and chillier energy.

5.4.1. (Case 3A): Base case + Roof upgrading only as recommended by Pearl Rating System.

This section will examine the exact base case size, orientation and weather data as well as construction data but will upgrade the roof data as promoted by PRS, its advised to have a maximum U-Value of roof as 0.150 W/m2. K, while the wall and glazing as 2.746 W/m2. K and 3.260 W/m2. K. The total energy consumption and CO_2 emissions are expected to achieve major changes because the roof U-Value has been reduced approximately 71.7 % from 0.530 W/m2. K to 0.150 W/m2. K.

The simulation of case 6A presents that total energy consumption is surprisingly (178 MWh) which is almost equal to total energy consumption in case 1 that reflects that upgrading the roof in the case study will not reduce the energy any noticeable percentage. Similarly the total system energy is equal to 108.9 MWh that is divided between 60.5% cooling consumption and 39.5% other consumptions. Moreover, the total energy is a summation of total system energy equal to 108.9 MWh, total light energy and total equipment energy as shown in Table 5.6.

The CO_2 emission has recorded 92380 $KgCO_2$ that is almost similar to the CO_2 emissions in case 1 that represents 92568 $KgCO_2$. With reference to chapter 2, Eng. Al –Orrayedh (2013) has highlighted that the ministry of housing in Bahrain has insulated the roofs and improved its thermal properties to reduce the heat gain through the roof. This is enforcing that upgrading the roof thermal properties will not reduce the energy consumption and CO_2 emission. Same wise the chillier energy was reduced 0.4 % against case 1.

Table 5.6: Case 3A- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.8001	2.1124	3.8336	10.7461
Feb 01-28	4.0795	1.8755	3.4183	9.3733
Mar 01-31	5.9292	2.0495	3.7477	11.7264
Apr 01-30	8.045	2.023	3.6809	13.7489
May 01-31	11.5766	2.081	3.7907	17.4483
Jun 01-30	12.8662	1.9915	3.6379	18.4956
Jul 01-31	14.0696	2.1124	3.8336	20.0157
Aug 01-31	13.7811	2.0495	3.7477	19.5784
Sep 01-30	11.6844	1.9915	3.6379	17.3139
Oct 01-31	10.6935	2.1124	3.8336	16.6396
Nov 01-30	6.3763	1.9915	3.6379	12.0057
Dec 01-31	5.0382	2.081	3.7907	10.9099
Summed total	108.9398	24.4711	44.5905	178.0017

5.4.2. (Case 3B): Base case + Roof upgrading only as recommended by QSAS.

This section will examine the exact base case but will upgrade the roof data as promoted by QSAS, its advised to have a maximum U-Value of roof as 0.250 W/m2.K, while the wall and glazing as 2.746 W/m2.K and 3.260 W/m2.K. The total energy consumption and CO2 emissions is expected to be within the same range of both case 1 and case 3A, because the differences between case 3A and 3B is 0.1 W/m2.K.

The simulation of case 3B presents that total energy consumption is equable to (178 MWh) which is almost equal to total energy consumption in case 1 and case 3A as mentioned above. Similarly the total system energy is equal to 108.9 MWh that is divided between 60.5% cooling consumption and 39.4 % other consumptions. Moreover, the total energy is a summation of total system energy equal to 108.9 MWh, total light energy and total equipment energy as shown in Table 5.7 and all other elements. In addition to that, The CO2 emission has recorded 92383 KgCO2 that is almost similar to the CO2 emissions in case 1 and Case 3A. In the other hand the chillier load in Case 3B recorded an equal figure to Case 3A that is 0.2 % reduction in the chillier load if compared to case 1.

Table 5.7: Case 3B- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.7984	2.1124	3.8336	10.7445
Feb 01-28	4.0796	1.8755	3.4183	9.3734
Mar 01-31	5.9277	2.0495	3.7477	11.725
Apr 01-30	8.0482	2.023	3.6809	13.752
May 01-31	11.5809	2.081	3.7907	17.4526
Jun 01-30	12.8712	1.9915	3.6379	18.5007
Jul 01-31	14.0726	2.1124	3.8336	20.0186
Aug 01-31	13.7858	2.0495	3.7477	19.583
Sep 01-30	11.6861	1.9915	3.6379	17.3156
Oct 01-31	10.6909	2.1124	3.8336	16.6369
Nov 01-30	6.3709	1.9915	3.6379	12.0003
Dec 01-31	5.0337	2.081	3.7907	10.9054
Summed total	108.946	24.4711	44.5905	178.0078

5.4.3. (Case 3C): Base case + Roof upgrading only as recommended by DGBR.

This section will examine the exact base case but will upgrade the roof data as promoted by QSAS, its advised to have a maximum U-Value of roof as 0.300 W/m2.K, while the wall and glazing as 2.746 W/m2.K and 3.260 W/m2.K. The total energy consumption and CO2 emissions is expected to be within the same range of both case 1 and case 3A, because the differences between case 3A and 3C is 0.1 W/m2.K.

The simulation of case 3C presents that total energy consumption is equable to (178.15 MWh) which is almost equal to total energy consumption in case 1 and greater than case 3A and 3B as mentioned above. Similarly the total system energy is equal to 109 MWh that is divided between 60.5% cooling consumption and 39.4 % other consumptions. Moreover, the total energy is a summation of total system energy equal to 109 MWh, total light energy and total equipment energy as shown in Table 5.8 and all other elements. In addition to that, The CO2 emission has recorded 92458 KgCO2 that is almost similar to the CO2 emissions in case 1 and slightly greater than Case 3A and 3B. In the other hand the chillier load in Case 3C recorded a slightly greater figure than Case 3A and 3B that is 0.1 % reduction in the chillier load if compared to case 1.

Table 5.8: Case 3C- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.7749	2.1124	3.8336	10.7209
Feb 01-28	4.0628	1.8755	3.4183	9.3566
Mar 01-31	5.9175	2.0495	3.7477	11.7147
Apr 01-30	8.0572	2.023	3.6809	13.7611
May 01-31	11.6153	2.081	3.7907	17.4869
Jun 01-30	12.9186	1.9915	3.6379	18.5481
Jul 01-31	14.1195	2.1124	3.8336	20.0655
Aug 01-31	13.8377	2.0495	3.7477	19.6349
Sep 01-30	11.7186	1.9915	3.6379	17.348
Oct 01-31	10.7026	2.1124	3.8336	16.6487
Nov 01-30	6.3584	1.9915	3.6379	11.9878
Dec 01-31	5.0073	2.081	3.7907	10.8789
Summed total	109.0903	24.4711	44.5905	178.1522

5.4.4. Comparison between case 3A, 3B and 3C against case 1

This section will discuss a straightforward comparison between the base case and the other cases upgrading the roof. It has been noticed that there no recognised reduction in upgrading the roof, however, the maximum reduction in the annual energy could be achieve 0.2 % in case 3A and 3B as recommended by PRS1 and QSAS, while its 0.1% in case DGBR lowest annual energy can be achieved in case 2B as recommended by QSAS as shown in Figure 5.6.

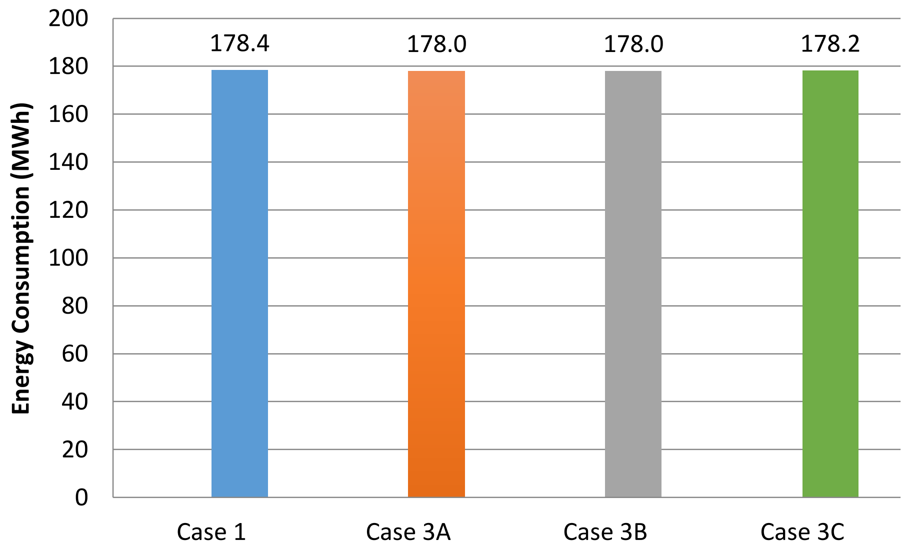


Figure 5.6: Compression between case 3A, case 3B, case 3C and case 1 annual energy consumption (Source: IES <VE> & Author, 2014).

Similarly, there was no reduction in the three cases 3A, 3B and 3C. However upgrading the roof in all the cases increase the chillier energy consumption during the summer months as highlighted in Figure 5.7 that means that adding insulation material to the roof has negative effect in the both summer and winter months due to the thermal storage properties. Therefore, upgrading the roof witnessed that there will not be any benefits or saving in energy due to the reasons mentioned earlier by Ministry of housing consultant Engineer Al-Orrayedh (2014) that and enforced by the simulation results of case 3A, 3B and 3C.

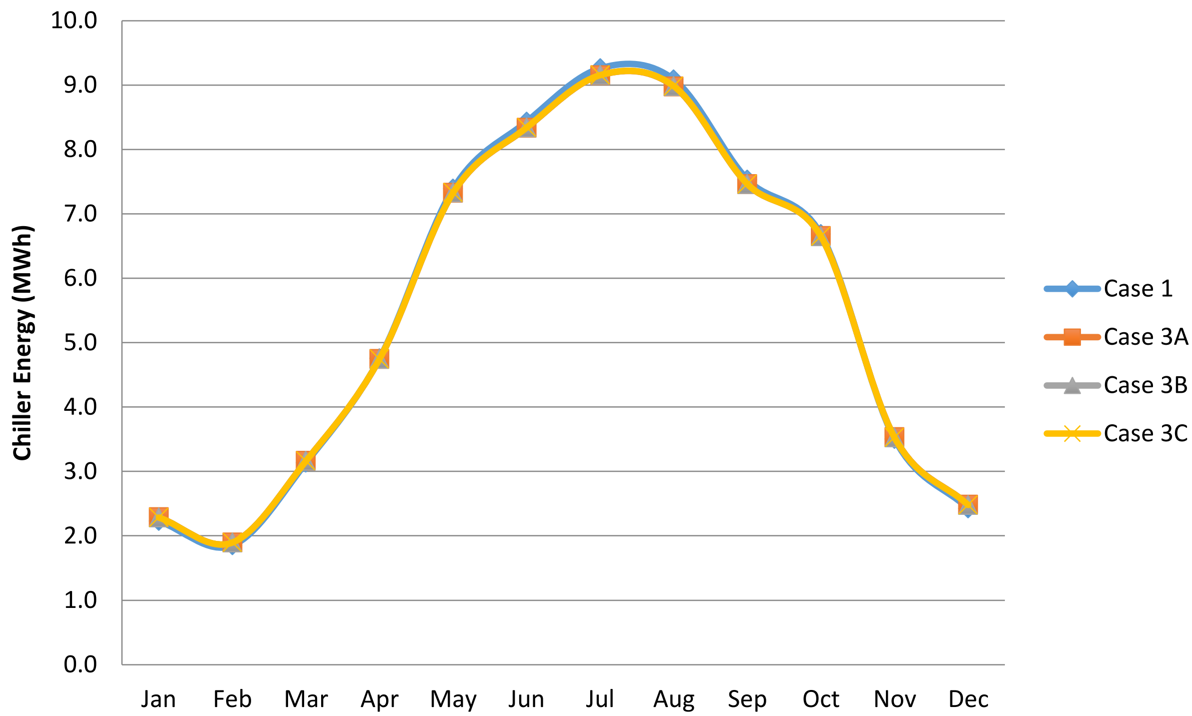


Figure - 5.7: Compression between case 2A, case 2B, case 3C and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

The following sections will examine case one with replacement of windows glazing separately as recommended by PRS, QSAS and DGBR.

5.5. Upgrading windows glazing only as per case 4A as per PRS 1, 4B as per QSAS and 4xC as per DGBR

While studying the current case of Bahrain it has been noted that the window to wall ratio is around 24.3 % as mentioned in chapter 4. Its expected that there will not be a dramatically reduction in annual overall energy, chillier energy and the CO2 emissions to the environment. But yet its important to evaluate the glazing systems recommended by PRS 1, QSAS and DGBR as shown in case 4A, 4B and 4C.

5.5.1. (Case 4A): Base case + Window glazing upgrading only as recommended by Pearl Rating System.

This section will examine the exact base case size, orientation and weather data as well as construction data but will upgrade the glazing data as promoted by PRS, its advised to have a maximum U-Value of glazing as 2.200 W/m2. K and 40% SHGC, while the wall and roof as 2.746 W/m2. K and 0.150 W/m2. K. The previous cases 3A, 3B and 3B showed that there are no changes in energy consumption and CO2 emissions if compared to case 1 and its expected to be the same in the following cases. The simulation of case 4A presents that total energy consumption is equable to (175.8 MWh) which is slightly greater than the total energy consumption in case 1.

Similarly the total system energy is equal to 106.7 MWh that is divided between 60.3% cooling consumption and 39.7 % other consumptions. Moreover, the total energy is a summation of total system energy, total light energy and total equipment energy in Table 5.9.

Table 5.9: Case 4A- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.7604	2.1124	3.8336	10.7065
Feb 01-28	4.0864	1.8755	3.4183	9.3802
Mar 01-31	6.0369	2.0495	3.7477	11.8342
Apr 01-30	8.0353	2.023	3.6809	13.7391
May 01-31	11.3048	2.081	3.7907	17.1765
Jun 01-30	12.4303	1.9915	3.6379	18.0597
Jul 01-31	13.5488	2.1124	3.8336	19.4948
Aug 01-31	13.2658	2.0495	3.7477	19.0631
Sep 01-30	11.3298	1.9915	3.6379	16.9592
Oct 01-31	10.5254	2.1124	3.8336	16.4715
Nov 01-30	6.4568	1.9915	3.6379	12.0862
Dec 01-31	5.005	2.081	3.7907	10.8767
Summed total	106.7857	24.4711	44.5905	175.8476

* Total System Energy includes: Air Conditioning System Energy and other energy consumption

The CO2 emission has recorded 91262 KgCO2 that is slightly lesser than CO2 emissions in case 1 by 1.8%. While the chillier energy has reduced 2.8% and hits its maximum in August due to the high dry bulb temperature 35.2 C ○ and high solar radiation 1107 W/m2 shown in Figure 5.8.

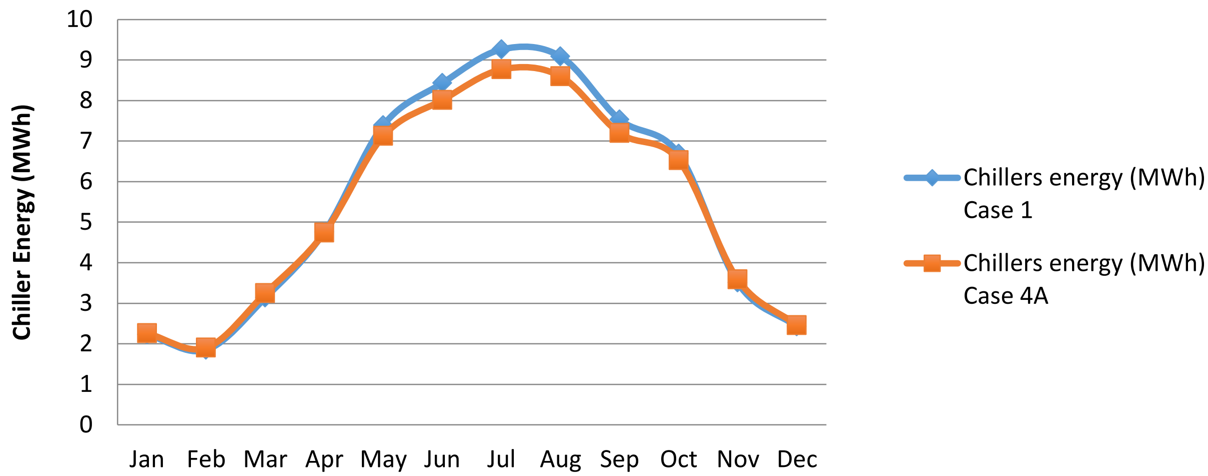


Figure 5.8: Compression between case 4A and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.5.2. (Case 4B): Base case + Window glazing upgrading only as recommended by QSAS.

This section will examine the exact base case but will upgrade the glazing data as promoted by QSAS, it's advised to have a maximum U-Value of glazing as 2.100 W/m2. K and 40% SHGC, while the wall and roof as 2.746 W/m2. K and 0.150 W/m2. K. The previous case 4A showed that there is a minor incensement in both energy consumption and CO2 emissions and its expected to be similar in this case. The simulation of case 4B presents that total energy consumption is equable to (175.20 MWh) which is almost equal to the total energy consumption in case 4A and slightly lesser that case 1.

Similarly the total system energy is equal to 106 MWh that is divided between 60.1% cooling consumption and 39.9% other consumptions. Moreover, the total energy is a summation of total system energy, total light energy and total equipment energy equal as shown in Table 5.10.

Table 5.10: Case 4B- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.7508	2.1124	3.8336	10.6968
Feb 01-28	4.0665	1.8755	3.4183	9.3603
Mar 01-31	5.9791	2.0495	3.7477	11.7764
Apr 01-30	7.9669	2.023	3.6809	13.6708
May 01-31	11.2175	2.081	3.7907	17.0892
Jun 01-30	12.3437	1.9915	3.6379	17.9731
Jul 01-31	13.4579	2.1124	3.8336	19.404
Aug 01-31	13.1807	2.0495	3.7477	18.9779
Sep 01-30	11.262	1.9915	3.6379	16.8914
Oct 01-31	10.4635	2.1124	3.8336	16.4095
Nov 01-30	6.4131	1.9915	3.6379	12.0425
Dec 01-31	4.9941	2.081	3.7907	10.8658
Summed total	106.0958	24.4711	44.5905	175.1577

* Total System Energy includes: Air Conditioning System Energy and other energy consumption

The CO2 emission has recorded 90903 KgCO2 that is almost equal to the CO2 emissions in case 1 that represents 128449 KgCO2. While the chillier energy has reduced 3.6%, which is slightly better than case 4A as shown in Figure 5.9. This minor reduction in chillier and energy consumption is a result of the reduction of the glazing U-value when compared to case 1 and case 4A.

The following section will also examine the impact of upgrading the window glazing system as per the recommendation of Dubai Green Building regulations that calls for a lower U-Value for the glazing. Therefore it's anticipated that it will record a better results than case 4A and 4B when compared to case 1.

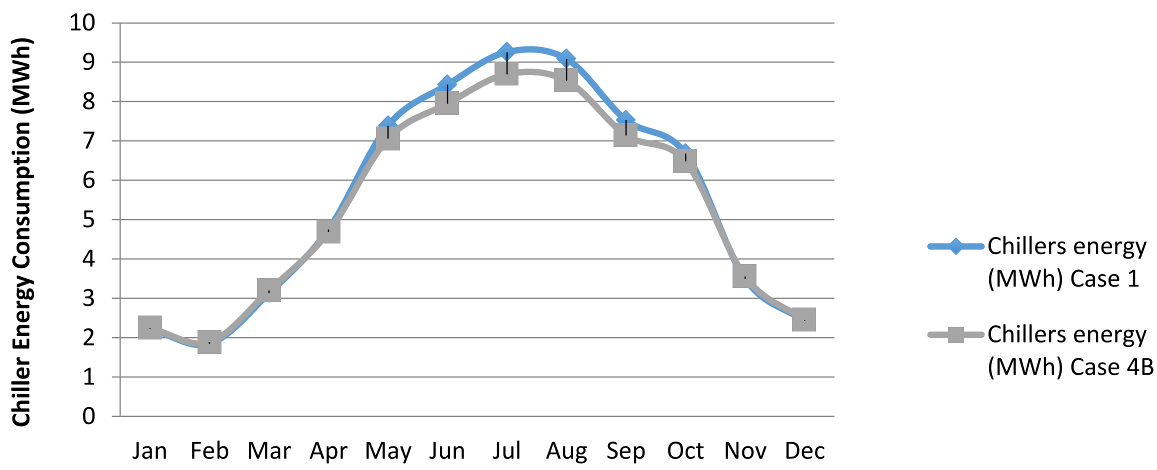


Figure 5.9: Compression between case 4B and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.5.3. (Case 4C): Base case + Window glazing upgrading only as recommended by QSAS.

This section will examine the exact base case but will upgrade the glazing data as promoted by DGBR, it's advised to have a maximum U-Value of glazing as 1.700 W/m2. K and 50% SHGC, while the wall and roof as 2.746 W/m2. K and 0.150 W/m2. K. The previous cases 4A and 4B showed a minor reduction in the total energy consumption and CO2 emissions but a slightly higher reduction in the chillier energy reaches up to 3.6%. The simulation of case 4C presents that total energy consumption is equable to (174.7 MWh) which is slightly lesser than case 4A and 4B.

Similarly the total system energy is equal to 105.6 MWh that is divided between 60.1% cooling consumption and 39.9% other consumptions. Moreover, the total energy is a summation of total system energy equal to 175.2 MWh, total light energy and total equipment energy equal as shown in Table 5.11.

The CO2 emission has recorded 90669 KgCO2 that is slightly lesser than CO2 emissions in case 1 and reduced 2.1%. While the chillier energy has reduced 4.1%, which is slightly better than case 4A and 4B when compared to case 1 as shown in Figure 5.10.

Table 5.11: Case 4C- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	4.7429	2.1124	3.8336	10.689
Feb 01-28	4.0501	1.8755	3.4183	9.3439
Mar 01-31	5.9292	2.0495	3.7477	11.7264
Apr 01-30	7.915	2.023	3.6809	13.6189
May 01-31	11.1619	2.081	3.7907	17.0335
Jun 01-30	12.2945	1.9915	3.6379	17.924
Jul 01-31	13.4091	2.1124	3.8336	19.3552
Aug 01-31	13.1347	2.0495	3.7477	18.9319
Sep 01-30	11.2235	1.9915	3.6379	16.8529
Oct 01-31	10.4223	2.1124	3.8336	16.3684
Nov 01-30	6.3751	1.9915	3.6379	12.0045
Dec 01-31	4.9853	2.081	3.7907	10.8569
Summed total	105.6435	24.4711	44.5905	174.7054

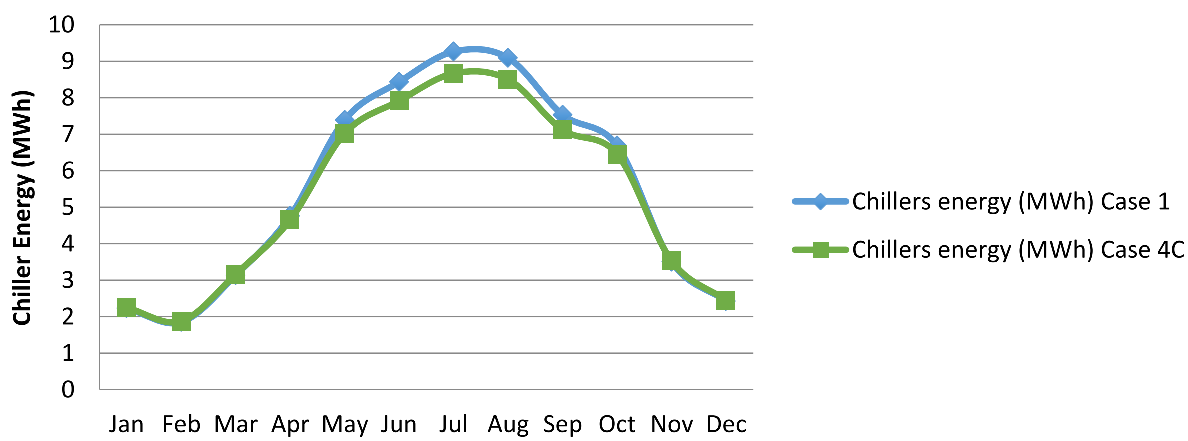


Figure 5.10: Compression between case 4C and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.5.4. Comparison between case 4A, 4B and 4C against case 1

This section will discuss a straightforward comparison between the base case and the other cases upgrading the glass. It has been noticed that the lowest annual energy can be achieved in case 4C as recommended by DGBR, the recorded energy consumption 2.1 % lesser than case 1 as well as the CO2 emissions as shown in Figure 5.11.

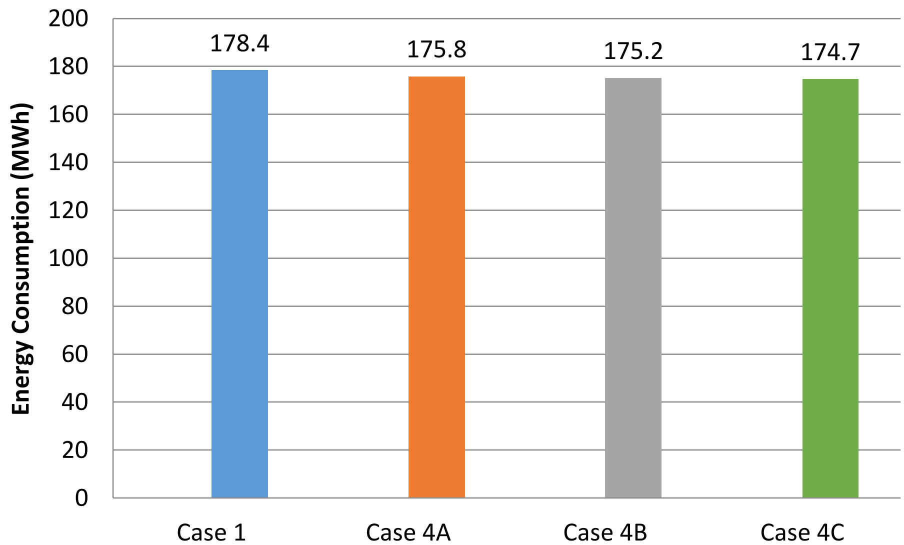


Figure 5.11: Compression between case 4A, case 4B, case 4C and case 1 annual energy consumption (Source: IES <VE> & Author, 2014).

However upgrading the glass in all cases reduced chillier energy consumption during the cold months as highlighted in Figure 5.12 that means that enhancing the thermal properties of glazing system will have positive effect during the winter but almost no effect during the summer. Moreover, the maximum chillier energy savings or reduction was achieved by upgrading the glazing system as per DGBR – case 4C up to 4.1 %.

It's must be noted that the window to wall ratio is very low therefore upgrading the window will not achieve dramatic savings as achieved via upgrading the walls in case 2A, 2B and 2C.

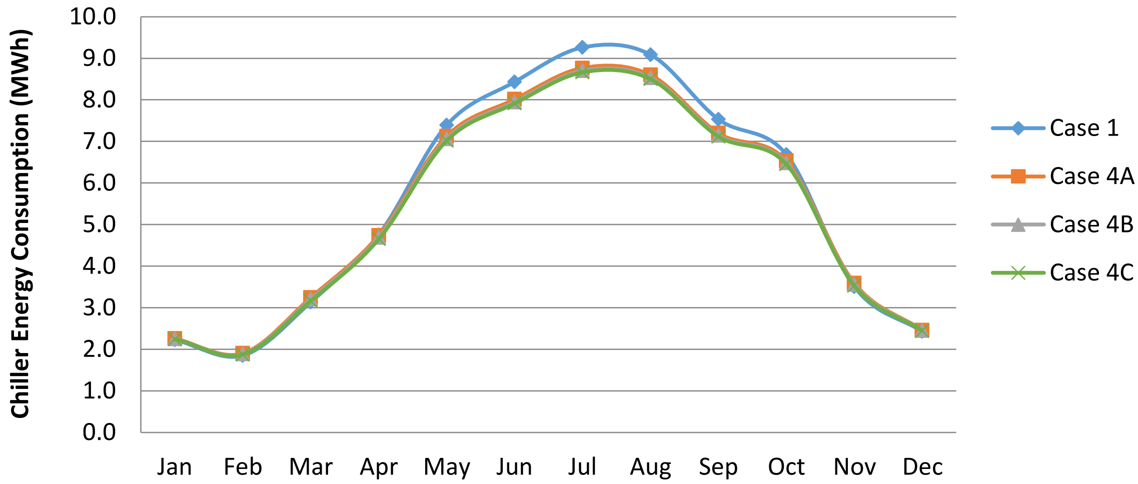


Figure 5.12: Compression between case 4A, case 4B, case 4C and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.6. Enhancing the base case building envelope separately: Discussion

The above section evaluated the possible reduction in energy consumption, CO2 emissions and chillier energy that could be achieved by enhancing the walls, roof and window glazing separately as recommended by PRS, QSAS and DGBR.

The first group case 2 (2A, 2B and 2C) evaluated the impact of upgrading the walls as per PRS, QSAS and DGBR and it has been noted earlier that the maximum reduction in annual energy was equal to 10.8% and the maximum reduction in chillier energy was equal to 21.5%. This reduction was achieved via upgrading the walls as per QSAS (case 2B).

The second group case 3 (3A, 3B and 3C) evaluated the impart of upgrading the roof as per PRS, QSAS and DGBR and it has been noted earlier that there was no recognised reduction however the maximum reduction in annual energy was equal to 0.2 % and the maximum reduction in chillier energy was equal to 0.5%. This reduction was achieved via upgrading the walls as per PRS and QSAS (case 3A and 3B).

The first group case 4 (4A, 4B and 4C) evaluated the impact of upgrading the window glazing as per PRS, QSAS and DGBR and it has been noted earlier that the maximum reduction in annual energy was equal to 2.1% and the maximum reduction in chillier energy was equal to 4.1%. This reduction was achieved via upgrading the walls as per DGBR (case 4C).

Figure 5.13 express an overall comparison between the annual energy of all the studied cases against case 1. This comparison will give the reader some glimpse of the possible ways to reduce annual energy consumption, CO2 emissions and specially the chillier energy because it is considered the main reason of the high energy bill in residential buildings and especially social housing in Bahrain.

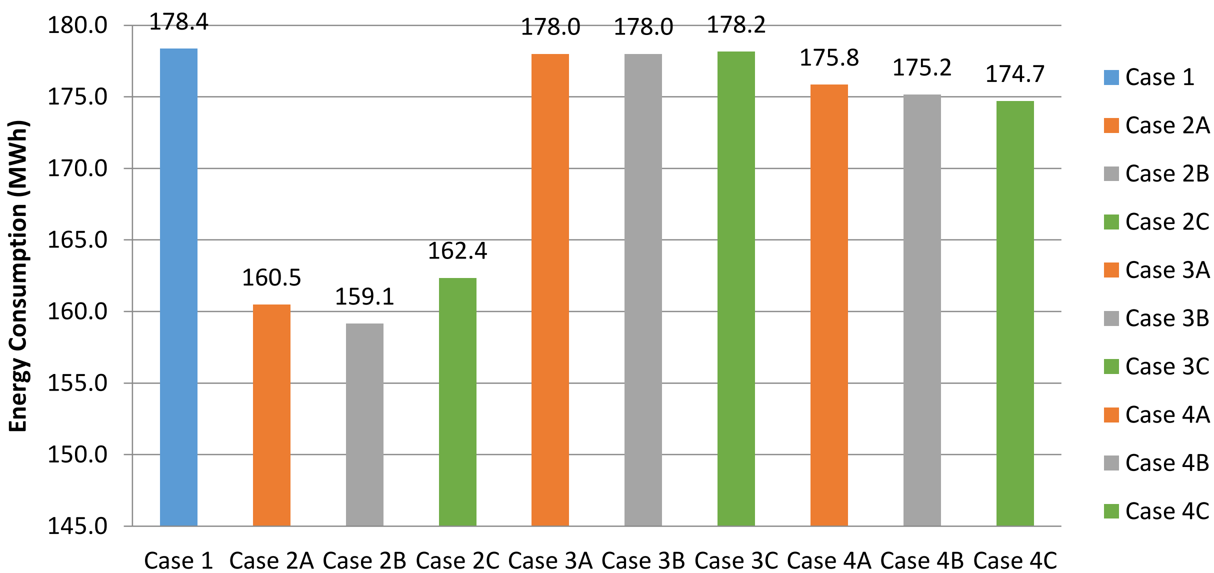


Figure 5.13: Compression between all cases and case 1 annual energy consumption (Source: IES <VE> & Author, 2014).

Figure 5.13 enforces that upgrading the walls can dramatically reduce the overall energy consumption as well as the CO2 emissions and consequently will achieve a huge reduction in the chiller energy consumption as shown in Table 5.12.

Table 5.12: Comparison between all cases chiller energy and case 1 (Source: IES <VE> and Author, 2014)

Case	Case 1	Case 2A	Case 2B	Case 2C	Case 3A	Case 3B	Case 3C	Case 4A	Case 4B	Case 4C
Saving	0.0%	20.0%	21.5%	17.9%	0.5%	0.5%	0.5%	2.9%	3.6%	4.1%

Since that there was a recognized reduction in total energy, chiller energy and CO2 emissions when enhancing the building envelope separately as per PRS, QSAS and DGBR. The following sections will upgrade the entire building envelop as walls, roof and window glazing as per the PRS, QSAS and DGBR because it's anticipated that it will record even more saving in the overall energy consumption, chiller energy as well as the CO2 emissions.

5.7. (Case 5): Implementing PRS1 rating system: UAE, Abu Dhabi

This section will examine the exact base case size, orientation and weather data but will upgrade the construction data as promoted by Pearl 1, its advised to have a maximum U-Value of walls, roofs and glazing as 0.320 W/m2.K , 0.150 W/m2.K and 2.200 W/m2.K. The figures above, the figures have been discussed in chapter 2 Table 2.4. Its clear that these figures are completely different than Case 1 as built in Bahrain. These figures have already been mentioned in chapter 4, Table 4.2.

The simulation of case 2 shows that total energy consumption is (161.3 MWh) which is 9.5% reduced if compared to case 1 as well as the CO2 emissions. Similarly, system energy is 92.3 MWh that is divided between cooling load equal to 58% and other consumption equal to 42%. The total energy is a summation of total system energy equal to total light energy equal total equipment energy that are constant in all cases as shown in Table 5.13.

Furthermore, it has been noticed that CO2 emissions has been reduced by upgrading the building construction from typical to green construction as recommended by Pearl 1. The CO2 emission is 83756 KgCO2 lesser than case 1 by 9.5 %. The reduction in energy consumption and CO2 emission are equal as mentioned earlier because theses two elements are always associated together, so whenever an upgrade in the building envelop has been done a noticeable reduction in both energy and CO2 emissions will be achieved.

Table 5.13: Case 5- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	6.0142	2.1124	3.8336	11.9603
Feb 01-28	5.1763	1.8755	3.4183	10.4701
Mar 01-31	6.6174	2.0495	3.7477	12.4146
Apr 01-30	7.4701	2.023	3.6809	13.1739
May 01-31	8.8816	2.081	3.7907	14.7533
Jun 01-30	8.9482	1.9915	3.6379	14.5777
Jul 01-31	9.5789	2.1124	3.8336	15.525
Aug 01-31	9.3355	2.0495	3.7477	15.1328
Sep 01-30	8.529	1.9915	3.6379	14.1584
Oct 01-31	8.876	2.1124	3.8336	14.8221
Nov 01-30	6.7177	1.9915	3.6379	12.3471
Dec 01-31	6.1792	2.081	3.7907	12.0508
Summed total	92.3241	24.4711	44.5905	161.386

* Total System Energy includes : Air Conditioning System Energy and other energy consumption

The results enforce that the reduction in U-value will increase the resistance of the building envelope and consequently will reduce the energy and CO2 emissions. However, the results shown in Table 5.13 clearly indicates that during the summer months a recognized reduction has been achieved, while in the cooler months there was a slightly increase in the energy due to the insulation addition and the extra thermal mall. AlAwaddhi (2011) found out a similar result when compared the traditional construction in Abu Dhabi to the refurbished models advised by Pearl Rating System 1 and 2 in Figure 2.11. Therefore, this study will only examine pearl 1 system because it’s more economical.

Energy consumption in February is lesser that in January, its due to the same reason mentioned in case 1 and besides that it's the increased thermal mass due to the added insulation materials in to the construction system. However, Balaras (1996) asserted that thermal mass has a positive effect on indoor climate and can reduce peak cooling loads in indoor spaces, because during the high solar gains days is stored and gradually released to the indoor space later which again justify the increase of energy consumption in January with relation to the local weather conditions.

Sullivan and Ward (2012) Generally, microclimate design and technologies are there to support greater energy efficiency and further human comfort, therefore this research will continue to examine and identify the best arena of technological interventions that could be applied to reduce energy consumption in standard or low income housing units. Hence the following section will examine another green building regulation with minimum acceptable thermal properties for wall, roofs and glazing.

Moreover, Figure 5.14 shows that reduction in chillier energy recorded 19 % when compared to case 1. However, there was an increase in chillier energy during the winter month due to the upgraded thermal storage mentioned earlier in case 2A, 2B and 2C.

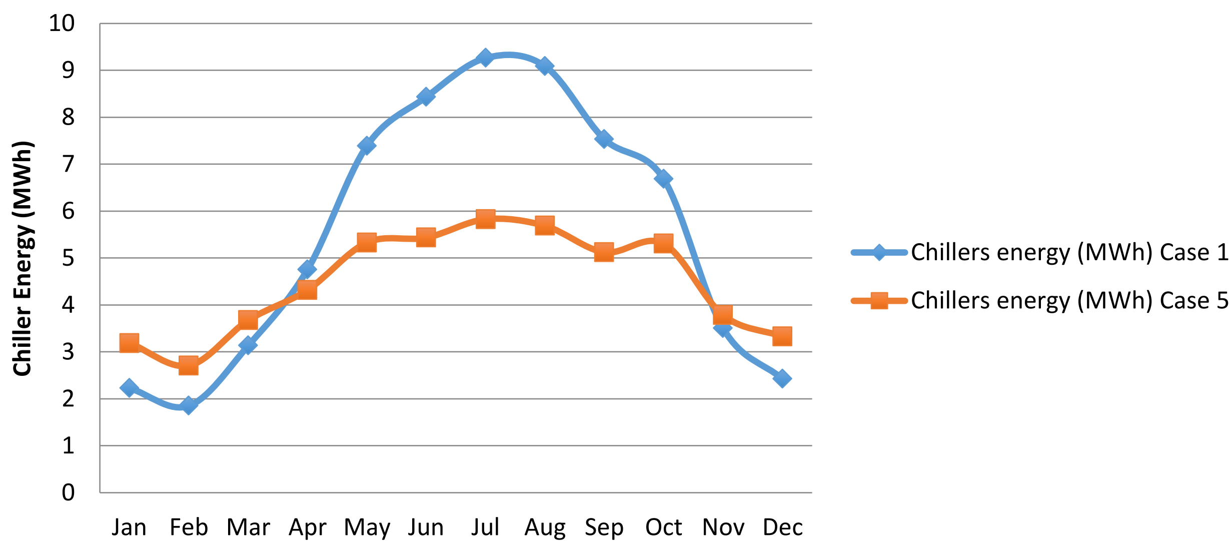


Figure 5.14: Compression between case 5 and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.8. (Case 6): Implementing QSAS rating system: Qatar, Doha

This section will examine the exact base case size, orientation and weather data as well as the constant lighting and equipment required energy, but will upgrade the construction data as promoted by QSAS, its advised to have a maximum U-Value of walls, roofs and glazing as 0.125 W/m2.K, 0.250 W/m2.K and 1.700 W/m2.K. The figures have been discussed in chapter 2 Figures 2.15 and 2.16 for wall composition. These figures have already been mentioned in the same chapter Table 2.5.

Once again the figures above is completely different than Case 1 and minor differences from Case 5. However, the U-value of walls and glazing has been reduced while the roof insulation is increased from 0.150 to 0.180 W/m2.K.

The simulation of case 6 shows that the total energy consumption is (159 MWh) which is lesser than the total energy consumption in case 1 by 10.8 %. Similarly the total system energy is equal to 90 MWh that is divided between 58% cooling consumption and 42% other consumptions. The total energy is a summation of total system energy, total light energy and total equipment energy that are constant in all cases as shown in Table 5.14.

Same wise, it has been noticed that upgrading the building construction from typical to green construction as recommended by QSAS has reduced CO2 emissions. The CO2 emission is 82565 KgCO2 lesser than case 1 by 10.8 %. Moreover, Figure 5.15 shows that reduction in chillier energy recorded 21.5 % when compared to case 1 and its clear that its even better than the reduction achieved case 5 as recommended by PRS 1. However, there was an increase in chillier energy during the winter month due to the upgraded thermal storage mentioned earlier.

By looking at the wall details presented in Figure 2.16, it is clear that the wall dynamic insulation cell was exclusively manufactured to match QSAS specification and there is no access to any information about the composition of this dynamic cell which will make it a bit difficult to use it in Bahrain due to its ambiguous content and to the expected associated costs.

Table 5.14: Case 6- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	6.1379	2.1124	3.8336	12.084
Feb 01-28	5.28	1.8755	3.4183	10.5738
Mar 01-31	6.6147	2.0495	3.7477	12.4119
Apr 01-30	7.3493	2.023	3.6809	13.0531
May 01-31	8.5382	2.081	3.7907	14.4098
Jun 01-30	8.4879	1.9915	3.6379	14.1174
Jul 01-31	9.0518	2.1124	3.8336	14.9979
Aug 01-31	8.826	2.0495	3.7477	14.6232
Sep 01-30	8.1451	1.9915	3.6379	13.7746
Oct 01-31	8.615	2.1124	3.8336	14.5611
Nov 01-30	6.6794	1.9915	3.6379	12.3088
Dec 01-31	6.3042	2.081	3.7907	12.1758
Summed total	90.0295	24.4711	44.5905	159.0914

* Total System Energy includes : Air Conditioning System Energy and other energy consumption

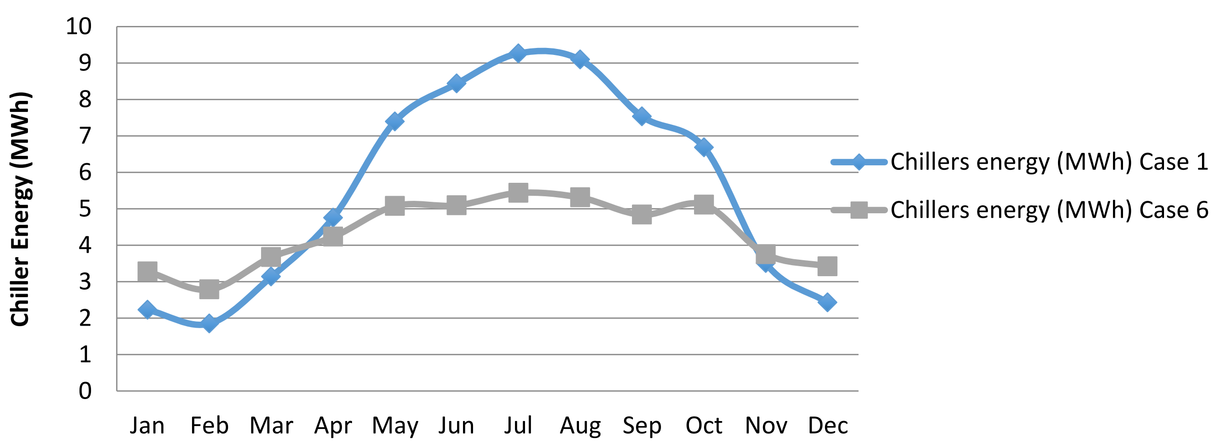


Figure 5.15: Compression between case 6 and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.9. (Case 7): Implementing DGBR rating system: UAE, Dubai

This section will examine the exact base case size, orientation and weather data, but will upgrade the construction data as promoted by DGBR that has already presented in chapter 2, Table 2.7.

The simulation of case 7 shows that the total energy consumption is (161.7 MWh) which is lesser than the total energy consumption in case 1 by 9.3 %. Similarly the total system energy is equal to 92.6 MWh, which is almost equal to case 2A and 2C. The total energy consumption is equal to the total system energy and constant light and equipment energy shown in Table 5.15. As mentioned earlier the energy reduction and the associated reduced CO2 emissions is anticipated to be between case 5 and 6. Therefore, upgrading the building envelope thermal performance is very important and should be carefully done in the most efficient way and minimum associated costs.

Table 5.15: Case 7- Total Energy consumption (Source: IES <VE> and Author, 2014)

Date	*Total System energy (MWh)	Total Light Energy (MWh)	Total equip energy (MWh)	Total energy (MWh)
Jan 01-31	5.6119	2.1124	3.8336	11.5579
Feb 01-28	4.8494	1.8755	3.4183	10.1432
Mar 01-31	6.3789	2.0495	3.7477	12.1761
Apr 01-30	7.4164	2.023	3.6809	13.1202
May 01-31	9.0938	2.081	3.7907	14.9655
Jun 01-30	9.3263	1.9915	3.6379	14.9557
Jul 01-31	10.0232	2.1124	3.8336	15.9693
Aug 01-31	9.7893	2.0495	3.7477	15.5865
Sep 01-30	8.8356	1.9915	3.6379	14.465
Oct 01-31	8.9961	2.1124	3.8336	14.9422
Nov 01-30	6.5568	1.9915	3.6379	12.1862
Dec 01-31	5.8098	2.081	3.7907	11.6815
Summed total	92.6875	24.4711	44.5905	161.7493

Same wise, it has been noticed that upgrading the building construction from typical to green construction as recommended by DGBR has reduced CO_2 emissions. The CO_2 emission is 82565 $KgCO_2$ lesser than case 1 by 9.3 %. Moreover, Figure 5.16 shows that reduction in chillier energy recorded 18.6% when compared to case 1 and its clear that it's the reduction achieved in case 5 and 7 is better than the reduction achieved case 7. However, there was an increase in chillier energy during the winter month due to the upgraded thermal storage mentioned earlier.

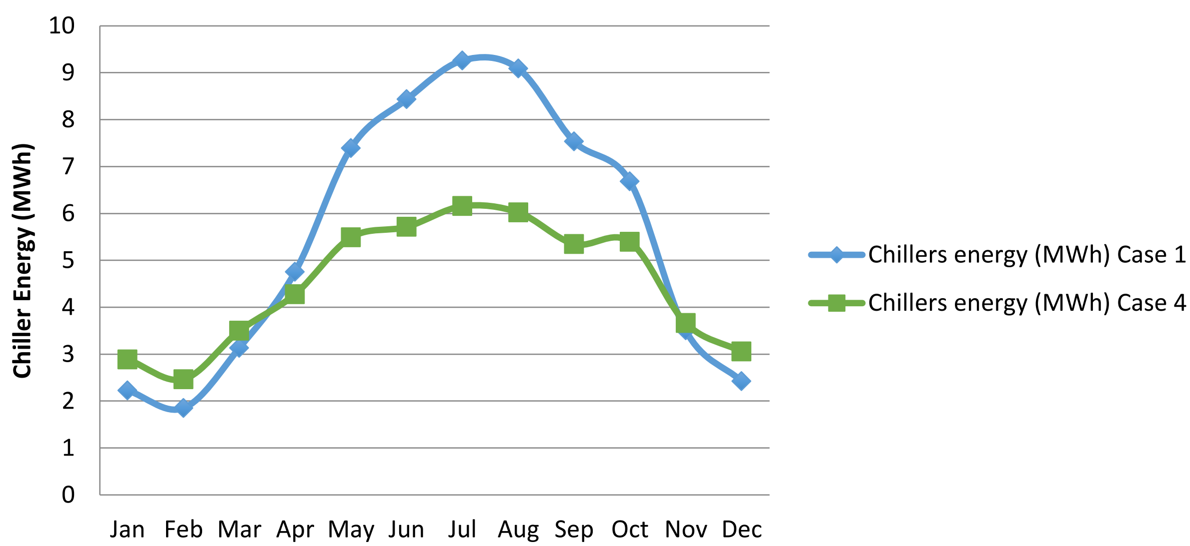


Figure 5.16: Compression between case 7 and case 1 chiller energy consumption (Source: IES <VE> & Author, 2014).

5.10. Comparison between Case 5, 6 and 7 against Case 1 (Base Case)

With reference to the presented results from case 5, 6 and 7 against case 1 as shown in Figure 5.17. it has been noticed that variations between all the cases is very small because all the scenarios are based on regional green buildings assessments and regulations are designed to increase the energy conservation in this particular region.

The blue line represents case 1 (Base Case), and it's clear that during the cold months November to mid of March the total energy consumption is the lowest among all the cases. This is a direct indication that upgrading building thermal performance has a positive effect during the hot summer months and less effect in the cold winter months.

This is directly related to the thermal storage properties that is associated with insulated building envelop in hot arid climate.

Furthermore, the grey line represents case 6 (as advised by QSAS) is the acts best during the summer months from April to mid of October while again it's the worst in the winter months due to the increased thermal mass. Moreover, the orange line represents case 5 (as advised by PRS 1) and the yellow line represents case 7 (as advised by DGBR), both cases has slight differences throughout the hot months. However, case 7 acts better in the winter months due to wall U-value when compared to the other cases.

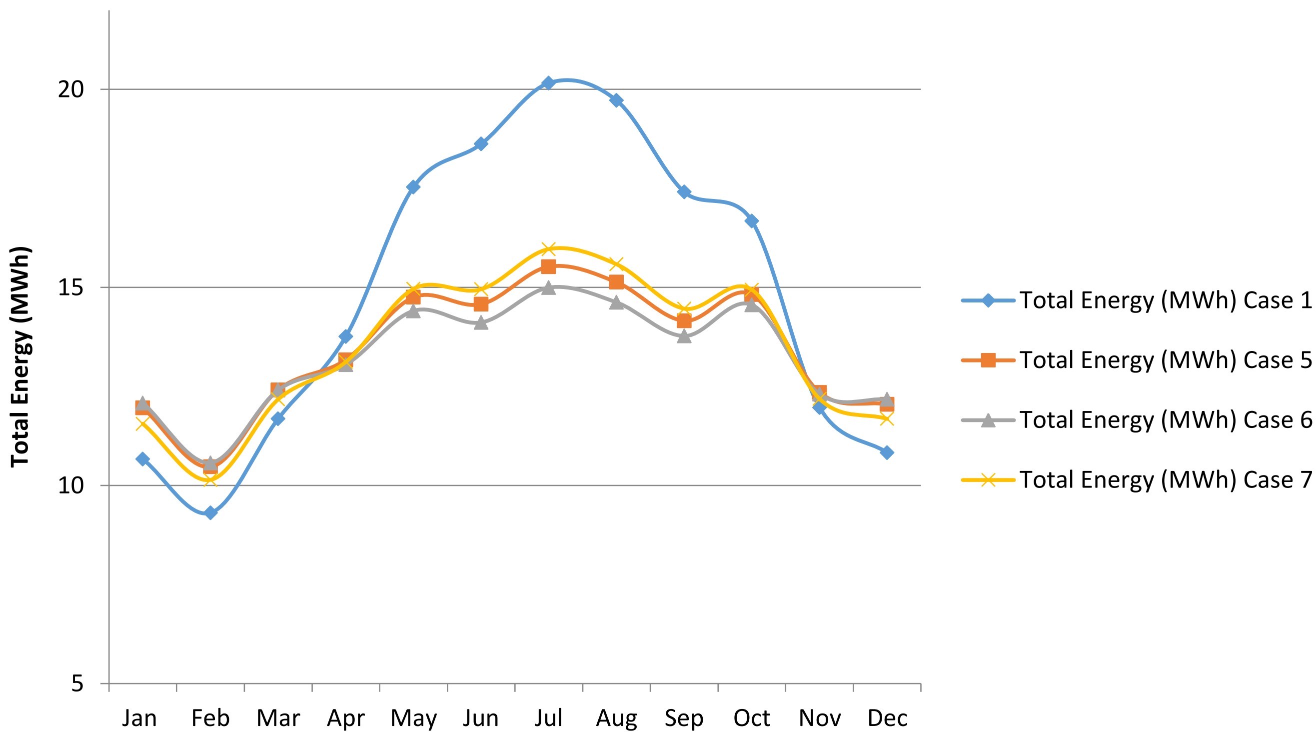


Figure 5.17: Compression between case 1, case 5, case 6 and case 7 Energy consumption (Source: IES <VE> & Author, 2014).

If it was a direct implementation, the scenario advised by case 6 is the best but it seems to be expansive because due to its special composition used in walls as mentioned in chapter 2, Figure 2.15 and 2.16 and will cause extra expenses for the ministry of housing to provide it for all the proposed housing units.

Carbon Dioxide emissions is a direct reflection to the energy consumption, thus the more energy consumed the more CO2 emissions will be associated. Comparing the CO2 emissions in the four cases, case 6 is the best in saving energy among all the other cases and similarly the best in reducing the CO2 emissions that represents approximately 10.8% reduction. Moreover, the chillier energy was reduced to its maximum in case 6 up to 21.5% when compared to case 1 as shown in Figure 5.18.

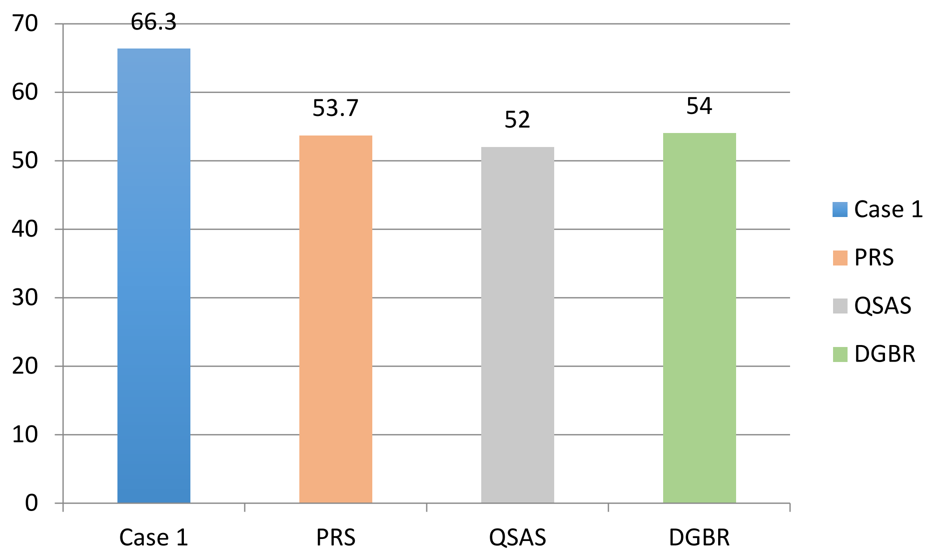


Figure 5.18: Compression between case 1, case 5, case 6 and case 7 Chiller Energy consumption (Source: IES <VE> & Author, 2014).

Last but not least, it's clear that replacing the building elements separately (wall, roof and glazing) as advised by Pearl Rating System (1 Pearl), QSAS and Dubai Green Building Regulations, will reduce the energy consumption, CO2 emissions and Chillier energy consumption. Also it was obvious that replacing the building envelope as wall, roof or glazing separately recorded reductions in energy, CO2 emissions and chillier energy. However, upgrading the wall only was the best way to achieve savings as shown in case 2A, 2B and 2C.

Therefore, the following section will present another three new scenarios that are based on the available construction materials in local Bahraini market but yet it has the high thermal properties. The three scenarios will focus on the wall-building envelope because its considered the main cause in enhancing the overall comfort.

5.11. Proposed upgrading scenarios: Based on the availability of materials in the local Bahraini market

This section will present three scenarios of upgrading the building envelope elements with the available materials in Bahrain market might is expected to be more economical due to the in sourcing of materials. The three scenarios will have a lesser U- Value of case 1 that has a 2.746 W/m2.K for walls, 0.530 W/m2.K for roof and 3.26 W/m2.K for glazing with a 30% of SHGC.

5.11.1. Case AA: Implementing ICF wall system and thermally insulated roof and glazing

This section will examine a new proposal of the entire building envelope composed from walls, roof and glazing with a minimum U-value for the wall as 0.29 W/m2. K, for the roof 0.44 W/m2. K and for the glazing as 1.69 W/m2. K with SHGC of 36%.

The Ministry of housing proposed the insulated concrete form wall system as shown in Figure 5.19. This system its described as forms made of block size staked on top of each other with a 100mm outer face and 50 mm inner face of wall thickness to be filled with lean concrete to form walls, window and door sides to be closed, foundation to be extended to parapet coping extended. The main advantage of this wall is having a very low insulating U-value that will leads to how cooling cost, while the main disadvantage is its initial cost as said by Al-Orrayedh (2014).

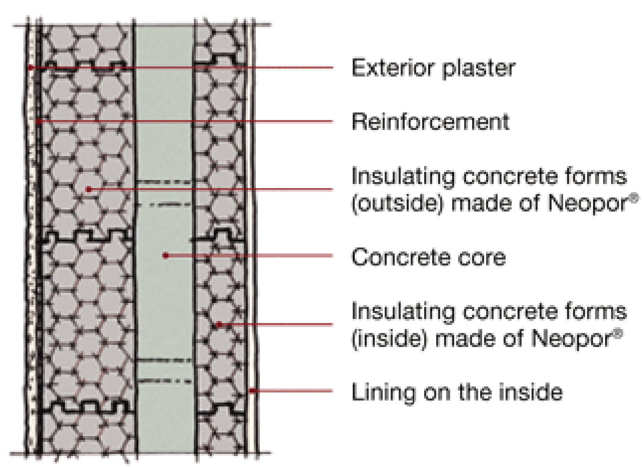


Figure 5.19: Insulated concrete form walls (ICE) (Source: BASF, 2013).

On the other hand, the proposed roof is kind of altered; it’s formed the following composition from out to in of roofing felt of 1.8 mm, screed of 100 mm. cast concrete of 300mm, cavity of 600 mm and the ceiling tiles of 50 mm. The roofing polymeric membrane is lacquer coated waterproofing and its characterised by being outstanding in resisting UV irradiation, has no risk of delimitation or water-wicking and its recyclable as mentioned in the Sanafil product data sheet (2012).

While the glazing was upgraded to be triple glazing composed of outer and inner pane of 6 mm and middle pane of clear glass of 4mm separated by 12 mm of both sides. The SHGC is almost 36 % that is more than the base line by 6%.

The simulation of case AA presents that total energy consumption is equable to (159.3 MWh) as shown in Table 5.16 that is between the total energy consumptions of case 6 and 5. In addition to that, The CO2 emission has recorded 82682 KgCO2 that is lesser than CO2 emissions in case 1 by 10.8 %. Similarly reduced the chillier energy 21.3 %.

Table 5.16: Case AA - Total Energy consumption compared to case 1, 5, 6 and 7 (Source: IES <VE> and Author, 2014)

	Total energy (MWh)	Saving %	Chillers energy (MWh)	Saving %
Case 1	178.4	0.0	66.3	0.0
Case 5	161.4	9.5	53.7	19.0
Case 6	159.1	10.8	52.0	21.6
Case 7	161.7	9.3	54.0	18.6
Case AA	159.3	10.7	52.2	21.3

The displayed results indicates that upgrading the entire building envelope and specially the wall thermal properties using construction materials from the local market in Bahrain can reduce the overall energy, chillier energy and CO2 emissions, the reduction in the overall energy and CO2 emissions is almost equal to 10.7 % and almost equal to case 6 that implement QSAS in the whole building envelope.

5.11.2.(Case BB): Implementing Cavity wall system and thermally insulated roof and glazing

This section will examine the same previous proposal but will only change the wall composition to a cavity wall block work that's filled with Polystyrene as shown in Figure 5.19. Therefore, the U-value for the wall will be 0.32 W/m2. K, while the roof and glazing remain the same as 0.44 W/m2. K for the roof and1.69 W/m2. K for the glazing with SHGC of 36%.

The cavity wall system as shown in Figure 5.20 is described as two layers of block work filled with a 50 mm Polystyrene. This wall is to be built externally all around with a tie bars every other layer. The main advantages of this system are having a continuous insulation all around with a low U value and it's easy to construct. However, it has several disadvantages such as additional area required for the walls and dampness that may accrue in the cavity. But yet it's considered a cheaper proposal as mentioned by Al-Orrayedh (2014).

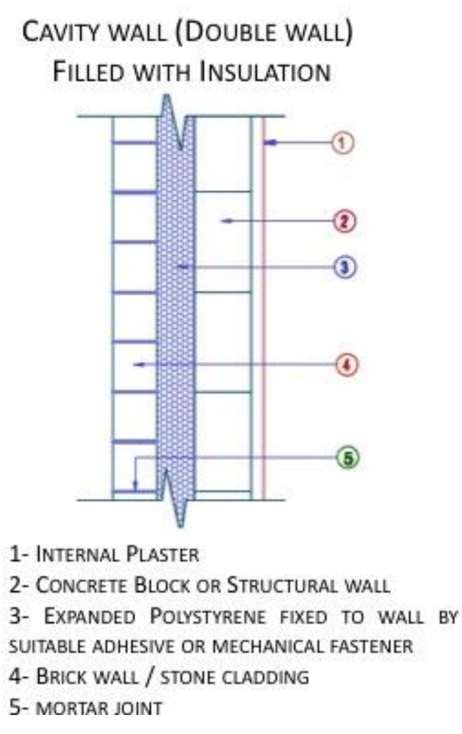


Figure 5.20: Cavity block wall filled with 50 mm polystyrene (Source: EWA, 2013).

The simulation of case BB presents that total energy consumption is equable to (159.75 MWh) that is almost equal to the energy consumptions of case 6 and case 2B. In addition to that, it reduced the energy and CO2 emissions 10.5 % and 20.8 % of the chillier energy when compared to case 1. However, case AA still saves 21.3 % that is slightly more in both energy and chillers as shown in Table 5.17.

From many recourses it has been noticed that this system will create an even temperature in your spaces, prevent condensation on walls and reduce the electricity bills which means that the housing unit is consuming less fuel to provide the energy and will be more sustainable and will consequently reduce the amount of CO2 emissions to the atmosphere.

Table 5.17: Case BB - Total Energy consumption compared to case 1, 2B, 6 and AA (Source: IES <VE> and Author, 2014)

	Total energy (MWh)	Saving %	Chillers energy (MWh)	Saving %
Case 1	178.4	0.0	66.3	0.0
Case 6	159.1	10.8	52.0	21.6
Case 2B	159.1	10.8	52.0	21.5
Case AA	159.3	10.7	52.2	21.3
Case BB	159.7	10.5	52.5	20.8

5.11.3.(Case CC): Implementing external insulation wall system with plaster and thermally insulated roof and glazing

This section will examine the same previous proposal but will only change the wall composition to an external insulation system with plaster. Therefore, the U-value for the wall will be 0.21 W/m2. K, while the roof and glazing remain the same as 0.44 W/m2. K for the roof and1.69 W/m2. K for the glazing with SHGC of 36%.

The external insulated wall shown in Figure 5.21 is mechanically fixed and its described as traditional constructed wall that is externally insulated by expanded polystyrene followed by a reinforcement glass fibber sheet and a polymer modifier renders from outside to inside. This proposal is based on international standard and the main advantage of this composition is blocking the thermal bridging with a very low U value of 0.21 W/m2. K and protecting the inner structure, also its easy to repair due to its arrangement among the wall layers. Furthermore, it improves that internal environment. On the other hand, the main disadvantage is that the owner may damage the wall system while renovation. This system is considered cheaper that the system proposed in Case AA but more or less equal to Case BB as mentioned by Al-Orrayedh (2014).

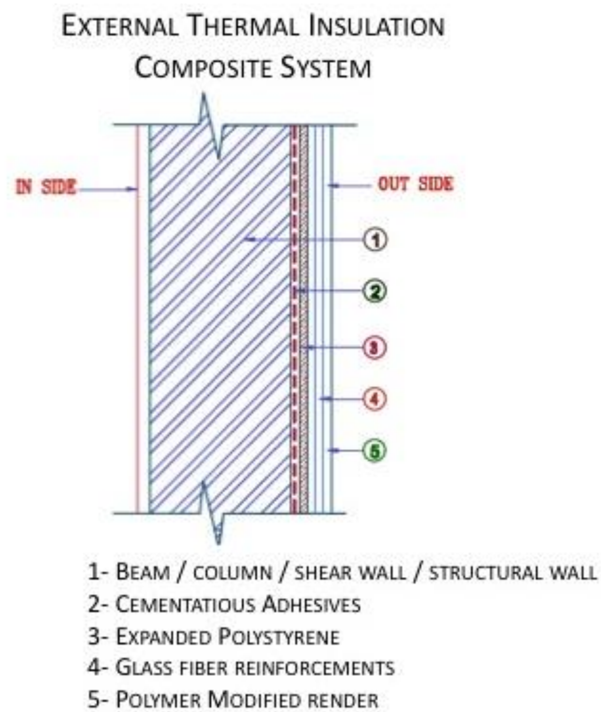


Figure 5.21: External thermal insulation composite system (Source: EWA, 2013).

The simulation of case CC presents that total energy consumption is equable to (159.1 MWh) as shown in Table 5.19 that is equal to the energy consumptions of case 2B. In addition to that, The CO_2 emission has recorded 120539 $KgCO_2$ that is lesser than CO_2 emissions in cases AA and almost equal to case 3 and case 5B. In addition to that, it reduced the energy and CO_2 emissions 10.8 % and 21.6 % of the chillier energy when compared to case 1. Saraiva (2013) highlighted that using the ETICS system for residential buildings in Bahrain could reduce the overall energy and chillier energy more than any other system. The results of this paper enforced that it's the best system when compared to the other scenarios. Table 5.18 will present a comparison between the cases that has more or less similar results compared to case 1 to express how powerful is the case CC that used the external insulation system.

Table 5.18: Case CC - Total Energy consumption compared to case 1, 2B, 5, AA, and BB (Source: IES <VE> and Author, 2014)

	Total energy (MWh)	Saving %	Chillers energy (MWh)	Saving %
Case 1	178.4	0.0	66.3	0.0
Case 2B	159.1	10.8	52.0	21.5
Case 6	159.1	10.8	52.0	21.6
Case AA	159.3	10.7	52.2	21.3
Case BB	159.7	10.5	52.5	20.8
Case CC	159.1	10.8	52.0	21.6

5.12. Proposed upgrading scenarios: Based on the availability of materials in the local Bahraini market: Discussion

From the above analysis it has been noted that upgrading the glazing in case 4A, 4B and 4C seems to be not comparable to the reduction in upgrading the walls in case 2A, 2B and 2C as well as the CO_2 emissions. However, case 2B was the best among the cases and able to reduce 10.4 % of the total energy and CO_2 emissions, as well as the chillier load have been reduced to 21.5 %.

Moreover, the proposed case CC using the external insulation system recorded a similar reduction in overall energy and CO_2 emissions to case 6 and 2B equal to 10.8 % but a slightly better reduction in saving the chillier energy up to 21.6% as mentioned in section 5.11.3.

Table 5.19 will express a summary of all the possible savings achieved in each case and from each factor such as reduction in total energy and chillier energy. The reduction in CO2 emissions is reflected in the overall energy that's why it will not be mentioned in the table.

Table 5.19: Total energy and chiller energy savings in all cases (Source: IES <VE> and Author, 2014)

		Total energy (MWh)	Saving %	Chillers energy (MWh)	Saving %
Base Case	**Case 1**	178.4	0.0	66.3	0.0
Wall	**Case 2A**	160.5	10.0	53.0	20.0
	Case 2B	159.1	10.8	52.0	21.5
	Case 2C	162.4	9.0	54.4	17.9
Roof	**Case 3A**	178.0	0.2	66.0	0.5
	Case 3B	178.0	0.2	66.0	0.5
	Case 3C	**178.2**	**0.1**	**66.0**	**0.5**
Glazing	**Case 4A**	175.8	1.4	64.4	2.9
	Case 4B	175.2	1.8	63.9	3.6
	Case 4C	174.7	2.1	63.6	4.1
PRS 1	**Case 5**	161.4	9.5	53.7	19.0
QSAS	**Case 6**	159.1	10.8	52.0	21.6
DGBR	**Case 7**	161.7	9.3	54.0	18.6
Proposed	**Case AA**	159.3	10.7	52.2	21.3
	Case BB	159.7	10.5	52.5	20.8
	Case CC	**159.1**	**10.8**	**52.0**	**21.6**

(yellow) Best Case for saving Total Energy and Chiller Energy savings

(grey) Worst Case for saving Total Energy and Chiller Energy savings

It's clear that the maximum energy reductions was achieved in case CC, where it is 21.6 % reduction in chillier energy and 10.8 % in total energy consumption and CO2 emissions.

Although the above results are rough outcome of studying one of the many prototypes of social housing units in Bahrain. It is considered as indicative study of the overall energy consumption and CO_2 emissions resulted from thermal performance of the building envelope. The study tested several building envelopes scenarios that have been applied in the GCC countries to understand and evaluate the possible savings that could be achieved from different scenarios.

The following chapter will present a set of recommendations for further studies in this research including the cost aspect and payback period. Furthermore, it will conclude the study via presenting the main important findings of this research.

Chapter 6
Conclusion

6.1. Overview

The kingdom of Bahrain has faced a rapid growth in the urban development during the past decades. Since 1960's Bahrain witnessed a major increase in population. Also the construction industry has been a very active sector in this country. Along with this rapid development, a huge growth rate in energy consumption was noticed and according to Radhi (2009 b) the residential sector accounted 54% of the total electricity energy consumption and CO_2 emissions in Bahrain. More over, the current and traditional construction techniques increase the electricity consumption due to the poor thermal properties for the building envelope elements – walls, roof and glazing – and consequently will lead to extra expenses on excessive use of energy to reach to the comfort level inside spaces and will also lead to negative environmental impacts for the long term. Similarly, some of the GCC countries such as the UAE and Qatar have established some green and sustainable building assessments that are based on international green building evaluating tools such as PRS, QSAS and DGBR. All the assessments tools and regulation aims to reduce the negative impacts on the environment.

The current situation of Bahrain and the lessons learned from the regional and international green buildings assessments triggered the question weather applying green building regulations learned from the gulf can significantly reduce the energy consumption and CO_2 emissions in the social housing units. Also if it can positively contribute to goals and achievements of the kingdom of Bahrain national vision 2030 that is based around three guiding principles; sustainability, fairness and competitiveness.

6.2. Conclusion

The research studied the residential urban development in Bahrain constructed by the Ministry of Housing and specifically in Hamad Town. As mentioned earlier in chapter 4 the ministry of housing is responsible of building several housing typologies that varies in area from 209 m2 to 442 m2 but yet responding to the traditional construction methods and materials used in Bahrain. Housing model T3M of gross area equal to 209 m2 is one of the most housing typology used in Bahrain for a standard low-income family. Therefore, it has been chosen as the case study for this research and to conclude rough findings of the possible saving that could be achieved. The study concluded the ministry of housing have started applying the green building regulations via insulating the roof for all the housing units but not the walls. However, they have applying the thermal wall insulation only on the multi storey apartment buildings as asserted by Eng. Al-Orraydeh (2013). Also it has been noted from Bahrain Municipality board (2012) that the thermal insulation is mandatory for all the building envelop but yet its not applied in all commercial buildings but yet its not applied in all the housing units in Bahrain that accounted to cover more than 50% of the entire building stock.

The research studied 15 building envelope scenarios of the same selected housing unit and upgraded its envelope thermal properties based on several green building assessments learned from the region and compare it against case 1 (As built in Bahrain). The first three group of cases were:

- Case 2A, 2B and 2C that upgrade the wall only as per PRS 1, QSAS and DGBR.
- Case 3A, 3B and 3C that upgrade the roof only as per PRS 1, QSAS and DGBR.
- Case 4A, 4B and 4C that upgrade the wall only as per PRS 1, QSAS and DGBR.

Followed by another three cases based on the regional green building assessments and regulations, which are:

- Case 5: As per PRS 1 (ESTIDAMA)
- Case 6: As per QSAS (Qatar)
- Case 7: As per DGBR (Dubai Green Building Regulations)

And then followed by another three proposed cases based on the available construction materials in Bahrain market, which are:

- Case AA: Implementing ICF wall system and thermally insulated roof and glazing at 0.44 W/m2. K and 1.69 W/m2. K.
- Case BB: Implementing Cavity wall system and thermally insulated roof and glazing at 0.44 W/m2. K and 1.69 W/m2. K

- Case CC: Implementing external insulation system with plaster for walls and thermally insulated roof and glazing at 0.44 W/m2. K and 1.69 W/m2. K.

It has been noticed from all the above cases that upgrading the wall is the best solution to reduce the total energy consumption as shown in Case 2B upgrading the wall system only as recommended by QSAS and remaining with the current construction of roof and glass in Bahrain. It reduces the total energy and CO_2 emissions up to 10.8%, while the chillier energy reduced up to 21.5 %.

Moreover, the result of case CC using the external insulation system with plaster, low roof and glass U-values reduced the total energy and CO_2 emissions up to 10.8%, while the chillier energy reduced up to 21.6 % that is equal to upgrading the wall as shown in Case 2B.

Furthermore, upgrading the entire envelope as recommended by QSAS showed in case 6 reduced the total energy and CO_2 emissions up to 10.8%, while the chillier energy reduced up to 21.6 % that is equal to upgrading the wall as shown in Case 2B and Case CC.

Finally, the study concluded that upgrading the walls thermal performance would achieve maximum reduction on both energy consumption and CO_2 emissions more than upgrading any other building envelope elements. Furthermore, the results of this study is an indicative study of one of the smallest housing prototypes in Bahrain and if it was applied on a large scale of housing urban development and even bigger housing units, national energy consumption and CO_2 emissions will be reduced, and consequently will reduce the total carbon dioxide foot print.

6.3. Recommendations for future research

In addition to the research done for one typology of the housing units provided by the ministry of housing, there are several opportunities for investigating different building envelop proposals to find out potential energy saving, cooling load reduction and CO_2 emissions reduction. Also it’s worth comparing the studied typology to another larger prototypes to understand the savings that could be achieved when having different wall to window ratio as well as larger are of solar gain through both walls and roof.

Furthermore, detailed economic feasibility study could be conducted to evaluate the additional associated benefits associated with upgrading the buildings envelope as the associated costs that are anticipated to increase the current overall cost of the housing unit and consequently increase the pressure on the national economy.

Finally, after having a full data of all the possible options of reducing total energy consumption and CO2 emissions, calculate the feasibility of the study its durability and ease of application. A set of Bahrain Green building regulation (BGBR) can be established and coordinated between the ministry of housing and municipality of Bahrain and afterwards will be officially published and used in all the upcoming housing units to fulfil one of the main goals of the national economical vision 2030 that is "Sustainable Life Style".

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APPENDIX A

ESTIDAMA APPROVED WALLS

APPENDIX B

CONSUPTION ANALYSIS OF INSULATED AND NON-INSULATED HOUSE (DATA SOURCE: EWA)

APPENDIX C

BAHRAIN CLIMATE INFORMATION