Assessing Energy Saving Potential in Existing Buildings in Abu Dhabi through Passive Retrofitting Strategies: Case Study –Office Buildings

تقييم إمكانية توفير الطاقة في المباني القائمة في أبوظبي من خلال استراتيجيات تحديث المباني: دراسة حالة للمباني التجارية

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ABSTRACT

The UAE as a leading country in the region has set goals to reduce CO_2 emissions by 2020 in line with Copenhagen Accord. However, the challenge is considered great since the UAE has been identified as one of the highest ecological footprint in the World in 2007. The future plans in the country invest heavily on sustainability frameworks and future plans such as Abu Dhabi Plan 2030. While the sustainability codes and regulatory frameworks have been recently developed in the country, the regulations are only applicable to minor percentage of the overall building stock. In general the new buildings represent only 0.5% to 2% of the total building stock. Therefore, sustainability guidelines for existing building refurbishment are considered to be critical to reduce the energy consumption in the built environment and associated CO_2 emissions.

This research has studied the existing urban development in the Emirate of Abu Dhabi, and identified the commercial buildings as a major contributor to the energy consumption in the capital, with almost one third of the total energy consumption being accounted for commercial uses. An additional 25% for governmental usage has common elements with commercial buildings, yet needs to be further detailed for their sub-categories. The paper has identified two building prototypes as representation of the existing commercial building stock for the periods from 1980-1989 and 1990-1999 and prior to the implementation of the Estidama pearl building rating system for new construction.

Computer modelling was used to assess the savings in electricity consumption, associated cooling loads, energy consumption, and CO_2 emissions for the selected 1980s prototype, with an indication of the annual electricity savings for a typical floor layout for a 1990s prototype. The 1980s case study of 17 stories building was modeled in three simulation models; typical floor, roof floor, and ground and mezzanine floors. Building simulations for each of the models were conducted to assess savings due to individual elemental refurbishment and combined scenarios considering upgrades to 1 and 2pearl rating thermal properties. The potential reduction in cooling loads for the overall building varies dramatically depending on the refurbishment application. For the upgrades to 1 pearl rating standard, the savings ranged from 0.21% in the case of roof, to 5.13% and 11.90% in the case of the wall and fenestration upgrades respectively. However, for the upgrades to 2-5 pearls rating requirements, the savings were estimated at 0.22% for the roof upgrades, 5.61% and 14.67 for the wall and fenestration upgrades respectively.

The study indicated that the savings achieved through refurbishment of the roof is negligible compared to that for the replacement of glazing due to the roof area being 6.4% of the building’s external envelope while the glazing forms 25.2% of the same. In this context, the glazing upgrades are considered the most efficient

solution. The study also concluded that individual elements of the building, and individual floors could be looked at for prioritized refurbishment strategy depending on the individual savings that could be achieved, easement of implementation, and economic feasibility.

Moreover, the study highlights that combined solutions achieve greater savings than when individual refurbishment applications are considered. The savings for the overall building are considered significant estimated at 18.90% and 22.12% for the 1 pearl and 2 pearls upgrades respectively.

Solar gain and external conduction gain analysis indicated that the elements behavior and specifically the external conduction gain profile varies for the various applications. As an example, the 2 pearl combined scenario has 0.0727 MWh less annual conduction gain than the sum of the individual scenarios.

The economic feasibility study indicated that the most feasible refurbishment solution for the building prototype of 1980s is for 2 pearls glazing upgrade, where 9 years payback period could achieve savings of 164.2157 MWhe of annual electricity consumption. However, it was noted that the highest savings for the combined solution in the case of 2 pearls upgrades would return its capital cost in around 16 years. The simple payback period calculations excludes the savings in government electricity cost subsidies, evaluation of building envelop performance upgrades such as humidity resistance, air tightness, aesthetical appearance, as well as future increases in the cost of electricity. It is expected that once all the benefits are quantified, the Simple Payback Period (SPP) analysis will result in reasonable timeframe for the owners to recoup their initial investment cost.

Finally, the research is concluded by extrapolating the annual reduction in electricity consumption to represent the savings across Abu Dhabi. For the 1980s, the implementation of a combined retrofitting scenario to 2 pearls rating requirements; is estimated to achieve annual reduction in electricity consumption of 18,433 MWeh/yr. Whereas, the refurbishment of the most economically feasible solution to upgrade the building glazing to 2 pearl rating standards, can achieve an overall reduction of 12,214 MWeh/yr. CO2 emissions reduction for the combined solution of 2 pearls rating is estimated at 9,530,968 KgCO2/yr.

Moreover, an indication of the typical building prototype upgrade for the period from 1990-1999 has indicated that the overall savings for Abu Dhabi for the 1990s buildings, when the glazing elements are upgraded, are 28,599 MWeH/yr and 20,152.MWeh/yr for the 2 pearls and 1 pearl rating respectively.

الملخص التنفيذي

لقد وضعت دولة الإمارات العربية المتحدة كدولة رائدة في المنطقة أهداف للحد من انبعاثات غاز ثاني أكسيد الكربون بحلول عام 2020 تماشيا مع اتفاق كوبنهاغن . ومع ذلك ، يعتبر هذا تحديا كبيرا حيث أن دولة الإمارات العربية المتحدة واحدة من أعلى دول العالم في البصمة البيئية في في عام 2007. الخطط المستقبلية في البلاد تستثمر بشكل كبير على الأطر الاستدامة و الخطط المستقبلية مثل خطة أبوظبي عام 2030. في حين أن رموز الاستدامة و الأطر التنظيمية قد وضعت مؤخرا في البلاد ، إلا أن اللوائح تنطبق على نسبة ضئيلة من الأسهم بناء الكلية فقط. بشكل عام تمثل المباني الجديدة 0.5٪ إلى 2 ٪ من إجمالي الأسهم بناء . وبالتالي، تعتبر المبادئ التوجيهية تحت نظام الاستدامة والتي تنطبق فقط على المباني الجديدة , غير فعالة لتجديد المباني الحالية و للحد من استهلاك الطاقة في البيئة المبنية وانبعاثات غاز ثاني أكسيد الكربون المرتبطة بها.

وقد بحثت هذه الدراسة التنمية الحضرية الموجودة في إمارة أبوظبي ، و حددت المباني التجارية باعتبارها مساهما رئيسيا في استهلاك الطاقة في العاصمة ، مع ما يقرب من ثلث الاستهلاك الكلي للطاقة التي تمثل الاستخدامات التجارية . بالإضافة إلى 25 ٪ إضافية للاستخدام الحكومية لديها عناصر مشتركة مع المباني التجارية ، ولكن يجب أن يكون أكثر تفصيلا للفئات الفرعية. وقد حددت الورقة نموذجين للمباني التجارية القائمة للفترتين من 1980-1989 و 1990-1999 و قبل تنفيذ نظام تصنيف المباني استدامة اللؤلؤ للبناء الجديد .

تم استخدام النمذجة الحاسوبية لتقييم التوفير في استهلاك الكهرباء و الأحمال التبريد المرتبطة بها، استهلاك الطاقة ، وانبعاثات غاز ثاني أكسيد الكربون في 1980s النموذج المحدد، مع الإشارة إلى توفير الكهرباء السنوي لنموذج 1990s . نموذج 1980s يتمثل في 17 طابق تم تمثيله على ثلاثة نماذج المحاكاة ؛ متكرر ، طابق السطح ، و الطوابق الأرضية و الميزانين . أجريت المحاكاة بناء لكل من نماذج لتقييم وتوفير بسبب تجديد عنصري الفردية والسيناريوهات مجتمعة النظر في ترقيات ل 1 و تصنيف pearl2 الخواص الحرارية . الانخفاض المحتمل في الأحمال التبريد لمبنى الكلية يختلف بشكل كبير عن تطبيق التجديد. للترقيات إلى 1 لؤلؤة تحت معيار التصنيف، تراوحت الوفورات من 0.21 ٪ في حالة السقف ، إلى 5.13 ٪ و 11.90 ٪ في حالة الجدار و النوفاذ على التوالي. ومع ذلك ، للترقيات ل 2-5 لؤلؤة بحسب متطلبات تصنيف اللؤلؤ ، قدرت الوفورات عند 0.22 ٪ لل ترقيات سقف ، 5.61 ٪ و 14.67 للجدار و النوافذ على التوالي.

وأشارت الدراسة إلى أن الوفورات التي تحققت من خلال تجديد السقف لا يكاد يذكر مقارنة بما كان عليه لاستبدال الزجاج نظرا لكون المساحة الطابقية للسقف 6.4 ٪ من الغلاف الخارجي للمبنى في حين أن الزجاج يشكل 25.2٪ من مساحة الغلاف الخارجي للمبنى. وفي هذا السياق، يعتبر تجديد الزجاج الحل الأكثر كفاءة. وخلصت الدراسة أيضا إلى أن العناصر الفردية للمبنى، و الطوابق الفردية يمكن النظر في استراتيجية لإعطاء الأولوية في التجديد اعتمادا على المدخرات الفردية التي يمكن تحقيقها ، تكاليف التنفيذ، و الجدوى الاقتصادية .
علاوة على ذلك، تسلط الدراسة الضوء على أن الحلول مجتمعة تحقق وفورات أكبر مما كانت عليه عندما يتم النظر في التطبيقات الفردية للتجديد . تعتبر مقدار الوفورات للبناء الكلي كبيرة تقدر بنحو 18.90 ٪ و 22.12 ٪ لؤلؤة 1 و 2 لؤلؤة على التوالي.
وأشارت الدراسة التحليلية لمقدار الطاقة الشمسية المكتسبة و الطاقة الخارجية المكتسبة عن طريق الغلاف الخارجي للمبنى, أظهرت أن سلوك العناصر و تحديدا الطاقة الخارجية المكتسبة عن طريق التوصيل الحراري يختلف عن حالة المبنى عندما يتم تجديده بالتطبيقات المختلفة في آن واحد. كمثال ، فإن المكاسب السنوية لسيناريو التجديد لمعايير 2 لؤلؤة لكل العناصر تقدر ب 0.0727 ميجاوات أقل من مجموع السيناريوهات الفردية.

وأشارت دراسة الجدوى الاقتصادية أن الحل الأكثر جدوى لتجديد النموذج بناء 1980s هو لمعايير 2 اللؤلؤ لتجديد الزجاج الخارجي، حيث أن الفترة المقدرة ب 9 سنوات كفترة الاسترداد يمكن أن تحقق وفورات بمقدار 164.2157 MWhe من استهلاك الكهرباء السنوية. ومع ذلك ،

لوحظ أن أعلى الادخار لسيناريو التجديد لكافة العناصر مجتمعة بحسب معايير 2 لؤلؤة سيعود بتكلفة رأس المال في نحو 16 عاما. ومن المهم التنويه إلى أن حسابات فترة الاسترداد بسيطة تستبعد الوفورات في تكلفة الكهرباء الناتجة عن الدعم الحكومية ، وتقييم الأداء من حيث الاستفادة المتعددة الأخرى للتجديد مثل مقاومة الرطوبة ، وتقليل تسرب الهواء ، والمظهر الجمالي ، فضلا عن الزيادات المستقبلية في تكاليف الكهرباء. ومن المتوقع أنه إذا ما تم تقييم كافة الاستفادات، فإن فترة الاسترداد ستحقق في إطار زمني معقول لأصحاب المباني لاسترداد التكلفة الاستثمارية الأولية.

وأخيرا، خلص البحث عن طريق استقراء الحد السنوي في استهلاك الكهرباء لتمثيل الوفورات في أبوظبي . ل s1980، و تنفيذ سيناريو التجديد لكافة العناصر مجتمعة بحسب معايير 2 لؤلؤة تحت متطلبات تصنيف نظام الاستدامة ؛ ويقدر بتحقيق خفض سنوي في استهلاك الكهرباء بنحو 18433 MWeh / سنة . في حين، تجديد الحل الأكثر جدوى اقتصاديا لرفع مستوى الزجاج بناء على معايير تصنيف اللؤلؤ 2 ، يمكنه تحقيق خفض إجمالي بنحو 12 MWeh،214 / سنة . ويقدر الحد من انبعاثات غاز ثاني أكسيد الكربون في حال تجديد جميع العناصر بحسب معايير 2 لؤلؤةمن تصنيف اللؤلؤ بنحو 9530968 KgCO2/yr .
وعلاوة على ذلك ، قدمت الدراسة مؤشرا على تجديد بناء النموذج الممثل للفترة من 1990-1999 للوفورات الكلية للمباني في أبوظبي إن الوفورات في مباني s1990، عندما تتم تجديد العناصر الزجاج ، هي 28599 MWeH / سنة و 20،152 .MWeh / سنة ل اللؤلؤ 2 و 1 تقييم اللؤلؤ على التوالي.

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CHAPTER 1: INTRODUCTION

1 INTRODUCTION

1.1 OVERVIEW

Climatic change has been globally recognized as a serious challenge. International agreements, conferences, and protocols have aimed to set mitigation measures to reduce CO2 emissions. In 2010, in a correspondence for the United Nations Framework Convention on Climatic Change, the UAE has announced their decision to being associated with the Copenhagen Accord (MoFA 2010). The accord targets reduction in CO2 emissions by 2020. However, the mitigation measures vary depending on the local sources of CO2 emissions within each of the participating countries. The source of energy and the rates in energy consumption directly related to the CO2 emissions released into the atmosphere.

Energy consumption in the built environment represents a great percentage of the total energy consumed in different sectors. The built environment is responsible for approximately 40% of primary energy consumption (Petersdorff et al 2010). It is also one of the major contributors to the greenhouse gases (GHG) emission, and heat island effect. Opportunities to conserve energy in buildings are very broad and can contribute to achieving highly efficient buildings.

In the UAE, the building construction sector has been an active and fast growing business for the past two decades. According to The UAE National Media Council (2010) the construction sector represented the second highest gross domestic product (GDP) growth in 2008. This continuous growth of the construction industry in the UAE has led to raised concerns of its impacts on the environment. The recognition of the sustainable development approach is relatively new in the Gulf region including the UAE. In this context, sustainable development is defined as “Development that provides people with a better life without sacrificing or depleting resources or causing environmental impacts that will undercut the ability of future generations to meet their needs.” (Richard & Dorothy 2011, p. 655).

The new trend in sustainable construction is a natural response to mitigate the environmental impacts of the building construction industry, especially since the UAE has been identified as the country with the highest ecological footprint per person worldwide on 2007 (WWF 2010). The ecological footprint is defined as “A concept for measuring the demand placed on Earth’s resources by individuals from different parts of the World, involving calculations of the natural area required to satisfy human needs.” (Richard & Dorothy 2011, p. 639).

In the UAE, the governmental agencies are playing a great role to mitigate the situation through building regulations that aim in reducing the environmental impact of the built environment. The UAE's commitment to reduce CO2 emissions in the near future are reflected in the sustainability frameworks in 2020 and 2030. A recent announcement in November 2013 has been to announce the first commercial Carbon capture and storage project in the UAE. The project is led by Masdar and ADNOC, and aims to reduce the CO2 emissions related to oil industry (The National 2013). All efforts with no doubts are targeting the achievement of a sustainable living in the future. In light of such efforts, and efforts to reduce energy consumption within the built environment, it has to be noted that even if the regulatory frameworks aims at developing a net-zero CO2 emissions for the new buildings, there will remain an excessive building stock with high energy consumption hence high Carbon emissions. Although the new sustainability standards and regulations targets new buildings, the existing building stock adds up only to a total of 0.5 to 2% of the total construction. Peacock et al (2008) & Langston et al (2008). Therefore, the building stock prior to implementation of sustainability and energy efficient building standards, remain a major contributor to the CO2 emissions. The only solution to mitigate this situation is by implementing building refurbishment strategies to energy consumption and associated CO2 emissions.

Many researches have been conducted on this regard, and shared knowledge on building refurbishment supports the idea that low-cost refurbishment applications can greatly benefit the existing structure, reduce CO2 emissions, and reduce reliance on renewable energy to offset the CO2 emissions released.

1.2 BUILDING REFURBISHMENT

Energy saving strategies include both active and passive techniques, and are applicable to both new designs and existing buildings. There are many aspects that were previously investigated under this subject; they include mechanical systems, thermal comfort, GHG emissions, economic feasibility, users' behavior, social aspects, standards and regulations. The list of parameters and related topics in which energy saving strategies could be approached seem endless, and are interlinked.

Many researches were conducted to investigate the strategies in which energy savings in buildings could be achieved. Refurbishment of existing building stock is envisaged as a mean of reducing CO2 emissions in the short to medium term, which makes it a preferable option compared to pure reliance on green energy sources. Sunikka & Boon (2003). According to Lockwood (Lockwood 2009 , p. 48), the US Green Building Council has identified green retrofitting as "any kind of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise—all done in a way that it is financially beneficial to the owner. Then, the building and its equipment must be maintained to sustain these improvements over time."

With the main target of reduction in energy consumption in existing buildings, the refurbishment process is applicable to most of the existing building typologies and uses including residential, commercial, governmental, healthcare, education, etc. he outcome from the refurbishment process, specifically those targeting energy savings, are of great importance for future governmental planning of construction of new power plants, management of existing and future energy demand, reduction of CO2 emissions, and reduction of peak loads across the country. The savings also impact the planning for future infrastructure utilities, and public services. There are many refurbishment strategies that could be implemented in existing buildings. However, the applicability, feasibility, and outcome of each strategy can vary dramatically. Prior to making decisions on which refurbishment strategy is to be implemented, a pre-assessment study helps identifying the feasibility and expected outcome of the technique. For example, in an office building, an improved Heating, Ventilation, and Air Conditioning (HVAC) system can achieve great savings in energy consumption but will be a costly application. Whereas, looking at improvements through passive techniques might achieve less saving in energy consumption but will be much more feasible.

Refurbishment for office buildings has been envisaged as the next big thing by Lockwood (2009). It has also been preferred over a complete redevelopment of an office building from an economic feasibility perspective as highlighted by Addy and McCallum (2012). Another research conducted by Anderson and Mills (2002) highlighted that refurbishment of existing office buildings has a reduced environmental impact over the building's redevelopment. The study indicated that the building redevelopment has increased impact over refurbishment of an air conditioned office building by 13-14%, and 20% for naturally ventilated offices. The environmental impact estimated includes 40-50% embodied energy.
However, there are constrains that usually are considered as limitations for any refurbishment process for an office building. Rhoads (2010) has identified the unavailability of capital cost and lack of incentives as the financial related limitations to the refurbishment process. Moreover, the limitations in technologies and its implementation process applicable to building refurbishment could contribute to the restrictions of application. Another aspect related to enforcement of policies and regulatory frameworks for building refurbishment.

1.3 THE IMPACT OF PASSIVE REFURBISHEMENT

Passive design has been an integrated design approach for decades. The passive design is a regionally responsive design that responds to the climatic conditions by minimizing heat gain, heat loss, maximizing natural ventilation benefits, and natural daylight. Similar to the approach in the new buildings, passive refurbishment techniques follow the same concept for existing buildings. Passive refurbishment strategies include upgrades in thermal performance of building envelope, minimizing thermal bridging impact, maximizing benefits from shading devices, optimizing natural daylight, etc. Whereas active refurbishment strategies targets upgrades in mechanical building systems, such as upgrades in HVAC system which seems to be one of the most common active retrofitting techniques. Others include integration of Building Management Systems (BMS).

Passive refurbishment strategies aim at increasing building performance with no or minimal use of energy after installation, whereas active strategies are usually requires or produces energy. The cost associated with any of the refurbishment strategies shall be carefully selected. Prior to making decisions on which refurbishment approach is feasible, it is important to analyze the existing conditions of the building to be retrofitted. Based on the current conditions, the building can be categorized into any of the four levels of refurbishment as identified by BRE (2002) based on their actual conditions at the time of assessment. The four levels of refurbishment are categorized based on levels of interventions required, as following;

- Level 1: requires minimal intervention such as addition of internal blinds, repainting of the building interior, replacement of low-energy IT solutions
- Level 2: is an intermediate level of refurbishment beyond what is identified in the previous level. This level is expected to incorporate lighting and systems control integration or replacement
- Level 3: represent major refurbishment applications such as raising floors, external walls, addition of external solar applications, etc.
- Level 4: is when the building requires demolition or redevelopment due to very poor conditions.

For passive refurbishment strategies, the applications might range between any of the three intervention levels. However, the reduction of environmental impact of the building is considerable. For example, upgrading thermal insulation of the building envelope can reduce cooling loads by 26% as highlighted by a study conducted by Hiroshi et al (2006) in Shanghai. Another study on office buildings in Malaysia, has indicated that a strategy as simple as increasing the air conditioning temperature set point is a costless strategy that can achieve up to 24% savings if the set point in increased by 4° C compared to the base case of 22° C (Saidur 2009). Another study in the UAE highlighted that upgrades in thermal performance of building envelope and glazing in residential villas can achieve up to 37.2% reduction in cooling loads. (AlNaqabi *et* al 2012).

1.4 SUSTAINABLITY STANDARDS FOR EXISTING BUILDINGS

Countries around the World have already established sustainability rating systems that aim to reduce the environmental impact of the buildings. Such rating systems like Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), and Green Star are used as tools to assess the sustainability aspects of the building during the design and construction stages. However, recently emphasis has been to minimize environmental impact of existing buildings during operation stages. For example, LEED Existing Buildings +n Operation and Maintenance (LEED EB+OM) sustainability rating system has been introduced by the US Green Building Council as a rating system that addresses the operation and maintenance of the existing buildings. LEED stands for Leadership in Energy and Environmental Design, the rating systems established by USGBC set measures to design, construct, and operate a sustainable development both on building scale and urban development scale (USGBC 2013).

The UAE as a young country, however, has only introduced green building regulations recently. The Emirate of Abu Dhabi introduced the Estidama Pearl Rating System; which is a green building rating system; and enforced mandatory requirements on all new buildings since 2010. Estidama provides three sustainability tools targeting the villas, building, and large developments. The Pearl systems corresponding to these three tools are Pearl Villa Rating system, Pearl Building Rating System, and Pearl Community Rating System. The Pearl Building System is used for several building uses i.e. offices, multi-residential, retail, school, and mixed use buildings. The Pearl Rating System is used to rate the developments from 1 to 5 pearls, where 1 pearl rating is mandatory for all developments, and 2 pearls are mandatory for all governmental buildings. This research will use the Pearl rating system standards.

Although the green building regulations were made mandatory, such regulations target new buildings only, whereas the larger stock is represented in the existing buildings. The lack of policies and sustainability standards for existing buildings in the UAE, and the limited research addressing energy savings through building refurbishment, have triggered this research.

1.5 AIMS AND OBJECTIVES

The study primarily focus on identifying existing building typologies of commercial buildings in Abu Dhabi, which represent the development in construction methods, material use, architectural style which influence the behavior of the building in terms of energy consumption and thermal performance parameters.
The building prototype shall be assessed against several retrofitting scenarios to investigate an effective yet economically feasible strategy to upgrade the existing building stock to reduce energy consumption. The research investigates the upgrades in thermal performance of building envelope.

AIM

The purpose of the study is to explore the potential of energy savings by retrofitting existing buildings in Abu Dhabi Metropolitan through passive design techniques with main focus on commercial buildings.

OBJECTIVES

The objectives identified for the study include the following:

- To assess the energy consumption in the existing commercial buildings in Abu Dhabi
- To identify sample building typologies corresponding to the evolution of construction practices and building regulations in 1980s & 1990s
- To understand the chronological development in building construction and its relation to energy consumption and CO_2 emissions

- To explore the impact of retrofitting existing buildings through passive techniques on energy savings and CO_2 emissions reduction. The passive techniques include;
  - Upgrade of thermal insulation for the external walls, for two different wall sections U-value
  - Upgrade of the thermal insulation for the roof, for two different roof sections U-value
  - Replacement of the glazing materials, for two different glazing solar heat gain coefficient and U-value
  - Combined Solutions

- To assess the feasibility and economic viability of the retrofitting process through simple payback applications
- To assess the refurbishment impact on the total existing building stock represented by the studied typology. This aims to allow for policy makers to understand the estimated energy savings on a large scale.

1.6 RESEARCH OUTLINE

This research is presented in six main chapters, supported by 5 appendices. The following is a brief description of the content for each of the chapters.

The first chapter:
This chapter is an introductory chapter that provides an overview of the major topics addressed in the research in general terms. The chapter is concluded by listing the research aims and objectives.as well as outlining the research paper.

The second chapter:
The literature review provides detailed study of the previous researches conducted to assess potential of energy savings in existing buildings through buildings refurbishment. The chapter also identifies the energy consumption pattern in the UAE, then identifies the major sectors within the built environment which highly contributes to the energy consumption in the country. The chapter then reviews the existing building stock in Abu Dhabi, and analyze the construction development to identify representative prototypes for commercial buildings in the 1980s and 1990s.

The third chapter:
This chapter identifies the various research methods related to this topic, and compares the method to identify the most relevant research method within the context of this study. The chapter then presents the preferred research methodology and discusses the relevant tools. The chapter also presents a comparison between building simulation tools, and provides a validation of the selected tool. A summary of the research methodology for this study is then concluded.

The fourth chapter:

The fourth chapter presents the case study, the simulation data input, and the simulation method. The chapter also provides an identification of the user validation for the case study, The simulation scenarios are also presented in details.

The fifth chapter:

This chapter presents the results concluded from the research and provides a critical discussion of the results. The chapter highlights the results for cooling loads energy, and CO_2 emissions of the studied models. It also highlights the solar gain and external conduction gains associated with each of the scenarios. The chapter then presents an economic feasibility study of the refurbishment solutions, and then is concluded by magnifying the result on a larger scale to represent the saving in Abu Dhabi.

The sixth chapter:

This chapter is considered the final chapter within the research, which presents the conclusion of this study and recommendations for future studies.

CHAPTER 2: LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 OVERVIEW

Energy consumption in the built environment represents a great percentage of the total energy consumed in different sectors. The built environment is responsible for approximately 40% of primary energy consumption (Petersdorff *et* al 2010). It is also one of the major contributors to the greenhouse gases (GHG) emission, and heat island effect. Opportunities to conserve energy in buildings are very broad and can contribute to achieving highly efficient buildings.

Many researches were conducted to investigate the strategies in which energy savings in buildings could be achieved. Energy saving strategies include both active and passive techniques, and are applicable to both new designs and existing buildings. There are many aspects that were previously investigated under this subject; they include mechanical systems, thermal comfort, GHG emissions, economic feasibility, users' behavior, social aspects, standards and regulations. The list of parameters and related topics in which energy saving strategies could be approached seem endless, and are interlinked.

This chapter presents the literature review and collected data which leads to the identification of the existing gap and highlights the opportunities for investigations in this field. First, the chapter discusses previous researches conducted to estimate energy savings through various refurbishment strategies with focus on passive techniques over active strategies. Then, the chapter presents the current status in the UAE and primarily in Abu Dhabi to identify the existing building stock, building typologies, and construction methods. The chapter is concluded by identification of the problem statement and setting the aims and objectives of this research in light of the collected data.

The following section highlights the outcome of previous studies conducted in this field to investigate potential energy savings through building refurbishment techniques. The studies cover different climatic conditions, different building typologies, and both direct and passive retrofitting techniques.

2.2 ASSESSMENT OF REFURBISHMENT STRATEGIES THROUGH PREVIOUS STUDIES

There are many refurbishment strategies that could be implemented in existing buildings. However, the applicability, feasibility, and outcome of each strategy can vary dramatically. Prior to making decisions on which refurbishment strategy is to be implemented, a pre-assessment study helps identifying the feasibility and expected outcome of the technique. For example, in an office building, an improved Heating, Ventilation, and Air Conditioning (HVAC) system can achieve great savings in energy consumption but will be a costly application. Whereas, looking at improvements through passive techniques might achieve less saving in energy consumption but will be much more feasible.

Following is a summary of selected previous studies conducted to assess potential of energy savings in existing buildings. The studies cover building typologies ranging from low-rise residential buildings to office buildings and high rise commercial buildings. The selected studies mainly focus on cooling strategies; however few addressed the implications during heating days. The literature review below categorizes the reviewed studies according to the refurbishment systems investigated being passive techniques or active techniques.

2.2.1 PASSIVE STRATEGIES

Passive design strategies can be used to reduce energy consumption not only during the early design stages, but also can be employed to achieve energy savings in existing buildings. Techniques such as upgrading building glazing, thermal performance for walls and roof, using shading devises, using various window typologies, the use of natural ventilation, and many other strategies have been tested by researchers for various building typologies, and different climatic conditions.

A study conducted by Gugliermetti & Bisegna (2007) investigated the potential energy savings in residential buildings and small office buildings in five different cities in Italy, representing the Mediterranean climate, due to the integration of reversible windows. The study highlighted that previous studies undertaken on the same topic did not take into consideration the occupants' thermal comfort and the cooling loads in summer. Another aspect of the study is considering overheating effects in winter due to heat gains through the reversed window system. Previous studies were conducted for different building properties in relation to winter overheating, but those did not explore the reversed window system specifically.

The reversed window system suggested in the study has one clear pane, and another reflective one, and the system allows the window to be closed on both ways. The study investigated the impact of thermal properties and the reflectance of different glazing materials and systems. In order to estimate the energy savings using the reversed window system, the paper defines several scenarios of heating, cooling, and glare control strategies in which occupants contribute to the control system such as openings. The strategies include natural ventilation, shading devices (external shutters and internal curtains), forced ventilation, and mechanical HVAC systems.

The results of this study have highlighted that reversible windows system can contribute to energy savings in the residential buildings and small offices located in Mediterranean climatic conditions. The reflective pane is always facing the warmer environment, in other words the reflective coat is external in summer, and internal in winter. The potential for energy savings depend on the techniques used to mitigate the overheating that occurs in winter. While energy savings are less in buildings located in colder winters due to use of natural ventilation to overcome winter overheating problem, the mechanical ventilation reduces the savings in warmer winters.
Also, it has been indicated that both the reversed window system utilized for both east and west facades increases the energy saving by 10%-15% compared to the south facing windows.

Another study was conducted on a case study of a conventional design of a residential building in Spain where the study investigated energy savings through passive strategies. Ruiz & Romero (2011) recommended several passive strategies for both reducing heating and cooling levels. Energy savings of a combined solution has been estimated to be 13% of the original building design.

The paper has analyzed the context of the building and listed its characteristics and features. Then simulated two groups of passive strategies, the first group included the heating strategies running one simulation for each strategy same has been performed for the cooling strategy.
All results were compared to the basic model which reflects the conventional design
Final model has been recommended using the most appropriate at all strategies, those were changing building orientations to south, increasing glazing area to 20% at both the north and south facades
Adding a 35 cm framings to the windows and adding a 2 cm XPS CO2 expendable polystyrene insulation to the external walls. The cost analysis has indicated that minimal costs are added to the conventional design to achieve the energy savings of 13%.

On a different level, a study was conducted to assess the potential of energy savings on a large development scale, under an initiative by the US Environmental Protection Agency (EPA), which was launched to measure the contribution of the heat island reduction (HIR) techniques. This initiative led to the conduction of a pioneer project named the Urban Heat Island Pilot Project (UHIPP) taking into consideration five cities within the United States. The project realized the urbanization's great role in the increase of carbon emissions and the heat island effect. This study, conducted by Akbari & Konopacki (2005), is perceived as a continuation of the previous studies, and expanding the HIR strategies assessment to include all the states.

The study identified building prototypes for residential, office, and retail buildings both for the pre 1980s buildings, and post 1980s taking into consideration both electricity and gas systems. The study assessed energy saving potential through considering three sets of strategies;

- Direct HIR strategies, i.e. reflective roofs, and trees for shading;
- Indirect HIR strategy which consider the urban setting in terms of the use of reflective materials in paving and buildings, as well as increase in vegetated surfaces; and
- A scenario considering a combination of indirect and direct HIR strategies
  Energy savings were presented in relation to the heating-degree-days, and cooling-degree-days (HDD, and CDD).

The results of the study have indicated that the direct HIR strategies contribute to more than three quarters of the energy savings for all buildings. They also indicate that the highest potential for energy savings in a gas-heated building is in residential typology with a maximum of 25% savings for pre 1980s, and 20% for post 1980s.The highest savings in peak electricity demand is in the office buildings typology which is estimated to be a maximum of 1.0 kW/1000 sq.ft for pre-1980s buildings, whereas both the residential and office buildings has a maximum savings of 0.4 kW/1000 sq.ft for post-1980s buildings.

2.2.2 COMBINED PASSIVE AND ACTIVE STRATEGIES

Another research addressed an office building typology, with focus on passive strategies to achieve reduction in energy consumption. In Malaysia, Saidur (2009) conducted a study to assess the potential of energy savings in office buildings by calculating energy intensity, global warming gas emissions, and economic viability of the suggested energy saving strategies. The strategies include: upgrading building insulation, improved glazing system, use of compact fluorescent lamps (CFL), adjusting the temperature set point for the air conditioning system to a higher temperature, as well as savings by higher efficiency electric motors. It has to be noted here that energy savings and emissions have been calculated for high-efficiency motors (HEM), and the variable speed drives (VSD) at different operational loads. The economic viability has also been estimated through calculating the expected payback periods of the strategies. The study used extensive database provided by the Malaysian Energy Center (PTM) collected through energy auditing for 68 office buildings.

As part of the study, the results have been compared to other countries where several researchers have conducted similar studies. This is perceived not only as comparison of the energy consumption and emissions, but also it is a validation to the research methodology conducted since the results were similar to those from Thailand which has similar climatic characteristics.

The results of the study have indicated that air conditioning is the highest energy consumer among building appliances and equipment, followed by lighting system, lifts and pumps, and others which are represented by the following percentages respectively: 59%, 19%, 18%, and 6%. Also, it has been indicated that both the CFL fixtures, and upgrading building insulation are cost effective measures with an estimated payback period of less than 33% of the product life span. A strategy such as increasing the air conditioning temperature set point is a costless strategy that can achieve up to 24% savings if the set point in increased by 4° C compared to the base case of 22° C. Moreover, the study concluded that the utilization of the HEM and VSD are considered economically viable.

Another study conducted on an auditorium building typology highlighted the potential of reducing cooling loads up to 70% of the building's original status. The study, conducted by Flores *et* al (2008), investigated the integration of passive design strategies to achieve a better thermal performance hence reduction in energy consumption with minimal addition to the conventional building costs. It was conducted on an existing auditorium building in Santa Rosa, Argentina. Based on this study, an improved design of the same building is to be constructed in a different location in Argentina. The new design is to consider several passive solar strategies for energy savings while maintaining minimal additional costs. A comparison between the original design and the modified one is conducted. In order to validate the results on the ground, field measurements were taken.

A study was conducted on the first project - an auditorium building in Santa Rosa- in winter to understand the thermal behavior of the building. The building heating and cooling strategies included building insulation, double glazed openings, heating system with controls for heating degree-days, natural ventilation, glazing areas, and thermal capacity for cooling season. The researchers measured the outdoor climatic conditions, and the dry bulb temperature inside the building through field measurements.

The assessment on the first model was based on building parameters and data including; outdoor temperature, solar irradiance on horizontal surface, building parameters and properties, site, building materials, and building orientation. The results indicated general thermal satisfaction except where great differences in temperature between the coldest and warmest spaces within the auditorium occur, as it gets colder in higher levels. The study recommended to reduce the heating loads required through passive techniques while avoiding the overheating effect in summer.

Based on the first project, another auditorium building is to be designed in a different city – General Pico- which has a warmer winter but has higher cooling loads in summer. The base model is simulated exactly as the first project built in Santa Rosa, but then was modified to reduce energy consumption for both heating and cooling loads. For heating, the modified design used both solar air collectors and glazing areas for solar heat gains. The model indicated overheating in Summer, therefore, cooling strategies were incorporated. Those include natural ventilation, shading, insulation, paint color, and vegetation, as well as a cooling system. The simulation indicated 70% reduction in cooling loads.

After the second project was built and in order to validate and compare the results, the field measurements were taken for the modified design after construction. The measurements were taken in winter –unoccupied building- and summer –fully occupied building. The measurements indicated a success in terms of reducing the vertical differences in temperature to only 1°C within the building. In summer, the average temperature is about 23°C which is within the comfort zone. The cooling system is required to perform in the extremely hot summer days.
The new design achieved around 50% reduction in heating loads due to improved envelope insulation, direct and indirect solar heat gain, and air collectors. Another 70% reduction in cooling loads was achieved during summer time.

A study by Ehsan *et* al (2012) investigated the provision of an optimized solution for retrofitting buildings in terms of cost efficiency and energy savings. The authors recognize the complicated inter-linked nature of the problem where multi aspects contribute to the overall performance of the building. The researchers reviewed several optimization solutions including cost-benefit analysis, multi-criteria analysis, multi-objective optimization, and energy rating systems, and therefore decided to approach the problem by applying a multi-objective optimization model. The problem was approached by presenting the multi-objective optimization model, then applying the model to an existing residential building in Portugal constructed in 1945. A list of building refurbishment strategies have been presented comparing the implementation costs vs. the energy savings obtained.

The study has taken into consideration four variables for retrofitting strategies which are different solar collectors, alternative insulation of building materials for walls and roof, and alternative window properties. The calculations have considered each strategy separately for simplification of equations. It has to be noted also that the equations used to calculate energy consumption for heating purposes took into consideration 26 parameters, while 6 were considered for cooling, and 5 for domestic hot water. Thermal performance and energy consumption of the base case model before applying the retrofitting strategies has been calculated using the Portuguese building thermal model (RCCTE) which did not take into consideration energy consumption by lighting systems.

The results of the study have emphasized that the application of a multi-objective optimization model on a residential building in Portugal has a non-linear relationship, where it is critical to study the deviation of implementation costs vs. energy savings for the various retrofitting actions, i.e. the cheapest implementation cost presented in the study was around 1791 € with about 15,263 kWh/year energy savings, whereas a one level advanced retrofitting strategy would cost about 1834 € with about 20,229 kWh/year savings.
Such a study provides decision makers with a good insight to establish a criterion for selection of an optimized building retrofitting scenario without compromising the cost efficiency of the solution.
The study has also recommended a further development to similar optimization model that would take into consideration other factors related to indoor environment such as thermal comfort, and air quality.

On a different aspect, a research was conducted to evaluate efficiency of design strategies in energy savings for different climatic zones, with focus on comparison on thermal performance in temperate-humid and hot-dry climate. Similar to the studies conducted by Gugliermetti & Bisegna (2007) and Ehsan et al (2012), the study addressed thermal performance of the building envelope. Building envelope is one of the major building elements which contribute to energy consumption due to heat transfer. The study indicated that a one level upgrade in refurbishment solutions although of around 2.5% increased cost would result in 32% additional annual energy savings.

Another study conducted by Yilmaz (2007) investigated the thermal behavior of the building envelope in terms of the walls U-value and thermal storage characteristics. In order to emphasize the importance of considering both parameters, the study considers two different climatic zones which are the hot-dry, and the temperate-humid climates. A typical living room in a residential building with same orientation has been selected in two different cities in Turkey, one in Istanbul which has temperate-humid climate, the other in Mardin which has hot-dry climate. Three different wall compositions have been analyzed, wall 1 and 2 has the same U-value, whereas wall 3 has almost three times higher U-value but is a thick masonry wall.
The calculations indicate that although the U-value is the same in wall 1 and 2, their thermal behavior is different. What is more important to note is that the traditional masonry wall which has higher U-value is more suitable for hot-dry climate because of its high thermal mass property.

The researcher also addressed the problem in two case studies in Mandrin using experimental method. Field measurements were taken for two rooms in each of the two residential buildings. One building is a traditional 17th century building –Mungan house, the other is a modern building –Demir House 1990- that applied the Turkish Standards TS 825, Heating Energy Conservation Standard for Building in Turkey.
The field measurements were taken hourly for rooms of same orientation, and measured the temperature in several points. The first set of measurements showed the differences in temperature in the rooms for the traditional and the modern houses, as well as the overheating problem in summer for the modern house.
A second set of measurements were taken hourly for a third room, which measured the air temperature, wall surface temperature, and humidity level. The purpose of this study is to study of the contribution of thermal mass in the design. The results indicated that the indoor temperature is almost even throughout the day and night due to the high thermal capacity of the traditional wall.

As a final step, a questionnaire was conducted for the residents in both traditional houses and modern houses in the city to study their perception in terms of thermal, visual and air quality aspects. The survey included 68 traditional houses, and 32 modern ones. The questionnaire consisted of 36 questions with answered scaled in five points from being cold to being hot. The results of the survey supported the results of the experimental study.

In conclusion, the paper indicated the importance of thermal mass concept over the U-value characteristics in hot-dry climate. As well as highlighting that although the degree-day concept specified both Istanbul and Madrin within the same climatic zones, the cities do not have the same climatic characteristics. Therefore, the application of the TS 825 standards for both cities is not the best decision for energy conservation.

Further to the studies highlighted above, another study was conducted in China addressing upgrading of building insulation as one of the effective solutions to reduce energy in existing buildings. A combination of active and passive strategies, however, has proven to be efficient and achieve reductions in annual load up to 40% and 67% in Beijing and Shanghai respectively. The study conducted by Hiroshi *et* al (2006) addressed the thermal quality of the indoor environment in the urban areas within the residential sector. A three layered study approach was developed which included a questionnaire survey, experimental method, and mathematical method. Both the questionnaire and the field measurements were conducted for 8 cities in China representing the different climatic zones in china. The cities included: Harbin, Urumqi, Beijing, Xian, Shanghai, Changsha, Chongqing, Kunming, and Hong Kong. The survey period ranges from 1998 till 2004, included a total of 810 houses for questionnaire survey, and 76 for field measurements.

The questionnaire was based on a questionnaire model previously developed for a study in Japan. The survey meant to collect data related to building characteristics, heating periods, operation time for heating/ cooling systems, clothing types, and so on. The questionnaire was distributed to different social classes in the different cities, including pupils and their families, middle class families, and high class families. Along with the questionnaire, the families were provided with two liquid crystal thermometers, and were asked to measure the temperature in the living room and the bedroom, for five days, three times a day. Another set of field measurements were conducted to measure indoor and outdoor temperature, as well as humidity levels.

The results were discussed for winter and summer seasons based on the conducted survey. The results were summarized for eight parameters including buildings year of construction, building height, floor area, heating/cooling systems, operation periods of heating/cooling systems, peak heating/cooling periods, temperature differences between the outdoor and indoor living room and bedroom temperatures, and the relation between the clothing factor and the room temperature.

The results of the experimental study was summarized for the eight cities indicating the thermal comfort levels using the psychrometric chart compared to the ASHRAE thermal comfort definition. The results were also summarized to indicate the variation in indoor temperatures and humidity levels for three cities in winter: Urumqi, Changsha, and Chongqing, and for Shanghai and Hong Kong in summer.

Based on the data collected from the questionnaire survey, and the field measurement, as well as weather data previously developed by ZHANG, mathematical calculations were used to estimate the heating and cooling loads for a model apartment both in Shanghai, and Beijing. The calculations were conducted for a base case model for both cities, and then developed cases 2 to 11 with several energy saving techniques including building insulation, increased ventilation, and shading by a balcony element, as well as a combination of several cases. In Beijing, the thermal insulation contributes to a maximum of 26% reduction in annual loads, whereas the reduction of air exchange rate contributes to a maximum of 28.4% savings. The shading through balconies was not an effective strategy. The combination of the best strategies contributes to total savings of 40% in heating and cooling loads. In Shanghai, thermal insulation tends to increase the cooling loads, whereas reduction of air exchange rate contributes to a maximum of 13.1% reduction in annual loads. With regards to shading by balcony, higher savings occur in summer but the overall annual reduction is estimated to be 1%. The combination of the strategies contributes to about 67% reduction in annual loads.

2.2.3 ACTIVE SYSTEMS

A research conducted in Hong Kong to assess potential of energy savings in existing high rise commercial buildings representing 15% of the total building stock. The study indicated that this sector contributes to around 60% of total energy consumption in buildings, and that the Mechanical Ventilation and Air Conditioning (MVAC) system is the major contributor of the energy consumption. This research conducted by Philip & Chow (2007) addressed the direct refurbishment techniques to improve building energy efficiency. The strategies included the following areas: enhancements in chillers, mechanical ventilation system, fresh air delivery, optimization of airside systems, increasing temperature by 2° C, integration of interior shading, and

Geothermal Heat Pump (GHP) system. With regards to the active systems, the findings of the research were positive as it concluded that major reduction in energy consumption within existing high rise commercial buildings could be achieved as following; The low-temperature air distribution system reduces the MVAC electricity consumption by 27%; GHP system reduces the total energy consumption of the building by 17% compared to the baseline model, at the same time the reduction of 31-41% of the peak MVAC load and peak building demand can be dropped by 31-41% respectively.

In conclusion, the study investigated the different heating and cooling systems within the eight cities for residential buildings. It also investigated the users' contribution to the thermal environment, whether it was by opening the windows for cooling, the pattern in which they operate the mechanical systems if existed, their clothing patter, and so on. Also, the study suggested economical energy saving strategies applicable for residential apartments in Beijing and Shanghai.

In addition to the research conducted globally to assess the potential of energy savings in existing buildings through refurbishment strategies and their economic feasibility. The following section aims at investigating the case of the Emirate of Abu Dhabi, the energy consumption in the built environment, Abu Dhabi's existing building stock, applicable building codes and regulations through the history, and identifying building prototypes based on chronological development of construction methods, architectural style, materials use, and building performance.

2.3 ENERGY CONSUMPTION IN THE UAE

After the discovery of oil in the UAE in 1960s, and the formation of the United Arab Emirates in 1971, the UAE witnessed a rapid development in all sectors. The energy consumption increased dramatically, which mainly is due to growth in population, economy, and urbanization. According to Kazim (2007) the population has doubled every 5 years since 1980 to reach around 3.25 million capita by year 2000. During this duration the UAE continued to have the highest energy consumption per capita compared to average rates in Europe, Middle East, the United States, and the World as shown in Figure 1. The peak energy consumption per capita in this duration has occurred in the 1990s, where it has gradually started to reduce towards 2000s. Similarly, Al-Iriani (2005) indicates that the electricity consumption average annual growth rate in UAE for the period from 1980 to 2000 is around 10% which is much higher than the world average growth rate of 3%.

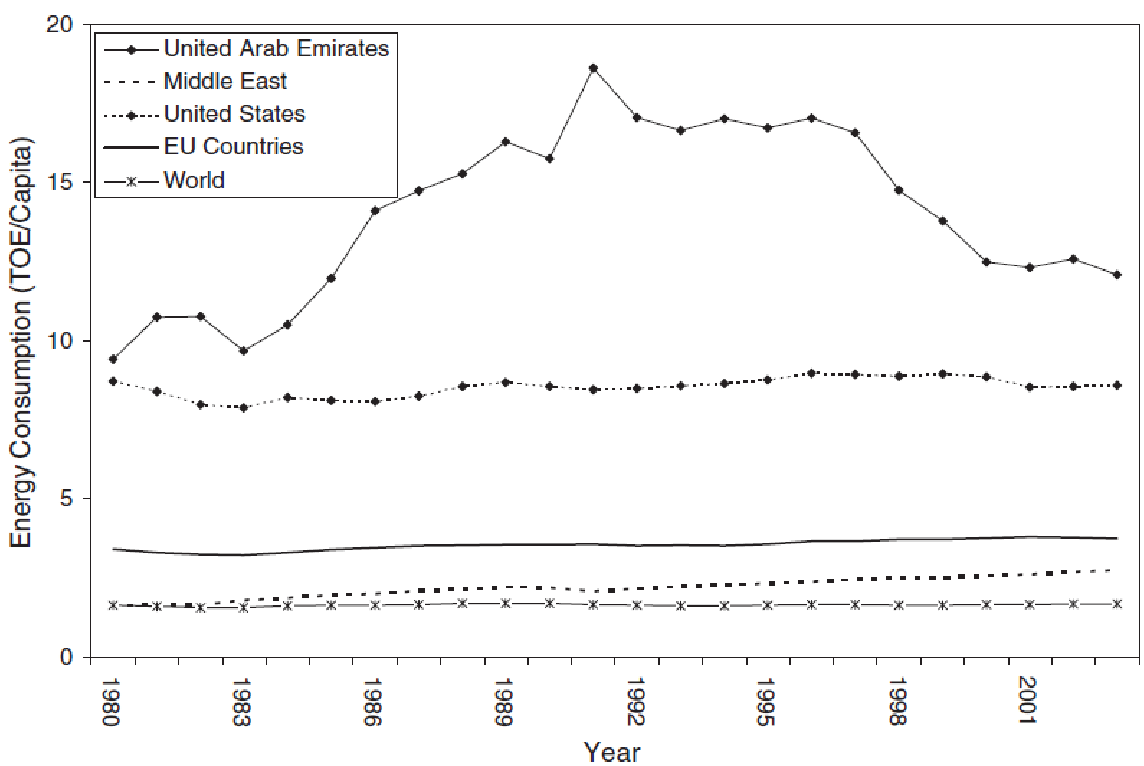


Figure 1 UAE's energy consumption per capita compared to other regions from 1980 to 2003. (Kazim 2007, p. 434)

2.3.1 ENERGY CONSUMPTION PROFILE IN THE EMIRATE OF ABU DHABI

According to the recent release of Abu Dhabi Census Center (SCAD 2012), electricity consumption profile witnessed constant increase since 1972. However, there has been slight fluctuation in certain periods which can be best explained in the economical, industrial, and building construction development in the Emirate.

The data collected from the Abu Dhabi Statistics Center, Appendix A Table A1, the data stipulates the electricity consumption in MWH in the three regions of the Emirate: Abu Dhabi, Al Ain, and Al Gharbeia. It is with no doubt that Abu Dhabi witnessed the highest consumption of all time due to its status among the three regions in terms of economic development and political importance.

Based on the collected data, the following line chart -Figure 2- has been developed to illustrate the chronological increase in electricity consumption on a cumulative yearly basis. It compares all three regions together with the total consumption in the Emirate as a whole.

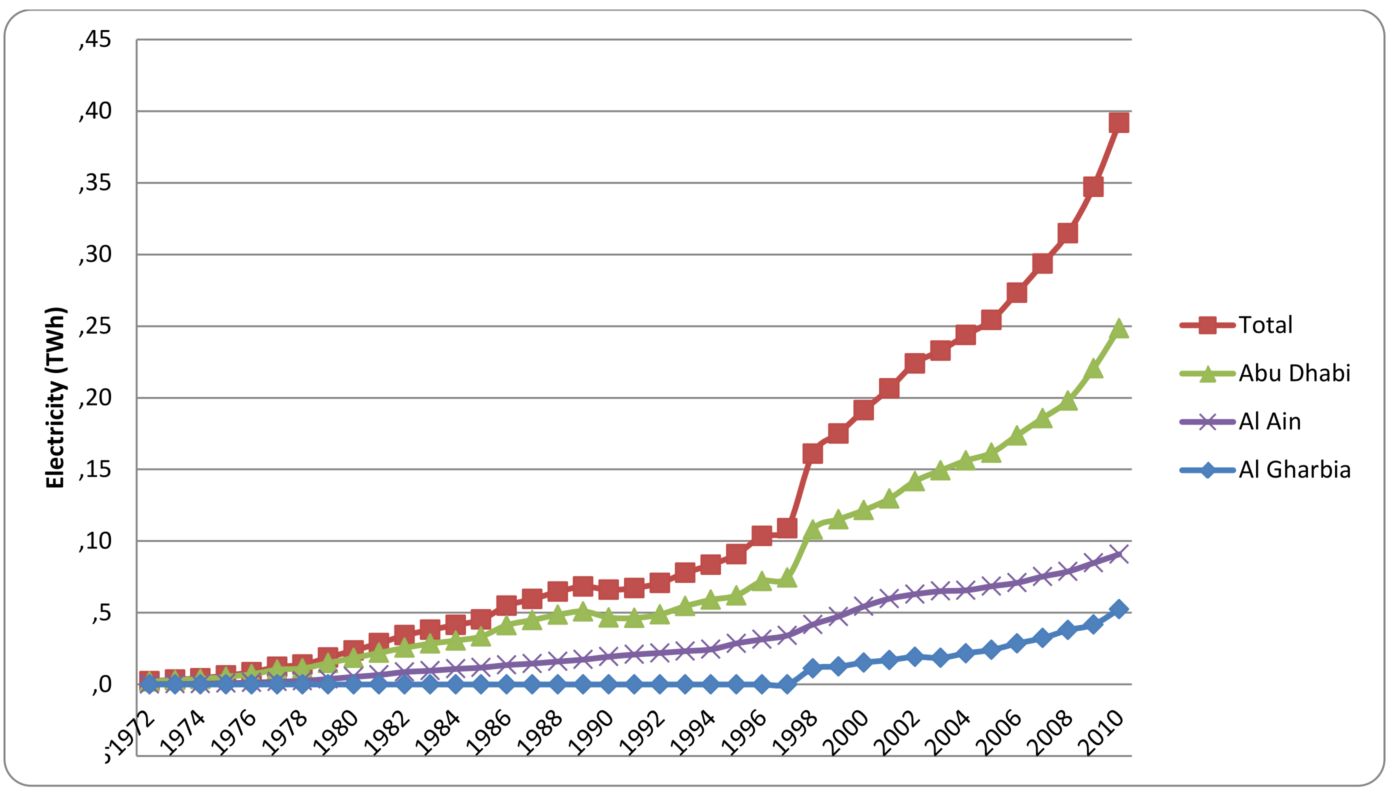


Figure 2 Consumption of Electricity by Region in the Emirate of Abu Dhabi from 1972 – 2010. (SCAD 2012)

2.3.2 SECTORAL ENERGY CONSUMPTION

It is important to understand the energy consumption per building sector in the UAE in order to identify the most critical areas where refurbishment opportunities have the greatest impact in energy savings.
Building Sectors in the UAE can be grouped under the following sectors based on the building uses;

- Residential Sector
- Commercial Sector – Offices, Retail, etc.
- Governmental Sector – Community facilities, and other governmental buildings
- Industrial Sector
- Agriculture Sector
- Others

The above sectors are based on the land use categories specified by the Abu Dhabi Urban Planning Council, which is the legislative body which controls and regulates Abu Dhabi urban development.
UPC (2013) states the guidelines for development review process applicable to both master planning urban scale projects as well as single building projects.

Table 1 lists both main land use categories and sub-categories of each sector.

Table 1 General Land Use Type in the Emirate of Abu Dhabi. (UPC 2013, p.2)

General Land Use Types	Specific Land Use Types	General Land Use Types	Specific Land Use Types
Residential	*Single unit household* *Two to four households* *Multi households* *Institutional living* *Employee housing (permanent)* *Employee housing (temporary)* *Guest worker housing (permanent)* *Guest worker housing (temporary)* *Palace residential*	**Infrastructure**	*Transportation* *Utilities*
Commercial	*Automobile/vehicle sales, leasing & rental* *Business services* *Personal services* *Restaurants, cafes and fast-food* *Retail sales* *Convenience Retail* *Shopping Complex* *Office* *Commercial recreation* *Hotel*	**Community Services**	*Governmental services* *Police* *Civil defence* *Community centre* *Cultural institutions* *Petrol Station* *Mosque* *Other religions* *Post secondary education* *Private school* *Public school*

	Conference/Convention/Exhibition Centre *Other sales and service (walk in)*		*Public health care* *Other*
Industrial	*General Industrial* *Heavy Industrial* *City serving industrial* *Research and Development*	**Open Space & recreation**	*Developed open space* *Natural open space* *Archeological*
Agricultural	*Farm* *Other*		

According to the categories mentioned previously, Abu Dhabi Statistics Center (SCAD) 2011c has identified the electricity usage percentage per sector in the Emirate of Abu Dhabi since 2008. The data acquired from both Abu Dhabi Distribution Company, and Al Ain Distribution Company was presented in the SCAD (2011c) publication regarding energy and environmental statistics.

Table 2 shows the percentage of electricity consumed per sector in the emirate of Abu Dhabi for the period from 2008 until 2011.

Table 2 Percentage of Electricity Consumption Per Sector. (SCAD (2011c), p.6)

Sector	2008	2009	2010	2011
Total	**100**	**100**	**100**	**100**
Domestic Sector	39.6	37.7	35.9	30.7
Commercial	30.8	31.7	32.1	28.8
Government	16.9	16.2	16.1	25.1*
Agriculture	9.1	9.2	8.2	7.0
Industry	2.4	3.7	7.2	8.0
Other Sectors	1.2	1.4	0.6	0.4

Source: Abu Dhabi Distribution Company, Al Ain Distribution Company
*Note: New meters were installed from 2008 and the cumulative reading of those meter were billed in 2011 for Al Garbia (Al Marfa)

The latest figures for the year 2011 indicates nearly an equal percentage of electricity consumption in the residential and commercial sector; both contributing to almost 60% of overall electricity consumption in the Emirate.

However, Radhi (2009) has indicated that the energy consumption for the residential sector in Al Ain for year 2005 accounts for the nearly 46% of its energy consumption. The industrial sector is the second highest consumer of energy among all sectors which accounts for nearly 25% of the consumed energy in 2005.

Figures 3 & 4 highlight the sectoral energy consumption in year 2005 and 2011 for Al Ain and Emirate of Abu Dhabi respectively.

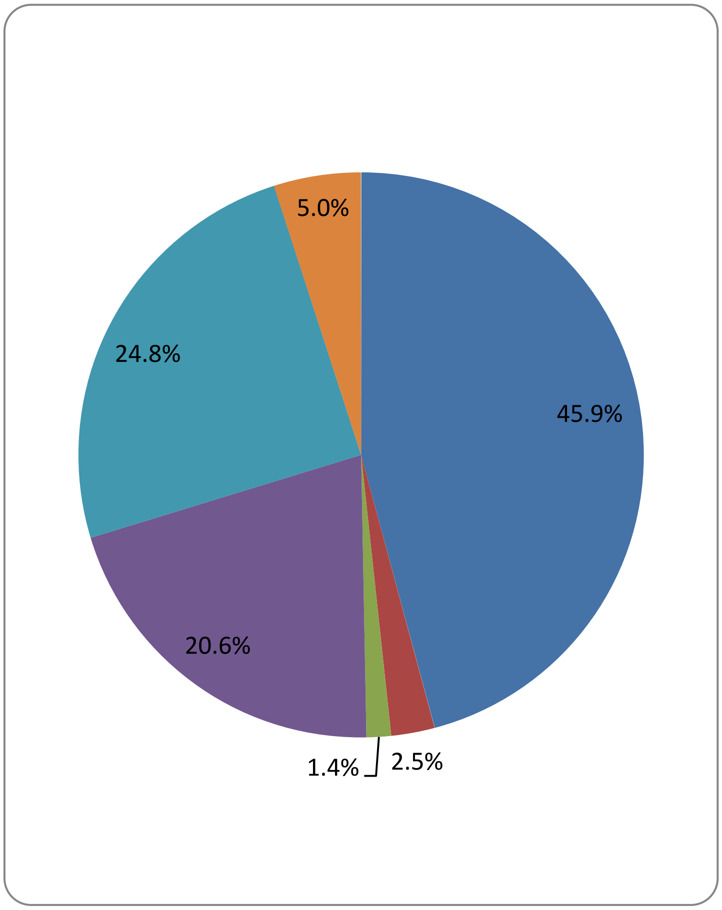


Figure 3 Sectoral Energy Consumption in Al Ain 2005. (Radhi 2009)

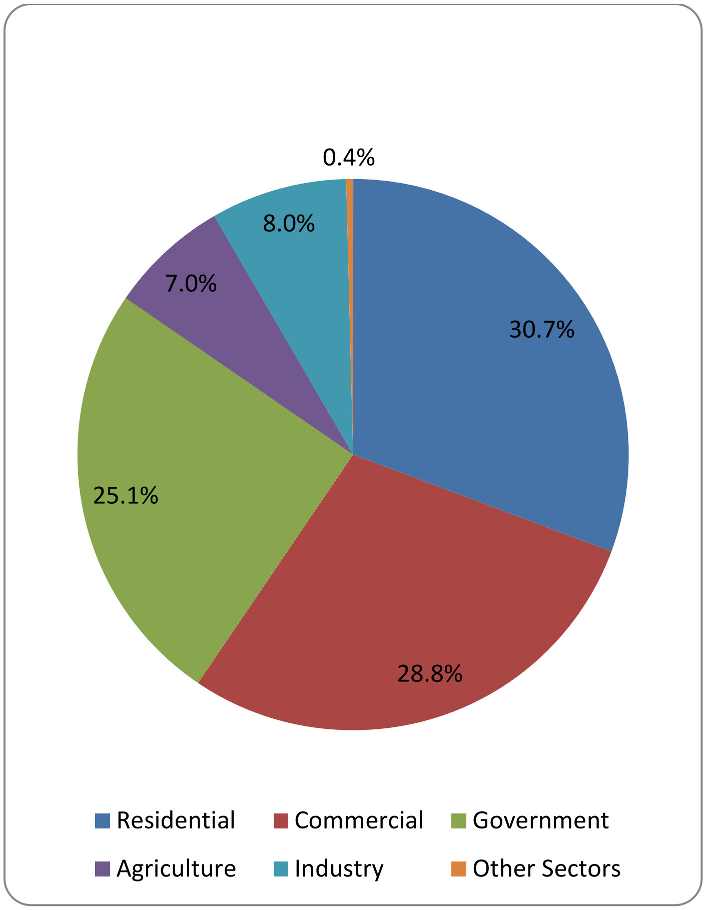


Figure 4 Sectoral Energy consumption in the Emirate of Abu Dhabi 2011 (Source: SCAD 2011c and Author)

Since this study focuses on the buildings prior to Estidama Pearl Rating implementation and the endorsement of the International Building Code tailor fir for the Emirate of Abu Dhabi, it is important to have an insight to the building stock prior to 2000s. According to Kazim (2007), in 1998, commercial sector in the UAE was responsible for 15.1% of its energy consumption, whereas 16.2% was caused by the residential sector. Again, this confirms that the energy consumption of both residential and commercial sector is almost equal. This trend has been almost consistent in the capital city of Abu Dhabi. However the residential sector contributes highly to energy consumption in other cities such as Al Ain. This is mainly due to Abu Dhabi having established a central business district (CBD) in an early stage during its development contrary to a city like Al AinSince the existing data indicates high energy consumption within the built environment in the UAE, and in light of the efforts internationally which highlights the potential of energy savings in existing buildings, the following section highlights the gap in refurbishment studies in the UAE.

2.4 THE GAP IN REFURBISHMENT STUDIES IN THE UAE

In the UAE, there has been limited research addressing energy savings through building refurbishment. In the past decade, there has been an increased awareness towards the need for implementing sustainable design approaches in new buildings which lead to establishing sustainability rating system in Abu Dhabi. However, there are no policies strictly addressing the energy saving aspect in existing building retrofitting. Unlike other countries which already implement sustainability ratings specifically designed for existing buildings, the UAE has not yet enforced any regulations in this area. The US Green Building Council, for example, has already set guidelines as part of the optional LEED rating system for existing buildings. LEED stands for Leadership in Energy and Environmental Design, the rating systems established by USGBC set measures to design, construct, and operate a sustainable development both on building scale and urban development scale (USGBC 2013).

However, a group of researchers in the UAE has launched a research project to assess the potential of energy saving in existing buildings in five of the Emirates; Abu Dhabi, Dubai, Sharjah, Ajman, and Ras Al Khaimah (AlNaqabi *et* al., 2012 and Alawadi *et* al., 2013). First, the research aimed at identifying the existing building stock in all five emirates in order to identify typologies for the second phase of analysis. However, due to lack of data at the time of research, especially in Abu Dhabi, the study focused on federal housing built by the Ministry of Public Works (MoPW). The first phase identified four prototypes responsive to the construction in 1974-1979, 1980-1989, 1990-1999, and 2000-2012. The first stage concluded that in a 1991 villa typology, approximately 37.2% reduction in annual cooling loads could be achieved if thermal insulation is upgraded to the requirements of 1 Pearl Rating based on the Abu Dhabi Urban Planning Council, Estidama requirements (UPC 2013b).

The second phase of the research was more detailed, where five villa typologies were simulated through IES-VE virtual environment software tool. The five prototypes represented the periods from 1970s, 1980s, 1990s, 2000s, and 2010s. the study conducted at minimum three simulations for each prototype; a base case, upgrade to 1 pearl rating, and upgrade to 2 pearl rating. The upgrade targeted thermal insulation for external walls, and roof, and glazing solar heat gain coefficient and u-value. The total reduction in annual cooling loads ranged from 27.5% to 29.8% in the case of upgrading to 1 pearl requirement, and from 28.5% to 30.8% in the case of upgrades to 2 pearl rating requirements. The study, however, recommended upgrading the houses to 1 pearl rating as the additional savings were minimal in the case of upgrading to 2 pearl.

Based on the pioneer research project highlighted above, a significant gap in available validated information in the field of building refurbishment and energy savings in existing buildings has been identified. Also, as noted earlier, the lack of data to enable such studies has been identified. Therefore, it is essential to bridge this gap and further investigate the potential of energy savings in existing building stock through applications of refurbishment strategies. As one of the research contributors to the previously conducted research project, the author is aiming to investigate the potential in energy savings in existing buildings in Abu Dhabi through building retrofitting strategies. However, this study aims to focus on commercial building typologies rather than residential buildings.

The following section investigate the history of urban development in Abu Dhabi, this is to identify the existing settlements and the relevant periods of which the existing building stock is referred to, which also identifies the existing commercial building stick.

2.5 DEVELOPMENT HISTORY IN ABU DHABI

The Emirate of Abu Dhabi is considered one of the growing Emirates in the country and the region. It has notably been developed in the past decade. This development was a natural response to the increase of population. The Statistics Center – Abu Dhabi (SCAD 2011a) has indicated that the growth of Abu Dhabi population in 2010 is estimated to be nine times compared to 1975, with a growth rate of 4.5% from 2001 to 2005. This growth is directly linked to increasing land development and building construction industry.

In order to understand the status of the existing building stock in Abu Dhabi, and due to lack of data on existing building stock, an insight of the urban development of the Emirate is essential within the economic and urban growth context. The Emirate of Abu Dhabi pre-1960 and oil discovery was an organic vernacular settlement, which grew according to the needs of the residents. The settlements were mostly nearby the coast; since the residents were reliant on fishery and pearl collection from the Gulf Sea.
Pre-1960s the buildings were mostly two storeys buildings as seen in the following Figure 5

Figure 5 "Ariel View Showing Residential Neighborhoods in the 1950s in Al Bahya Town." (Abu Dhabi Municipality & Town Planning Department 2003, cited in AlKaabi 2011, p. 123)

According to AlKaabi (2011), the first master plan prepared for Abu Dhabi Island was proposed in 1962 and later updated in 1966. In 1968, settlement in Abu Dhabi was still around the north-west along the cost, as shown in Figure 6. These master plans produced after the discovery of oil from Abu Dhabi have to be assessed in conjunction with the economic and political developments which occurred during the late 1960s and early 1970s; as economic and political development had great impact on the status of both Abu Dhabi and Dubai.

The United Arab Emirates was announced as a state in 2nd of December 1971. That is also happened to be after the first exports of oil both in Dubai and Abu Dhabi in 1962 and 1969 respectively. (National Media Council 2008). Parallel to those events, the Municipality of Abu Dhabi was founded in 1962. At first, the municipality was named as "Department of Abu Dhabi Municipality and Town Planning". Later, the need for a well-planned city had led to the issuance of a royal decree in 1969 to appoint the first municipal board. (ADM 2013).

Figure 6 Ariel View of Abu Dhabi in 1968. (Abu Dhabi Municipality & Town Planning Department 2003, cited in AlKaabi 2011, p. 134)

Similar to the recordings of AlKaabi (2011), in conference the 17th ICOMOS General Assembly (2011), researchers from Abu Dhabi Authority of Culture and Heritage (ADACH) explained that the initial master plans proposed for Abu Dhabi city early 1960s have been put into implementation later in the decade.

From that point onwards, Abu Dhabi city witness a transformable urban development, introducing various land uses including residential developments and supportive infrastructure and community facilities.

The initial implementation phase of the master plan was planned between 1962 and 1968. Later stage was proposed by 1974. During that stage, the Department of City Planning in Abu Dhabi was chaired by Dr. Abdul Rahman Hassanein Makhlouf. (Abu Dhabi awards 2013).

As noticed in Figure 7, the city is based on a grid-system urban morphology. The majority of the urban development occurred in the northern-east part of the island. The residential and mixed-use developments were mainly between the streets currently known as Corniche Street, and Electra Street North-South and Salam Street to the East until the Old Souq area to the west. The industrial zone was further down towards the south-east of Electra St.

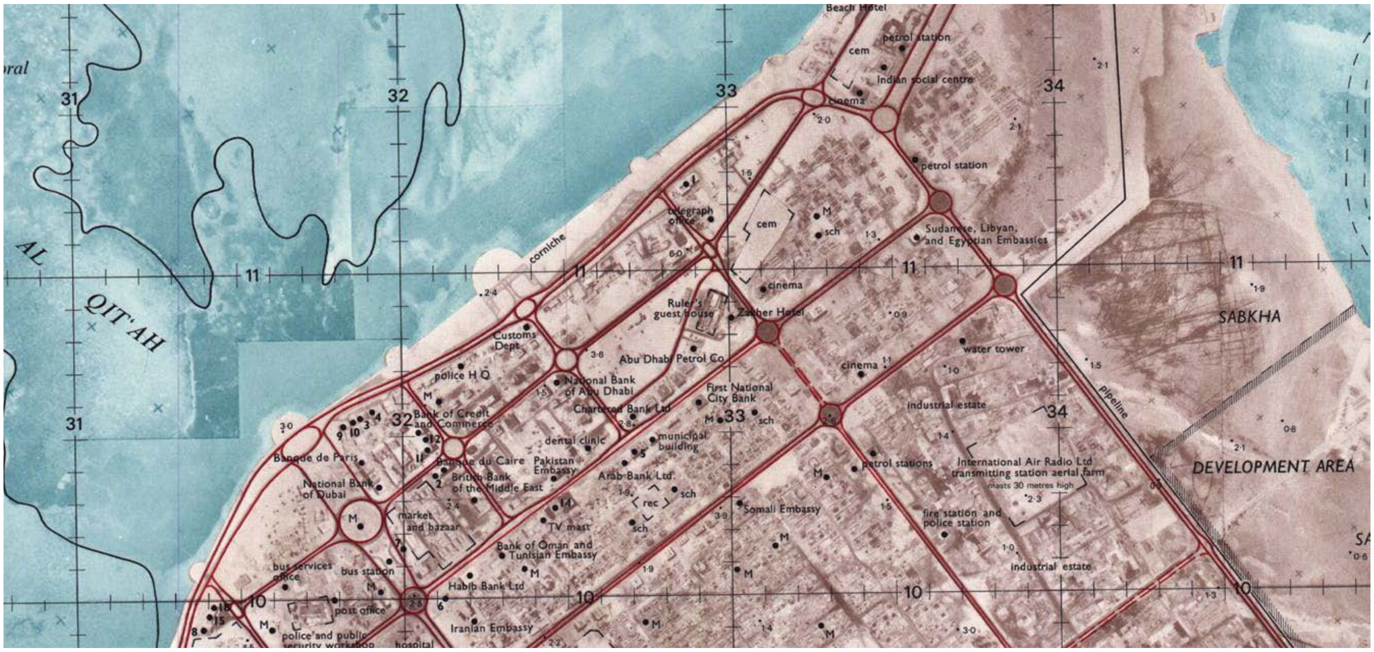


Figure 7 Part of Abu Dhabi in 1974. (ADSIC 2009, p.4)

2.5.1 FIRST BUILDING DEMOLITION MOVEMENT

As the Department of City Planning in Abu Dhabi became functional, the implementation of the planned urban development took place. Unfortunately, and according to Chabbi & Mahdy in conference The 17th ICOMOS General Assembly (2011), p.77;

"*The design and construction of the buildings had often been of inferior quality because the demand was so high and quality control mechanisms were not fully in place, therefore in the following decade, a wave of "reconstruction" was undertaken to replace this stock of buildings*."

It is obvious that the population growth that started in 1970s has led to great transformation in the urban development in the Emirate of Abu Dhabi. But what is also clear, is that the building construction which took place as the expatriates movement towards the country increased, has been of poor quality that many of the buildings had to be deconstructed later on. Another reason why building demolition took place at that point in time, is that the low-rise horizontal city development was moving towards vertical developments where new building heights were allowed. Of course this led to more and more structures being reconstructed to allow for higher buildings.

2.5.2 ABU DHABI AFTER 1980s

Contrary to the situation during 1970s, the urban development in the Emirate was more organized and controlled since 1980s. That is basically due to the earlier formation of the Department of City Planning, and the efforts that took place as the city developed. This, if anything, indicates that the majority of the existing building stock in the Emirate of Abu Dhabi, and within the Island in particular, has been developed in the 1980s onwards.

Although, great efforts have been made after the establishment of the department of City Planning in Abu Dhabi; it wasn't until 2007 when the Abu Dhabi Urban Planning Council (UPC) was formed by the law 23 of 2007. (UPC 2011). The Urban Planning Council has developed the 2030 vision of the Emirate and published the Urban Framework Plans for the Emirate of Abu Dhabi. This vision aimed at a well-planned sustainable built environment in the Emirate of Abu Dhabi including plans for the Western Region, Abu Dhabi, and Al Ain.

2.6 BUILDING STOCK IN ABU DHABI

This section aims at identifying the geographic boundaries of the study within th Emirate of Abu Dhabi, as well as understanding the existing building stock. The section first explains the jurisdiction of the Emirate of Abu Dhabi and identifying the major cities then narrows down to the area of the study. This is followed by the analysis of the existing settlement and the understanding of the existing building stock.

2.6.1 DEFINING GEOGRAPHIC BOUNDARIES

The Emirate of Abu Dhabi which accommodated nearly 2.0 million residents in 2010, consists of three regions: Abu Dhabi, Al Ain, and the Western Region as well as the Emirates Islands. (SCAD 2011a).
A recent survey by the General Census of Population, Housing and Establishment, 2005 (SCAD 2012b) has indicated that Abu Dhabi Region is the first contributor to the provision of housing units in the Emirate with 137,857 housing units, followed by Al Ain with 83,528 housing units. While the Western region contributed to only 20,002 units of a grand total of 243,251 housing units in the Emirate in 2005.

Both Abu Dhabi and Al Ain regions are the most inhabited and developed regions within the Emirate of Abu Dhabi. And since Abu Dhabi region contributes to 85% of completed buildings within the Emirate (SCAD 2011b); the research project has considered Abu Dhabi region to be the focus of the study.

In order to understand the chronological order of building construction in Abu Dhabi in a geographical context, analysis of the settlement growth and expansion of urban development is essential. The analysis is required, to develop a detailed understanding of the urban settlement in Abu Dhabi City and Abu Dhabi Metropolitan in particular.

Abu Dhabi Metropolitan includes Abu Dhabi City and the sub-urban and rural settlements outside the Island. Abu Dhabi Island is the core settlement where the major development has taken place for the past forty or more years. Other recent developments such as Mohammad Bin Zayed City, Khalifa A City, Khalifa B City, Masdar City, Al Raha Beach Development, And other future cities are all developments located outside the Island. There are also other sub-urban and rural settlements outside the Island within Abu Dhabi Metropolitan which are relatively old and includes low density housing projects such as Al Rahba, Al Shamkha, Al Bahia, Al Wathba, Al Samha, and others which were developed mainly with prototypes of extended family housing.

Figure 8 illustrates the precincts of Abu Dhabi Metropolitan based on Plan Abu Dhabi 2030 as part of the urban structure framework plan.

Figure 8 Precincts map of Plan Abu Dhabi 2030. (UPC 2010, p. 85)

2.6.2 URBAN DENSITY - AN INDICATION OF CHRONOLOGICAL SETTLEMENT

It is understood that areas with higher densities are the areas where the urban development first started to expand, which does not necessarily imply that existing buildings in those areas are the oldest but could be for the most part.

The following map –Figure 9- illustrates the population density in Abu Dhabi Island in 2005. It shows that the northern central and northern eastern part of the Island has the highest densities, which happens to be also the part where the relatively older buildings exist. This has been also highlighted by Dr. Essam Saleh – from the town planning department of the Abu Dhabi Municipality- during an interview on June 28th, 2012.

The same has been concluded in the previous section 2.5, where the urban development after discovery of oil all through the formation of the town planning department in the Abu Dhabi Municipality and later after the formation of Abu Dhabi Urban Planning Council has been explained. The chronological urban development reflects the existing building stock in each of the timeframes.

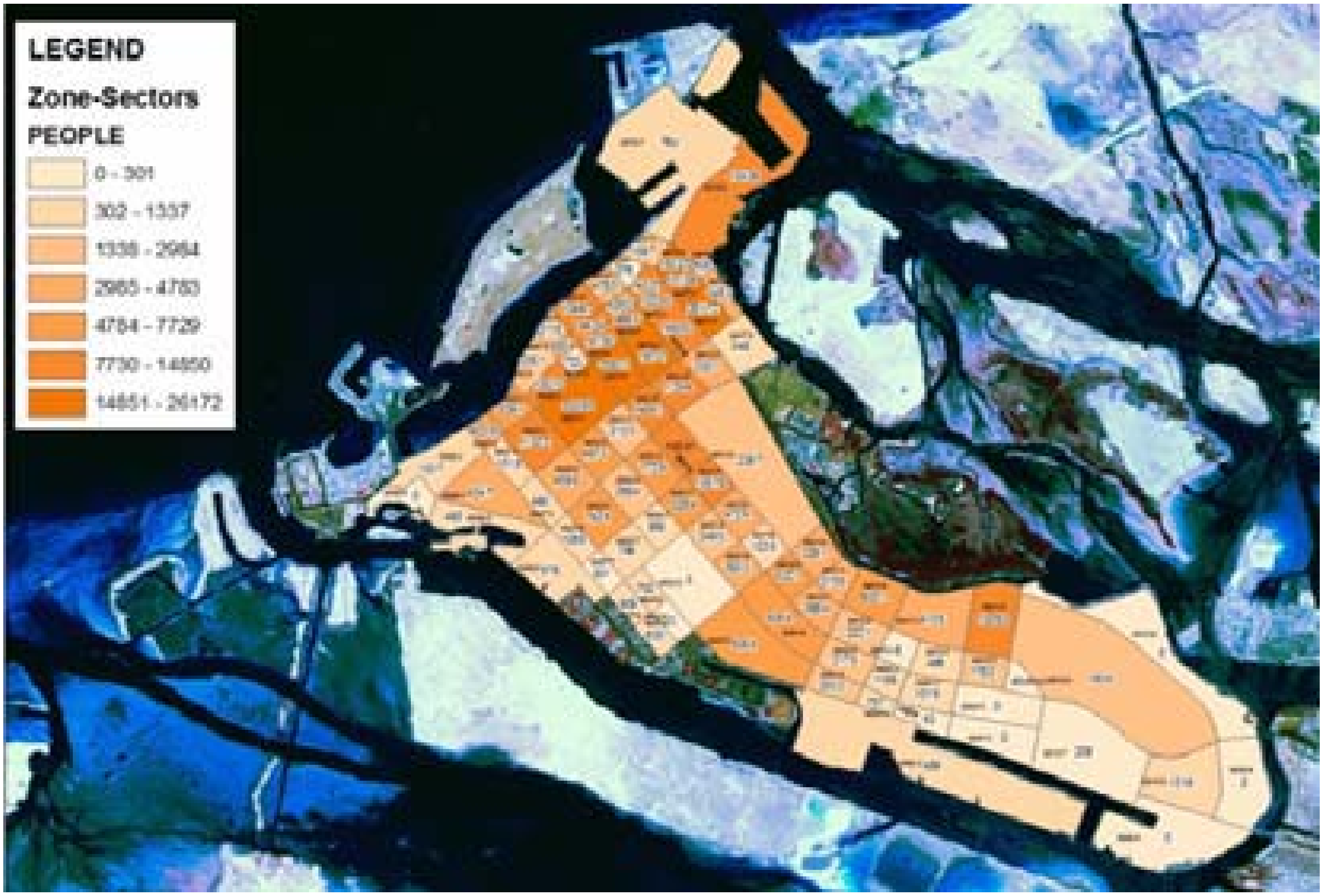


Figure 9 Population density by sector on Abu Dhabi Island matching DPE census data and building points with DMA sector boundaries. (Abu Dhabi Spatial Data Infrastructure 2012, p.1).

As highlighted earlier, this research mainly focuses on the commercial buildings inclusive of mixed-use and office buildings in Abu Dhabi. Therefore, the industrial zone located outside the Island which is Mussafah Industrial City will be beyond the scope of this study.

Having set the research project physical boundaries based on population and building densities as well as land use structure, it is critical to analyze the building construction development in this context based on the various land uses throughout the intended timeframe scope of the study.

2.6.3 EXISTING BUILDING STOCK DATA

As explained earlier, building construction in Abu Dhabi has started after the discovery of oil in the 1960s. The earliest census data obtained from the Census Center – Abu Dhabi is dated back to 1975 with 10 years' time interval for data collected. Other data was available from official publications in Abu Dhabi which mainly covers the years from 2001 to 2010. The data collected is combined and presented in Table 3.

Table 3 Summary of Abu Dhabi Existing Building Stock (Statistics Center – Abu Dhabi)

Year/Type of Building		1975 Number	1985 Number	1995 Number	2001 Number	2005 Number	2010 Number
Residential*	Villa	1,601	4,741	7,194	5,289	10,803	N/A
	Apartment/ multistorey	4,468	29,235	47,925	15,095	3,632	
	Deluxe Apartment	0	0	617	160	0	
	Arabic House	13,450	1,475	230	0	0	
	Popular/ low-cost House	6,386	7,871	6,987	11,644	13,434	
	Single Storey Building	0	0	1,206	5,413	4,602	
	Others	8,742	20,506	23,679	27,427	7,537	
	Total	34,647	63,828	87,838	65,028	40,008	270,428
Healthcare Facilities	Hospitals (all)	N/A	N/A	N/A	N/A	33	33
	Health Centers (all)	N/A	N/A	N/A	N/A	435	435
	Clinics (all)	N/A	N/A	N/A	N/A	239	239
	Government Hospitals	2	10	13	12	13	12
	Government Clinics - Centers	N/A	N/A	N/A	N/A	48	48
Education	Private Schools	12	54	149	178	201	184
	Governmental Schools	77	159	246	316	322	
	Universities (all)	N/A	N/A	N/A	N/A		9
	Colleges and Institutes (all)	N/A	N/A	N/A	N/A		20
Hotels		10	19	39	49	55	115
Commercial**		13,736	55,635	76,419	98,917	117,254	165,072

Sources: SCAD (2010): Abu Dhabi in Figures: 2010.
SCAD (2011a): Abu Dhabi in Figures: 2011.
SCAD (2011b): Building Completion Statistics: March Quarter 2011.
SCAD (2012): Abu Dhabi: Development Statistics: 1960-2010.
SCAD Census Data for Abu Dhabi from 1975 to 2005 obtained directly from the Statistics Center of Abu Dhabi

Notes:
* For Residential units, data reflects the units within Abu Dhabi only. However the total number of units for Year 2005 includes residential units in the Emirate inclusive of Al Ain and the Western Region
** Commercial category is assumed to reflect the building stock categorized under "Buildings" as per SCAD (2012) data.

The data collected from Abu Dhabi Statistics Center (SCAD 20120) - represented in Appendix A Table A2- is summarized in the chart representation of the data provided in Figure 10. The chart indicates that the building stock in the Emirate of Abu Dhabi gradually increased from 1968 to late 1970s. The years 1978-1980 witnessed a great increase in the number of buildings constructed with almost 22,600 new units were constructed. The increase in the total number of new buildings constructed in Abu Dhabi continued until 1986 were the existing building stock started to decrease gradually. However, the construction industry picked up again and the building stock was increasing steadily from 1993 onwards with minor fluctuations.

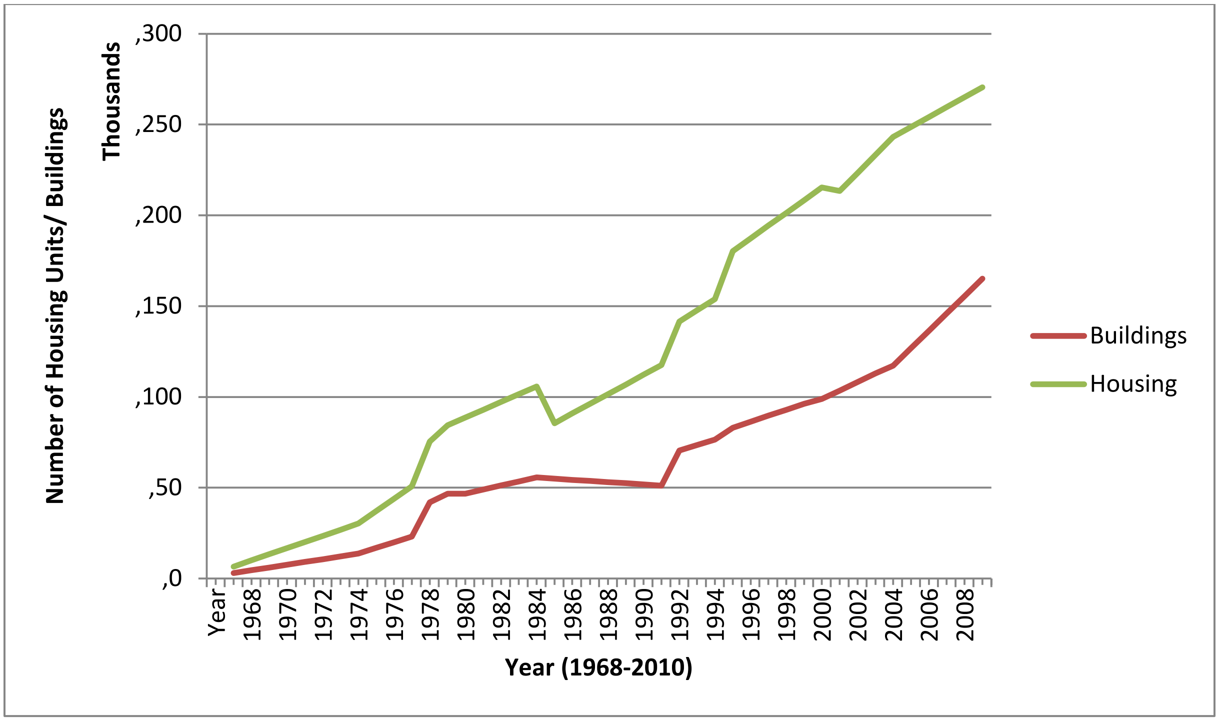


Figure 10 Key Statistics of Construction Activity in The Emirate of Abu Dhabi. (SCAD 2012)

Data collected from the Statistics Center – Abu Dhabi included a breakdown of different building land uses in terms of building permits numbers, mostly for years from 2005 to 2010. The land uses include:

Residential	Public Utilities	Temporary
Commercial	Agricultural	Annex of low cost house
Industrial	Residential and Commercial	Others

Also, the various types of building permits were obtained for the same period. This includes total number of permits for the following categories: New, Refurbishment, Temporary, Demolition, and Others.

Based on the data collected, and as indicated in Table 4, both the Residential use and Temporary buildings have the highest number of building permits from year 2005 to 2009, followed by the industrial and public utilities uses. Total number of building demolished for years 2009 & 2010 combined in Abu Dhabi is 371 permits.

Table 4 Building/ Demolition Permits in Abu Dhabi (2005-2010). (SCAD)

Permit Category	Permit sub-category	Number of Permits					
		2010* (AD)	2009** (AD)	2008 (AD +WR)	2007 (AD+ WR)	2006 (AD+ WR)	2005 (AD+ WR)
New	New Buildings	2,066	1,429				
Refurbishment	Permits for Renewal or amendments	642	655				
	Additions	1,872	2,609				
	Improvements and decorations	2,028	22				
Demolition	Demolition	107	264				
Others	Others types of permits	274	211				
Residential		4,473	3,718	1,401	852	907	705
Commercial		968	388	222	134	67	67
Industrial		638	338	229	252	192	169
Public Utilities		3	424	335	240	250	278
Agricultural		80	0	0	0	0	0
Residential and Commercial		6	296	0	0	0	0
Temporary		279	3,629	1,768	949	3,682	3,162
Annex of low cost house				174	889	957	1,566
Others		821	26	0	0	0	0
Total		7,268	8,819	4,129	3,316	6,055	5,947
	Sources:						
	* SCAD (2011a)						
	** SCAD (2010)						
	Notes: Years 2005-2008 includes permits for Abu Dhabi and the Western Region						

As concluded from the above statistics and data, commercial buildings are one of the major contributors to energy consumption in Abu Dhabi. Therefore, it is vital to further study and analyze the status of the existing commercial building stock to identify the best typologies representing the buildings in Abu Dhabi. Also, it is important to investigate the total Gross Floor Area (GFA) of the commercial buildings. This will allow identifying the impact of the refurbishment strategies –topic of this study- on a large scale covering the overall existing commercial building stock.

The following section addressed the statistics and data regarding the existing commercial building stock.

2.6.4 EXISTING COMMERCIAL BUILDING STOCK

As indicated in the chronological development in the city of Abu Dhabi, and through the construction and demolition stages that affected the existing building stock in the Island, it is noted that the majority of the existing commercial building stock from mid-1980s is located in the northern east part of the island -namely, the developments between the streets currently known as Corniche Street, and Electra Street North-South and Salam Street to the East until the Old Souq area to the west. This zone includes the Central Business District (CBD) in Abu Dhabi.

From mid-1990s onwards, the development in Abu Dhabi island extended towards Al Muroor Street and Airport Road to the south, and towards Al Bateen and the west side on the Corniche. In the recent years, the mixed use developments reached out to the Grand Mosque District starting. The following Figure 11 indicates the units per building within the northern part of the island, and Figure 12 provides an indicative breakdown of the existing uses within the island of Abu Dhabi. Both figures representing units densities and land use breakdown supports the data provided earlier, and defines clear separation between three decades of existing mixed-use development;

1. 1980s - 1990s
2. 1990s - 2000s
3. 2000s - 2010s

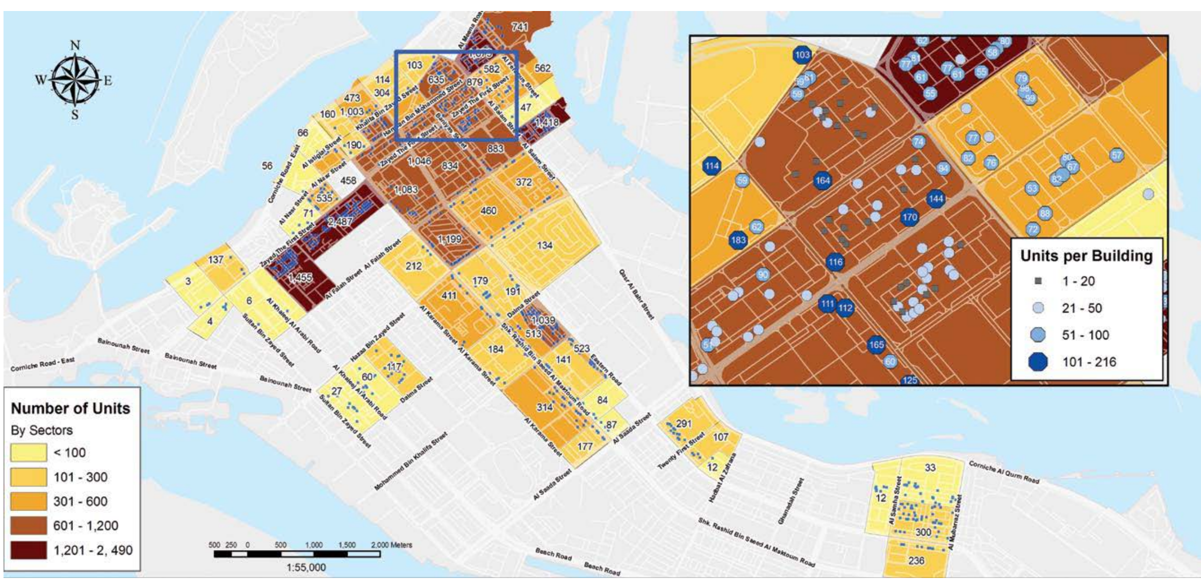


Figure 11 ADCP Properties Units by Sector in Abu Dhabi Island. (ADSIC 2009, p.5)

Figure 12 Abu Dhabi Land Use Allocation Tracking. (ADSIC 2009, p.9)

Besides the analysis conducted on the urban development and master planning level development in Abu Dhabi to understand the existing building stock and commercial building stock; and due to the lack of data and information; interviews with contemporary architects and engineers were conducted. Interviews with Arch. Munir Kosnik and Eng. Elias Shahin on The 2nd of April 2013 and The 25th of August 2013 respectively concluded that the leasable spaces in the island of Abu Dhabi were considered as commercial uses, and that the buildings designed since 1980s were considered for either office or residential uses. Therefore majority of the existing commercial building stock are residential conversion of the buildings, especially for the buildings constructed from 1980s to mid-1990s.

A recent publication by the Abu Dhabi Urban Planning Council included an assessment of the existing office market (UPC 2010b). The study highlighted that the existing building stock as of 2009 is of poor quality office space, and that residential conversion contributes to a good portion of the available office space.

The study gave a ranking of four levels A to D; A being the best quality office space based on international quality and professionally managed space to D being the worst quality.

- Grade A offices represent less than 17% of the existing building stock majority of which are built recently (after 2005) for governmental or semi-governmental entities such as Abu Dhabi Investment Authority, Al Mamoura Building, AlDar HQ, etc.
- Grade D offices represent residential conversions with the poorest quality of office spaces.

The following chart -Figure 13- provides a percentage breakdown of an overall 1.8 million square meters of office space as of 2009 in Abu Dhabi.

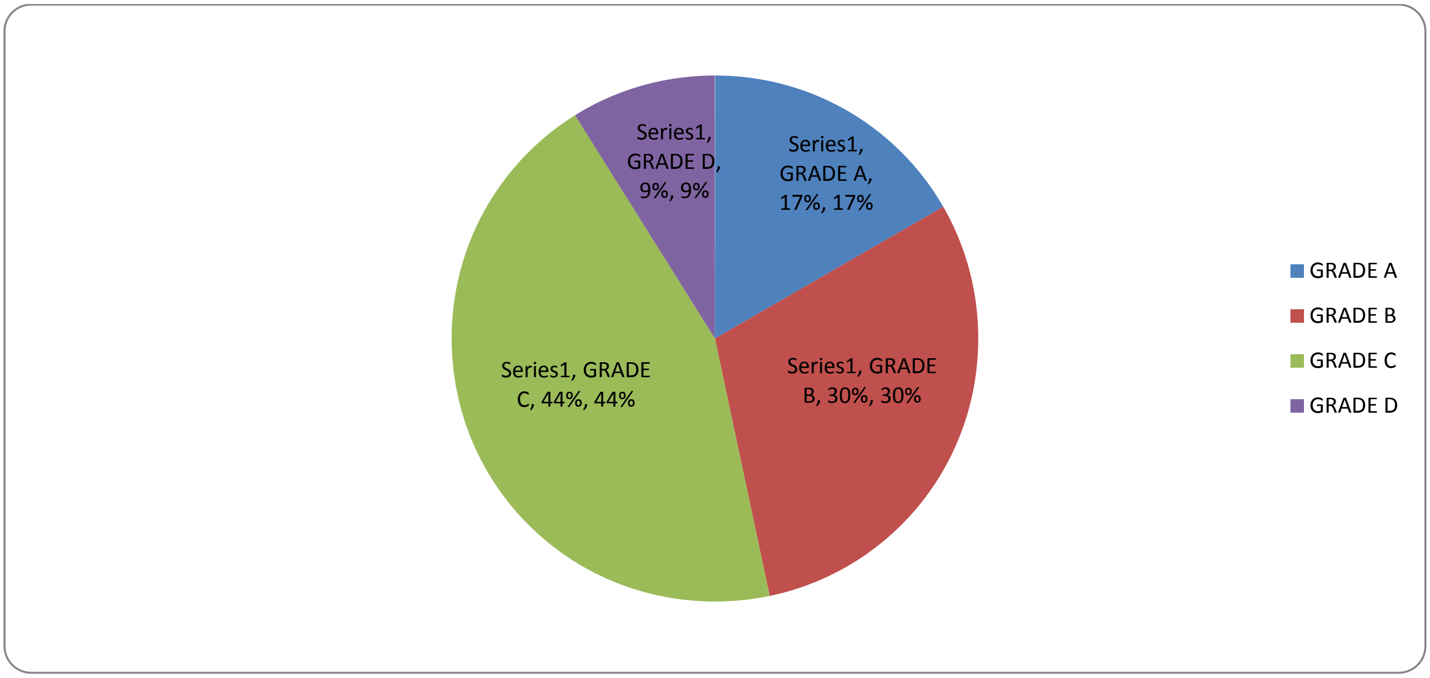


Figure 13 Percentage breakdown of the existing office space in Abu Dhabi as of 2009. (UPC 2010b, Author)

According to the study, around 800,000 square meters of office space is provided within the Central Business District. Whereas around 550,000 square meters of grades B and C office spaces are provided along Al Muroor road and Abu Dhabi road. Most of the other office supplies within the island of Abu Dhabi are also of Grades B and C. Around 200,000 square meters of Grade A office spaces are provided outside the island within the Abu Dhabi Metropolitan. (UPC 2010b).

The total office space in Abu Dhabi in 2007 was indicated at 1.4 million square meters (UPC 2010a). And since the Grade A office buildings represent around 300,000 square meters and has just recently been developed, 200,000 square meters of which were developed outside the island, then it is assumed that at least 93% of the 1.4 million square meters office space as of 2007 are grades B,C and D.

Moreover, and based on the previous data, it is concluded that Grade D office space of 160,000 square meters are those who were built in early to mid-1980s, and within the CBD area. It is also concluded that the Grade B and C buildings within the Almuroor and Airport roads represent the building stock in 1990s.

For this study, and based on the above, the following figures in Table 5 will be considered;

Table 5 Summary of Office Building Survey from 1980-1999. (UPC 2010a, UPC 2010b, Author)

Period	Location	Grade	Office Space – GLA* (Square Meters)	Office Space – GFA*(Square Meters)
1980-1985	CBD	D	160,000	200,000
1986-1989	CBD	C (44% of 800,000)	280,000	350,000
1990-1999	CBD	B (30% of 800,000)	360,000	450,000
1990-1999	Muroor – Airport Roads	C (60% of 550,000)	330,000	412,500
1990-1999	Muroor – Airport Roads	B (40% of 550,000)	220,000	275,000

Note: * GLA = 0.8 * GFA (Gross Floor Area) (Source: UPC 2010b).

It has to be noted that the office space available per capita as of 2009 is much lower than the international standards representing only 1.9 square meters per person. (UPC 2010b).

According to the data provided in the previous sections, the following is concluded;

- Commercial buildings as well as residential buildings are the major contributors to energy consumption within the existing building stock in Abu Dhabi city.
- Commercial buildings – with reference to statistics collected under the category of Buildings- witnessed a boom in construction late 1970s to mid-1980s. From 1986-1993 the existing stock decreased. After 1993, building stock increased gradually till 2010.
- Around 3% of total permits issued on 2009 in Abu Dhabi were demolition permits. However, 4.5% were the permits given for new commercial building construction.

The following section provides an insight to the different building regulations that governed the building design and construction in Abu Dhabi.

2.7 BUILDING REGULATIONS IN ABU DHABI

Buildings codes and regulations are usually set by the government to regulate building performance and building design parameters. In Abu Dhabi, the Municipality of Abu Dhabi (ADM) is the regulatory authority which sets the building codes, review the building applications, and issue the building permit. The Municipality of Abu Dhabi (ADM) was found in 1962. It was called “Department of Abu Dhabi and Town Planning”. However, the need for a well-established municipal board was recognized. In 1969, the first municipal board was appointed by the issuance of a royal decree (ADM 2013).

The first local order (1) of 1976 was issued related to building regulations. These regulations were followed by the issuance of Decree (4) of 1983 related to building construction regulations, followed by an amendment concluded by Decree (4) of 1985. Administrative law (20/94) of 1994 was later issued related to executive list of the previous building regulations. The issued regulations did not set a specific criteria or requirements for building performance related to energy savings such as building envelope thermal performance. However, recommendations were stipulated under Article (43) of 1983 - Chapter 2 Architecture and Design Building Regulations. The recommendations included the following (ADM 1983);

Building orientation and use of shading elements in relation to prevailing wind

- The use of thick walls and insulated walls
- The use of thermal insulation and water proofing for the roof. As well as using shading devices for the roof such as pergolas
- Provide windows to floor ratio that do not exceed 1:6. It is recommended to use shading devices for the windows
- For glazing, reflective glazing is recommended. Where direct solar gain is anticipated, double glazed reflective glazing is recommended
- The selection of windows framing with minimal infiltration
- For exterior building finishing, paints selection of white and light colors is recommended.

While all the above relate to building thermal performance, these recommendations were not set as regulations and were never enforced on any building development.

It was not until 2009 that the Department of Municipal Affairs (DMA) –Higher committee of Abu Dhabi Building Codes has issued the 2009 International Building Code for Abu Dhabi. However, the building code has not been made mandatory as yet. (DMA 2013).

In 2010, Estidama Pearl Rating Systems minimum requirements were made mandatory by the Executive Council Order of May 2010. For all new buildings, at least 1 pearl rating must be met, whereas governmental buildings are required to meet a minimum of 2 pearls under the Pearl Building Rating System. (UPC 2013b).

Estidama is the Arabic word of sustainability. Estidama team has been formed in 2007 as part of the Abu Dhabi Urban Planning Council. Estidama issued three different rating systems including;

- Pearl Building Rating System (PBRS)
- Pearl Community Rating System (PCRS)
- Pearl Villa Rating System (PVRS)

As highlighted above, all buildings subject to this study fall within the timeframe where no specific regulations were enforced relevant to building performance and energy savings. However, it has been noted that after the building demolition which occurred in 1970s, many international consultancy firms moved to establish new business in the UAE. Also, many professionals and contractors were inspired by the international trends and best practices in building design and construction. This trend influenced the quality of the building design and construction, therefore many of the buildings designed late 1980s onwards started to use thermally insulated walls and double glazing windows providing a better building envelope performance than that specified in the concurrent regulations at that time. Interviews conducted with Arch. Munir Kosnik, Eng. Elias Shahin, Arch. Azza Al Sayed who worked in Abu Dhabi during that time all confirmed the same.

The following section presents the different trends in building design and construction in Abu Dhabi with regards to commercial buildings. The section identifies representative building typologies for existing buildings subject to this study for the timeframe from 1980-1989 and 1989-1999.

2.8 DEFINING BUILDING TYPOLOGIES

As highlighted in the previous sections, the existing building stock in Abu Dhabi mostly refers back to mid-1980s. However, there were no regulations set to control building performance in terms of energy efficiency and thermal performance of the building envelope. It wasn’t until 2010 that Estidama pearl rating systems were made mandatory. Therefore, in terms of regulatory framework, the existing building stock should have been treated the same with regards to energy and thermal performance. However, as noted earlier, this wasn’t the case since the buildings designed in the late 1980s were of better design and construction quality. This section will further investigate the identified timeframes for this study being 1980-1989 and 1990-1999. In order to identify the building typologies, the architectural character and construction materials of each period have to be identified. Besides the background research conducted earlier, the lack of available data and information has been bridged through the following;

- Review of data collected through EMPORIS database which provides buildings related information globally (EMPORIS 2013)
- Personal interviews with Architects and Engineers who have worked in the construction industry in the UAE since 1970s.
- Field observation in Abu Dhabi

The building database collected and provided by EMPORIS online is presented in a comparative format in Appendix B. A total of 217 buildings are provided with information related to their height, year of construction, architectural style, location, visual image representation, consultants, etc.

The analysis of the data collected indicates that the majority of the buildings go back to 1980s with few exceptions which are hotel establishments, or iconic buildings such as Etisalat tower, and other few residential buildings which were constructed early 1980s and late 1970s.

The buildings from mid-1980s until 2010s range from 15-25 storeys in height with low to high rise buildings category. The higher the building the recent it was constructed. Also, it is noted that the majority of buildings pre-1990s were of postmodern architectural style and with concrete structures. Steel was introduced late 1990s, and more complex structures after 2010 as taller buildings and skyscrapers were constructed. Modern architectural style was introduced from mid-1990s onwards, and it was more evident after year 2000.

Furthermore, personal interview with Eng. Elias Shahin on 25th of August 2013 –who has been working in Abu Dhabi since 1970s- highlighted the following;

- Buildings in 1970s were low-rise buildings from 3-5 storeys usually ground floor, mezzanine floor, and two typical floors. In 1970s there was no building review process similar to what is existing nowadays, however the building design was reviewed as part of the review process run by Sheikh Khalifa Committee, which was a governmental department responsible for providing loans for Emirati residents to build their houses. There was also the social services and commercial buildings department. Very few of those buildings still exist, and mostly around what is known as Electra and Jawazat streets
- Buildings in 1980s and 1990s were on average around 20 stories height.
- The buildings in 1980s were mainly conventional window design, single glazing, solid concrete structure with plaster or paint finishing. Stone cladding was introduced at a later stage in the same period. Majority of the buildings used no wall insulation (hollow block) and were poor in terms of thermal performance.
- Towards the end of 1980s, the buildings started using wall insulation and double glazing. Also curtain walls and aluminum cladding started to appear in some of the buildings designed late 1980s and early 1990s.
- There is a change in the AC system used between pre-1990s and post-1990s. The majority of the buildings used window type air conditioning units before 1990s with few exceptions of iconic buildings. It was later that the central AC system was used for provision of cooling systems within the buildings.
- It has also been noted that the majority of the existing building stock from the 1980s is around whats is known as Tourist club area, Hamdan Street, and Khalifa Street.
- Office buildings were defined under what was called commercial building. The buildings were designed to suite residential units, offices, and ground floor retail spaces.
- Integration of external shading was not given attention at any time because the building regulations did not allow for any extrusions beyond the plot line, and the building owners wanted the maximum built area to be used for profitability.

Another interview conducted with Architect Munir Kosnik on 2nd of April 2013 – who has been working in the UAE since late 1980s- highlighted the following;

- In late 1980s and 1990s any leasable space was called under commercial space. In other words, whether the building is designed for a residential apartment or for offices both were accommodated under commercial building terminology
- It is difficult to identify existing stand-alone office buildings which go back to 1980s.
- Buildings in 1980s followed a conventional design approach with concrete buildings.
- A mix of glazing and solid external cladding was used still used in late 1980s and early 1990s.
- Building insulation and double glazing were in use in 1989 onwards.

An interview with Architect Azza Al Sayed on 5th January 2012 – who has been working in Abu Dhabi since 1970s- highlighted the following;

- There were no specific requirements for building performance in terms of energy consumption and thermal performance. International Building Code however was made available in 2009 but was not mandatory; however some consultants were guided by the draft code.
- Sheikh Khalifa Committee -which was a part of the Abu Dhabi Municipality and is no longer available- had in position all buildings drawings and specifications pre and during 1980s; as they were approving the grants for Emirati people.
- There were main consultants and contractors who had influenced the market and provided a better quality product based on best practices. Some of which are still working till date.

Based on the data provided above, the interviews, and personal walk-throughs and observatory analysis of the existing building stock in Abu Dhabi, the following summary of the existing commercial building typologies is concluded –presented in Table 6.

Table 6 Comparison Summary of Existing Commercial Building Typologies in Abu Dhabi from the period from 1980 to 2000. (Author)

Comparison Criterion	Buildings from 1980 to 1989	Buildings from 1990 to 1999
Building use	Mixed use- offices as residential conversion	Mixed use- offices as residential conversion. Stand-alone office buildings
Building Height	15-20 floors	20-25 floors
Architectural Style	Post-modern	Post-modern and Modern
Construction Material	Concrete	Concrete and Steel structures
Cladding Type	Block wall with plaster or paint finishing. Stone cladding introduced later.	Curtain wall type. Aluminum cladding. Stone Cladding
Wall Insulation	No wall insulation	Thermal insulation provided
Glazing type	Single glazing	Double glazing
Shading	Not prioritized	Not prioritized
Air Conditioning System	Window type unit	Central AC system

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

2.9 PROBLEM STATEMENT

Since the discovery of oil in 1960s, the UAE has been rapidly developing. The construction industry has negatively impacted the environment on many levels, one of which is related to the huge consumption of energy in the built environment which contributed to nearly two-fifth the total energy consumption. Recently, the country became effectively involved in global environmental initiatives such as Montreal Protocol in 2013. Such involvement reflects the growing awareness of the country towards protecting the environment and saving the natural resources.

The efforts of the Abu Dhabi Urban Planning Council through mandating minimum requirements for building, villa, and community developments through the enforcement of the Estidama Pearl Rating Systems, is considered a step towards achieving the goals set for the country to reduce energy consumption, use of alternative clean energy resources, and many others. The environmental initiatives, regulations, and requirements adopted in the UAE are applicable and targeting new buildings only. However, in Abu Dhabi the existing building stock, which contributes to more than 70% of the existing building stock as of 2005 to 2010 statistics, lacked any enforcement of sustainable building regulations.

In the Emirate of Abu Dhabi, around 85% of the existing building stock is accommodated in Abu Dhabi city. In 2011, the energy consumption of commercial buildings and residential buildings evenly contributed to nearly 60% of the total energy consumption of the built environment. Moreover, additional 25% was identified as the energy consumed by governmental buildings, which also included governmental offices and facilities.

Having mentioned the above, it is essential to investigate the means to reduce energy consumption in the existing building stock in Abu Dhabi, specifically for office buildings which together with the governmental buildings contributes to around 55% of total energy consumption in the built environment. In this context, and due to lack of validated information, this research aims to investigate the energy savings potential in refurbishing existing buildings in Abu Dhabi through passive strategies. The study focuses on commercial buildings in the Abu Dhabi Metropolitan, and it covers the buildings built pre-1970s to 2010 with focus on two case studies of one building built in 1980s and another in 1990s. A financial feasibility study will be conducted to weigh the passive strategies proposed within the refurbishment process in terms of its cost versus its efficiency in achieving higher energy savings.

CHAPTER 3: METHODOLOGY

3 METHODOLOGY

3.1 METHOD SELECTION

Selection of an appropriate research method is essential to enable the study being conducted within the applicable limitations of the studied program. A full understanding of the applicable research method used to assess the energy savings in existing buildings is important prior to initiating the study. Also, a comprehensive understanding of the limitations of the preferred methodology is required to assist in the application of the methodology during the research timeframe. Such limitations include research resources, time, applicability to the research problem, validity of the research method, and economic feasibility.

3.2 COMPARISON OF RESEARCH METHODS APPLICABLE TO THE RESEARCH

The assessment of the contribution of passive design strategies in energy savings in existing buildings could be investigated through the following four research methods, i.e. laboratory approach, modeling approach, field measurement approach, and literature review approach. Each of those approaches has its limitations when applied to this research, as discussed in this section.

In general, there are two approaches mostly applied by the researchers in this field which are modeling and field measurement approaches.

3.2.1 LABORATORY APPROACH

The laboratory approach is an experimental type of research methods. It involves a controlled environment in a physical lab, where controlled variables are standardized forming a baseline to enable the investigation related to the effect of an independent variable throughout the study. The results of the study will be seen through the dependent variables or the outcomes in comparison to the standardized (baseline) scenario (Ross & Morrison, 2012).

Within the context of this particular research, the application of this approach to the designed research problem is quite limited. Not only this approach would be expensive and requires a lot of time to perform, it also is complicated to structure due to requirements of research instruments, and the means to control the research environment. Researchers in this field do not tend to apply this approach to their studies. And for the purpose of this study, it is also not preferred.

3.2.2 MODELING APPROACH

The modeling approach is another type of experimental research method defined by Ross & Morrison (2012). Typically, a representative physical model of the experiment is developed to clone the actual conditions and context from reality to a different scale controlled environment in order to facilitate conducting the experiment.

The application of the modeling approach to this study could be translated through a digital model instead of a smaller scale physical model. That is to simulate the exact conditions from real life through simulation software and digital tools. This application of the modeling approach is less time and resource consuming. It is also widely applied by the researchers in this field.

3.2.3 MODELLING APPROACH THROUGH SIMULATION MODEL

The simulation tools can provide the best assessment and flexibility when it comes to assessing and comparing several strategies in terms of thermal and energy performance. It is a cheaper method compared to experimental method, and does not require extensive human and physical resources.
The validation process is a key element when it comes to utilizing a simulation method. If the model was not validates, the results could not be validated as well.
The errors in simulation tools are related to the users input. i.e. weather data.
The limitations of this method include the assessments of aspects such as social and users behavior which are best approached in the survey method.

Energy modeling and building simulation has become a widely popular and reliable tool used by researcher and designers in the past few decades. Designers tend to use such tools prior to building construction to ensure a highly efficient building performance. On the other hand, researches utilize these tools in conducting studies and investigations on the built environment in timely manner, minimal human and financial resources. Building simulation has proven to be reliable research method with several software packages available both on commercial and academic scales. Building simulation software are capable of conducting CFD analysis, thermal modeling, energy simulation, daylight analysis , and many other parameters. Software such as Energy Plus (Ruiz & Romero 2011, Fumo et al. 2010), DOE-2 (Akbari & Konopacki 2005, Cho & Haberl 2010, Lam et al. 2010), eQUEST (Ke et al. 2013), EOTECT (Raia et al. 2011, Saadah & AbuHijleh 2010), IES Virtual Environment (Azhar et al. 2010, Al-Masri & Abu-Hijleh 2012, AlNaqabi 2012, Alawadi 2013) have been utilized for researches to assess energy consumption and thermal comfort.

Moreover, some researches were conducted on simulation tools specifically developed for the academic research, or for specific purposes. Examples of such tools were used by Philip & Chow (2007), who used PRISM CO simulation tool for cooling and heating load estimations, and used TRACE 600 for energy simulation. However, Gugliermetti & Bisegna (2007) used TMY, and WINDOWS 4.1 for thermal simulation but were not validated but only referred to previous papers who used same tools. IENUS a research-only energy simulation tool was utilized, and was validated through comparison with the results of a small office building with same Mediterranean climatic conditions.

Another research by Ruiz & Romero (2011) used Energy Plus TM tool for thermal simulation, that was developed by the US Department of Energy. Also employed LIDERIT software tool for assessing compliance with the Codigo Technico de La Edification regulations. Another tool that was employed for assessing environmental impact of the modified model vs. the original model is CALENDER.

3.2.4 FIELD MONITORING APPROACH

Field monitoring approach is a type of observational research method (Research Methodology c. 2005).
Typically, the study is directly related to the actual physical environment where the variables are measured through adequate instruments, and then extract the recorded data for analysis.

In this study, field monitoring approach could be applied to monitor several variables within the existing buildings. This includes measurements of Lux levels, thermal heat gain of the building elements, and other variables needed for the study. The field monitoring approach requires field measurement equipment, human resources, and a well-designed methodology to where and when the field measurements are taken and the existing building is monitored.

Many researchers use this approach to explore the existing conditions and then study the impact of a specific independent variable after implementation such as the study undertaken by Flores et al (2008) where two physical buildings were monitored including an original building, and another modified design.

Limitations of this approach are reflected through the time constraints limiting the study, as well as the requirements for various field measurement equipment that would offset the cost of the study to higher levels as more detailed data is required.

Also, it has to be noted that within the context of this study, the passive strategies will have to be implemented in order to be tested. Therefore the application of this approach is deemed incompatible for this study.

3.2.5 EXPERIMENTAL FIELD RESEARCH

The experimental research method is best used for studying thermal comfort levels for existing buildings when discussing parameters such as dry-bulb temperature, humidity levels, daylighting. The calibration of the measurement tools is a critical issue, unfortunately none of the papers discussed have mentioned the equipment calibration process, instead have mentioned the types of equipment, and their specific location and function.

The field measurement method is found appropriate only when the study is considering certain parameters as mentioned previously, and when the time of the study is not limited. It has to be noted that the equipment might be expensive which adds to the research project costs.

It has to be noted here that none of the papers discussed under this group had employed the field measurement method as the only research method employed. The results were usually compared to questionnaire survey results, or results obtained through simulation tools.

3.2.6 LITERETURE REVIEW APPROACH

Literature review approach is typically used as a research method when extensive database of previous studies have been conducted on a specific topic. Basically, the new study reviews the existing data available through previous researches, and applies analytical studies to explore a proposed problem of a study.

In this study, the previous studies in the same field in UAE are limited. Therefore the literature review approach could be applied only through comparing the proposed problem to other studies conducted in the same region with similar climatic conditions stating the similarities and limitations of the study, in other words a case study approach. This usually gives indicative figures to how much passive techniques are able or not to reduce energy consumption in existing buildings.

3.2.7 MATHMATICAL CALCULATION APPROACH

The mathematical calculation research method is heavily dependent on other supporting methods for data collection which is basically utilized in the mathematical analysis of the problem. Therefore, the validation of the results are usually more complicated, and might require other methodologies for validation, such as field measurements, case studies, or comparison with literature review.

There are several mathematical analysis methods including linear and non-linear calculations. The greater the number of parameters considered, the more complexity levels are present in applying the mathematical method.

An example of the level of complexity is found in the study conducted by Saidur (2009) where a multi-objective optimization model was developed and had to utilize programming softwares to present the results. This method has also been utilized by Ehsan *et* al (2012) and Ibrahim (2002) supported by other research methods.

However, the calculation method is useful to employ this methodology for economical and feasibility studies.

3.3 PREFERRED RESEARCH METHOD

Having briefly discussed alternative research approaches above, and through further assessment and understanding of the pros and cons of each method, the preference has been given to the modeling approach to conduct this particular study. This judgment has taken into consideration the limitations in the research timeframe, the human resources required, the instruments/ equipment needed to conduct the research and other aspects such as cost of the study.

Computer modeling is a time efficient research method, it allows the researcher to study multi dependent and independent factors, and it is most suitable to compare several energy saving strategies prior to implementation for the specific context, geographic location, and climatic characteristics of a building–unlike the measurement field method.

Following is a brief of each of the limitations considered during the process of the research method selection for this study.

3.3.1 RESEARCH TIME DURATION

Among the research methods highlighted earlier, the literature review would require the minimal timing since no experiments are required and that it is purely based on previous studies. Second least time consuming is the modeling approach since it requires more time modeling the sample buildings and performing the simulation, as well as the time required for training to learn the energy simulation software selected for the study. Similarly, the laboratory approach will require more time to structure and prepare the experiment, and will require more observation time throughout the study. Moreover, the field monitoring approach will consume the longest time duration since the study aims to study the existing buildings all year round including summer and winter energy consumption, and peak times. Therefore, a minimum estimate for collecting this data will be minimum one year.

3.3.2 RESARCH RESOURCES

Here again literature review will only require the efforts of the researcher himself/herself, while extensive database of previous studies required to be available. Similarly, the modeling approach will require the same human resources, but more research facilities such as an IT Lab, and energy simulation software.

On the other hand, both the laboratory and the field measurements approaches will require additional resources including research assistants, research instruments and equipment. And in the case of laboratory approach, there should be a physical research facility available to conduct the experiment.

3.3.3 FINANCIAL COSTS

With regard to the overall cost of the research, the least research expenses will be where less research resources are required. Therefore literature review approach will not require high financial costs, whereas modeling approach will require additional costs of the simulation software and training. Higher costs are estimated for both laboratory and field monitoring approaches due to additional human resources, and research instruments requirements.

3.3.4 MODELLING APPROACH SELECTION

Having mentioned the above factors, it is noted that although literature review approach is the most efficient in time, cost, and resources it will be insufficient for this study due to technical data requirements and limited previous studies conducted in UAE in this field.
Also, it is noted that the laboratory approach requires high research resources, time duration, and financial costs. In addition, it is not a common research method in this field.

Field measurements approach is one of the research methods best applicable to this type of study, it will provide sufficient technical data, but will require more time and cost compared to the modeling approach. Therefore, the field monitoring approach has been eliminated for this particular study.

The modeling approach is deemed sufficient for this study since it is considered feasible in time, cost, and resources requirements. Moreover, it provides the tools necessary to study the interdependent relation between many variables at the same time, which is critical in this study that requires assessment of alternative scenarios of passive design retrofitting techniques prior to implementation.

3.4 SELECTION OF SIMULATION TOOL

There are several building modeling softwares available that could be employed for this study. Many available softwares have been verified by different agencies and have the capability to perform highly accurate energy simulation of the model.

Those softwares could be grouped into two categories;

- a whole building energy simulation, which analyze the total energy consumption of the building; and
- a detailed simulation tool, which considers a particular aspect of the building such as thermal bridging, natural ventilation, etc. (Hirsch et al 2011)

For the purpose of this study a detailed energy simulation is required to identify the potential of energy savings due to integrating passive retrofitting techniques.

A research conducted by Crawley *et* al (2005) analyzed twenty simulation softwares, their capabilities in thermal modeling, CFD analysis, solar insulation, building envelope, and other capabilities. The compared simulation softwares included 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, and TRNSYS.

The research stipulated the pros and cons of each of the computer modeling softwares. Appendix A includes an extract of the summary comparison of the 20 computer modeling softwares (Tables A3 – A7). The tables indicated that IES VE, EnergyPlus, and TRANSYS tools are capable of conducting most of the solar analysis and insolation analysis requirements. However, for advanced fenestration analysis, other software tools are deemed sufficient such as IDA ICE.

For this study, building envelope calculations is considered critical. The study highlighted that calculations for outside surface convection were based on ASHRAE requirements in the case of IES VE software. It also highlighted that IES VE is the only software that is capable of conducting general building envelope calculations related to inside radiation view factors, radiation-to-air component separate from the exterior detailed convection, and air emissivity/ radiation coupling.

However, other studies have utilized other computer modeling tools. As highlighted earlier, Gugliermetti & Bisegna (2007) has conducted a study using a research-only software (IENUS) as a main tool for energy simulation. Although the study has mentioned that the software allowed for adjustments to include several parameters, the author did not validate the model employed for his study.

Another study conducted by Ruiz & Romero (2011), successfully estimated the energy savings through Energy Plus. However, it was not clear what were the heating and cooling systems used in the conventional design studied, and whether parameters such as infiltration has been considered through the building thermal simulation.

A more complex study conducted by Akbari &Konopacki (2005) analyzed data which included both statistical analysis and energy simulation. The paper discussed the data collected and the parameters that were used as an input for the simulation tool. The data did not only include the building characteristics, but it also included the weather data. A clear classification of the climatic zones were identified and discussed as it was utilized throughout the study to obtain the results.
Since this paper is a continuation of previous studies by the same authors, the verification of the DOE-2 simulation tool has been referenced to their previous work. And the methodology is also validated by referencing to the project of the US Environmental Policy Act (EPA) which is the Urban Heat Island Pilot Project (UHIPP).

Another study has utilized several software tools. A study conducted by Philip & Chow (2007), highlighted in the previous chapter, have used the simulation through PRISM CO which utilized data from energy audit. The PRISM CO model, and even the further developed models mostly were used for a single variable/ parameter. The models ignored the electricity consumption used for lighting. With regard to the energy simulation software TRACE600, few variables were still under the uncertainty zone such as people load.

For this study, IES VE has been used as an energy modeling tool to assess energy savings and reductions in cooling loads for the building prototype. In a comparison with 20 commonly used energy simulation software, IES VE provided various interlinked parameters and assessment options including building envelope, daylight and solar variables which are important for this study (Crawley *et* al. 2008). IES has proven high reliability and accuracy of its results with advanced features.

3.5 IES VIRTUAL ENVIRONMENTN SOFTWARE VALIDATION

As highlighted previously, many researchers have been using IES VE for energy simulation and thermal modeling. The software, which was compared with another 19 computer modeling tools was proven to be of high capabilities and reliability, especially for this type of research and analysis. (Crawley *et* al. 2008). This simulation software has also been used for the previous research project, of which this study is a continuation for. The study has assessed energy consumption of five housing typologies and analyzed annual cooling load savings through IES VE 6.4. (AlNaqabi *et* al., 2012 and Alawadi *et* al., 2013).

It is important through to validate the software within the context of the study. A study conducted by AlNaqabi (2013) have validated the software by modeling an existing villa as a case study and comparing the results with the actual total energy consumption. The researcher has also contributed to the previous study (AlNaqabi *et* al. 2012) which adopted IES software for the research.

The software validation case study was selected from the Emirate of Sharjah, and is presented in the following Table 7 and Figure 14 below. The IES model indicated similar trend in total monthly energy consumption, with minor deviations in the monthly energy consumption for the months from May to August. AlNaqabi (2013) explained that the deviation is justified due to the building typology which is a school, in which the occupancy profile varies in the summer months due to minimal occupancy of the building facilities where students are mostly off during Summer.

Table 7 Validation model results. (AlNaqabi (2013), pp. 60)

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

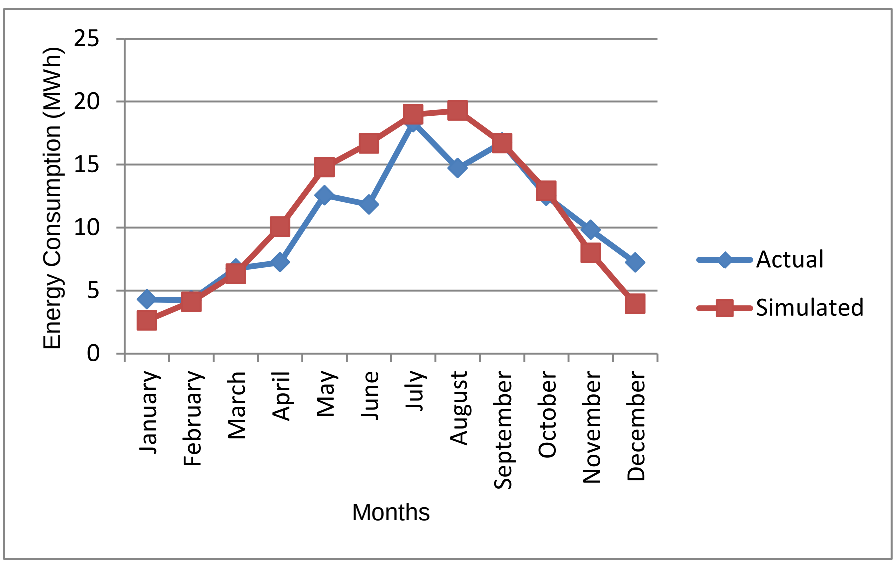


Figure 14 Comparison of tested villa actual and simulated energy consumption. AlNaqabi (2013), pp. 60)

As a conclusion of the validation case study an average annual energy consumption deviation of 6% from the actual results was identified. However, the deviation is much less for the months where the building is fully occupied.

3.6 SUMMARY RESEARCH METHODOLOGY

The research methodology which best applies to this particular study is the modeling approach, in which data collected will be analyzed through a quantitative, qualitative, and graphical quantitative analysis, as well as interpretations of interviews and observations.

3.6.1 LITERATURE REVIEW, DATA COLLECTION AND ANALYSIS

The study requires investigation to identify the existing building typologies which represents the total stock of buildings in Abu Dhabi Metropolitan. The data collected should reflect the total number of buildings in each category as well as building Gross Floor Area (GFA). The data collected should be analyzed to identify the common design and construction building typology of commercial buildings in 1980s and 1990s. An understanding of existing and previous building regulations is also essential.

The data collected is presented within the literature review section of this study, and further analysis will be curried on in relevant chapters as required.

3.6.2 BUILDING MODELING AND SIMULATION

The study will conduct two sets of building simulation using IES Virtual Environment 6.4 software;

- The first set will model and analyze the existing buildings as they are currently with no modifications
- The second set will model and analyze the modified buildings assessing the various proposed passive retrofitting techniques by conducting several simulation runs independently.

The following passive retrofitting techniques will be explored:

- Thermal insulation for external walls
- Thermal insulation for roof
- Glazing materials for external openings

The following parameters will be assessed using the software;

- Room cooling plant sensible load

- Chiller energy
- Auxiliary chiller energy
- Heat rejection fan/ pump energy
- Total system energy
- Total equipment energy
- Total energy
- Sensible heat balance
- Sensible internal gains breakdown
- Total Carbon emissions

The details of the simulation models and scenarios will be further discussed in the following chapter.

3.6.3 SIMPLE PAYBACK PERIOD COST ANALYSIS AND STATISTICAL ANALYSIS

A simple payback period cost analysis will be conducted to assess the financial feasibility of the building refurbishment process. The analysis will be conducted based on simple payback period, similar to what have been implemented in the previous research project conducted by AlNaqabi *et* al (2012) and Alawadi *et* al (2013). The analysis will be based on market based prices of the proposed retrofitting applications.

3.6.4 ANALYSIS METHOD

- Analysis of data collected regarding stock of existing buildings in Abu Dhabi Metropolitan to identify two case studies representing commercial buildings in 1980s and 1990s.
- Analysis and assessment of energy savings of refurbishment strategies for the selected case studies in comparison with the baseline as built model.
- Cost analysis of retrofitting strategies and comparing energy savings achieved with reference to expenses.

The following Chapter identifies the simulation models, scenarios, input parameters, and output parameters addressed in the study.

CHAPTER 4: SIMULATION MODELS

4 SIMULATION MODELS

4.1 INTRODUCTION

In order to initiate the computer modeling and simulation for the studied case, it is important to identify the simulation scenarios, simulation input data, and any associated assumptions. Since the research addresses building typologies from earlier decades, it is deemed necessary to understand the simulation input parameters to reflect the exact conditions and not using the software default values and assumptions.

The research targets to conduct energy simulation and thermal modeling for 9 simulation models including the baseline model, and 8 refurbished building scenarios. The first section explains the parameters of the case study, followed by an explanation of the general input data for the baseline model. Then the chapter presents the simulation input for the 8 refurbishment scenarios besides the trial scenarios explanation. The chapter also presents a summary of the simulation variables which concludes the simulation input parameters to be assessed through the computer modeling and simulation for the 9 scenarios.

4.2 THE CASE STUDY

The case study building is a mixed-use building typology located in Abu Dhabi in Electra Street. The building is located on a 50 x 80 square feet plot. The building represents a typical prototype of the 1980s in Abu Dhabi. It is a concrete structure building, single glazed, with no walls insulation. The building consists of 15 typical floors each of 3.4 meters height, and a mezzanine and ground floor building with a total height of 7.4 meters. Figure 15 is a photo of the case study building.

The building is designed as a mixed-use building following the norms in Abu Dhabi during the time of design and construction. The typical floor was designed to either be utilized for office spaces or accommodate a four two bedrooms residential units. However, the ground floor has been allocated for retail-office spaces, and the mezzanine was allocated for office spaces.

Figure 15 Real time case study building photo.

4.2.1 TYPICAL FLOOR

The typical floor covers an area of 447.1 square meters. The external walls surface area is 289.68 square meters, and a net external glazing area of 93.84 square meters. The following Figure 16 and Figure 17 are extracted from the simulation model of the typical floor which represents the typical floor plan and an external perspective image of the model.

4.2.2 MEZZANINE FLOOR

The mezzanine floor covers an area of 344.1 square meters. The external walls surface area is 269 square meters, and a net external glazing area of 73.68 square meters. The following Figure 16, Figure 17 and Figure 18 are extracted from the simulation model which represents the mezzanine floor plan and an external perspective image of the model.

4.2.3 GROUND FLOOR

The ground floor covers an area of 344.1 square meters. The external walls surface area is 132.64 square meters, and a net external glazing area of 270.56 square meters. Figure 16, Figure 17 and Figure 18 are extracted from the simulation model of the ground floor which represents the floor plan and an external perspective image of the model.

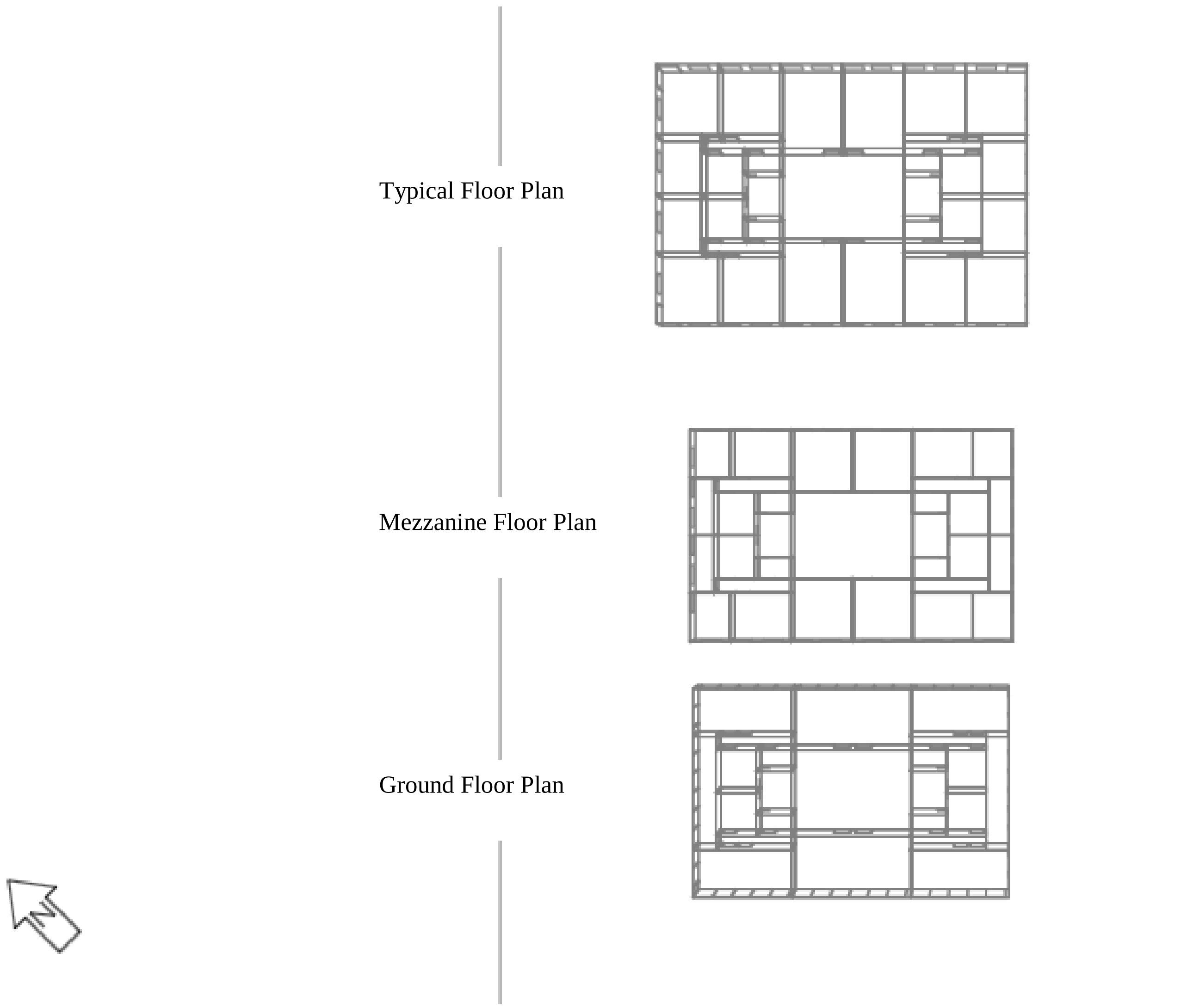


Figure 16 Typical floor plans of the IES-VE model.

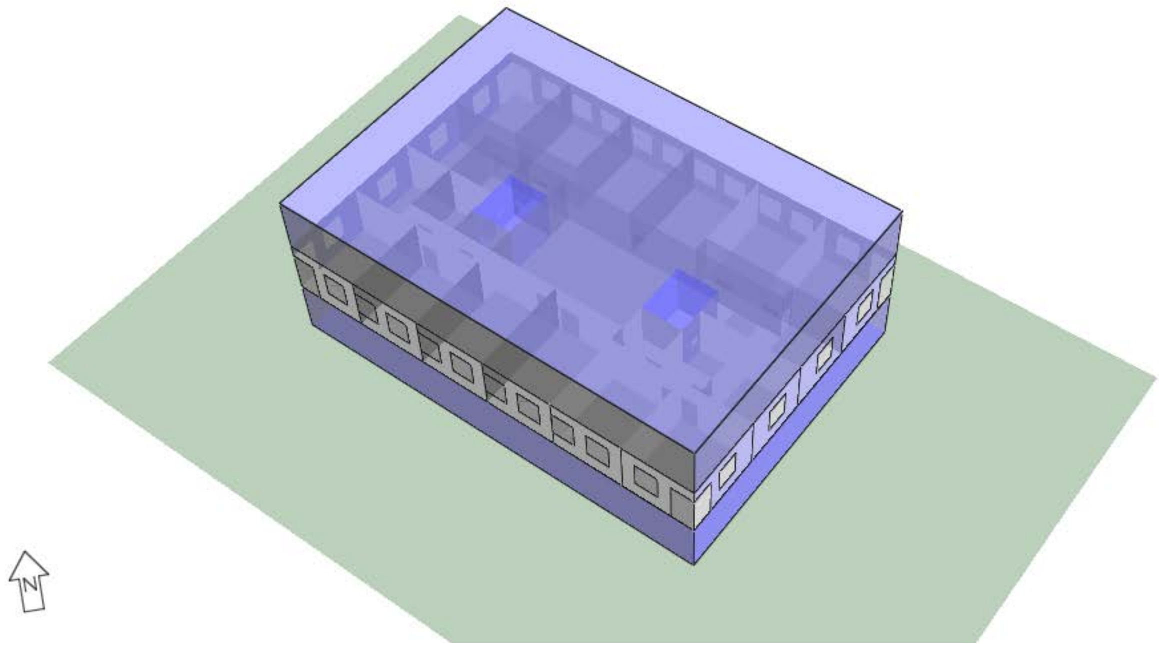


Figure 17 Typical floor three dimensional image of the IES-VE model.

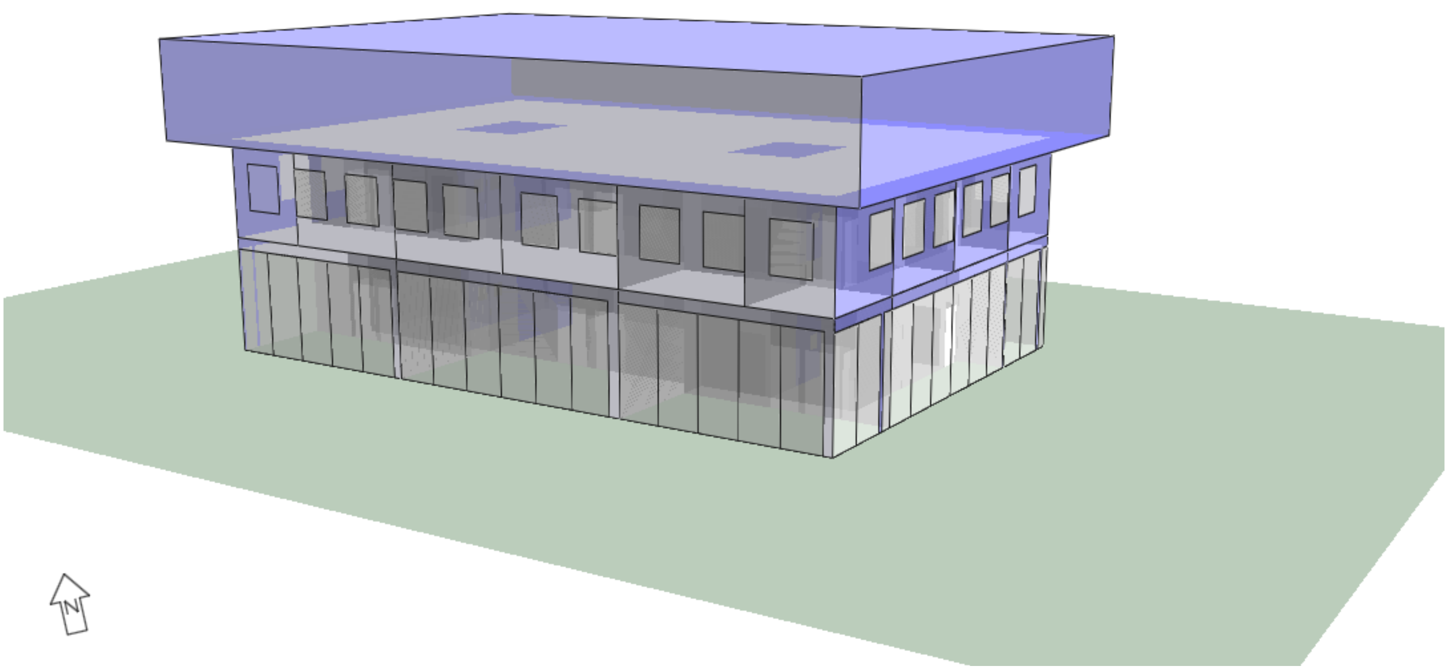


Figure 18 Three dimensional image of the IES-VE model for ground and mezzanine floor.

4.3 BASELINE MODEL INPUT

4.3.1 GEOGRAPHICAL LOCATION AND WEATHER DATA

The case study building is located in Abu Dhabi City in Electra Street. The building is oriented approximately 45 degrees East-North. In order to set the weather data file and geographic setting of the building, the computer model used the IES-VE tool of APLocate. Thorough this tool, the identified location data was linked to the the software built-in data related to Abu Dhabi Intl Airport, United Arab Emirates. Daylight adjustments have been set to zero. Following are the location data and site data input used for APLocate tool;

Location Data:

- Longitude: 54.65° E
- Latitude: 24.43° N
- Altitude: 27m meters above sea level
- Time Zone (hours ahead of GMT): 4 hours

Site Data

- Ground reflectance: 0.20
- Terrain Type: City
- Wind exposure (CIBSE heating loads): Normal

4.3.2 ABU DHABI's CLIMATIC CONDITIONS

The United Arab Emirates is characterized by its hot arid desert climatic, whereas the main characteristics are known to be the high temperature, and the low rainfall levels (The UAE National Media Council. 2010). The outside maximum dry bulb temperature can reach to 46.5°C. The weather data design file is based on ASHRAE Standards; however, the weather data file selected was AbuDhabiIWEC.fwt which is generated by IES-VE.

The following Table 8 provides more details of the assumption. The table is a generated report from the baseline model.

Table 8 Location and Site Data. (Source: IES-VE APLocate)

Location & Site Data

Location	*Abu Dhabi Intl Airport*
Region	United Arab Emirates
Latitude	24.43 N
Longitude	54.65 E
Altitude	27.0m
Time zone	4.0 hours
Hours ahead of GMT	
• *Daylight Saving Time*	
Time adjustment	0.0 hours
From	
Through	
Adjustment for other months	0.0 hours
• *Site Data*	
Ground reflectance	0.2
Terrain type	City
Wind exposure	Normal
(CIBSE Heating Loads)	

Weather Simulation Data	
ApacheSim File	AbuDhabiIWEC.fwt

Design Weather Data

• *Design Weather Data Source & Statistics*	
Source of Design Weather	ASHRAE design weather database
ASHRAE weather location	Abu Dhabi Intl Airport , United Arab Emirates
Monthly percentile for Heating Loads design weather	99.6 %
Monthly percentile for Cooling Loads design weather	0.4 %
• *Heating Loads Weather Data*	
Outdoor Winter Design Temperature	11.5°C
• *Cooling Loads Weather Data*	
Max. Outside Dry-Bulb	46.5°C
Max. Outside Wet-Bulb	23.6°C

Weather model data

	Temperature		**Humidity**	**Solar Radiation**
	Dry bulb T Min (°C)	**Dry bulb T Max (°C)**	**Wet bulb T at Max dry bulb (°C)**	**Linke Turbidity Factor**
Jan	19.50	29.50	18.00	2.31
Feb	23.40	33.80	17.80	2.37
Mar	26.70	38.00	18.90	2.56
Apr	28.60	41.80	20.30	2.85
May	29.60	44.10	21.10	3.06
Jun	31.00	45.20	21.90	3.22
Jul	33.80	46.10	23.60	3.29
Aug	34.00	46.50	23.30	3.13
Sep	30.40	43.10	23.10	2.84
Oct	30.20	43.10	21.60	2.65
Nov	23.50	35.00	19.80	2.44
Dec	20.70	31.20	18.80	2.38

4.3.3 THERMAL CONDITIONS

This section stipulates the simulation input and assumptions used to generate the thermal properties of the baseline model. It has to be noted that many of the parameters deviate from the default software tools settings due to the nature of the project as an old dated building design and systems.

4.3.3.1 ROOM CONDITIONS

All rooms are set to the same profile as following;

- Heating: heating profile is set off continuously
- District Hot Water System (DHW): is set to zero consumption
- Cooling: Cooling profile is set working between 8:00am to 6:00pm with constant profile. The cooling set point is set to 23 °C based on comfort zone set by ASHRAE. UCLA Energy Design Tools Group (2011).
- Plant Auxiliary System: the auxiliary system is set on between 8:00am to 6:00pm
- Model Setting: model settings are set to defaults; with solar reflected fraction of 0.05, and furniture mass factor of 1
- Humidity Control: humidity is set within 30% to 70% relative humidity based on thermal comfort guidelines of ASHRAE. UCLA Energy Design Tools Group (2011).

4.3.3.2 SYSTEM

The main system utilized is a cooling only system, where low efficient air conditioning systems were used.
The COP was assumed to be 2.2 based on the ASHRAE 90-1975 effective in 1980.

4.3.3.3 INTERNAL GAINS

The building zoning was divided into five zones based on functionality and relevant thermal conditions. The detailed report of the thermal conditions input of all zones has been generated through IES-VE tools and is provided in Appendix C, Table C1.

- **Corridor:** Corridor internal gains include Fluorescent lighting is assigned to maximum power consumption of 13W/m2

- **Kitchen:** Kitchen internal gains include Fluorescent lighting is assigned to maximum power consumption of 9W/m2, and cooking assigned to maximum power consumption of 10W/m2
- **Lobby:** internal gains include Fluorescent lighting is assigned to maximum power consumption of 12W/m2, and miscellaneous lift assigned to a maximum power consumption of 5W/m2 . Based on Abu Dhabi building code which was in use in 1980s, Article (55) regarding provision of elevators states that for buildings over 15 storeys minimum three elevators should be provided of minimum capacity of 6 people each (ADM 1983). However the estimated consumption of 5W/m2 is assigned to the maximum power consumption in the simulation model based on the KONE energy calculator (KONE 2013).
- **Office:** Office internal gains include computers set at 20W/m2 for maximum sensible gain and maximum power consumption, and is set to a profile from 8:00am to 6:00pm.

  The default setting is also similar to what has been used in a study conducted by Hammad & Abu-Hijleh (2010) which is conducted for a typical office space in Abu Dhabi. The study assumed occupancy of two computer desks per 32 square meters, where the computer uses 370W. When the same is calculated based on the total office area of the simulated building the average power consumption for computers would be 22W/m2 which is close to the default setting.

  Use of fluorescent lighting was selected for internal heat gain based on illuminance level of 500 lux for office spaces based on IESNA requirements (Block 2000), accordingly maximum power consumption is assumed 11W/m2.

  For people occupancy, the assumption is to dedicate 12 square meters per person. Although the average office space in Abu Dhabi as per UPC (2010b) was 1.9 square meters per person, this is not considered a representative ratio for this type of buildings, since the building prototype is typically designed for either residential or office uses. According to Hammad & Abu-Hijleh (2010), a typical office space in Abu Dhabi provides 16 square meters per person. However, based on the layout of this building an average of 36 people could be accommodated, therefore the habitable space dedicate to each person is around 12 square meters. Based on these assumptions, the occupancy density for the building simulation is assigned to 12 m2/person with maximum sensible gain of 90W/person, and latent sensible gain of 60/person.
- **Washroom:** washroom internal gains include fluorescent lighting set at 9 W/m2 for maximum sensible gain and maximum power consumption.

4.3.3.4 AIR EXCHANGES

- All rooms are set to an infiltration rate of 0.25 air change per hour.
- Auxiliary ventilation is set to a maximum of 2 air change per hour, and a variation profile set from 8:00 am to 6:00pm.

4.4 SIMULATION MODELS

4.4.1 TEST SIMULATION MODELS

Prior to starting the final simulation of the studied scenarios, and due to complexity of the simulation for high-rise building model, it is necessary to run test simulations to minimize modeling errors to minimal.
Therefore, the author conducted several test simulations on a typical floor of the studied building. The test model was tested to identify the following parameters are within the expected range;

4.4.1.1 AIR TEMPURATRE

The model thermal conditions for cooling set point was defined as 23° C and the cooling profile is set to a daily profile from 8:00 am to 6:00 pm. Therefore, a successful simulation model shall reflect a flat line of 23°C where the cooling system is operational. Figure 19 present the output of annual air temperature profile in one sample room within the typical floor. As noticed in the figure, the air temperature profile is responsive to the outdoor air temperature profile where the cooling is off, and is represented in a constant formula –flat line- where the cooling is operational.

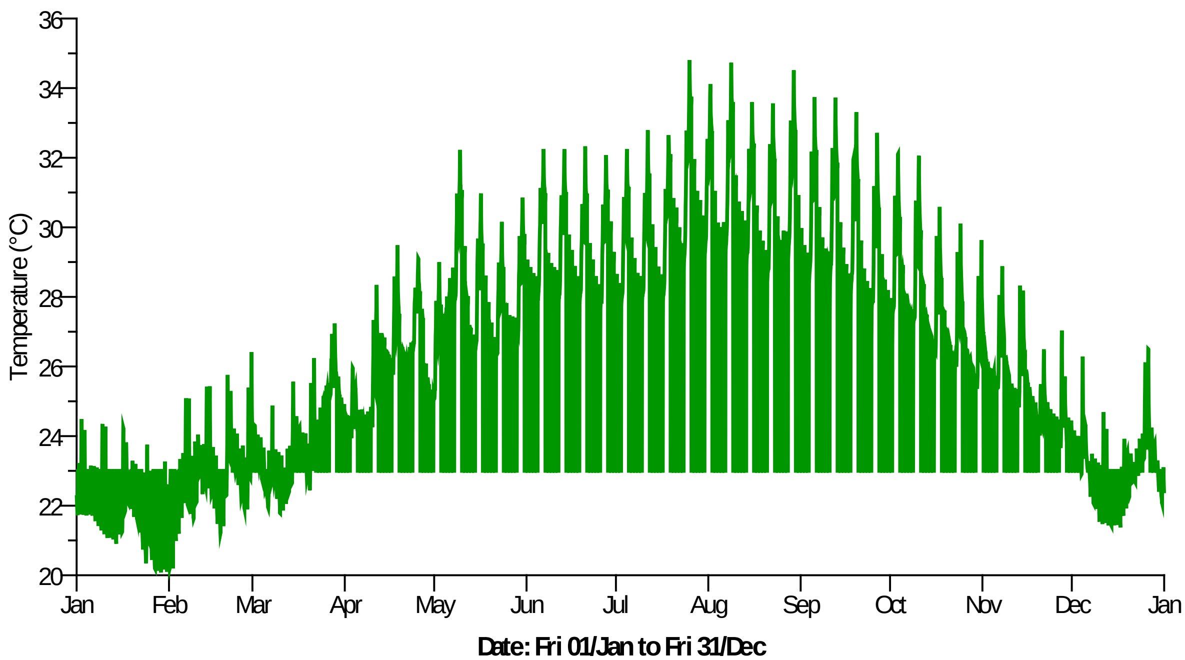


Figure 19 Annual air temperature profile for room identified Living-01. (IES VE Tool)

4.4.1.2 RELATIVE HUMIDITY

The relative humidity has been set within the recommended range as per ASHRAE thermal comfort parameters which are in the range between 30% and 70%. Figure 20 present the output of annual relative humidity profile in one sample room within the typical floor. The figure highlights that the annual relative humidity profile is responsive to the limits set for relative humidity with maximum value of 70% and minimum value of 30%. Where the cooling system is off –outside the occupancy profile settings- the relative humidity profile represents the actual outdoor conditions.

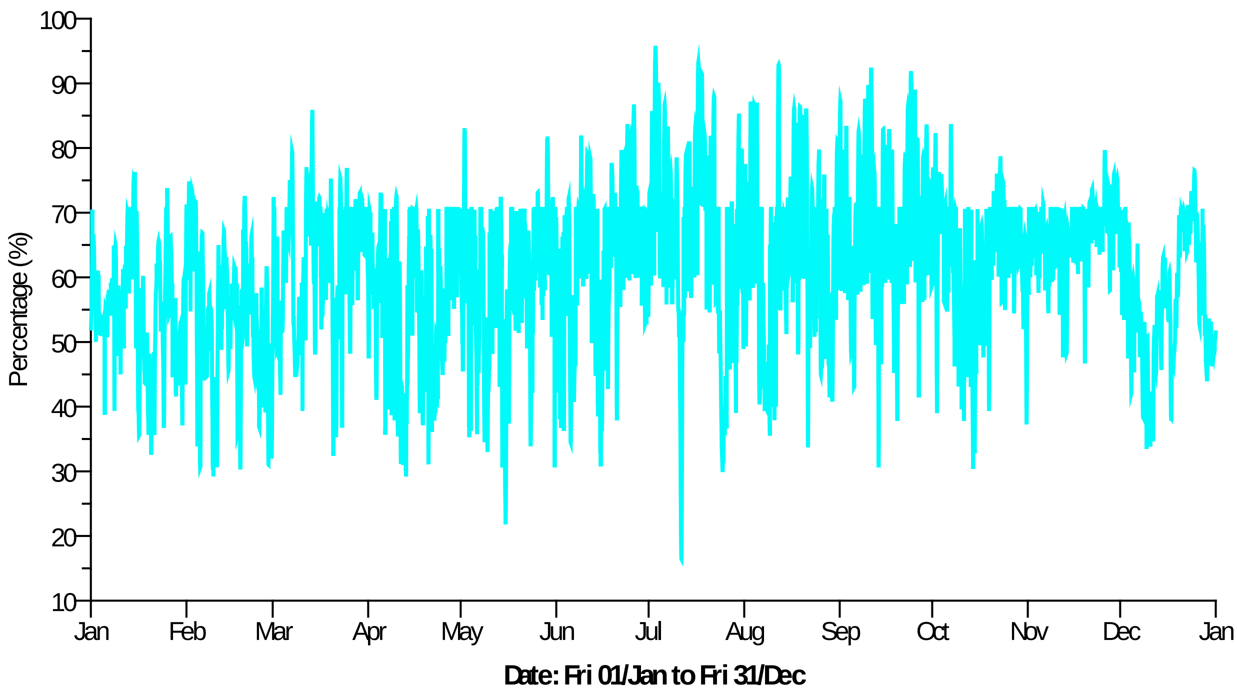


Figure 20 Annual relative humidity profile for room identified Living-01. (IES VE Tool)

4.4.1.3 ROOM CO2 CONCENTRATION

An important indication of whether the modeling is representatives of the as-built conditions, is the room CO2 concentration. CO2 concentration is one parameter that indicates a habitable space and is directly linked to the cooling loads. High room CO2 concentration could be identified where reductions in cooling loads beyond the actual conditions occur. According to ASHRAE the room CO2 concentration shall be less than 1000 ppm. Figure 21 present the output of annual room CO2 concentration profile in one sample room within the typical floor. The figure highlights that the maximum CO_2 concentration level is around 595 ppm where the cooling is off. However, it is further reduced to around 360 ppm when the cooling system is operational.

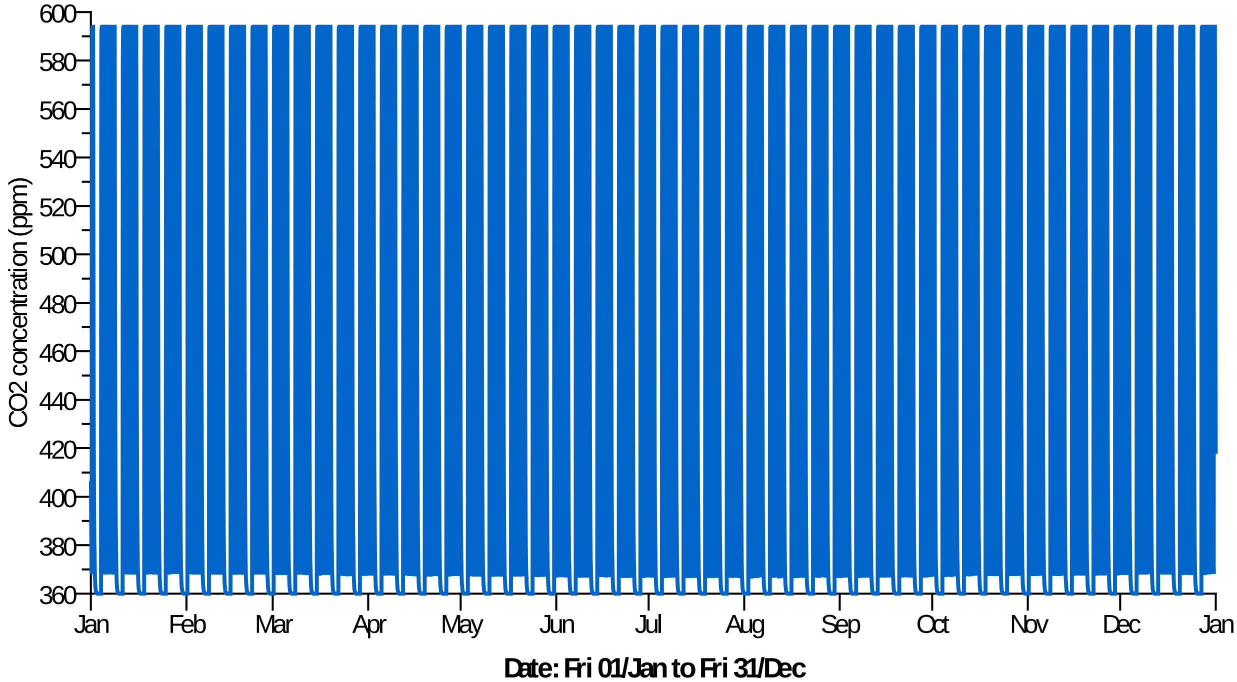


Figure 21 Annual room CO_2 concentration profile for room identified Living-01. (IES VE Tool)

4.4.1.4 COOLING PLANT SENSIBLE LOAD

Similar to the air temperature profile, the annual cooling plant sensible load is an indication of the model behavior compared to the actual conditions. Since the cooling system is set to a daily profile from 8:00 am to 6:00 pm; the simulation results shall reflect the same. Figure 22 present the output of annual cooling plant sensible load profile in one sample room within the typical floor. The figure highlights that the annual cooling load profile is responsive to the outdoor conditions; i.e. during the Summer months, the cooling load is at peak, where it is reduced during Winter Months. Also, it is noticed that the cooling load is zero when the cooling system is off.

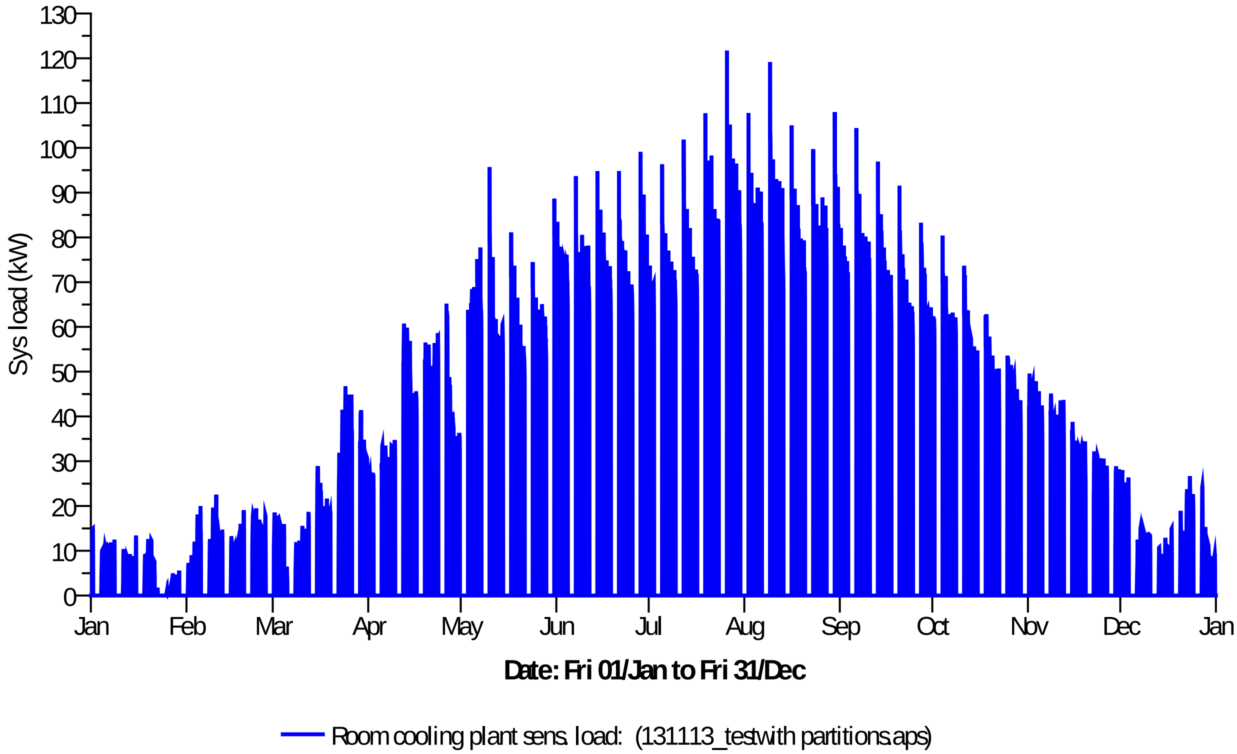


Figure 22 Annual cooling plant sensible loads profile for room identified Living-01. (IES VE Tool)

4.4.1.5 THERMAL ZONING

Moreover, a trial simulation was conducted for the typical floor with the internal partitions, and without the internal partitions. The comparison of sensible cooling loads for both models is used to identify whether the internal zoning will have impact on the study. Based on this comparison, the final model for the overall structure is defined. Figure 23 indicates the typical floor models as-built, and with connected spaces. The model to the left defines the rooms as different zones, which typically consumes more time for analysis. To the right, a modified model has considered the IES ModelIT function to connect spaces. The function was used for the office spaces only, and was selected with removal of partitions.

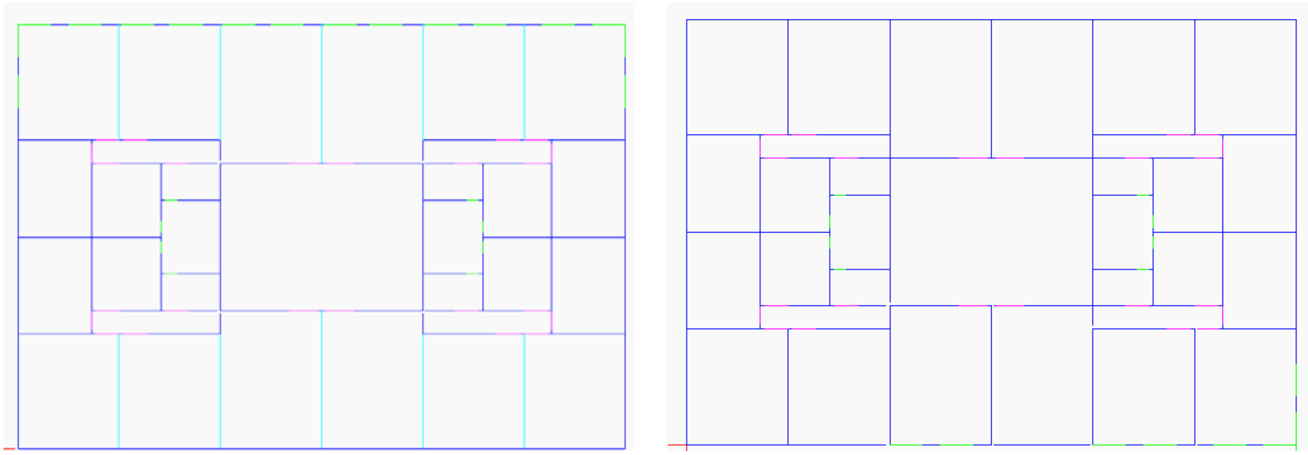


Figure 23 Typical plan IES model. To the left is the model as-built conditions, to the right is the model with connected spaces.

The results highlighted an overall difference of 5% on the total room cooling sensible load. The differences range from 3.4% to 5.2% on the monthly cooling loads. Table 9 stipulates the monthly and yearly room cooling plant sensible loads in MWh for the typical floor based on a simulation model for the as-built conditions of separate spaces, and a simulated model with connected spaces for office spaces. Figure 24 summarizes the difference in cooling load profile of the two models graphically. It is noticed that the difference during the Summer from May to September witness the greatest deviation in the results.

Based on the comparison highlighted above, the author decided to simulate the building on the basis of as-built conditions to minimize the modeling errors.

Table 9 Comparison on room cooling plant sensible loads between connected spaces model and as built model.

Room cooling plant sens. load (MWh)		
Date	**Typical Floor as built**	**Typical Floor with connected spaces**
Jan 01-31	0.9059	0.8651
Feb 01-28	1.8522	1.7698
Mar 01-31	4.8052	4.5588
Apr 01-30	9.6783	9.1826
May 01-31	14.0266	13.314
Jun 01-30	17.2003	16.3085
Jul 01-31	18.6062	17.694
Aug 01-31	19.5397	18.5494
Sep 01-30	16.8354	15.961
Oct 01-31	11.9635	11.3382
Nov 01-30	7.5186	7.1125
Dec 01-31	2.5366	2.3937
Summed total	**125.4686**	**119.0477**

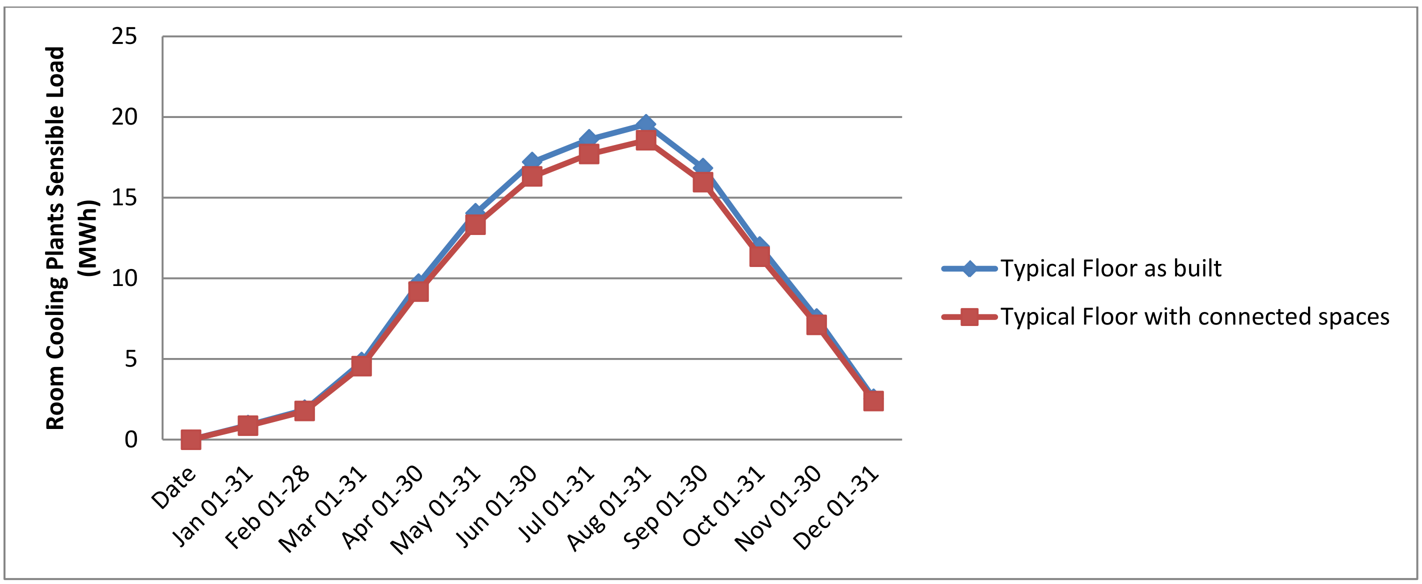


Figure 24 Typical floor space zoning comparison.

4.4.2 SIMULATION SCENARIOS

The simulations scenarios are set to analyze the thermal parameters of the building envelope, and the impact of the upgrades for the external wall insulation, roof insulation, and external glazing. This research will use the minimum requirements for the 1 pearl rating for the building envelope upgrades, that will be based on the requirements stipulated under the Estidama U-value calculator for the 1 pearl rating and 2-5 pearl rating. Where the 2-5 pearl rating standards are used, the research will refer to the standards as 2 pearl scenario.

The first set of simulation is the baseline scenario for the as-built conditions. The second set targets the thermal insulation upgrades for the external walls to the requirements of the Abu Dhabi Urban Planning Council Estidama requirements as stipulated in the Pearl Rating System set for Abu Dhabi. This set includes two scenarios; the first is the upgrade to 1 Pearl rating with the requirements for wall U-value of 0.32 (W/m2.K), the second is for 2Pearls rating with the requirements of 0.29 (W/m2.K).

The third set consists of two scenarios for upgrades of glazing properties to 1 Pearls rating requirement for glazing U-value of 2.2 (W/m2.K) and glazing SHGC value of 0.4. The second scenario improves the performance for 2 Pearl rating to 1.9 (W/m2.K) and 0.3 respectively.

The fourth set consists of upgrades of the roof thermal insulation in two scenarios similar to the above. The 1 pearl rating scenario requires roof u-value of 0.14 (W/m2.K), whereas the second scenario for 2 pearl rating requires roof u-value of 0.12 (W/m2.K).

The fifth and final set of model is a scenario of all combined solutions of 1 pearl, and 2- pearls requirements.

Table 10 provides a summary of the minimum requirements in compliance with 1 Pearl rating, and the advanced requirements to achieve the optional credit 2 Pearls (Abu Dhabi Urban Planning Council 2010).

Table 10 Summary of thermal performance requirements in compliance with 1 pearl & 2-5 pearls rating.

Element	Baseline Model	1 Pearl RE-R1 Required Target Value		2-5 Pearls RE-2 Optional Target Value	
Infiltration	2.000 ach	0.350	ach	0.200	ach
Wall (U-value)	1.600 W/m2.K	0.320	W/m^2.K	0.290	W/m^2.K
Floor (U-value)	0.25 W/m2.K	0.150	W/m^2.K	0.140	W/m^2.K
Roof (U-value)	0.505 W/m2.K	0.140	W/m^2.K	0.120	W/m^2.K
Glazing (U-value)	5.811 W/m2.K	2.200	W/m^2.K	1.900	W/m^2.K
Glazing (SHGC)	81 %	40	%	30	%

Table 11 summarizes the scenarios based on different simulation input variables which were used for the case study. For easy comparison the table uses two different symbols for the baseline and the modified parameter. The symbol O is used where the baseline value is used, and the symbol X is used where an upgrade is proposed and evaluated.

Table 11 Summary of IES model simulation input variables

Scenario / Variables	U-value (W/m2.K)	SHGC (%)	Baseline Model	Wall 1 Pearl	Wall 2-5 Pearls	Glazing 1 Pearl	Glazing 2-5 Pearls	Roof 1 Pearl	Roof 2-5 Pearls	Combined 1 Pearl	Combined 2-5 Pearls
External Walls	Baseline	n.a.	O	-	-	O	O	O	O	-	-
	0.320	n.a.	-	X	-	-	-	-	-	X	-
	0.290	n.a.	-	-	X	-	-	-	-	-	X
Glazing	Baseline	Baseline	O	O	O	-	-	O	O	-	-
	2.200	0.4	-	-	-	X	-	-	-	X	-
	1.900	0.3	-	-	-	-	X	-	-	-	X
Roof	Baseline	n.a.	O	O	O	O	O	-	-	-	-
	0.140	n.a.	-	-	-	-	-	X	-	X	-
	0.120	n.a.	-	-	-	-	-	-	X	-	X

Notes:

O : the baseline value is applied

X : an upgrade is applied

n.a.: not applicable

4.5 SIMULATION PROCESS

The case study building consists of a total 17 floors with 15 typical floors, mezzanine and ground floors. Therefore, the simulation processing through IES-VE is likely to be interrupted by model complexity and its requirements for advanced IT systems. In order to minimize any unwanted IT related errors and delays, the researcher decided to split the simulation into three different models.

The simulation process begins with identifying the breakdown of the building structure for easy analysis and arrangement of the results. The building has been divided into three models as following;

- Typical floor simulation model
- Ground floor and mezzanine floor simulation model
- Roof floor simulation model

The simulation and the study will be conducted separately for each of the models. For each of the models the 8 scenarios will be generated, as described in the earlier section. A total of 23 simulations shall be conducted inclusive of;

- 7 simulations for the typical floor model
- 7 simulations for the ground and mezzanine floors model
- 9 simulations for the roof floor model

All results from the models will be presented statistically and imported into a table form using MS Office – Excel program. The results from the typical floor model will be multiplied by 14 to represent the overall results for all typical floors except for the roof floor. The results will be added to the ground and mezzanine floors results as well as the roof floor model results.

Although the roof floor is represented architectural in the same manner as the typical floor, it has been identified as a separate IES model since the roof is exposed directly to the external atmosphere, which shall increase the solar gain and energy consumption for this floor in particular.

The final step shall be presenting the overall results for the whole structure in the coming sections of this paper.

CHAPTER 5: RESULTS AND DISCUSSION

5 RESULTS AND DISCUSSION

5.1 INTRODUCTION

This chapter will include the results of this research and discuss the savings that are achieved through various refurbishment strategies. This section will also discuss the economic feasibility of the proposed scenarios to nominate the most feasible option which achieves the greatest energy savings within an economically viable solution context. The study presented in this chapter will also evaluate the overall savings of the existing building stock in Abu Dhabi which is represented by the studies typology.

Comprehensive and critical analysis of the results is required to understand the potential of energy savings by employing thermal envelope upgrades. The results will be presented for the room cooling plant sensible loads, the system energy, the auxiliary system energy, the total electricity consumption. It is also essential to understand the sensible heat balance which includes the conduction gain in the external building envelope elements. It has to be noted that during the studies conducted for the previous research project –refer to Chapter 2- that the behavior of the cooling load profile and related energy savings when combined refurbishment solutions are employed, has to be explained through the elemental heat gain, and overall envelope sensible heat balance.

The chapter will first present the outcome of the refurbishment solutions for thermal insulation upgrades for external walls, followed by glazing upgrades, thermal insulation upgrades for the roof, and the combined refurbishment solutions. A discussion around the building envelope performance in terms of solar gain and external conduction gain will be presented to support and justify the results of combined versus individual refurbishment scenarios. The chapter will then provide an economic feasibility assessment section. The chapter will be concluded by assessing the potential of energy saving for the total GFA of the existing building stock in Abu Dhabi, which is represented by the case study.

5.2 EXTERNAL WALLS INSULATION REFURBISHMENT

The refurbishment application for the external walls of the building focuses on upgrading the thermal performance of the walls. Therefore, the refurbishment technique proposed is addition of thermal insulation.

There are two types of thermal insulation upgrades to the existing buildings, which are locally common. These include thermal insulation boards of different thicknesses, thermal properties, and material properties, and the application of a curtain wall which could be externally fixed to the existing structure.

This section will present and discuss the results of two different scenarios to upgrade the thermal performance of the external walls. The scenarios selected are the upgrades to U-value of 0.32 W/m2.K and 0.29 W/m2.K; which are based on the Estidama Pearl Rating System requirements for 1 pearl, and 2-5 pearls rating.

5.2.1 TYPICAL FLOOR

The results for the typical floor –presented in Table 12- indicated cooling loads savings of around 5.67% for the 1 pearl wall upgrade, and 5.80% for the 2 wall pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 5.14% and 5.26% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 3.54% and 3.63% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl wall upgrades is estimated at 3.752 MWeh/yr, and 3.840 MWeh/yr for the 2 pearls wall. Also, the annual reduction in CO2 emissions are estimated at 1,940 KgCO2 and 1,985 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. CO2 emissions were estimated based on the IES Vista Analysis results of Total Carbon Emissions CE including carbon emissions from the building and its systems and based on type of fuel used to generate electricity in Abu Dhabi excluding any contribution from renewable energy.

For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 12 Load, Energy and Carbon results of external wall upgrades for typical floor model.

Output	Baseline	Wall- 1 Pearl	Wall- 1 Pearl Savings (%)	Wall-2 Pearl	Wall-2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	125.4686	118.3528	5.67%	118.1854	5.80%
Chillers energy (MWh)	56.1426	53.2564	5.14%	53.1885	5.26%
Ap Sys chillers energy (MWh)	56.1426	53.2564	5.14%	53.1885	5.26%
Ap Sys heat rej fans/pumps energy (MWh)	16.8428	15.9769	5.14%	15.9566	5.26%
Total system energy (MWh)	83.2134	79.4628	4.51%	79.3745	4.61%
Total electricity (MWh)	105.8156	102.0636	3.55%	101.9753	3.63%
Total energy (MWh)	105.897	102.1464	3.54%	102.0581	3.63%
Total CO2 Emissions ((kgCO2)	54,723.00	52,783.00	3.55%	52,738.00	3.63%

It is noticed that the additional savings beyond the 1 pearl rating upgrades and minimal for external wall upgrades in the typical floor, with a range of 0.08% to 0.13%. Also, it is noticed that the overall savings in the case of 1 pearl upgrade from the baseline case is still modest. This is explained due to the fairly good thermal performance of the external wall section which is calculated to have a U-value of 1.6 W/m2.K. The construction of the external wall as-built, although has no thermal insulation application, it was designed with air gap between two high density concrete blocks. This explains the modest reductions in cooling loads, energy consumption, and CO2 emissions.

5.2.2 ROOF FLOOR

The results for the roof floor –presented in Table 13- indicated cooling loads savings of around 5.94% for the 1 pearl wall upgrade, and 6.09% for the 2 wall pearl upgrade. This is slightly greater than the results shown for the typical floor, and that is mainly due to the external building envelope in case of the roof floor includes the roof element which is almost three times of better insulation than the baseline wall section. This means that the overall building envelope in case of the roof floor will have better performance than that for the typical floor. The results also indicate a reduction in annual chillers energy and related auxiliary chiller system and heat rejection system, estimated at 5.39% and 5.52% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 3.73% and 3.82% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl wall upgrades is estimated at 3.9896 MWeh/yr, and 4.0848 MWeh/yr for the 2 pearls wall. Also, the annual reduction in CO2 emissions are estimated at 2,062 KgCO2 and 2,112 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 13 Load, Energy and Carbon results of external wall upgrades for roof floor model.

Output	Baseline	Wall- 1 Pearl	Wall- 1 Pearl Savings (%)	Wall-2 Pearl	Wall-2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	127.3355	119.7668	5.94%	119.5863	6.09%
Chillers energy (MWh)	56.8844	53.8155	5.39%	53.7423	5.52%
Ap Sys chillers energy (MWh)	56.8844	53.8155	5.39%	53.7423	5.52%
Ap Sys heat rej fans/pumps energy (MWh)	17.0653	16.1447	5.39%	16.1227	5.52%
Total system energy (MWh)	84.1811	80.1926	4.74%	80.0975	4.85%
Total electricity (MWh)	106.78	102.7904	3.74%	102.6952	3.83%
Total energy (MWh)	106.8647	102.8762	3.73%	102.781	3.82%
Total CO2 Emissions ((kgCO2)	55,222.00	53,160.00	3.73%	53,110.00	3.82%

Similar to the typical floor, the additional savings beyond the 1 pearl rating upgrade were minimal, estimated to be within a range of 0.09% to 0.14%. Generally, the savings in cooling loads, energy consumption, and CO2 emissions are greater than the typical floor, which has been explained earlier.

5.2.3 GROUND AND MEZZANINE FLOORS

The results for the ground and mezzanine floors –presented in Table 14- indicated cooling loads savings of around 3.88% for the 1 pearl wall upgrade, and 3.98% for the 2 wall pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 3.58% and 3.67% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 2.53% and 2.59% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl wall upgrades is estimated at 5.0284 MWeh/yr, and 5.1512 MWeh/yr for the 2- pearls wall. Also, the annual reduction in CO2 emissions are estimated at 2,600 KgCO2 and 2,663 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 14 Load, Energy and Carbon results of external wall upgrades for GF and Mezz floor model.

Output	Baseline	Wall- 1 Pearl	Wall- 1 Pearl Savings (%)	Wall-2 Pearl	Wall-2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	245.7228	236.1836	3.88%	235.9506	3.98%
Chillers energy (MWh)	107.9103	104.0423	3.58%	103.9478	3.67%
Ap Sys chillers energy (MWh)	107.9103	104.0423	3.58%	103.9478	3.67%
Ap Sys heat rej fans/pumps energy (MWh)	32.3731	31.2127	3.58%	31.1843	3.67%
Total system energy (MWh)	155.2918	150.2647	3.24%	150.142	3.32%
Total electricity (MWh)	198.4932	193.4648	2.53%	193.342	2.60%
Total energy (MWh)	198.6329	193.6059	2.53%	193.4831	2.59%
Total CO2 Emissions ((kgCO2)	102,649.00	100,049.00	2.53%	99,986.00	2.59%

The results indicate higher energy consumption for the ground and mezzanine floors compared to the typical and roof floors. That is due to the high ratio of glazing in the ground floor level which is used for retail and office spaces. The additional savings beyond the 1 pearl rating upgrades were minimal and even less than the previous two models for the typical and roof floors. The additional savings ranges between 0.06% and 0.09%.

5.2.4 ALL BUILDING

The results for the building consist of 14 typical floors, roof floor, and ground and mezzanine floors. The results –presented in Table 15- indicated cooling loads savings of around 5.13% for the 1 pearl wall upgrade, and 5.61% for the 2 wall pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 4.98% and 5.10% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 3.44% and 3.52% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl wall upgrades is estimated at 61.5460 MWeh/yr, and 63.0002 MWeh/yr for the 2 pearls wall. Also, the annual reduction in CO2 emissions are estimated at 29,760 KgCO2 and 32,565 KgCO2 for the 1 pearl and 2 pearls upgrades respectively.

Table 15 Load, Energy and Carbon results of external wall upgrades for the building.

Output	Baseline	Wall- 1 Pearl	Wall- 1 Pearl Savings (%)	Wall-2 Pearl	Wall-2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	2129.6187	2020.4583	5.13%	2010.1325	5.61%
Chillers energy (MWh)	950.7911	903.4474	4.98%	902.3291	5.10%
Ap Sys chillers energy (MWh)	950.7911	903.4474	4.98%	902.3291	5.10%
Ap Sys heat rej fans/pumps energy (MWh)	285.2376	271.034	4.98%	270.6994	5.10%
Total system energy (MWh)	1404.4605	1342.9365	4.38%	1341.4825	4.48%
Total electricity (MWh)	1786.6916	1725.1456	3.44%	1723.6914	3.53%
Total energy (MWh)	1788.0556	1726.5317	3.44%	1725.0775	3.52%
Total CO2 Emissions ((kgCO2)	923,993.00	894,233.00	3.22%	891,428.00	3.52%

The annual cooling load profile for the three scenarios i.e. baseline, Wall 1 Pearl and Wall 2 Pearls; are presented in Figure 25. It is noticed that the upgrades positively impacted the building performance in terms of cooling loads reduction. The greatest reductions are noticed during the summer months from June to September. For monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

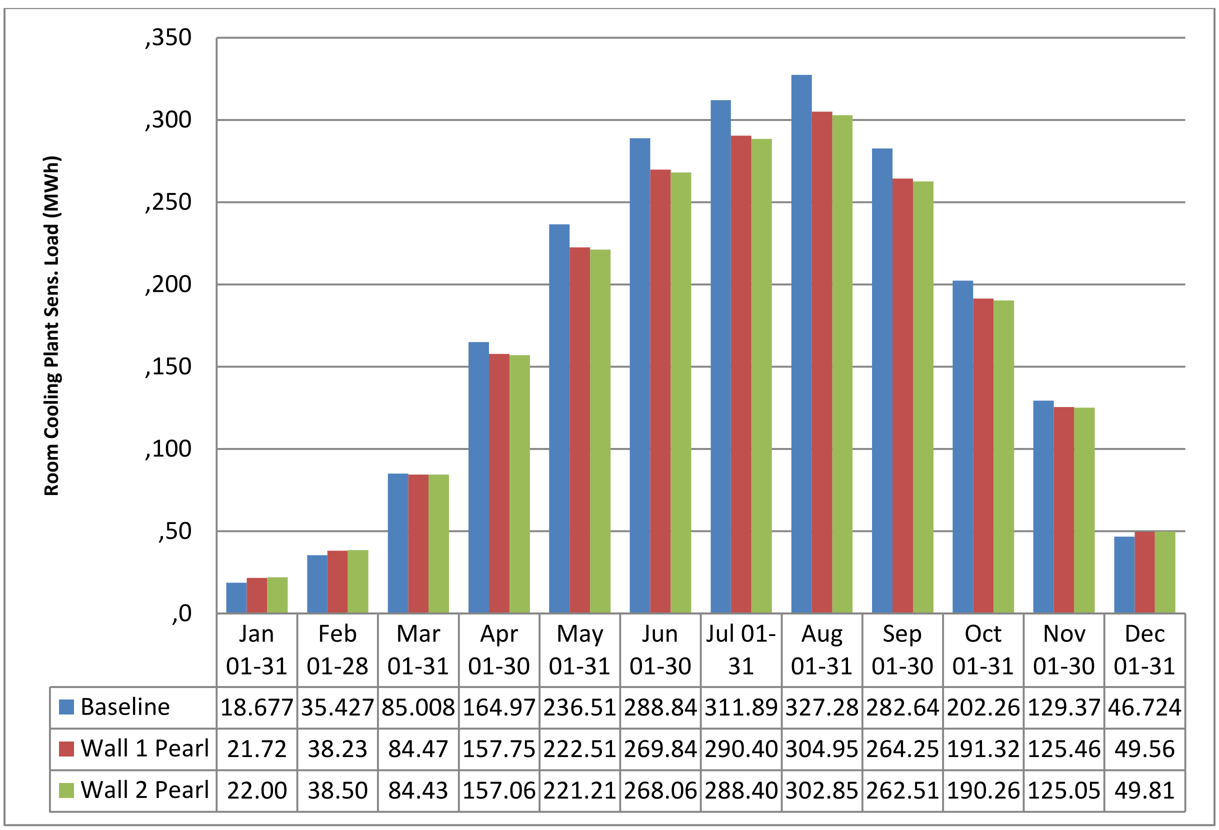


Figure 25 Comparison for Monthly Room Cooling Plant Sens. Load (MWh) for Wall Upgrades.

5.3 BUILDING FENESTRATION REFURBISHMENT

The refurbishment application for the building fenestration focuses on upgrading the thermal performance of the glazing. The external glazing could be replaced with higher performance of thermal resistance, and improved solar heat gain coefficient (SHGC).This section will present and discuss the results of two different scenarios to upgrade the thermal performance of the building fenestration. The scenarios selected are the upgrades to U-value of 2.2 W/m2.K and 1.9 W/m2.K; and SHGC of 0.4 and 0.3; which are based on the Estidama Pearl Rating System requirements for 1 pearl, and 2-5 pearls rating.

5.3.1 TYPICAL FLOOR

The results for the typical floor –presented in Table 16- indicated cooling loads savings of around 11.02% for the 1 pearl glazing upgrade, and 13.50% for the 2 glazing pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 9.96% and 12.20% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 6.87% and 8.41% for the 1 pearl scenarios and 2- pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl glazing upgrades is estimated at 7.271 MWeh/yr, and 8.901 MWeh/yr for the 2 pearls glazing. Also, the annual reduction in CO2 emissions are estimated at 3,760 KgCO2 and 4,603 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 16 Load, Energy and Carbon results of external glazing upgrades for typical floor model.

Output	Baseline	Glazing- 1 Pearl	Glazing - 1 Pearl Savings (%)	Glazing -2 Pearl	Glazing -2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	125.4686	111.6365	11.02%	108.5303	13.50%
Chillers energy (MWh)	56.1426	50.5493	9.96%	49.2955	12.20%
Ap Sys chillers energy (MWh)	56.1426	50.5493	9.96%	49.2955	12.20%
Ap Sys heat rej fans/pumps energy (MWh)	16.8428	15.1648	9.96%	14.7887	12.20%
Total system energy (MWh)	83.2134	75.9404	8.74%	74.3098	10.70%
Total electricity (MWh)	105.8156	98.5444	6.87%	96.9144	8.41%
Total energy (MWh)	105.897	98.624	6.87%	96.9934	8.41%
Total CO2 Emissions ((kgCO2)	54,723.00	50,963.00	6.87%	50,120.00	8.41%

It is noticed that the additional savings beyond the 1 pearl rating upgrades are greater than that achieved through external wall upgrades in the typical floor. The savings in the case of fenestration upgrades ranges from 1.54% to 2.48% which is almost 19 times greater than the case of wall upgrades. Also, it is noticed that the overall savings in the case of 1 pearl upgrade from the baseline case is significant. This is explained due to the significant difference between the thermal performance of the external glazing as-built conditions; which is a clear single glazed window panels; and the proposed upgrades.

5.3.2 ROOF FLOOR

The results for the roof floor –presented in Table 17- indicated cooling loads savings of around 11.57% for the 1 pearl glazing upgrade, and 14.20% for the 2-5 glazing pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 10.48% and 12.86% for the 1 pearl and 2-5 pearls scenarios respectively. The savings in the annual energy consumption were 7.25% and 8.90% for the 1 pearl scenarios and 2-5 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl glazing upgrades is estimated at 7.7473 MWeh/yr, and 9.5098 MWeh/yr for the 2-5 pearls glazing. Also, the annual reduction in CO_2 emissions are estimated at 4,006 $KgCO_2$ and 4,917 $KgCO_2$ for the 1 pearl and 2-5 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 17 Load, Energy and Carbon results of external glazing upgrades for roof floor model.

Output	Baseline	Glazing - 1 Pearl	Glazing - 1 Pearl Savings (%)	Glazing -2 Pearl	Glazing -2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	127.3355	112.6073	11.57%	109.2521	14.20%
Chillers energy (MWh)	56.8844	50.925	10.48%	49.5692	12.86%
Ap Sys chillers energy (MWh)	56.8844	50.925	10.48%	49.5692	12.86%
Ap Sys heat rej fans/pumps energy (MWh)	17.0653	15.2775	10.48%	14.8708	12.86%
Total system energy (MWh)	84.1811	76.4326	9.20%	74.6696	11.30%
Total electricity (MWh)	106.78	99.0327	7.26%	97.2702	8.91%
Total energy (MWh)	106.8647	99.1162	7.25%	97.3532	8.90%
Total CO2 Emissions ((kgCO2)	55,222.00	51,216.00	7.25%	50,305.00	8.90%

Similar to the typical floor, the additional savings beyond the 1 pearl rating upgrades are greater than that achieved through external wall upgrades in the typical floor. The savings in the case of fenestration upgrades ranges from 1.35% to 2.63% which is almost 15 to 19 times greater than the case of wall upgrades. Also, it is noticed that the overall savings in the case of 1 pearl upgrade from the baseline case is still significant, similar to the case in the typical floor. However, it is slightly reduced than the savings in the typical floor since the contribution of the glazing to the overall exposed envelope is less in the case of the roof. The glazing to the exposed surface area of the building envelope in the case of the roof floor is 12.7%, whereas in the typical floor it is 32.3%.

5.3.3 GROUND AND MEZZANINE FLOORS

The results for the ground and mezzanine floors –presented in Table 18- indicated cooling loads savings of around 18.32% for the 1 pearl glazing upgrade, and 23.27% for the 2 wall glazing upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 16.89% and 21.45% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 11.93% and 15.16% for the 1 pearl scenarios and 2- pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl glazing upgrades is estimated at 23.6931 MWeh/yr, and 30.0891MWeh/yr for the 2-5 pearls glazing. Also, the annual reduction in CO2 emissions are estimated at 12,250 KgCO2 and 15,557 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 18 Load, Energy and Carbon results of external glazing upgrades for GF and Mezz floor model.

Output	Baseline	Glazing - 1 Pearl	Glazing - 1 Pearl Savings (%)	Glazing -2 Pearl	Glazing -2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	245.7228	200.7012	18.32%	188.5416	23.27%
Chillers energy (MWh)	107.9103	89.6848	16.89%	84.7648	21.45%
Ap Sys chillers energy (MWh)	107.9103	89.6848	16.89%	84.7648	21.45%
Ap Sys heat rej fans/pumps energy (MWh)	32.3731	26.9054	16.89%	25.4294	21.45%
Total system energy (MWh)	155.2918	131.5977	15.26%	125.201	19.38%
Total electricity (MWh)	198.4932	174.8001	11.94%	168.4041	15.16%
Total energy (MWh)	198.6329	174.9389	11.93%	168.5421	15.15%
Total CO2 Emissions ((kgCO2)	102,649.00	90,399.00	11.93%	87,092.00	15.16%

The results indicate significantly higher energy savings for the ground and mezzanine floors compared to the typical and roof floors, when the building fenestration is upgraded. That is due to the high ratio of glazing in the ground floor level which is used for retail and office spaces; which is 2 times greater than solid external walls area where window to wall ratio is around 67%. The additional savings beyond the 1 pearl rating upgrades were considerably greater than the previous two models for the typical and roof floors with approximately 5% additional reduction in cooling loads.

Generally, the additional savings range from 3.22% to 4.95%; which is 53 to 55 times greater than the additional savings in the case of wall upgrades from 1 to 2 pearl rating. This is one of the significant notes, where great emphasis shall be given on glazing upgrades for similar buildings over wall upgrades. However, the economic feasibility will be addressed at a later section to understand the financial viability of such refurbishment application.

5.3.4 ALL BUILDING

The results for the building consist of 14 typical floors, roof floor, and ground and mezzanine floors. The results –presented in Table 19- indicated cooling loads savings of around 11.90% for the 1 pearl glazing upgrade, and 14.67% for the 2 pearl glazing upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 10.78% and 13.29% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 7.45% and 9.19% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl glazing upgrades is estimated at 133.2372 MWeh/yr, and 164.2157 MWeh/yr for the 2 pearls glazing. Also, the annual reduction in CO2 emissions are estimated at 68,896 KgCO2 and 84,916 KgCO2 for the 1 pearl and 2 pearls upgrades respectively.

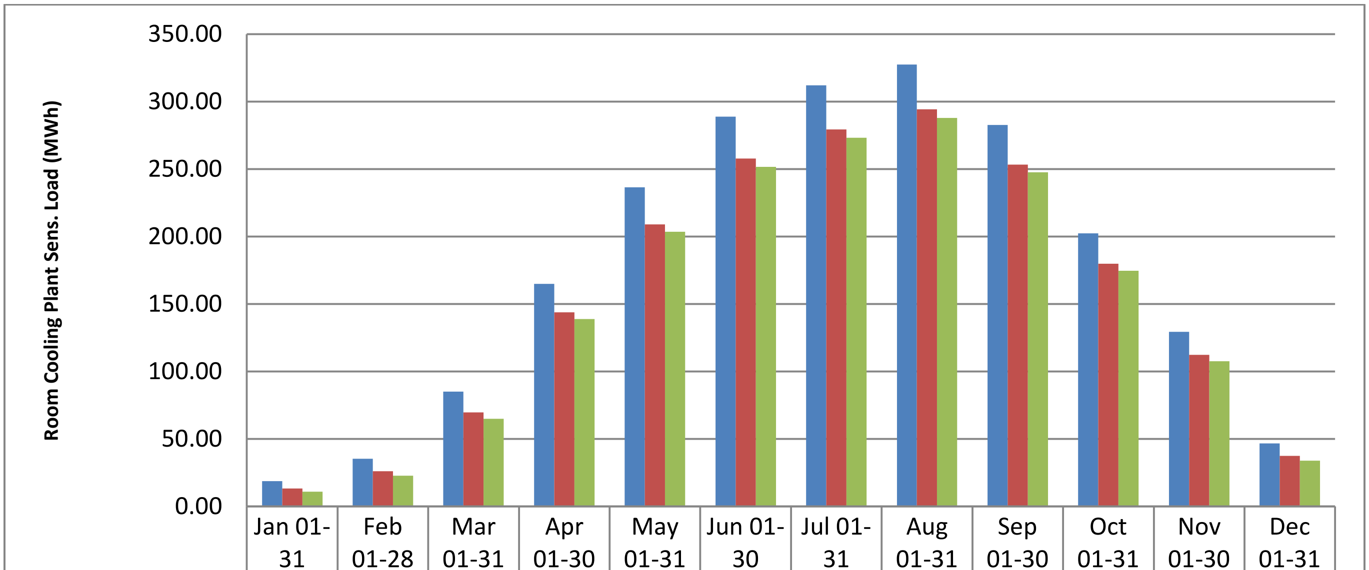
Table 19 Load, Energy and Carbon results of external glazing upgrades for the building.

Output	Baseline	Glazing - 1 Pearl	Glazing - 1 Pearl Savings (%)	Glazing -2 Pearl	Glazing -2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	2129.6187	1876.2195	11.90%	1817.2179	14.67%
Chillers energy (MWh)	950.7911	848.3	10.78%	824.471	13.29%
Ap Sys chillers energy (MWh)	950.7911	848.3	10.78%	824.471	13.29%
Ap Sys heat rej fans/pumps energy (MWh)	285.2376	254.4901	10.78%	247.342	13.29%
Total system energy (MWh)	1404.4605	1271.1959	9.49%	1240.2078	11.70%
Total electricity (MWh)	1786.6916	1653.4544	7.46%	1622.4759	9.19%
Total energy (MWh)	1788.0556	1654.7911	7.45%	1623.8029	9.19%
Total CO2 Emissions ((kgCO2)	923,993.00	855,097.00	7.46%	839,077.00	9.19%

The results indicate significant energy savings which is closer to the percentage identified in the typical floor. The additional savings beyond the 1 pearl rating upgrades were considerably greater than the previous case for wall upgrades. The additional savings estimated at 2.77% for the cooling loads, compared to a 0.48% for the wall upgrade.

Generally, the additional savings range from 2.73% to 2.77%; which is 5 times greater than the additional savings in the case of wall upgrades from 1 to 2 pearl rating. However, the 1 pearl refurbishment for the building fenestration is estimated to save 2.3 times greater cooling loads than for the wall refurbishment application. The economic feasibility study will emphasize on the viability of the solution.

The annual cooling load profile for the three scenarios i.e. baseline, Glazing 1 Pearl and Glazing 2 Pearls; are presented in Figure 26. Similar to the wall upgrades, the glazing upgrades positively impacted the building performance in terms of cooling loads reduction. The greatest reductions are noticed during the summer months from June to September. For monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
Baseline	18.68	35.43	85.01	164.97	236.51	288.84	311.89	327.28	282.64	202.26	129.37	46.72
Glazing 1 Pearl	13.23	26.21	69.66	143.93	209.06	257.70	279.24	294.14	253.36	179.82	112.39	37.48
Glazing 2 Pearl	10.86	22.81	64.99	138.80	203.45	251.71	273.12	287.89	247.47	174.66	107.58	33.87

Figure 26 Comparison for Monthly Room Cooling Plant Sens. Load (MWh) for Glazing Upgrades.

5.4 EXTERNAL ROOF INSULATION REFURBISHMENT

The refurbishment application for the building's roof implies upgrading the thermal performance of the externally exposed element of the roof. Therefore, the refurbishment technique proposed is addition of thermal insulation. This section will present and discuss the results of two different scenarios to upgrade the thermal performance of the roof. The scenarios selected are the upgrades to U-value of 0.14 W/m2.K and 0.12 W/m2.K; which are based on the Estidama Pearl Rating System requirements for 1 pearl, and 2-5 pearls rating. Since the roof insulation upgrade is only applicable on the roof floor; the results presented in this section will be specifically for the roof floor model, and the overall building.

5.4.1 ROOF FLOOR

The results for the roof floor –presented in Table 20- indicated cooling loads savings of around 3.44% for the 1 pearl roof upgrade, and 3.64% for the 2-5 roof pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 3.12% and 3.30% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 2.16% and 2.28% for the 1 pearl scenarios and 2 pearl scenario respectively. It is noticed that the savings are generally the lowest when compared to wall or glazing upgrades, that is mainly because the roof area is only around 6.4% of the overall building envelope.

Annual reductions in electricity consumption for the 1 pearl roof upgrades is estimated at 2.3083 MWeh/yr, and 2.4396 MWeh/yr for the 2 pearls roof. Also, the annual reduction in CO_2 emissions are estimated at 1,193 $KgCO_2$ and 1,261 $KgCO_2$ for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 20 Load, Energy and Carbon results of roof upgrades for roof floor model.

Output	Baseline	Roof- 1 Pearl	Roof - 1 Pearl Savings (%)	Roof-2 Pearl	Roof -2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	127.3355	122.9523	3.44%	122.7032	3.64%
Chillers energy (MWh)	56.8844	55.1088	3.12%	55.0079	3.30%
Ap Sys chillers energy (MWh)	56.8844	55.1088	3.12%	55.0079	3.30%
Ap Sys heat rej fans/pumps energy (MWh)	17.0653	16.5326	3.12%	16.5024	3.30%
Total system energy (MWh)	84.1811	81.8729	2.74%	81.7417	2.90%
Total electricity (MWh)	106.78	104.4717	2.16%	104.3404	2.28%
Total energy (MWh)	106.8647	104.5565	2.16%	104.4252	2.28%
Total CO2 Emissions ((kgCO2)	55,222.00	54,029.00	2.16%	53,961.00	2.28%

It is noticed that roof insulation upgrades are less effective than wall and glazing elements refurbishment. The results for roof insulation upgrades for 1 pearl rating indicated 2.5% less savings in annual cooling loads compared to wall insulation for the same rating level. Moreover, the additional savings for the upgrades from 1 pearl rating to 2 pearl rating for roof u-value is minimal, which ranges between 0.08% and 0.20%. Generally, the cooling loads, energy consumption, and CO2 emissions for the baseline model are greater than that for the typical floor. However, the savings are not greater due to the existing insulation for the roof compared to the walls with no thermal insulation application for the existing conditions.

5.4.2 ALL BUILDING

The results for the building consist of 14 typical floors, roof floor, and ground and mezzanine floors. The results –presented in Table 21- indicated cooling loads savings of around 0.21% for the 1 pearl roof upgrade, and 0.22% for the 2-5 roof pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 0.19% and 0.20% for the 1 pearl and 2-5 pearls scenarios respectively. The savings in the annual energy consumption were 0.13% and 0.14% for the 1 pearl scenarios and 2-5 pearl scenario respectively.

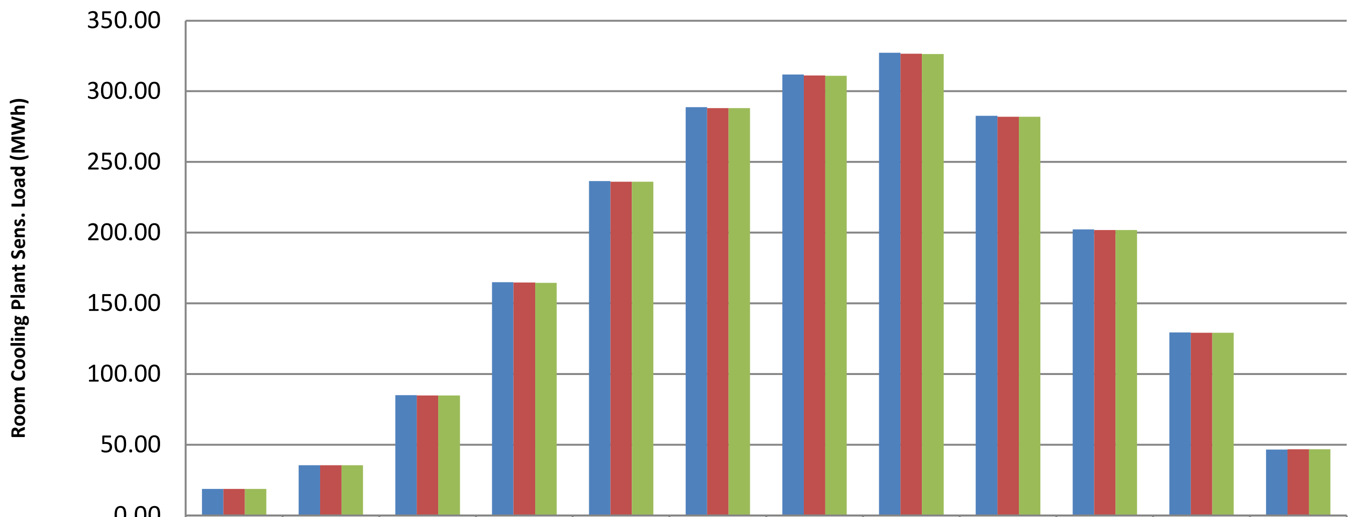
As mentioned in the previous section, the nominal savings are the same as achieved for the single floor of the roof. Annual reductions in electricity consumption for the 1 pearl roof upgrades is estimated at 2.3083 MWeh/yr, and 2.4396 MWeh/yr for the 2-5 pearls roof. Also, the annual reduction in CO2 emissions are estimated at 1,193 KgCO2 and 1,261 KgCO2 for the 1 pearl and 2-5 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 21 Load, Energy and Carbon results of roof upgrades for the building.

Output	Baseline	Roof - 1 Pearl	Roof - 1 Pearl Savings (%)	Roof -2 Pearl	Roof -2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	2129.6187	2125.2355	0.21%	2124.9864	0.22%
Chillers energy (MWh)	950.7911	949.0155	0.19%	948.9146	0.20%
Ap Sys chillers energy (MWh)	950.7911	949.0155	0.19%	948.9146	0.20%
Ap Sys heat rej fans/pumps energy (MWh)	285.2376	284.7049	0.19%	284.6747	0.20%
Total system energy (MWh)	1404.4605	1402.1523	0.16%	1402.0211	0.17%
Total electricity (MWh)	1786.6916	1784.3833	0.13%	1784.252	0.14%
Total energy (MWh)	1788.0556	1785.7474	0.13%	1785.6161	0.14%
Total CO2 Emissions ((kgCO2)	923,993.00	922,800.00	0.13%	922,732.00	0.14%

Contrary to the refurbishment applications for the glazing and external walls, the refurbishment of the building roof has minimal if not negligible contribution to the reduction in the overall building's cooling load, energy and electricity consumption. For example, the external wall upgrades to 1 pearl rating contributes to electricity saving 26 times higher than that for the roof upgrade for the same rating level.

The annual cooling load profile for the three scenarios i.e. baseline, Roof 1 Pearl and Roof 2 Pearls; are presented in Figure 27. Similar to the wall & glazing upgrades, the roof upgrades positively impacted the building performance in terms of cooling loads reduction. The greatest reductions are noticed during the summer months from June to September. However, it has to be noted that the annual cooling loads exceed 300 MWh for the 1 & 2 pearls upgrade in July and August unlike the results shown for the wall and glazing. That is mainly due to the minimal impact of the roof upgrades in the case of tall buildings as explained earlier. For monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
Baseline	18.68	35.43	85.01	164.97	236.51	288.84	311.89	327.28	282.64	202.26	129.37	46.72
Roof 1 Pearl	18.76	35.46	84.88	164.65	235.97	288.13	311.09	326.47	281.96	201.85	129.21	46.79
Roof 2 Pearl	18.77	35.46	84.88	164.63	235.94	288.09	311.04	326.43	281.92	201.83	129.21	46.80

Figure 27 Comparison for Monthly Room Cooling Plant Sens. Load (MWh) for Roof Upgrades.

5.5 COMBINED REFURBISHMENT SOLUTION

The combined refurbishment solution investigates the savings that could be achieved if all above three scenarios are applied all together. This section presents the results for the individual models for the typical floor, roof floor, ground and mezzanine floors, and the overall building; in which the combined solution refers to refurbishment for the external wall and glazing in the typical floor, ground and mezzanine floors. However, combined refurbishment solution for the overall building and the roof floor model implies the refurbishment for the external walls, glazing, and roof.

This section will present and discuss the results of two different scenarios for each of the models. The scenarios selected are the upgrades of the u-values for the external envelope, and glazing upgrades that responds to the requirements stipulated to achieve Estidama Pearl Rating System requirements for 1 pearl, and 2 pearls rating.

5.5.1 TYPICAL FLOOR

The results for the typical floor –presented in Table 22- indicated cooling loads savings of around 17.93% for the 1 pearl upgrade, and 20.82% for the 2-5 wall upgrades. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 16.22% and 18.82% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 11.18% and 12.98% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl upgrade is estimated at 11.8381 MWeh/yr, and 13.7393 MWeh/yr for the 2 pearls upgrade. Also, the annual reduction in CO2 emissions are estimated at 6,121 KgCO2 and 7,104 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 22 Load, Energy and Carbon results of combined upgrades solution for typical floor model.

Output	Baseline	Combined-1 Pearl	Combined - 1 Pearl Savings (%)	Combined - 2 Pearl	Combined - 2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	125.4686	102.9726	17.93%	99.3509	20.82%
Chillers energy (MWh)	56.1426	47.0364	16.22%	45.5739	18.82%
Ap Sys chillers energy (MWh)	56.1426	47.0364	16.22%	45.5739	18.82%
Ap Sys heat rej fans/pumps energy (MWh)	16.8428	14.1109	16.22%	13.6722	18.82%
Total system energy (MWh)	83.2134	71.3749	14.23%	69.4731	16.51%
Total electricity (MWh)	105.8156	93.9775	11.19%	92.0763	12.98%
Total energy (MWh)	105.897	94.0586	11.18%	92.1567	12.98%
Total CO2 Emissions ((kgCO2)	54,723.00	48,602.00	11.19%	47,619.00	12.98%

It is noticed that the additional savings beyond the 1 pearl rating upgrades are greater than in the individual elements upgrades scenarios. This is explained through the difference in the solar gain and external conduction profiles for the external envelope; further investigations has been conducted and presented later in this chapter.

The results indicated additional savings that ranges from of 1.80% to 2.98%. Also, it is noticed that the overall savings in the case of 1 pearl upgrade from the baseline case is considerable. The total of the individual savings for the glazing and external walls in the typical floor model add up to 16.70%. This is less than the savings in the cooling load when both upgrades are implemented simultaneously; which results in 17.93% savings.

5.5.2 ROOF FLOOR

The results for the roof floor –presented in Table 23- indicated cooling loads savings of around 23.62% for the 1 pearl upgrade, and 27.19% for the 2 pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 21.42% and 24.65% for the 1 pearl and 2- pearls scenarios respectively. The savings in the annual energy consumption were 14.82% and 17.06% for the 1 pearl scenarios and 2- pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl wall upgrades is estimated at 15.8382 MWeh/yr, and 18.228 MWeh/yr for the 2 pearls wall. Also, the annual reduction in CO2 emissions are estimated at 8,188 KgCO2 and 9,424 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 23 Load, Energy and Carbon results of combined upgrades solution for roof floor model.

Output	Baseline	Combined-1 Pearl	Combined-1 Pearl Savings (%)	Combined-2 Pearl	Combined-2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	127.3355	97.2532	23.62%	92.7087	27.19%
Chillers energy (MWh)	56.8844	44.7012	21.42%	42.8629	24.65%
Ap Sys chillers energy (MWh)	56.8844	44.7012	21.42%	42.8629	24.65%
Ap Sys heat rej fans/pumps energy (MWh)	17.0653	13.4104	21.42%	12.8589	24.65%
Total system energy (MWh)	84.1811	68.3432	18.81%	65.9531	21.65%
Total electricity (MWh)	106.78	90.9418	14.83%	88.552	17.07%
Total energy (MWh)	106.8647	91.0268	14.82%	88.6367	17.06%
Total CO2 Emissions ((kgCO2)	55,222.00	47,034.00	14.83%	45,798.00	17.07%

Similar to the typical floor, the additional savings beyond the 1 pearl rating upgrades are greater than in the individual elements upgrades scenarios. The results indicated additional savings that ranges from of 2.24% to 3.57%. It has to be noted, however, that the results for the roof floor model indicates better savings than the typical floor for the combined scenario. That is because the roof refurbishment adds to the overall savings with additional 5% for the cooling loads.

The total of the individual savings for the roof, glazing and external walls in the roof floor model for the 1 pearl rating add up to 20.95%. This is less than the savings in the cooling load when both upgrades are implemented simultaneously; which results in 23.62% savings. This is explained through the difference in the solar gain and external conduction profiles for the external envelope; further investigations has been conducted and presented later in this chapter.

5.5.3 GROUND AND MEZZANINE FLOORS

The results for the ground and mezzanine floors –presented in Table 24- indicated cooling loads savings of around 23.42% for the 1 pearl upgrade, and 28.80% for the 2 pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 21.60% and 26.56% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 15.25% and 18.76% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reductions in electricity consumption for the 1 pearl wall upgrades is estimated at 30.2955 MWeh/yr, and 37.2588 MWeh/yr for the 2 pearls wall. Also, the annual reduction in CO2 emissions are estimated at 15,663 KgCO2 and 19,263 KgCO2 for the 1 pearl and 2 pearls upgrades respectively. For a monthly breakdown of the Load, Energy and Carbon results; refer to Appendix E.

Table 24 Load, Energy and Carbon results of combined upgrades solution for GF and Mezz floor model.

Output	Baseline	Combined - 1 Pearl	Combined - 1 Pearl Savings (%)	Combined - 2 Pearl	Combined - 2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	245.7228	188.179	23.42%	174.9468	28.80%
Chillers energy (MWh)	107.9103	84.6061	21.60%	79.2497	26.56%
Ap Sys chillers energy (MWh)	107.9103	84.6061	21.60%	79.2497	26.56%
Ap Sys heat rej fans/pumps energy (MWh)	32.3731	25.3818	21.60%	23.7749	26.56%
Total system energy (MWh)	155.2918	124.9974	19.51%	118.0336	23.99%
Total electricity (MWh)	198.4932	168.1977	15.26%	161.2344	18.77%
Total energy (MWh)	198.6329	168.3385	15.25%	161.3748	18.76%
Total CO2 Emissions ((kgCO2)	102,649.00	86,986.00	15.26%	83,386.00	18.77%

The results indicate higher energy consumption for the ground and mezzanine floors compared to the typical floor for the combined solution; however the savings in cooling loads are slightly less than the roof floor. That is due to the high ratio of glazing in the ground floor level which is used for retail and office spaces, where refurbishment of the glazing components highly contribute to the savings compared to the typical floor. However, the savings for the roof floor are almost the same as the ground and mezzanine floors savings; due to the additional savings achieved through roof refurbishment. The additional savings beyond the 1 pearl rating upgrades are greater than that for the individual elements refurbishment. The additional savings ranges between 3.51% and 5.39%.

The total of the individual savings for the glazing and external walls in the ground and mezzanine floor model for the 1 pearl rating add up to 22.20%. This is less than the savings in the cooling load when both upgrades are implemented simultaneously; which results in 23.42% savings. This is explained through the difference in the solar gain and external conduction profiles for the external envelope; further investigations has been conducted and presented later in this chapter.

5.5.4 ALL BUILDING

The results for the building consist of 14 typical floors, roof floor, and ground and mezzanine floors. The results –presented in Table 25- indicated cooling loads savings of around 18.90% for the 1 pearl upgrade, and 22.12% for the 2 pearl upgrade. The reduction in annual chillers energy and related auxiliary chiller system and heat rejection system are estimated at 17.14% and 20.05% for the 1 pearl and 2 pearls scenarios respectively. The savings in the annual energy consumption were 11.85% and 13.86% for the 1 pearl scenarios and 2 pearl scenario respectively.

Annual reduction in electricity consumption for the 1 pearl upgrades is estimated at 211.8671 MWeh/yr, and 247.837 MWeh/yr for the 2 pearls. Also, the annual reduction in CO_2 emissions are estimated at 109,545 $KgCO_2$ and 128,143 $KgCO_2$ for the 1 pearl and 2 pearls upgrades respectively.

Table 25 Load, Energy and Carbon results of combined upgrades solution for the building.

Output	Baseline	Combined - 1 Pearl	Combined - 1 Pearl Savings (%)	Combined - 2 Pearl	Combined - 2 Pearl Savings (%)
Room cooling plant sens. load (MWh)	2129.6187	1727.0486	18.90%	1658.5681	22.12%
Chillers energy (MWh)	950.7911	787.8169	17.14%	760.1472	20.05%
Ap Sys chillers energy (MWh)	950.7911	787.8169	17.14%	760.1472	20.05%
Ap Sys heat rej fans/pumps energy (MWh)	285.2376	236.3448	17.14%	228.0446	20.05%
Total system energy (MWh)	1404.4605	1192.5892	15.09%	1156.6101	17.65%
Total electricity (MWh)	1786.6916	1574.8245	11.86%	1538.8546	13.87%
Total energy (MWh)	1788.0556	1576.1857	11.85%	1540.2053	13.86%
Total CO2 Emissions ((kgCO2)	923,993.00	814,448.00	11.86%	795,850.00	13.87%

The results indicate significant energy, cooling load, and CO_2 emissions savings for the overall combined refurbishment solutions applied to the building. The reduction in cooling loads is slightly higher than achieved in the typical floor. That is due to the contribution of roof retrofitting application, as well as the high savings in the ground and mezzanine floors for glazing refurbishment. Generally, the savings in the typical floor could be generalized for the overall building as a representation of the reduction in cooling loads, energy, and CO_2

emissions reduction. Although, it has to be noted that the behavior of the ground, mezzanine and roof floors vary than that for the typical floor. That is due to the high ratio of glazing in the ground floor level which is used for retail and office spaces, where refurbishment of the glazing components highly contribute to the savings compared to the typical floor. And, the savings for the roof floor are almost the same as the ground and mezzanine floors savings; due to the additional savings achieved through roof refurbishment. The additional savings beyond the 1 pearl rating upgrades are greater than that for the individual elements refurbishment. The additional savings ranges between 2.01% and 3.22%.

The total of the individual savings for the roof, glazing and external walls for the overall building for the 1 pearl rating add up to 17.23%. This is less than the savings in the cooling load when both upgrades are implemented simultaneously; which results in 18.90% savings. This is explained through the difference in the solar gain and external conduction profiles for the external envelope; further investigations has been conducted and presented later in this chapter.

5.6 SOLAR GAIN AND EXTERNAL CONDUCTION GAIN

The results as presented on the previous sections indicated that the combined refurbishment solutions, where several retrofitting applications are applied simultaneously, are more efficient than when individual scenarios are implemented. In order to explain the buildings behavior according to the results indicated, further investigations were conducted to understand the thermal performance of the building envelope when individual elements are refurbished, and when the combined solutions are implemented. This study has been conducted on a sample room within the building floors, which is the southern-west corner room.

Prior to presenting the results for solar gain and external conduction gain, it is necessary to define both parameters as measured in the IES-VE tool for better understanding of the results. The following are the definitions as stipulated in the IES-VE manual (IES 2013, p. 42)

“Solar gain: Solar radiation absorbed on the internal surfaces of the room, plus solar radiation absorbed in glazing and transferred to the room by conduction.

External conduction gain: Heat conducted into (or if negative, out of) the room through the internal surfaces of externally exposed elements, including ground floors.”

According to the definitions above, the solar gain depends on the radiation absorbed on the internal surface of the room. Therefore, the results presented in Figure 26 indicates that the external wall refurbishment in the typical floor have the same exposure to solar gain as for the baseline. However, since the composition of the glazing varies than the baseline, the solar gain when the glazing elements are replaced is less than that for the walls. It is also noted that the for the combined solutions, for 1 pearl rating and 2-5 pearls rating, that the solar gain is similar to that for the glazing respective to the same rating upgrades. This is explained through the calculations criteria for the solar; in the case of walls upgrade only, the glazing elements still transfers great amounts for solar radiation, which results in all models where no glazing upgrades are implemented remain of the same total solar gain value; meaning that the glazing elements are the weakest elements within the building envelope that allows for the solar radiation transfer into the building.

However, once the glazing elements are upgraded, less solar radiation is allowed into the building. This is why the upgrades for the glazing elements into 1 pearl, and 2-5 pearls rating result in similar solar gain for the overall upgrades for the typical floor respectively. This behavior has also been noticed for the other floors, where the glazing has been the weakest element for solar radiation exposure and solar gain transfers. For further details on the results, please refer to Appendix E.

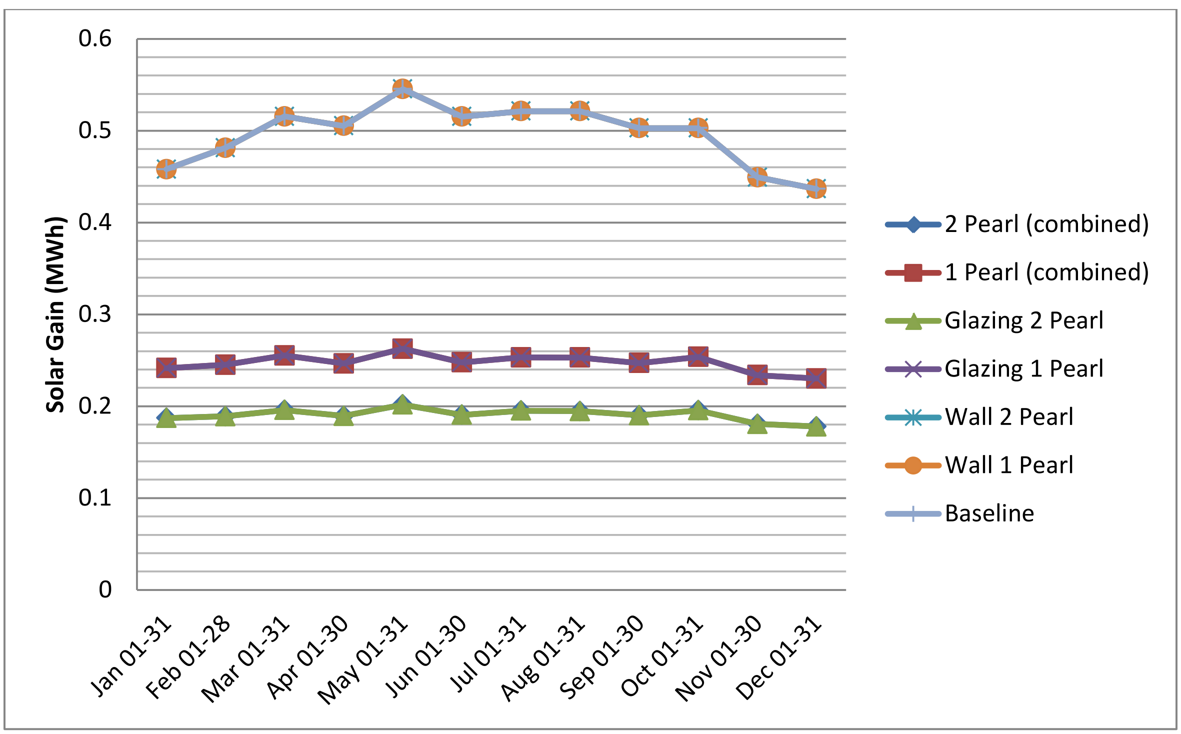
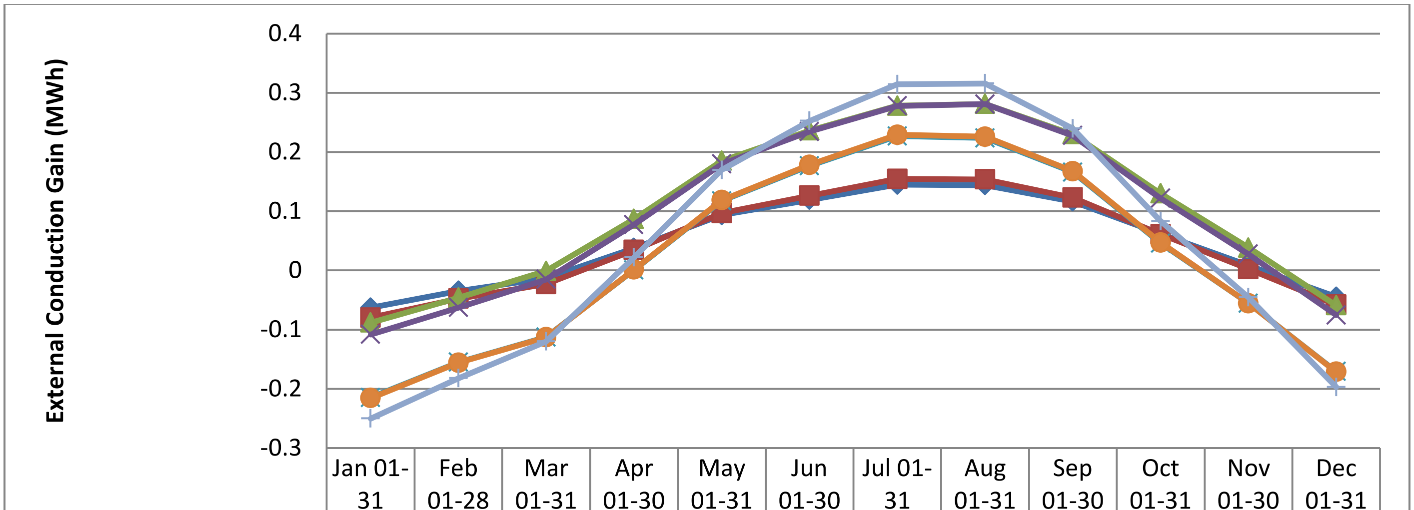


Figure 28 Solar gain profile for the typical floor.

Having analyzed the building envelope reaction to solar gain, it is necessary to understand the external conduction gain which will further explain the behavior of the building through refurbishment of the individual elements versus the combined refurbishment solution. The following Figure 27 presents the results for the external conduction gain for the sample room in the typical floor. The results indicate negative figures for the months between November to March for the baseline, and wall upgrades scenarios, and December to March for the glazing and combined refurbishment models. The negative figures indicate that the heat transfers from inside the building to outside, unlike the summer months where the building interior is heated through the external conduction gain properties.



	Jan 01-31	Feb 01-28	Mar 01-31	Apr 01-30	May 01-31	Jun 01-30	Jul 01-31	Aug 01-31	Sep 01-30	Oct 01-31	Nov 01-30	Dec 01-31
2 Pearl (combined)	-0.063	-0.0347	-0.0131	0.0376	0.0935	0.1191	0.1447	0.1441	0.1165	0.0617	0.0086	-0.0446
1 Pearl (combined)	-0.0798	-0.0476	-0.0231	0.0345	0.0968	0.1261	0.1546	0.1538	0.123	0.061	0.0022	-0.0578
Glazing 2 Pearl	-0.0881	-0.0461	-0.001	0.0867	0.1849	0.2363	0.2781	0.2812	0.2299	0.13	0.0384	-0.0591
Glazing 1 Pearl	-0.1082	-0.0628	-0.0153	0.0774	0.1796	0.2343	0.2779	0.2808	0.2276	0.1219	0.0273	-0.0754
Wall 2 Pearl	-0.2146	-0.1552	-0.1127	0.0008	0.1173	0.1766	0.2269	0.2237	0.1658	0.046	-0.0556	-0.1708
Wall 1 Pearl	-0.2154	-0.1558	-0.1129	0.0014	0.1185	0.1783	0.2289	0.2257	0.1675	0.047	-0.0554	-0.1713
Baseline	-0.2501	-0.1821	-0.1199	0.0221	0.1696	0.2526	0.3144	0.3156	0.2396	0.0832	-0.0455	-0.197

Figure 29 External conduction gain (MWh) for Typical Floor.

In order to tabulate the difference in the building behavior when combined solutions are applied and when individual elements are applied, the following comparison for 1 pearl rating upgrades –presented in Table 26- indicates that the nominal difference in the external conduction gain between the sum of the individual refurbishment solutions to the baseline, and the combined solution to the baseline vary slightly. Although the difference is minimal, which around 0.0386 (MWh), it still contributes to the additional savings when a combined solution is implemented over individual scenarios. Figure 28 presents the results for the 1 pearl ratings upgrades graphically for the walls, glazing, and combined solution for the typical floor. It is noticed that the difference between the individual refurbishment applications, and combined scenario in terms of external conduction gains are the greatest during the summer from June to September, and in the winter from December to January.

Table 26 External conduction gain (MWh) for the typical floor.

	External conduction gain (MWh)				*Absolute Difference (MWh)*			
Date	1 Pearl (combined)	Glazing 1 Pearl	Wall 1 Pearl	Baseline	Baseline - wall	Baseline - glazing	Baseline - combined	Sum of individual savings
Jan 01-31	-0.0798	-0.1082	-0.2154	-0.2501	0.0347	0.1419	0.1703	0.1766
Feb 01-28	-0.0476	-0.0628	-0.1558	-0.1821	0.0263	0.1193	0.1345	0.1456
Mar 01-31	-0.0231	-0.0153	-0.1129	-0.1199	0.007	0.1046	0.0968	0.1116
Apr 01-30	0.0345	0.0774	0.0014	0.0221	0.0207	0.0553	0.0124	0.076
May 01-31	0.0968	0.1796	0.1185	0.1696	0.0511	0.01	0.0728	0.0611
Jun 01-30	0.1261	0.2343	0.1783	0.2526	0.0743	0.0183	0.1265	0.0926
Jul 01-31	0.1546	0.2779	0.2289	0.3144	0.0855	0.0365	0.1598	0.122
Aug 01-31	0.1538	0.2808	0.2257	0.3156	0.0899	0.0348	0.1618	0.1247
Sep 01-30	0.123	0.2276	0.1675	0.2396	0.0721	0.012	0.1166	0.0841
Oct 01-31	0.061	0.1219	0.047	0.0832	0.0362	0.0387	0.0222	0.0749
Nov 01-30	0.0022	0.0273	-0.0554	-0.0455	0.0099	0.0728	0.0477	0.0827
Dec 01-31	-0.0578	-0.0754	-0.1713	-0.197	0.0257	0.1216	0.1392	0.1473
Summed total	0.5437	1.1652	0.2566	0.6027	0.5334	0.7658	**1.2606**	**1.2992**

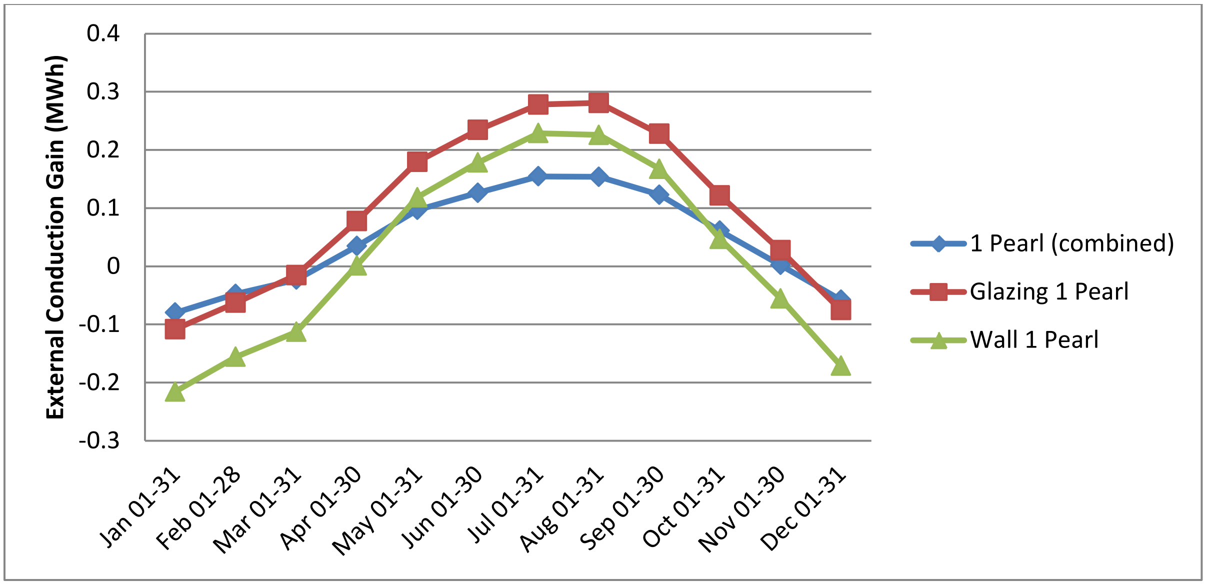


Figure 30 External Conduction Gain (MWH) for 1 Pearl refurbishment scenarios for the typical floor.

The study has been conducted for the typical floor, roof, and ground and mezzanine floor. It has been noticed that the external building envelope behavior –in all cases- had the same differences in the external conduction gain profile for the individual versus the combined solutions. The study was conducted for both the 1 pearl upgrades set, and 2 pearls upgrades set. The following Figure 29 highlights the external conduction gain for the roof floor when the refurbishment applications for 2 pearls rating are simulated. It is noted that both the external walls, and roof have similar behavior profile, which varies from the glazing. That is again supports the results highlighted for the solar gain analysis, where glazing has been identified as the weakest element for solar gain. In this example, the 2 pearl combined scenario has 0.0727 MWh less conduction gain than the sum of the individual scenarios. For the results of the 1 and 2 pearls sets of refurbishment scenarios for all models, refer to Appendix E.

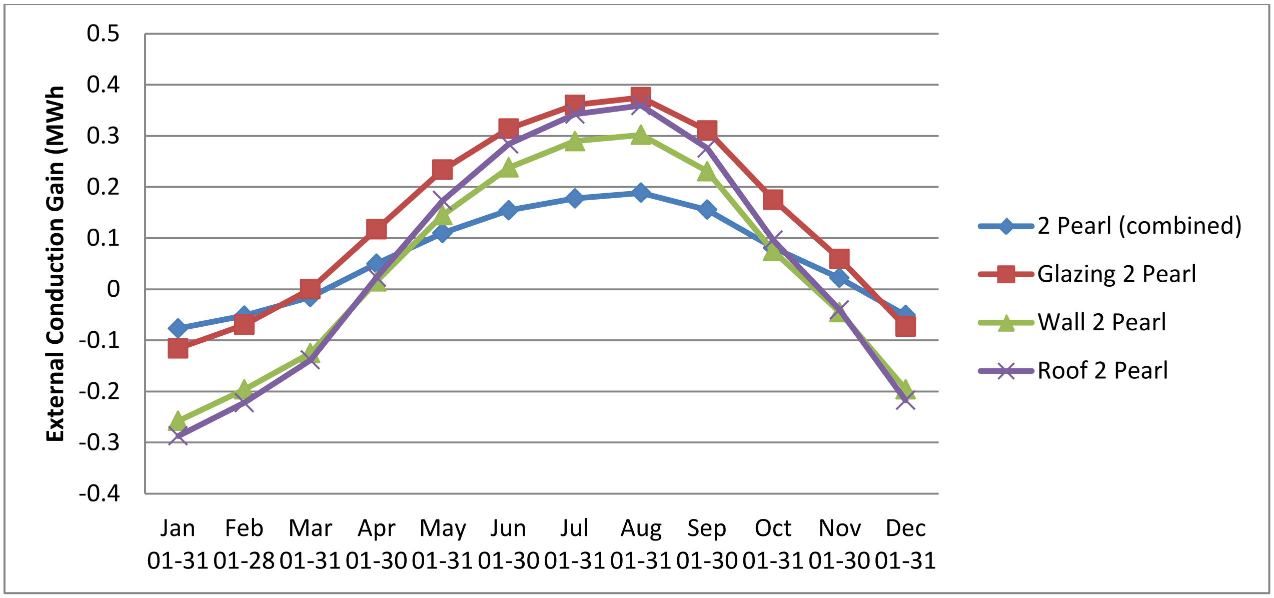


Figure 31 External Conduction Gain (MWH) for 2 Pearl refurbishment scenarios for the roof floor.

In this section above, it is concluded that the combined refurbishment scenario results in higher savings and better building envelope performance. However, in order to understand the economic feasibility of these scenarios the following section presents a simple payback period study, for future considerations of optimal refurbishment solution.

5.7 ECONOMIC FEASIBILITY OF THE BUILDING ENVELOPE REFURBISHMENT

The economic feasibility study of the proposed refurbishment solutions is critical to allow for a comprehensive understanding prior to making decisions of which building elements and which refurbishment technique shall be implemented in order to reach the desired outcome to reduce energy consumption. The economic viability study presented in this section has been based on simple payback period analysis where the consideration of reduction in electricity consumption is the main objective. Similar, to the results presented for the energy savings earlier, this section will address the economic feasibility for the refurbishment applications to each of the models and for the overall building. The economic feasibility has been considered based on the current market analysis, and the available applications for wall insulation, roof insulation, and glazing replacement.

5.7.1 REFURBISHMENT APPLICATIONS AND CURRENT AVAILABILITY IN THE UAE MARKET

As highlighted earlier, there are two applications for external walls upgrades, which are available in the UAE market; the addition of thermal insulation boards, and the curtain wall application. For the roof refurbishment, a simple addition of thermal insulation boards is available, whereas the glazing panels are easily replaced.

For selection of available thermal insulation materials, and better understanding of the market applications, the research highlights the materials adopted by the UPC Estidama product database stipulated under Estidama Villa Product Database (EVPD) as guidance. (UPC 2013c). Figure 30 illustrates a thermal insulation product that could be used as a curtain wall application to provide additional external insulation mechanically fixed to the existing structure and then covered by external cladding finishing. Another method is shown in Figure 31 which illustrates insulation boards that could be fixed internally to the existing building envelope.

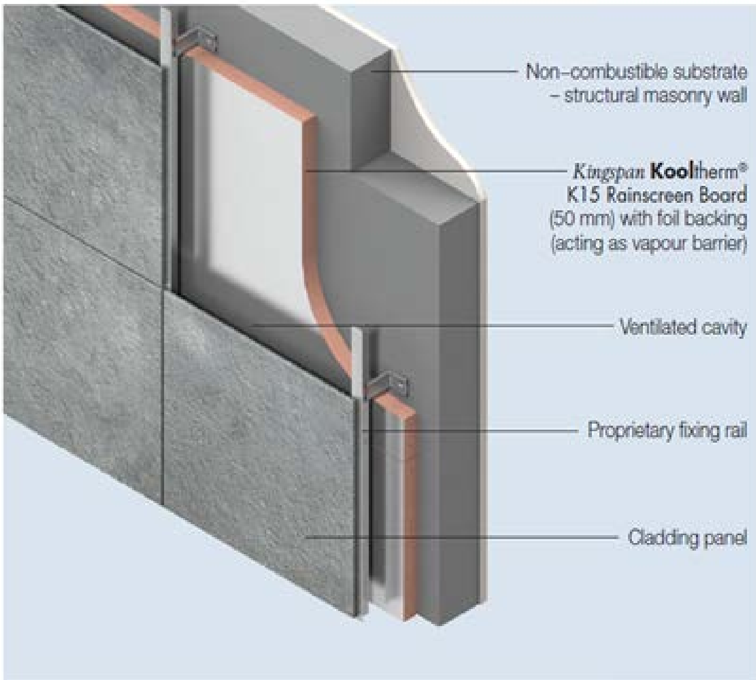


Figure 32 External insulation applicable for curtain wall solution. (UPC 2013c, p.1)

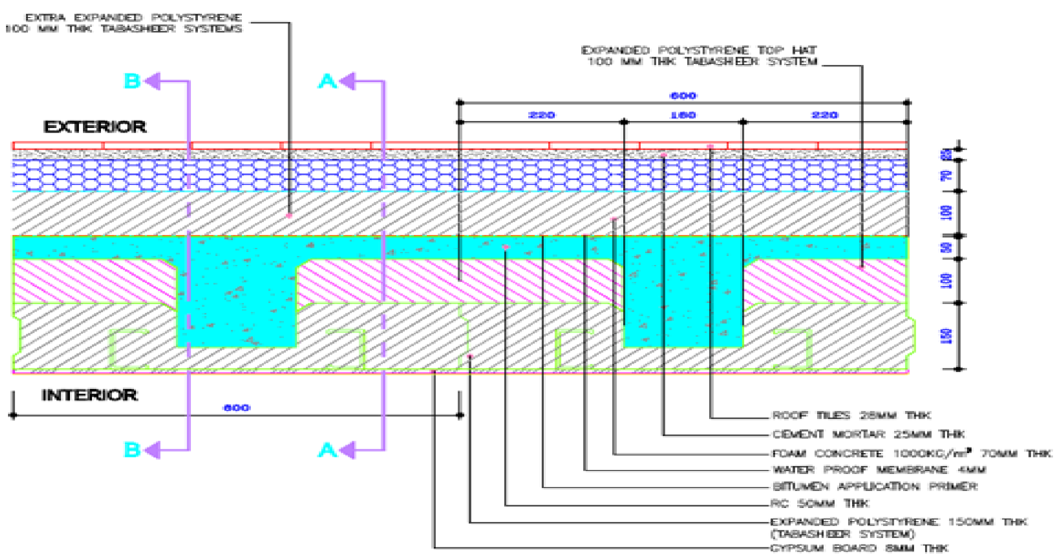


Figure 33 Insulation board application for building envelope. (UPC 2013c, p.1)

The estimated cost of the different refurbishment scenarios was calculated based on an estimated refurbishment unit cost inclusive of the material, transportation, and installation costs in the UAE. The estimated cost is highlighted in Table 27.

Table 27 Refurbishment unit cost in the UAE. (Manneh *et* al 2013, p. 5)

Refurbished construction element	Unit refurbishment cost (AED/ m2); inclusive of supply, installation and painting (not for glazing)	
	1 Pearl requirements	2 Pearls requirements
Wall (insulation boards)	140	165
Wall (curtain wall)	300	325
Roof	125	150
Glazing	260	280

5.7.2 REFURBISHMENT COST SAVINGS

Prior to calculating the simple payback period (SPP), the cost savings due to reduction in electricity consumption has to be calculated. Tables Tables 28 - 31 present the cost savings for each of the individual floors models, and the overall building for each of the refurbishment scenarios. The cost savings were estimated based on electricity unit cost rate of 0.33 AED/KWeh Which is highlighted in tables 28- 31.

Table 28 Cost savings due to refurbishment applications for the typical floor.

	1 Pearl Configuration			2 Pearls Configuration		
Refurbished construction element	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)
Wall	7.1158	3.7520	1,238.16	7.2832	3.8403	1,267.30
Roof	n/a	n/a	n/a	n/a	n/a	n/a
Glazing	13.8321	7.2712	2,399.496	16.9383	8.9012	2,937.40
All	22.496	11.8381	3,906.573	26.1177	13.7393	4,533.97

* Assuming a HVAC system with a coefficient of performance (COP) of 2.2 based on ASHRAE 90-1975

** Using electricity rate of 0.33 AED/kW_eh

Table 29 Cost savings due to refurbishment applications for the roof floor.

	1 Pearl Configuration			2 Pearls Configuration		
Refurbished construction element	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)
Wall	7.5687	3.9896	1,316.568	7.7492	4.0848	1,347.98
Roof	4.3832	2.3083	761.739	4.6323	2.4396	805.07
Glazing	14.7282	7.7473	2,556.609	18.0834	9.5098	3,138.23
All	30.0823	15.8382	5,226.606	34.6268	18.2280	6,015.24

* Assuming a HVAC system with a coefficient of performance (COP) of 2.2 based on ASHRAE 90-1975

** Using electricity rate of 0.33 AED/kW_eh

Table 30 Cost savings due to refurbishment applications for the ground and mezzanine floors.

	1 Pearl Configuration			2 Pearls Configuration		
Refurbished construction element	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)
Wall	9.5392	5.0284	1,659.372	9.7722	5.1512	1,699.90
Roof	n/a	n/a	n/a	n/a	n/a	n/a
Glazing	45.0216	23.6931	7,818.723	57.1812	30.0891	9,929.40
All	57.5438	30.2955	9,997.515	70.776	37.2588	12,295.40

* Assuming a HVAC system with a coefficient of performance (COP) of 2.2 based on ASHRAE 90-1975

** Using electricity rate of 0.33 AED/kW_eh

Table 31 presents both the overall cost savings and the unit cost savings. The unit cost savings will be used later to verify the overall savings that could be achieved in Abu Dhabi if the refurbishment applications are implemented on a wide scale for all buildings presented through the studied prototype.

Table 31 Cost savings due to refurbishment applications for the overall building.

	1 Pearl Configuration			2-5 Pearls Configuration		
Refurbished construction element	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)	Cooling load saving (MWh/yr)	Electricity* saving (MW_eh/yr)	Cost saving** (AED/yr)
Wall (4746.84 sq.m.)	109.1604	61.5460	20310.18	119.4862	63.0002	20,790.07
Roof (447.1 sq.m.)	4.3832	2.3083	761.739	4.6323	2.4396	805.07
Glazing (1751.84 sq.m.)	253.3992	133.2372	43968.276	312.4008	164.2157	54,191.18
All (GFA 7394.7 sq.m.)	402.5701	211.8671	69916.143	471.0506	247.8370	81,786.21
Unit Savings						
Wall (4746.84 sq.m.)	0.0148	0.0083	2.7466	0.0162	0.0085	2.8115
Roof (447.1 sq.m.)	0.0006	0.0003	0.1030	0.0006	0.0003	0.1089
Glazing (1751.84 sq.m.)	0.0343	0.0180	5.9459	0.0422	0.0222	7.3284
All (GFA 7394.7 sq.m.)	0.0544	0.0287	9.4549	0.0637	0.0335	11.0601

* Assuming a HVAC system with a coefficient of performance (COP) of 2.2 based on ASHRAE 90-1975

** Using electricity rate of 0.33 AED/kW_eh

5.7.3 SIMPLE PAYBACK PERIOD STUDY

The estimated SPP was calculated by dividing the refurbishment cost by the cost of the energy saved annually – as highlighted in the previous tables. Table 32 summerizes the results of the simple payback period study for all individual floors, and for the overall building. As highlighted, the glazing elements upgrade to 2-5 pearl rating is the most economically viable solution to in all scenarios, where 9 years payback period could achieve savings of 164.2157 MWhe of annual electricity consumption.

It also, have to be noted that the upgrades in the combined solution for the overall building to 2-5pearl rating when thermal insulation boards for the walls are used along with roof, and glazing refurbishment, has a SPP of around 16 years. Therefore, the additional cost used for the refurbishment could be justified by the significant savings as well as the fact that this simple payback period did only consider the rewards from energy savings perspective only. It is important to highlight – within this context- that the payback period calculations excludes the savings in government electricity cost subsidies, evaluation of building envelop climatic performance upgrade such as humidity resistance, air tightness, aesthetical appearance, as well as future increases in the cost of electricity. It is expected that once all the benefits are quantified, the SPP analysis will result in reasonable timeframe for the owners to recoup their initial investment cost.

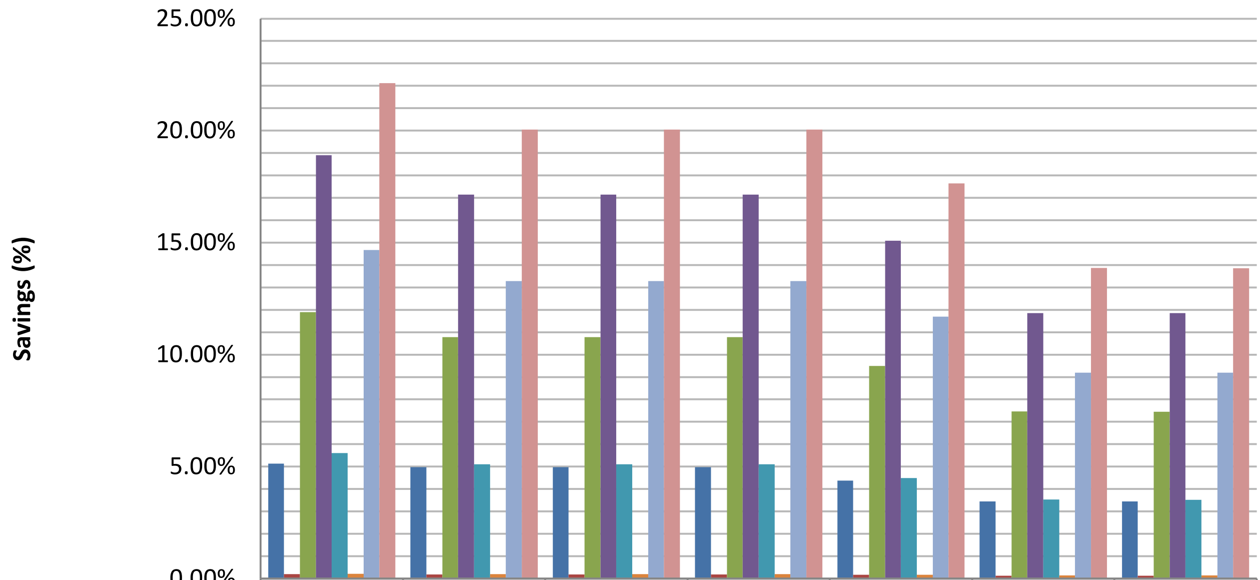
Table 32 Summary of the SPP for all configurations.

		1 Pearl Configuration			2-5 Pearls Configuration		
MODEL	Refurbished construction element	Refurbishment cost (AED)	Cost saving (AED/yr)	Simple payback period (yr)	Refurbishment cost (AED)	Cost saving (AED/yr)	Simple payback period (yr)
TYPICAL FLOOR	Wall (insulation boards)	40,555.20	1,238.16	32.75	47,797.20	1,267.30	37.72
	Wall (curtain wall)	86,904.00	1,238.16	70.19	94,146.00	1,267.30	74.29
	Roof	n/a	n/a	n/a	n/a	n/a	n/a
	Glazing	24,398.40	2,399.50	**10.17**	26,275.20	2,937.40	**8.95**
	All (insulation boards)	64,953.60	3,906.57	16.63	74,072.40	4,533.97	16.34
	All (curtain wall)	111,302.40	3,906.57	28.49	120,421.20	4,533.97	26.56
ROOF FLOOR	Wall (insulation boards)	40,555.20	1,316.57	30.80	47,797.20	1,347.98	35.46
	Wall (curtain wall)	86,904.00	1,316.57	66.01	94,146.00	1,347.98	69.84
	Roof	55,887.50	761.74	73.37	67,065.00	805.07	83.30
	Glazing	24,398.40	2,556.61	**9.54**	26,275.20	3,138.23	**8.37**
	All (insulation boards)	120,841.10	5,226.61	23.12	141,137.40	6,015.24	23.46
	All (curtain wall)	167,189.90	5,226.61	31.99	187,486.20	6,015.24	31.17
GROUND AND MEZZANINE FLOORS	Wall (insulation boards)	56,229.60	1,659.37	33.89	66,270.60	1,699.90	38.99
	Wall (curtain wall)	120,492.00	1,659.37	72.61	130,533.00	1,699.90	76.79
	Roof	n/a	n/a	n/a	n/a	n/a	n/a
	Glazing	89,525.80	7,818.72	**11.45**	96,412.40	9,929.40	**9.71**
	All (insulation boards)	145,755.40	9,997.52	14.58	162,683.00	12,295.40	13.23
	All (curtain wall)	210,017.80	9,997.52	21.01	226,945.40	12,295.40	18.46
ALL BUILDING	Wall (insulation boards)	664,557.60	20,310.18	32.72	783,228.60	20,790.07	37.67
	Wall (curtain wall)	1,424,052.00	20,310.18	70.12	1,542,723.00	20,790.07	74.20
	Roof	55,887.50	761.74	73.37	67,065.00	805.07	83.30
	Glazing	455,478.40	43,968.28	**10.36**	490,515.20	54,191.18	**9.05**
	All (insulation boards)	1,175,923.50	69,916.14	16.82	1,340,808.80	81,786.21	16.39
	All (curtain wall)	1,935,417.90	69,916.14	27.68	2,100,303.20	81,786.21	25.68

Based on the above, it is recommended to invest on a combined refurbishment scenario for the 2-5 pearl rating standards where the capital cost allows for such application. Where financial restrictions on the capital cost, it is recommended to upgrade the building glazing, especially for the ground floor since it is an easy application, and contributes greatly to the energy savings. Table 33 summerized the potential savings in the cooling loads, energy, and Carbon emissions for the overall building once the refurbishment scenarios are applied. Figure 32 highlights the savings in percentage compared to the baseline.

Table 33 Summary Comparison for Load, Energy, and Carbon Savings for the overall building.

	Refurbished construction element	Room cooling plant sens. load (MWh/yr)	Chillers energy (MWh/yr)	Ap Sys chillers energy (MWh/yr)	Ap Sys heat rej fans/pumps energy (MWh/yr)	Total system energy (MWh/yr)	Total electricity (Mweh/yr)	Total energy (MWh)	Total Carbon Emissions (KgCO2/yr)
	Baseline	2129.6187	950.7911	950.7911	285.2376	1404.4605	1786.6916	1788.0556	923,993.00
1 Pearl Configuration	Wall	2020.4583	903.4474	903.4474	271.034	1342.9365	1725.1456	1726.5317	894,233.00
	Roof	2125.2355	949.0155	949.0155	284.7049	1402.1523	1784.3833	1785.7474	922,800.00
	Glazing	1876.2195	848.3	848.3	254.4901	1271.1959	1653.4544	1654.7911	855,097.00
	All	1727.0486	787.8169	787.8169	236.3448	1192.5892	1574.8245	1576.1857	814,448.00
2-5 Pearl Configuration	Wall	2010.133	902.3291	902.3291	270.6994	1341.483	1723.691	1725.078	891,428.00
	Roof	2124.986	948.9146	948.9146	284.6747	1402.021	1784.252	1785.616	922,732.00
	Glazing	1817.218	824.471	824.471	247.342	1240.208	1622.476	1623.803	839,077.00
	All	1658.568	760.1472	760.1472	228.0446	1156.61	1538.855	1540.205	795,850.00



	Room cooling plant sens. load (MWh/yr)	Chillers energy (MWh/yr)	Ap Sys chillers energy (MWh/yr)	Ap Sys heat rej fans/pumps energy (MWh/yr)	Total system energy (MWh/yr)	Total electricity (Mweh/yr)	Total energy (MWh)
Wall Savings (%)	5.13%	4.98%	4.98%	4.98%	4.38%	3.44%	3.44%
Roof Savings (%)	0.21%	0.19%	0.19%	0.19%	0.16%	0.13%	0.13%
Glazing Savings (%)	11.90%	10.78%	10.78%	10.78%	9.49%	7.46%	7.45%
All Savings (%)	18.90%	17.14%	17.14%	17.14%	15.09%	11.86%	11.85%
Wall Savings (%)	5.61%	5.10%	5.10%	5.10%	4.48%	3.53%	3.52%
Roof Savings (%)	0.22%	0.20%	0.20%	0.20%	0.17%	0.14%	0.14%
Glazing Savings (%)	14.67%	13.29%	13.29%	13.29%	11.70%	9.19%	9.19%
All Savings (%)	22.12%	20.05%	20.05%	20.05%	17.65%	13.87%	13.86%

Figure 34 Summary Comparison for Load, Energy, and Carbon Savings for the overall building.

In conclusion, the significant 22.12% reduction in cooling loads could be achieved with a simple payback period estimated at 16 years, when 2-5 pearls rating combined solution refurbishment is applied.

5.8 POTENTIAL ENERGY SAVINGS ACROSS ABU DHABI

This study aimed at conducting an assessment of the potential energy savings in Abu Dhabi. Since this case study has been identified as a representation of the commercial building in Abu Dhabi for the period from 1980 – 1989, and based on the studies presented in the literature review; it is considered that the case study represents an overall of 550,000 square meters of office space GFA.

Table 34 presents the overall unit savings and the overall savings in electricity consumption in Abu Dhabi for the existing buildings stock built in the period from 1980 to 1989. The annual savings of the electricity consumptions are estimated at 18,433.52 MWeh for the combined solution upgrades to 2-5 pearl rating retrofitting application. Whereas, the refurbishment of the most economically feasible solution to upgrade the building glazing to 2-5 pearl rating standards, can achieve an overall reduction for the same buildings estimated at 12,213.97 MWeh/yr. CO2 emissions reduction for the combined solution of 2-5 pearls rating is estimated at 9,530,968.13 KgCO2/yr, whereas that for the 1 pearl combined solution upgrade is estimated at 8,147,693.62 KgCO2/yr.

Table 34 Summary of Annual Electricity Savings in Abu Dhabi for 1980s Buildings.

	Unit Savings		*Abu Dhabi 1980s Buildings*	
	1 Pearl Rating Electricity saving (MWeh/yr)	2-5 Pearl Rating Electricity saving (MWeh/yr)	1 Pearl Rating Electricity saving (MWeh/yr)	2-5 Pearl Rating Electricity saving (MWeh/yr)
Wall (4746.84 sq.m.)	0.0083	0.00852	4,577.64	4,685.80
Roof (447.1 sq.m.)	0.0003	0.00033	171.69	181.45
Glazing (1751.84 sq.m.)	0.0180	0.02221	9,909.86	12,213.97
All (GFA 7394.7 sq.m.)	0.0287	0.03352	15,758.17	18,433.52

Having stated the above, and in consideration of the building prototype identified earlier for the 1990s building stock, it can be concluded that the ground floor level with great percentage of external glazing can be considered as a representation for the 1990s buildings. The difference could be summarized for the baseline in the case of 1990s building; it shall use clear double glazed panels with U-value of 3.0 W/m2.K and SHGC of 0.7, HVAC COP of 3.0, and an open space plan. Therefore, the modifications above were introduced to the ground floor model to conclude a rough estimation as a start point for further investigation on the behavior of the typical office floor for a 1990s building, and the potential reduction in electricity when the building is upgraded to 1 pearl rating and 2 pearls rating for the glazing elements. Table 35 highlights the savings in electricity consumption in Abu Dhabi if glazing has been refurbished to the 1 pearl and 2 pearls rating standards. Since the existing building stock is higher for this building prototype (represented in a total GFA of 862,500 sq.m.); the overall savings for Abu Dhabi are estimated at 28,598.86 MWeH/yr and 20,152.07 MWeh/yr for the 2 pearls and 1 pearl rating respectively.

Table 35 Summary of Annual Electricity Savings in Abu Dhabi for 1980s Buildings.

	Unit Savings		*Abu Dhabi 1990s Buildings*	
	1 Pearl Rating Electricity saving (MWeh/yr)	2-5 Pearl Rating Electricity saving (MWeh/yr)	1 Pearl Rating Electricity saving (MWeh/yr)	2-5 Pearl Rating Electricity saving (MWeh/yr)
Glazing	0.0234	0.03316	20,152.07	28,598.86

Although, the above results for the 1990s prototype is rough, it is considered indicative of the situation and will require further studies to better estimate the savings for various techniques.

The following Chapter presents a set of recommendations for further studies in light of this research. Also, it concludes the study by presenting the major findings of this research.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6 CONCLUSION AND RECOMMENDATIONS CONCLUSION

The UAE has witnessed rapid growth in the urban development in the past few decades. Since the discovery of oil in 1960s, and the increase in population, the construction industry has been a greatly active sector in the country. This development, however, was accompanied with great growth rate in energy consumption in the Emirates. According to Al-Iriani (2005), the average growth rate in energy consumption in the UAE for the period between 1980 and 2000 was estimated at 10% annual growth rate, which topped that for the world estimated at 3%. In the UAE, the built environment is estimated to contribute to nearly 40% of the total energy consumption, in which around 98%-99.5% were built prior to enforcement of green building regulations in the country such as Estidama Pearl Rating System in Abu Dhabi. (Alawadi et al. 2013). Therefore it is estimated that the major savings in energy consumption can be achieved through refurbishment of the existing building stock. This increased demand in energy consumption, and the environmental impact of the existing building stock triggered the question whether refurbishment applications can significantly reduce the energy consumption and positively contribute to the achievements of the national goals in reducing CO2 emissions by 2030.

The research studied the urban development in Abu Dhabi since 1960s to identify the existing building stock, and the typologies responding to the development of construction methods and materials. It has been identified that around 54% of the existing building stock in Abu Dhabi is categorized under commercial and governmental sectors, which gives more value to conducting research on office buildings. The research also concluded that the existing building stock mainly include the buildings constructed in 1980s onwards. The buildings prior to 1980s were mostly demolished due to two main reasons; being of poor quality, and having changed the regulations for buildings heights to more vertical development. The study has investigated the building regulations applicable to the building envelope thermal performance, and concluded that there were no specific standards enforced on this regard. However, it wasn’t until the year 2010 when Estidama Pearl Rating requirements for minimum one pearl rating for all new buildings, and two pearls for governmental buildings have been enforced.

Based on the literature review, and the studies of the existing building stock, two building prototypes were identified to represent office buildings in the 1980s and 1990s. The major differences between both prototypes have been identified to be as following;

For the buildings in the 1980s;

- Mixed use buildings with conversion from residential to commercial spaces
- Post-modern Architecture
- 15-20 stories height
- Plaster finishing with stone cladding introduced in the late 1980s
- No external wall insulation
- Single glazing
- Window-type HVAC units

For the buildings in 1990s;

- Both mixed-use residential conversion, and stand-alone office buildings
- Post-modern and modern Architecture
- 20-25 stories height
- Curtain wall and/or fully glazed facades, aluminum cladding, and stone cladding
- Concrete and steel structure
- Double glazing
- Central AC system

The literature review of the existing building stock and analysis of the chronological order of the urban development in Abu Dhabi facilitated identifying the total GFA representative of each of the periods from 1980-1989 and 1990-1999.

Further to the identification of representative prototype for commercial buildings in 1980s and 1990s and the estimated total GFA for each decade, a case study of an existing building in Abu Dhabi has been selected. The building represents the mixed-use buildings built in the 1980s. Computer modelling was used to assess the savings in electricity consumption, associated cooling loads, energy consumption, and CO2 emissions for the selected prototype. The 17 stories building was modeled in three simulation models; typical floor, roof floor, and ground and mezzanine floors. Severn to Nine building simulations for each of the models were conducted to assess savings due to individual elemental refurbishment and combined scenarios considering upgrades to 1 and 2 pearls rating thermal properties. The potential reduction in cooling loads for the overall building varies dramatically depending on the refurbishment application. For the upgrades to 1 pearl rating standards, the savings range from 0.21% in the case of roof, to 5.13% and 11.90% in the case of the wall and fenestration upgrades respectively. However, for the upgrades to 2 pearls rating requirements, the savings were estimated at 0.22% for the roof upgrades, 5.61% and 14.67 for the wall and fenestration upgrades respectively.

The results indicated that the savings in the typical floor were the closest representation to the results for the overall building; that is because the total GFA representing the typical floor is around 82% of the total building GFA. Also, it has been noted that the savings from the roof refurbishment is considered negligible for the overall building savings. On the other hand, the glazing upgrades have proven to be the most effective solution which achieves the highest savings. One of the important conclusions of this study is the fact that individual elements of the building, and individual floors could be looked at for prioritized refurbishment strategy depending on the individual savings that could be achieved, easement of implementation, and economic feasibility.

Moreover, the study highlights that combined solutions achieve greater savings than when individual refurbishment applications are considered. Solar gain, and external conduction gain analysis was conducted to understand the results for the combined solution. Based on the analysis, it has been noticed that the elements behavior and specifically the external conduction gain profile varies for the various applications. The solar gain analysis identified the glazing as the weakest element, where the overall solar gain is always linked to the glazing properties. An example for the set of upgrades to 2 pearls was presented where it has been noted that both the external walls, and roof have similar behavior profile, which varies from the glazing.. In this example, the 2 pearls combined scenario has 0.0727 MWh less annual conduction gain than the sum of the individual scenarios.
For the combined solutions, the savings for the overall building were significant and were estimated at 18.90% and 22.12% for the 1 pearl and 2 pearls upgrades respectively.

The feasibility study indicated that the most feasible refurbishment solution for the building prototype of 1980s is for 2 pearls glazing upgrade, where 9 years payback period could achieve savings of 164.2157 MWhe of annual electricity consumption. However, it was noted that the highest savings for the combined solution in the case of 2 pearls upgrades would return its capital cost in around 16 years. It is important to highlight – within this context- that the payback period calculations excludes the savings in government electricity cost subsidies, evaluation of building envelop climatic performance upgrade such as humidity resistance, air tightness, aesthetical appearance, as well as future increases in the cost of electricity. It is expected that once all the benefits are quantified, the SPP analysis will result in reasonable timeframe for the owners to recoup their initial investment cost.

Finally, the research is concluded by magnifying the annual reduction in electricity consumption to represent the savings across Abu Dhabi. For the 1980s, the implementation of a combined retrofitting scenario which targets upgrading the external walls, roof, and glazing to 2-5 pearls rating requirements; is estimated to achieve annual reduction in electricity consumption of 18,433 MWeh/yr. Whereas, the refurbishment of the most economically feasible solution to upgrade the building glazing to 2-5 pearl rating standards, can achieve an overall reduction for the same buildings estimated at 12,213.97 MWeh/yr. CO2 emissions reduction for the combined solution of 2 pearls rating is estimated at 9,530,968.13 KgCO2/yr.

Moreover, an indication of the typical building prototype for the 1990s has been provided, based on the building characteristics concluded from the literature review. Since the buildings in the 1990s have a predominant feature of high ratio of external glazing –if not fully glazed- the refurbishment was targeted for the glazing elements only. Based on the initial estimates, the overall savings for Abu Dhabi for the 1990s buildings represented by the sample floor are estimated at 28,598.86 MWeH/yr and 20,152.07 MWeh/yr for the 2 pearls and 1 pearl rating respectively.

6.1 RECOMMENDATIONS FOR FUTURE RESEARCH

Further to this research, there are several opportunities for continuation and problems to be further investigated. With regards to potential of energy savings, cooling load reduction, and CO2 emissions reduction, further investigations could be conducted on the building prototype representative of the period from 1908 to 1989. The investigations could target refurbishment strategies of various types of glazing including triple-glazing panels.

Also, a combination between active and passive retrofitting strategies could be investigated.

As highlighted during the research, there is a major difference between the HVAC systems and their efficiency for those used in 1980s and 1990s. Further research could target the potential savings due to replacement of the HVAC system.

Moreover, further studies could be conducted on an existing building representative of the 1990s for comprehensive analysis of the cooling loads, energy, and CO2 emissions through implementation of various retrofitting strategies.

On another level, the research could be used as a basis to investigate formation of retrofitting policies and regulations similar to that established for the US Green Building Council as LEED for Existing Buildings. Since the Abu Dhabi Urban Planning Council has already established the Estidama Pearl Rating System, there is great benefit to form a rating system for existing buildings. The formation of standards, regulations, and policies for upgrades in the existing building thermal performance need to be further investigated from a regulatory framework perspective.

Another aspect that could be further investigated is the construction constraints and opportunities, implementation strategies, and other constructability aspects of the retrofitting strategies. Such investigations shall identify any potential risks associated with the retrofitting strategies suggested in this research.

Finally, detailed economic feasibility study could be conducted to evaluate the additional benefits associated with building envelope refurbishment inclusive of humidity resistance, air tightness, sound insulation, building durability, etc. Also, parameters such as governmental subsidies and inflation rates shall be taken into consideration to provide a better picture of the payback period versus the identified benefits of the building retrofitting.

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APPENDIX A - LITERATURE REVIEW SUPPORTING DATA

Table A36 Consumption of Electricity per Region in MWh. (Source: SCAD 2012, p. 67)

Year	Total	Abu Dhabi	Al Ain	Al Garbia
1972	223,314	198,741	24,573	0
1973	336,242	299,242	37,000	0
1974	428,537	377,537	51,000	0
1975	629,350	540,281	89,069	0
1976	845,072	710,324	134,748	0
1977	1,219,023	1,029,651	189,372	0
1978	1,377,251	1,121,522	255,729	0
1979	1,878,240	1,499,011	379,229	0
1980	2,376,367	1,846,765	529,602	0
1981	2,870,532	2,205,829	664,703	0
1982	3,426,085	2,557,424	868,661	0
1983	3,807,402	2,848,166	959,236	0
1984	4,148,898	3,065,922	1,082,976	0
1985	4,523,421	3,348,037	1,175,384	0
1986	5,490,985	4,139,064	1,351,921	0
1987	5,950,056	4,492,728	1,457,328	0
1988	6,464,509	4,863,535	1,600,974	0
1989	6,830,833	5,096,929	1,733,904	0
1990	6,605,690	4,670,690	1,935,000	0
1991	6,724,047	4,636,047	2,088,000	0
1992	7,079,949	4,881,949	2,198,000	0
1993	7,787,185	5,462,137	2,325,048	0
1994	8,351,385	5,906,447	2,444,938	0
1995	9,074,210	6,212,210	2,862,000	0
1996	10,346,470	7,201,470	3,145,000	0
1997	10,883,760	7,462,760	3,421,000	0
1998	16,104,368	10,810,768	4,181,580	1,112,020
1999	17,507,862	11,515,152	4,741,220	1,251,490
2000	19,128,380	12,158,360	5,442,130	1,527,890
2001	20,648,660	12,963,260	5,983,830	1,701,570
2002	22,398,850	14,178,270	6,295,720	1,924,860
2003	23,289,990	14,924,760	6,506,630	1,858,600
2004	24,365,800	15,620,760	6,569,450	2,175,590
2005	25,423,862	16,158,411	6,849,131	2,416,320
2006	27,323,017	17,376,073	7,091,412	2,855,532
2007	29,342,214	18,577,267	7,528,700	3,236,247
2008	31,480,854	19,803,499	7,881,926	3,795,429
2009	34,716,166	22,062,262	8,474,342	4,179,562
2010	39,173,140	24,850,010	9,081,380	5,241,750
		1972 to 2010 net change, %		
	17,442	12,404	36,857	_

Sources:
- Abu Dhabi Water and Electricity Company (ADWEC) (2000-2009)
- Abu Dhabi Water and Electricity Authority (ADWEA) (1994-1999)
- Department of Water and Electricity (1972-1993)

Notes:
1. 2002-2003 Al Ain and Al Ghrabia figures are estimates
2. Consumption include internal Electrical Consumption by Power Stations and Technical Losses Through the Network

Table A2 Key Statistics of Construction Activities (Source: SCAD 2012, p. 69)

Year	Buildings	Housing	Permits Issued by Region		
			Total	Abu Dhabi	Al Ain
1968	3,007	6,625	**53**	29	24
1969	4,540	10,001	**135**	71	64
1970	6,072	13,378	**55**	27	28
1971	7,604	16,754	**117**	74	43
1972	9,136	20,130	**222**	162	60
1973	10,668	23,506	**325**	232	93
1974	12,200	26,883	**552**	378	174
1975	13,736	30,259	**787**	488	299
1976	16,872	37,117	**2,310**	1,433	877
1977	20,007	43,975	**2,242**	1,475	767
1978	23,074	50,743	**2,758**	1,720	1,038
1979	41,905	75,447	**3,748**	1,619	2,129
1980	46,738	84,416	**4,188**	2,042	2,146
1981	46,746	88,683	**4,590**	2,468	2,122
1982	48,988	92,949	**5,130**	2,620	2,510
1983	51,230	97,216	**4,999**	2,808	2,191
1984	53,473	101,482	**4,636**	2,263	2,373
1985	55,635	105,749	**4,457**	2,380	2,077
1986	55,001	85,532	**7,854**	2,331	5,523
1987	54,367	90,865	**5,760**	2,946	2,814
1988	53,733	96,198	**5,301**	3,315	1,986
1989	53,099	101,532	**7,918**	3,423	4,495
1990	52,465	106,865	**5,064**	3,196	1,868
1991	51,831	112,199	**4,862**	3,062	1,708
1992	51,194	117,532	**5,989**	3,787	2,087
1993	70,431	141,514	**5,457**	3,482	1,777
1994	73,483	147,657	**6,028**	4,633	1,061
1995	76,419	153,800	**5,505**	4,036	1,162
1996	83,080	180,354	**5,925**	4,119	1,611
1997	86,358	187,338	**5,897**	4,224	1,501
1998	89,636	194,321	**7,844**	5,234	2,476
1999	92,914	201,305	**9,568**	7,348	2,096
2000	96,192	208,289	**7,366**	5,677	1,577
2001	98,917	215,273	**6,536**	4,241	2,164
2002	103,523	213,368	**7,513**	4,994	2,381
2003	108,202	223,329	**7,499**	5,073	2,293
2004	112,882	233,290	**7,606**	5,327	2,144
2005	117,254	243,251	**8,555**	5,947	2,608
2006	126,817	248,686	**9,631**	6,055	3,576

2007	136,380	254,121	**6,272**	3,316	2,956
2008	145,943	259,556	**6,603**	4,129	2,474
2009	155,506	264,991	**12,623**	9,674	2,949
2010	165,072	270,428	**11,532**	8,155	3,377
1968 to 2010 net change, %					
	5,389	**3,982**	**21,782**	**28,021**	**14,148**

Sources for building and houses:

- ❖ Building and housing unit Census (1995-2001)
- ❖ Central Statistical Administration (1985)
- ❖ Population and housing census (1980)
- ❖ Building and housing unit surveys (1972,1992)

Sources for number of permits:

- ❖ Department of Municipality and Agriculture (2003-2004)
- ❖ Abu Dhabi Municipality and Al Ain Municipality (1976-2002)
- ❖ Abu Dhabi Municipality (1975)
- ❖ Department of Town Planning, Abu Dhabi (1968-1974)

Note: Figures for buildings and housing for the period 2006 - 2009 estimated based on the primary result of the frame update project conducted by SCAD in October 2010

Table A3 Comparison of 20 simulation software according to their capabilities (Source: Crawley *et* al 2005, p. 21)

ABBREVIATIONS IN THE TABLES

X feature or capability that is available and in common use (e.g. a mature facility, well supported in documentation/interface/examples)

P feature or capability that is partially implemented (e.g., it addresses part of an issue, does not yet fully represent the underlying physics or is a work-in-progress)

O optional feature or capability that is not included in the standard distribution or requires additional payment and/or a download.

R optional feature or capability that is intended for research use (e.g., links to experimental data, validation tests, and options to invoke alternative correlations or modify the underlying solution technique)

E feature or capability that requires considerable domain expertise or knowledge of the underlying models (e.g., computational fluid dynamics, 2D/3D conduction, fire evacuation)

I feature or capability that requires input data that can be difficult to obtain (e.g., parameter estimates from optimization, difficult to obtain curve fits, no manufacturer data available, little or no research has been done to characterize model coefficients)

Table A4 Comparison of 20 simulation software according to their capabilities (Source: Crawley *et* al 2005, p. 26)

Table 3 ***Building Envelope, Daylighting and Solar***	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
Solar analysis																				
▪ Beam solar radiation reflection from outside and inside window reveals		X	P		X				X											X
▪ Solar gain through blinds accounts for different transmittances for sky and ground diffuse solar			X		[3]	X			X						X			X		X
▪ Solar gain and daylighting calculations account for inter-reflections from external building components and other buildings		P			X				X		X[57]				X	P		X		X[58]
▪ Creation of optimized shading devices					X															
▪ Shading surface transmittance	X			P	X		X		X	X					X			X[95]		
▪ Shading device scheduling	X	X	X	P	X				X	X			X[83]	X	X	P	X	X	X	X
▪ User-specified shading control		X	X	P	X[59]				X		X[60]		X[83]	X	X			X	X	X
▪ Bi-directional shading devices			P		[3]				X		X[61]			X	X			X	X	X
▪ Shading of sky IR by obstructions			X	X	[3]	X			X	X					X			X		X
Insolation analysis																				
▪ time-invariant and/or user stipulated[62]	X			P[63]					X	P	X		X				X			X
▪ distribution computed at each hour[64]	X			X[65]						X	X				X					E I[66]
▪ distribution computed at each timestep[67]									X						X					E I[66]
▪ Beam solar radiation passes through interior windows (double-envelope)		X	P		X				X	X[68]				X[69]	X	P		X		X
▪ Track insolation losses (outside or other zones)											X				X					

[57] Does not include specular reflection from obstructing bodies or diffuse shading. Insolation calculation for any shape of room and includes surfaces within the room.
[58] No specular reflection
[59] Using embedded scripting engine allows a function to be called each time-step to change shading parameters or shading masks.
[60] For two blind positions and daylighting accounted for in light switching for multiple sensors and circuits per thermal zone.
[61] Via surfaces
[62] User defines where direct sunlight (insolation) falls in a room, e.g., put 45% on the floor and 55% on the back wall or the application distributes insolation in the same pattern for all hours.
[63] Time-invariant except for sunspaces, where solar distribution is calculated hour-by-hour
[64] At each hour, application calculates the distribution of direct sunlight (insolation) entering via each window (at run-time or calculated and stored for retrieval at run time).
[65] Direct solar radiation impinging on surfaces is calculated every hour, but the obstructed fraction due to shading surfaces is calculated hour-by-hour every two weeks.
[66] Must be calculated outside the building model and requires additional data.
[67] At each timestep, application calculates the distribution of direct sunlight (insolation) entering via each window (at run-time or calculated and stored for retrieval at run time).
[68] For sunspaces (atriums) only, not used for double envelope buildings
[69] With separate add-in for double sheet facades

Table A5 Comparison of 20 simulation software according to their capabilities (Source: Crawley *et* al 2005, p. 27)

Table 3 ***Building Envelope, Daylighting and Solar***	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
Advanced fenestration																				
▪ Controllable window blinds		X	X	X	X[70]		X		X	X	X		X	X	X		X	X		X
▪ Between-glass shades and blinds			X	X	X				X	X	X[71]			X	X			X		X
▪ Electrochromic glazing					X[72]				X	X	X			X						E[73]
▪ Thermochromic glazing					X						X			X			I			E[73]
▪ Datasets of window types[74]		P[75]	X	P	X		P		X	X[76]	P[77]	X[78]	X[79]	X	X			X	P	X
▪ WINDOW 5 calculations					[3]				X	X[76]										X
▪ WINDOW 4.1 data import	X			X[76]	[3]					X[76]	X						X[80]		X	X
▪ Dirt correction factor for glass solar and visible transmittance			E	P	X				X	P				X						E[73]
▪ Movable storm windows			X		X				X		X[81]			X	X			X		X
▪ Bi-directional shading devices			P		[3]				X		X[61]			X	X			X	X	X
▪ Window blind model[82]			X		X				X	X	X[60]		X[83]		X					X
▪ User-specified daylighting control		X	X		X[84]				X		X[60]		X[83]	X	X			X	X	X
▪ Window gas fill as single gas or gas mixture			X		X				X		X				X			X		X
General Envelope Calculations																				
▪ Outside surface convection algorithm																				
○ BLAST/TARP	X				[3]				X										X	
○ DOE-2				X	[3]				X	X[85]									X	
○ MoWiTT					[3]				X		X								X	
○ ASHRAE simple	X				[3]	X		X	X				X		X			X	X	

[70] Using embedded scripting engine allows a function to be called each time-step to change glass parameters based on analysis results.
[71] Multiple representations possible: as part of a constructions optical properties, as solar obstructions associated with the zone or as explicit surfaces with full treatment of convection and radiation exchange.
[72] With freely available electrochromic/thermochromic plug-in developed at Welsh School of Architecture.
[73] By applying a correction factor outside the building model (Type-56) or defining several windows in WINDOW 5 and switching from one to the other during simulation based on conditions or control signal.
[74] Conventional, reflective, low-E, gas-fill, electrochromic, and WINDOW-5 layer-by-layer custom glazing description
[75] Extensible window library with possibility of defining individual 3rd order polynomial transmission versus angle of incidence curves.
[76] Window 4 single band calculation for layer-by-layer descriptions or accepts Window 5 multiband output for composite window descriptions.
[77] Window 5 import only by manual editing of optical data. Frames and edge-of-glass properties modeled via explicit surfaces.
[78] Configuration of window glazing and window assembly defined; performance calculations based on Window 4.
[79] Checklist with 11 glazing types and two frame types, or advanced numerical data input for up to 25 windows.
[80] Window 4.1, 5.1 and 5.2 data import capabilities
[81] Via general facility for substituting constructions thermophysical and optical properties during simulation.
[82] Slat-type shading devices such as Venetian blinds coupled to daylighting, with movable slats and associated slat-angle controls
[83] Intelligent controller manages operable exterior or interior window shades for passive heating/cooling/daylighting
[84] Using embedded scripting engine allows a function to be called each time-step to change shading parameters or shading masks.
[85] Uses combined MoWiTT, TARP and ASHRAE formulations for various portions

Table A6 Comparison of 20 simulation software according to their capabilities (Source: Crawley *et* al 2005, p. 28)

Table 3 ***Building Envelope, Daylighting and Solar***	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
○ Ito, Kimura, and Oka (1972) correlation											X			X						
○ User-selectable			X		[3]				X[86]		X			X	X	X		X	X	X
▪ Inside radiation view factors		X	X		[3]				X	X	X			X	X		P	X		
▪ Radiation-to-air component separate from detailed convection (exterior)		X	X		[3]				X	X	X			X	X		X	X	P	X
▪ Air emissivity/radiation coupling															X					
Sky model																				
▪ Isotropic[87]	X				X		X	X			X	X[88]	X		X	X	X	X		X
▪ Anisotropic[89]		X	X	X	X	X			X	X	X	X[90]		X	X				X	X
▪ User-selectable		X			X						X			X[91]	X					X
Daylighting illumination and controls																				
▪ Interior illumination from windows and skylights		X	X	X	X	X		X[92]	X	X	X		X	X	X			X	X	
▪ Stepped or dimming electric lighting controls[93]		X		X	[3]	X		X	X	X	X		X	X	X			X	X	X
▪ Glare simulation and control				X	P[3]				X	X	X[94]				X			X		
▪ Geometrically and optically complex fenestration systems using bidirectional transmittance									I		X[94]			X	X			X[95]		
▪ Radiosity interior light interreflection calculation					[3]				X		X[94]			X	X			X[95]		
▪ Daylight illuminance maps		X			X				X		X				X			X[95]		
▪ Daylighting shelves					X	X			X		X[96]				X			X[95]		
▪ Tubular daylighting devices[97]					[3]				X		X[96]				X					
Movable/transparent insulation	X	X	P	X	[3]				X		X		X[98]	X	X		P			X
Zone surface temperatures[99]	X	X	E	P[100]	X	X			X	X[101]	X[102]			X	X	X	X	X	X	X

[86] Can specify different correlations by surface type (e.g. all exterior windows)
[87] Uniform solar radiation and illumination distribution
[88] For energy simulation calculations
[89] Sky radiance, diffuse solar radiation and illumination vary with sun position
[90] For design day calculations
[91] ASHRAE, Perez and Kondratjev
[92] LBNL split-flux daylighting model
[93] Including heating and cooling effects
[94] Through a link with Radiance
[95] Through a link with Lumen Designer
[96] Resolution can be increased via use of Radiance to define shelf properties and light sensor characteristics. Tubular devices require combined Radiance & surfaces description.
[97] Including illuminance, solar gain, thermal resistance
[98] Automatic operable night time window insulation
[99] Wall, window, door, floor, ceiling, roof
[100] Reverse calculation from heat flows (module added by EMPA)

Table A7 Comparison of 20 simulation software according to their capabilities (Source: Crawley *et* al 2005, p. 29)

Table 3 Building Envelope, Daylighting and Solar	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
Airflow windows					X				X		X[103]			O	X	X	X	X		X
Surface conduction																				
▪ 1-dimension	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
▪ 2- and 3-dimension			P						X		R I			O						
Ground heat transfer																				
▪ ASHRAE simple method[104]																				X
▪ 1-dimension	P	X	X	P	X	X	X	X	X	X	X	X	X	X	X	X	X	X	P	O[105]
▪ 2- and 3-dimension slabs					3				X[106]		R			O		O[107]	R			O[105]
▪ 2- and 3-dimension basements			P		3				X		R			O		O[107]	R			O[105]
Variable thermophysical properties					X						I			X		X				
Phase change materials			O								I			O		R	X			E
Building integrated photovoltaic system accounts for heat removed from surfaces layers which have defined electrical characteristics		X			3				X	X	X					P				E

[101] User selectable in some versions
[102] Also temperatures within constructions as well as full energy balance at each surface.
[103] As an additional zone with flow network or CFD domain
[104] ASHRAE (2001a)
[105] Through additional component (optional TESS libraries)
[106] 2-D and 3-D ground calculations for basements and slabs using auxiliary programs.
[107] Through a link with the Solum software (Santos et al. 2003)

APPENDIX B – EXISTING BUILDING EMPORIS DATABASE

Table B1 List of Existing Buildings in Abu Dhabi and their properties. (Source: EMPORIS 2013)

Identification			Structure in General			Usage		Location in Emirate of Abu Dhabi			Technical Data							Involved Companies
Building Name	Year	Height	Building Type	Structural Material	Architectural Style	Primary Use	Secondary Use	Complex	Zone	City	Height (tip) in meters	Height (Architectural) in meters	Floors (above ground)	Construction Start	Construction End	Floor-to-ceiling height (m)	Elevators	
Sky Tower	2010	310 m	skyscraper	concrete	postmodern	commercial office,rental apartments	shopping center, fitness center	The gate	Shams	Abu Dhabi	310.00 m	310.00 m	74	2006	2010	2.70 m	27	Architect: A2so4 Architecture,RW Armstrong.
Etihad Tower 2 [Etihad Towers]	2011	305 m	skyscraper	concrete	modernism	residental		Etihad Towers		Abu Dhabi	305.30 m	305.30 m	79	2007	2011			Architect: DBI Design (Pty Ltd)
Etihad Tower 1[Etihad Towers]	2011	270 m	skyscraper	concrete	modernism	hotel/servical apartments		Etihad Towers		Abu Dhabi	277.61 m	277.61 m	70		2011			Architect: DBI Design (Pty Ltd)
Nation Towers Residential	2012	268 m	skyscraper			residental		Nation Towers		Abu Dhabi		268.00 m	65	2007	2012			general contractor
Etihad Tower 3[Etihad Towers]	2011	260 m	skyscraper	concrete	modernism	commercial office		Etihad Towers		Abu Dhabi	260.34 m	260.34 m	62		2011			Architect: DBI Design (Pty Ltd)
Etihad Tower 4[Etihad Towers]	2011	234 m	skyscraper	concrete	modernism	residental		Etihad Towers		Abu Dhabi	234.00 m	234.00 m	61		2011			Architect: DBI Design (Pty Ltd)
Etihad Tower 5[Etihad Towers]	2011	218 m	skyscraper	concrete	modernism	residental		Etihad Towers		Abu Dhabi	217.50 m	217.50 m	56		2011			Architect: DBI Design (Pty Ltd)
Capital Plaza Residential Towder	2011	210 m	skyscraper		postmodern	residental		Capital Plaza		Abu Dhabi		210.00 m	51	2004	2011			
Abu Dhai Investment Authority Tower	2006	185 m	skyscraper	concrete	modernism	commercial office		Corniche Street		Abu Dhabi	185.00 m	185.00 m	40	2001	2006		13	Architect: Kohn Pedersen Fox Associates
Al Maqam Tower [Sowwah Square]	2012	184 m	skyscraper	concrete		commercial office		Sowwah Square	Al Maryah Island	Abu Dhabi		184.00 m	37		2012			Architect: Goettsch Partners,inc.
Al khatem Tower [Sowwah Square]	2012	184 m	skyscraper	concrete		commercial office		Sowwah Square	Al Maryah Island	Abu Dhabi		184.00 m	37		2012			Architect: Goettsch Partners,inc.
National Bank of Abu Dhabi Headquarters	2002	173 m	skyscraper		modernism	commercial office		Sheikh Khalifa Street		Abu Dhabi		173.00 m	33	1999	2002		11	Architect: Architecture & Planning Group, Adel Al Mojil Engineering Consultant, Carlos Ott Architect
Baynunah Hilton Tower Hotel	1994	165 m	skyscraper		postmodern	hotel		Corniche Road		Abu Dhabi	164.90 m	164.90 m	40		1994			Architect: Arkan Architects, Consultants
Capital Gate	2010	160 m	skyscraper			office/hotel				Abu Dhabi		160.00 m	35	2008	2010			Architect: RMJM Dubai
Al Sarab Tower [Sowwah Square]	2012	160 m	skyscraper	concrete		commercial office		Sowwah Square	Al Maryah Island	Abu Dhabi		160.00 m	31		2012			Architect: Goettsch Partners,inc.
Al Sila Tower [Sowwah Square]	2011	160 m	skyscraper	concrete		commercial office		Sowwah Square	Al Maryah Island	Abu Dhabi		160.00 m	31		2011			Architect: Goettsch Partners,inc.
Etisalat Headquarters	2001	160 m	skyscraper		postmodern			Airport Road		Abu Dhabi		160.00 m	27		2001			Architect: Adel Al Mojil Engineering Consultant, Carlos Ott Architect
Capital Plaza Office Tower[Capital Plaza]	2011	157 m	skyscraper		postmodern	commercial office		Capital Plaza		Abu Dhabi	156.50 m	156.50 m	33	2004	2011			
Capital Plaza Hotel Tower [Capital Plaza]	2011	146 m	skyscraper		postmodern	hotel		Capital Plaza		Abu Dhabi	145.50 m	145.50 m	31	2004	2011			
Al Bahr Tower 1 [Al Bahr Towers]	2012	145 m	skyscraper	composite structure		governmental office		Al Bahr Tower		Abu Dhabi		145.00 m	29	2009	2012			
Al Bahr Tower 2 [Al Bahr Towers]	2012	145 m	skyscraper	composite structure		governmental office		Al Bahr Tower		Abu Dhabi		145.00 m	29	2009	2012			
Etisalat Radio Mast		138 m	mast (wired)							Abu Dhabi	138.00 m	138.00 m						
Le Royal Meridien Hotel	1993	121 m	skyscraper		modernism	hotel		Khalifa Bin Zayed Street		Abu Dhabi	120.70 m	120.70 m	32		1993			Architect: Arthur Ericksom Architectural Corporation, Norr Group Consultants International Ltd.
Union National Bank 2	1996	120 m	skyscraper			commercial office				Abu Dhabi		120.00 m	21		1996			Architect: Norr Group Consultants International Ltd, Carlos Ott Architect.
Abu Khabi Oil Refining Company Tower	2004	117 m	skyscraper		postmodern			ADNOC Headquarters		Abu Dhabi		117.00 m	29	2001	2004			
Abu Dhabi Gas Processing Company Tower	2004	117 m	skyscraper		postmodern			ADNOC Headquarters		Abu Dhabi		117.00 m	29	2001	2004			
Sheikh Zayed Bin Sultan Al Nahyan Mosqu		115 m	mosque		islamic	mosque				Abu Dhabi	115.00 m	115.00 m						lighting consultant, concrete supplier
Alder Headquarters	2010	110 m	skyscraper	composite structure	structural expressionism	commercial office				Abu Dhabi		110.03 m	23		2010			Architect: MZ Architects
Marina Mall Viewing Tower		100 m	ovservation tower							Abu Dhabi		100.00 m						
ZADCO Tower [Zadco and Gasco Towers]		93 m	high-rise building					Zadco and Gasco Towers		Abu Dhabi	93.00 m	93.00 m	20					Architect: Nikken Sekkei Ltd, Leo A. Daly
GASCO Tower [Zadco and Gasco Towers]		93 m	high-rise building					Zadco and Gasco Towers		Abu Dhabi	93.00 m	93.00 m	20					Architect: Nikken Sekkei Ltd, Leo A. Daly
Abu Dhabi National Oil Company Building		90 m	high-rise building							Abu Dhabi	89.92 m	89.92 m	24					
Fotouh Al Khair Centre I	1999	87 m	high-rise building	concrete	postmodern	rental apartments		Fotouh Al Khair Centre		Abu Dhabi		87.00 m	22		1999			
Fotouh Al Khair Centre II	1999	87 m	high-rise building	concrete	postmodern	rental apartments		Fotouh Al Khair Centre		Abu Dhabi		87.00 m	17		1999			
Fotouh Al Khair Centre III	1999	87 m	high-rise building	concrete	postmodern	rental apartments		Fotouh Al Khair Centre		Abu Dhabi		87.00 m	17		1999			
Emirates Palaace	2005	71 m	high-rise building	concrete	postmodern	hotel	shops,restaurant, fitness center	Corniche Road		Abu Dhabi	70.85 m	70.85 m	8	2003	2005			Architect: Wimberly Allisom Tong & Goo

Identification			Structure in General			Usage		Location in Emirate of Abu Dhabi			Technical Data							Involved Companies
Building Name	Year	Height	Building Type	Structural Material	Architectural Style	Primary Use	Secondary Use	Complex	Zone	City	Height (tip) in meters	Height (Architectural) in meters	Floors (above ground)	Construction Start	Construction End	Floor-to-ceiling height (m)	Elevators	
Ferrari World Abu Dhabi	2010	45 m	hall	steel		amusement		Yas Island	Yas Island	Abu Dhabi		45.00 m	3	2007	2010			design Architect: Benoy, Architect: Benoy, Glass supplier: interpane Glas Industrie AG, Interior fit-lut: Depa Ltd>
Sun Tower	2010		skyscraper	concrete		residential	restaurant	The gate District, shams Abu Dhabi	shams	Abu Dhabi	307.45 m		65	2007	2010			Design Architect: Arquitectonica, Architect: RW Armstrong
Marina Blue	2012		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			51		2012			
Ocean Terrace	2012		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			50		2012			
Tala Tower	2012		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			49		2012			
SEBA Tower	2011		skyscraper		modernism	commercial office, residential condominium	parking			Abu Dhabi	222.31 m		47	2008	2011			
Burooj Biews	2012		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			45	2006	2012			
Al Maha Tower	2012		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			43		2012			
RAK Tower	2011		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			43		2011			
Marina Heights II	2011		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			43		2011			
Marina Heights I	2011		skyscraper			residential		Marina Square	Al Reem Island	Abu Dhabi			43		2011			
Infinity Tower	2011		high-rise building		modernism	office condominium		Marina Square	Al Reem Island	Abu Dhabi			32		2011			
Silver Tower			high-rise building			residential		Corniche Road		Abu Dhabi	141.90 m		30					Architect: Cassia & Associates
Grand Millennium Al Wahda	2010		high-rise building			hotel	residential	Hezza Bin Zayed Street		Abu Dhabi			28		2010			Depa Ltd
Bin Arar Centre			high-rise building			commercial office, residential condominium	mercantile	Al Najda Street		Abu Dhabi	129.01 m		26					
Al Ain Tower			high-rise building			residential		Sheikh Hamdan Bin Mohammed Street		Abu Dhabi	122.98 m		26					
Nahda Tower	1998		high-rise building			hotel		Corniche Road		Abu Dhabi	135.04 m		26	1996	1998			consultant
Abu Dhabi Grand Hotel			high-rise building					Khalifa Street		Abu Dhabi	139.59 m		25					
Zayed Military City Tower I			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower II			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower III			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower IV			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower V			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower VI			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower VII			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower VIII			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower IX			high-rise building							Abu Dhabi	129.85 m		25					
Zayed Military City Tower X			high-rise building							Abu Dhabi	129.85 m		25					
Abu Dhabi World Trade Center Building			high-rise building							Abu Dhabi	116.14 m		25					
The Six Towers 1 [The Six Towers]	2005		high-rise building			commercial office, residential		The Six Towers		Abu Dhabi	124.05 m		25	2004	2005			
The Six Towers 2 [The Six Towers]	2005		high-rise building			commercial office, residential		The Six Towers		Abu Dhabi	124.05 m		25	2004	2005			
Bani Yas Tower	1988		high-rise building					Corniche Road and Lulu Street		Abu Dhabi	129.85 m		25		1988			
Etisalat Tower	1986		high-rise building		postmodern					Abu Dhabi	129.85 m		25	1985	1986			Architect: Arthur Erickson Architectural Corporation
Benkaram Tower			high-rise building							Abu Dhabi	124.65 m		24					
Alia Tower			high-rise building			office				Abu Dhabi	124.65 m		24					
Nizar Ahmed Al Obaidly Tower			high-rise building							Abu Dhabi	119.46 m		23					
Champer of Commerce & Industry Building			high-rise building					Corniche Road		Abu Dhabi	119.46 m		23					
Tower Sector E-07, Plot C-42			high-rise building			commercial office, residential		Sector E-07, Plot C-42, Sheikh Khalifa Bin Zayed Street		Abu Dhabi	114.12 m		23	2005	2007			Architect: Planar
Butti Bin Ahmad Building	1999		high-rise building			commercial office		Liwa Street		Abu Dhabi	119.46 m		23		1999			
Al-Muhairby Building	1997		high-rise building			commercial office				Abu Dhabi	119.46 m		23		1997			
Abdulla Al Murar Building	1993		high-rise building							Abu Dhabi	119.46 m		23		1993			
ADMO, OPCO & ADGAS Tower II			high-rise building							Abu Dhabi	114.27 m							
Al Maha Rotana Suites	2002		high-rise building			hotel		Sheikh Hamdan Bin Mohammed Street		Abu Dhabi	122.84 m		22		2002			
Al Nuwais Building II	1999		high-rise building					Al Nuwais Buildings		Abu Dhabi	114.27 m		22		1999			Architect: Dewan Architects & Engineers
Al Nuwais Building III	1999		high-rise building					Al Nuwais Buildings		Abu Dhabi	114.27 m		22		1999			Architect: Dewan Architects & Engineers
Al Nuwais Building I	1999		high-rise building					Al Nuwais Buildings		Abu Dhabi	114.27 m		22		1999			Architect: Dewan Architects & Engineers

Identification			Structure in General			Usage		Location in Emirate of Abu Dhabi			Technical Data							Involved Companies
Building Name	Year	Height	Building Type	Structural Material	Architectural Style	Primary Use	Secondary Use	Complex	Zone	City	Height (tip) in meters	Height (Architectural) in meters	Floors (above ground)	Construction Start	Construction End	Floor-to-ceiling height (m)	Elevators	
Three Sails Tower	1998		high-rise building			commercial office, residential				Abu Dhabi	109.16 m		22		1998			Architect: WZMH Architects
Abu Dhabi Marine Operating Company Headquarters	1997		high-rise building		postmodern	commercial office				Abu Dhabi	114.27 m		22		1997			Architect: Jung Brannen Associates,Inc. Taillibert Gulf Environment. Design Architect: Khtib & Alami Abu Dhabi
Dinna Tower	1995		high-rise building					Khalifa Street		Abu Dhabi	114.27 m		22		1995			
Ahmed Al Dhairi Building	1993		high-rise building							Abu Dhabi	114.27 m		22		1993			
Hanna Centre			high-rise building							Abu Dhabi	109.07 m		21					
Liwa Centre Tower I [Liwa Centre]			high-rise building			residental		liwa Centre		Abu Dhabi	99.33 m		21					
Liwa Centre Tower II [Liwa Centre]			high-rise building			residental		liwa Centre		Abu Dhabi	99.33 m		21					
Liwa Centre Tower III [Liwa Centre]			high-rise building			residental		liwa Centre		Abu Dhabi	99.33 m		21					
Al Hosan Plaza			high-rise building							Abu Dhabi	109.07 m		21					
Al Dana Tower			high-rise building	concrete		residental		Sector W-10, Plot C-36, Building n°206, Sultan Bin Zayed Stree		Abu Dhabi	99.33 m		21					
Al Diar Dana Hotel			high-rise building			hotel		Electra Street		Abu Dhabi	117.25 m		21					
Elnilein Bank Building			high-rise building			office		Lulu Street		Abu Dhabi	109.07 m		21					
Al Khazana Insurance Tower			high-rise building		modernism	commercial office		E-11, Plot No.126		Abu Dhabi	109.07 m		21					
Sheikha Shamsa Building	1995		high-rise building			commercial office				Abu Dhabi	109.07 m		21		1995			
Sheikh Mohammed Building	1995		high-rise building							Abu Dhabi	109.07 m		21		1995			
Al Masaood Tower			high-rise building					Bani Yas (Najda) Street		Abu Dhabi	103.88 m		20					property management, construction company
Al-Otaiba Tower			high-rise building					Hamdan Street		Abu Dhabi	103.88 m		20					
Ahmed Al Obaidaly Tower			high-rise building							Abu Dhabi	103.88 m		20					Architect: Architectural & Engineering Consultants
Liberty Tower			high-rise building					Khalifa Bin Zayed Street		Abu Dhabi	103.88 m		20					
Moderna			high-rise building			residental		Cannon Square		Abu Dhabi	94.60 m		20					
HSBC Building			high-rise building			office		Sheikh Rashid Bin Saeed Al Maktoum Street		Abu Dhabi	103.88 m		20					
Al Ghaith Tower			high-rise building			office		Sheikh Rashid Bin Saeed Al Maktoum Street		Abu Dhabi	103.88 m		20					
Tower Sector W-01 Plot C-13	2006		high-rise building			rental apartments		Rashid Bin Zayed Al Maktoum Street (2nd Street)		Abu Dhabi	94.60 m		20		2006			
Tower Sector E-06, Plot C-02	2006		high-rise building	concrete		residental	commercial office	Sector E-06, Plot C-02, Sheikh Khalifa Bin Zayed Street		Abu Dhabi	94.60 m		20		2006			
Abu Dhabi Trade Center Tower I	2002		high-rise building		modernism	commercial office, residential, hotel		Abu Dhabi Trade Center		Abu Dhabi	103.38 m		20	1998	2002			
Abu Dhabi Trade Center Tower II	2002		high-rise building		modernism	commercial office, residential, hotel		Abu Dhabi Trade Center		Abu Dhabi	103.38 m		20	1998	2002			
Abu Dhabi Trade Center Tower III	2002		high-rise building		modernism	commercial office, residential, hotel		Abu Dhabi Trade Center		Abu Dhabi	103.88 m		20	1998	2002			
Abu Dhabi Trade Center Tower IV	2002		high-rise building		modernism	commercial office, residential, hotel		Abu Dhabi Trade Center		Abu Dhabi	103.38 m		20	1998	2002			
Al Qubaisi Tower	1999		high-rise building					Plot C-18, Sector E-6		Abu Dhabi	103.88 m		20		1999			Architect: Dewan Architects & Engineers
Millenium Tower	1999		high-rise building		modernism	university		Sheikh Hamdan Bin Mohammed Street		Abu Dhabi	91.48 m		20		1999			Architect: Dewan Architects & Engineers
Darwish Bin Karam Tower	1998		high-rise building					Hamdan Street		Abu Dhabi	103.88 m		20		1998			
Crowne Plaza Hotel	1998		high-rise building		postmodern	hotel				Abu Dhabi	111.67 m		20	1995	1998			Architect: Cansult Limited
Al Khazraji Tower	1997		high-rise building			residental		Sheikh Rashid Bin Saeed Al Maktoum Street		Abu Dhabi	94.60 m		20		1997			Architect: Dewan Architects & Engineers
Mohammed Bin Zayed Building	1996		high-rise building							Abu Dhabi	103.88 m		20	1995	1996			Architect: Arkan Architects, Consultants
Rashed Al Dhaheri Building	1995		high-rise building							Abu Dhabi	103.88 m		20		1995			
Al Wahda Tower	1995		high-rise building					Salam Street		Abu Dhabi	103.88 m		20		1995			Architect: Planar
Hotel InterContinental	1982		high-rise building		modernism	hotel		Al Khalidya Street		Abu Dhabi	111.67 m		20		1982			Architect: BTA Architects, Inc.
Novotel Center Hotel	1976		high-rise building			hotel				Abu Dhabi	111.67 m		20		1976			
Hilton Corniche Residence			high-rise building			hotel		Corniche Road		Abu Dhabi	106.09 m		19					
Radisson SAS Hotel			high-rise building			hotel				Abu Dhabi	106.09 m		19					
Al Yasat Tower			high-rise building			office		Bani Yas Street		Abu Dhabi	98.68 m		19					
Green House			high-rise building			office		Bani Yas Street		Abu Dhabi	98.68 m		19					
Al Oteiba Tower			high-rise building			office		Bani Yas Street		Abu Dhabi	98.68 m		19					

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Building Name	Year	Height	Building Type	Structural Material	Architectural Style	Primary Use	Secondary Use	Complex	Zone	City	Height (tip) in meters	Height (Architectural) in meters	Floors (above ground)	Construction Start	Construction End	Floor-to-ceiling height (m)	Elevators	
Bin Sweed Building			high-rise building			commercial office, residential		Bani Yas Street (Najda) Street		Abu Dhabi	94.28 m		19					
Al Fardan Tower	1995		high-rise building			residental		Sheikh Hamdan Street		Abu Dhabi	89.87 m		19		1995			Engineers
Bin Suhail Building	1993		high-rise building							Abu Dhabi	98.68 m		19		1993			
Rumithi Building	1992		high-rise building							Abu Dhabi	98.68 m		19		1992			
Sheraton Residence			high-rise building							Abu Dhabi	93.49 m		18					
Bin Hamoodah Tower			high-rise building					Sheikh Khalifa Street		Abu Dhabi	93.49 m		18					Architect: Cassia & Associates
Sheikha Aysha Bint Ali Building			high-rise building							Abu Dhabi	93.49 m		18					
Al Diar Sands Hotel			high-rise building			hotel				Abu Dhabi	100.50 m		18					
City Centre			high-rise building			commercial office		Sheikh Hamdan Bin Mohammed Street		Abu Dhabi	93.49 m		18					
Eldorado Cinema Building			high-rise building			commercial office		Sheikh Zayed the Second (Electra) Street		Abu Dhabi	93.49 m		18					
ARBIFT Building			high-rise building			commercial office		Hamal Street		Abu Dhabi	93.49 m		18					Architect: Architectural Consulting Group
Sheikh Tahnoon Tower	2002		high-rise building			commercial office	commercial office			Abu Dhabi	93.49 m		18	2000	2002			
Khalidya Mall	1998		high-rise building					Khalidya Street		Abu Dhabi	93.49 m		18		1998			
Mohammed Sherife Hussein Building	1995		high-rise building			residental	shop(s)	5020 Liwa Street		Abu Dhabi	85.14 m		18		1995			
Badar Tower			high-rise building							Abu Dhabi	88.30 m		17					
E-15, Plots C-51			high-rise building							Abu Dhabi	88.30 m		17					
Al Safa Tower			high-rise building			modernism		Sheikh Zayed 1st Street		Abu Dhabi	88.30 m		17					
Al Muhairy Group Building	1998		high-rise building			commercial office, residential, mercantile		Khalidya Street		Abu Dhabi	84.35 m		17	1995	1998			Architect: Norr Group Consultants International Ltd.
ADCO Headquarters	1998		high-rise building					Corniche Road		Abu Dhabi	88.30 m		17	1996	1998			Architect: Norr Group Consultants International Ltd.
Sands Hotel			high-rise building			hotel		Zayed 2nd Street		Abu Dhabi	89.34 m		16					
Al Diar Regency Hotel	1991		high-rise building			hotel				Abu Dhabi	89.34 m		16		1991			Architect: Cassia & Associates
Abu Dhabi Corniche Residence Hotel			high-rise building			hotel				Abu Dhabi	83.75 m		15					
The Six Towers 3	2005		high-rise building			commercial office, residential		The Six Towers		Abu Dhabi	74.43 m		15	2004	2005			
The Six Towers 4	2005		high-rise building			commercial office, residential		The Six Towers		Abu Dhabi	74.43 m		15	2004	2005			
The Six Towers 5	2005		high-rise building			commercial office, residential		The Six Towers		Abu Dhabi	74.43 m		15	2004	2005			
The Six Towers 6	2005		high-rise building			commercial office, residential		The Six Towers		Abu Dhabi	74.43 m		15	2004	2005			
Crown Prince Tower I	1996		high-rise building							Abu Dhabi	77.91 m		15		1996			
Crown Prince Tower II	1996		high-rise building							Abu Dhabi	77.91 m		15		1996			
Crown Prince Tower III	1996		high-rise building							Abu Dhabi	77.91 m		15		1996			
Crown Prince Tower IV	1996		high-rise building							Abu Dhabi	77.91 m		15		1996			
Union National Bank	1996		high-rise building					Corniche Street		Abu Dhabi	77.91 m		15	1995	1996			Architect: Arkan Architects. Consultants
Golden Tulip Dalma Suites Hotel Tower I			high-rise building			hotel		Sheikh Hamdan Street		Abu Dhabi	78.17 m		14					
Al Rawda Rotana Suites Hotel			high-rise building			hotel		Old Airport Road		Abu Dhabi	78.17 m		14					
Abu Dhabi National Insurance Company Headquarters			high-rise building					Sh. Khafila Street		Abu Dhabi	72.71 m		14					
Golden Tulip Dalma Suites Hotel Tower II			high-rise building			hotel		Sheikh Hamdan Street		Abu Dhabi	78.17 m		14					
Sheikh Zayed Military Hospital			high-rise building			hospital				Abu Dhabi	58.62 m		14					
Al Diar Palm Hotel			high-rise building			hotel				Abu Dhabi	78.17 m		14					
Farook International Stationery Building			high-rise building			office		Lulu Street		Abu Dhabi	72.71 m		14					
Giffin Tower	1996		high-rise building							Abu Dhabi	72.71 m		14		1996			
Dewan Commercial Development Tower			high-rise building							Abu Dhabi	67.52 m		13					
Golden Tulip Dalma Suites I			high-rise building							Abu Dhabi	67.52 m		13					
Golden Tulip Dalma Suites II			high-rise building							Abu Dhabi	67.52 m		13					
Al Diar Mina Hotel			high-rise building			hotel				Abu Dhabi	72.59 m		13					
Bin Tahnoon Tower			high-rise building			residential	shopping center	Eastern Road		Abu Dhabi	56.76 m		12					
Yas Hotel Abu Dhabi	2009		high-rise building			hotel			Yas Island	Abu Dhabi			12	2007	2009			interior fit-out: Depa Ltd., Design Architect: Asymptote Architecture, Architect: Dewan Architects& Engineers,Tike & Partners W.L.L. Abu Dhabi

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Hilton International Abu Dhabi			low-rise building		modernism	hotel				Abu Dhabi	55.84 m		10					Architect: Adnan Z Saffarini Engr - Abu Dhabi
ADWEA Building			low-rise building			governmental office		Al Najda Street		Abu Dhabi	46.46 m		10					Interior fit-out: Depa Ltd
Sheraton Abu Dhabi	1979		low-rise building			hotel		Corniche Road		Abu Dhabi	46.46 m		10		1979			Interior fit-out: Depa Ltd
Ministry of Foreign Affairs			low-rise building			governmental office				Abu Dhabi	37.17 m		8					Interior fit-out: Depa Ltd
Shangri-La Hotel			low-rise building			hotel		Between the Bridges		Abu Dhabi	44.28 m		5					
Car Park			low-rise building					Zadco and Gasco Towers		Abu Dhabi	15.58 m		3					Architect: Nikken Sekkei Ltd , Leo A Daly
Al Ferdaws Tower			low-rise building					Salam Street		Abu Dhabi								
Bin Ghanem Tower			low-rise building					Hamdan Street		Abu Dhabi								
The Blue Tower			low-rise building					Khalifa Street		Abu Dhabi								
Dhabi Tower			low-rise building							Abu Dhabi								
Rabdan Complex			low-rise building					Airport Road		Abu Dhabi				1999				Architect: Golden Planners
Saadiyat Tower			low-rise building					Electra Street		Abu Dhabi								
Al Mansoori Office Tower			low-rise building			commercial office				Abu Dhabi								
Al Dhaheri Office Tower			low-rise building			commercial office				Abu Dhabi								
Arab Tower			low-rise building					Sheikh Hamdan Street		Abu Dhabi								
Falcon Tower			low-rise building					Al- Nasr Street		Abu Dhabi								
Bin Suwaid Tower			low-rise building					Al Najda Street		Abu Dhabi								
Al Manara Tower			low-rise building					A Muroor Tower		Abu Dhabi								
Bin Butti Tower			low-rise building					Electra Street		Abu Dhabi								
Al Khubairah Tower			low-rise building							Abu Dhabi								
Al Moosa Tower			low-rise building					Abu Dhabi Highway		Abu Dhabi								
Deena Tower			low-rise building					Khalifa Street		Abu Dhabi								
City Tower			low-rise building					Abu Dhabi Road		Abu Dhabi								
Sagar Tower			low-rise building					Nazda Street		Abu Dhabi								
Tawam Tower II			low-rise building					Khalifa Street		Abu Dhabi								
Plaza Tower			low-rise building							Abu Dhabi								
Hanna Tower			low-rise building							Abu Dhabi								
Al Mansour Tower			low-rise building					Al Salam Street		Abu Dhabi								
Al Sa'ada Tower			low-rise building							Abu Dhabi								
Al Bader Tower			low-rise building					Maidan Al Ittihad Street		Abu Dhabi								
Al Salam Tower			low-rise building							Abu Dhabi								
Sultan Tower Building			low-rise building							Abu Dhabi								
Garden Tower			low-rise building							Abu Dhabi								
Sheikh Sultan Bin Suroor al Fhaheri Office Tower			low-rise building			commercial office				Abu Dhabi								
Saman Tower			low-rise building					Hamdan Street		Abu Dhabi								
Airline Tower			low-rise building					Sheikh Khalifa Street		Abu Dhabi								
Abu Dhabi Airport Terminal 1			low-rise building			airport passenger terminal		Airport Road		Abu Dhabi								
Abu Dhabi Airport Cargo Terminal			hall					Airport Road		Abu Dhabi								
Abu Dhabi Air Traffic Control Tower			airport tower			aircraft traffic		Airport Road		Abu Dhabi								
Marina Mall			low-rise building			shopping center	ice skating			Abu Dhabi								
Etihad Passenger Terminal 3	2009		low-rise building			airport passenger terminal		Airport Road		Abu Dhabi				2006	2009			Architect: Skidmore, Owings & Merrill (New York)
Khalidya Tower 1	2006		low-rise building			commercial office		Khalidya Towers		Abu Dhabi				2005	2006			
Khalidya Tower 2	2006		low-rise building			residential		Khalidya Towers		Abu Dhabi				2005	2006			
Khalidya Tower 3	2006		low-rise building			residential		Khalidya Towers		Abu Dhabi				2005	2006			
Abu Dhabi Airport Terminal 2	2005		low-rise building			airport passenger terminal		Airport Road		Abu Dhabi					2005			
Gibca Tower	1993		low-rise building			office		Khalifa Street		Abu Dhabi					1993			Architect: Dewan Architects & Engineers

APPENDIX C – SIMULATION INPUT DATA

Table C1 Thermal Conditions Input in IES Baseline Model for Washroom Thermal Template

Thermal Template: Washroom

Room Conditions	
• ***Heating***	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• ***Cooling***	
Profile	8 - 6 weekday working (no lunch)
Setpoint: Constant	23 °C
• ***Model Settings***	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
Systems	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• ***Heating***	
Radiant Fraction	0.20
Capacity	unlimited
• ***Cooling***	
Radiant Fraction	0.00
Capacity	unlimited
• ***Humidity Control***	
Min. % Saturation	30 %
Max. % Saturation	70 %
• ***System outside air supply***	
Min. Flow Rate	0.80 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
Internal Gains	
• ***Fluorescent Lighting : Fluorescent Lighting Washroom***	
Max Sensible Gain	9.00 W/m²
Max Power Consumption	9.00 W/m²
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Dimming Profile	on continuously
Air Exchanges	
• ***Infiltration***	
Type	Infiltration
Variation Profile	on continuously
Adjacent Condition	External Air
Max A/C Rate	0.25 AC/h
• ***Auxiliary ventilation***	
Type	Auxiliary Ventilation
Variation Profile	8 - 6 weekday working (no lunch)
Adjacent Condition	External Air
Max A/C Rate	2.00 AC/h

Rooms using this template

Room ID	**Name**
[L01B0008]	L01 Bathroom
[L01B0005]	L01 Bathroom
[L01B0011]	L01 Bathroom
[L01B0002]	L01 Bathroom
[L01W0000]	L01 WC

Rooms using this template

Room ID	Name
[L01W0003]	L01 WC
[L01W0002]	L01 WC
[L01W0001]	L01 WC
[L01B0012]	L01 Bathroom
[L01B0013]	L01 Bathroom
[L01B0014]	L01 Bathroom
[L01B0015]	L01 Bathroom
[L01W0004]	L01 WC
[L01W0005]	L01 WC
[L01W0006]	L01 WC
[L01W0007]	L01 WC
[L01B0016]	L01 Bathroom
[L01B0017]	L01 Bathroom
[L01B0018]	L01 Bathroom
[L01B0019]	L01 Bathroom
[L01W0008]	L01 WC
[L01W0009]	L01 WC
[L01W0010]	L01 WC
[L01W0011]	L01 WC

Table C2 Thermal Conditions Input in IES Baseline Model for Office Thermal Template

Thermal Template: Office

Room Conditions

• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	8 - 6 weekday working (no lunch)
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
Systems	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	unlimited
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	30 %
Max. % Saturation	70 %
• System outside air supply	
Min. Flow Rate	0.80 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
Internal Gains	
• People : People Office	
Max Sensible Gain	90.00 W/P
Max Latent Gain	60.00 W/P

Occupant Density	12.00 m²/person
Variation Profile	8 - 6 weekday working (no lunch)
• Fluorescent Lighting : Fluorescent Lighting Office	
Max Sensible Gain	11.00 W/m²
Max Power Consumption	11.00 W/m²
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Dimming Profile	on continuously
• Computers : Computers Office	
Max Sensible Gain	20.00 W/m²
Max Power Consumption	20.00 W/m²
Radiant Fraction	0.22
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Air Exchanges	
• Infiltration	
Type	Infiltration
Variation Profile	on continuously
Adjacent Condition	External Air
Max A/C Rate	0.25 AC/h
• Auxiliary ventilation	
Type	Auxiliary Ventilation
Variation Profile	8 - 6 weekday working (no lunch)
Adjacent Condition	External Air
Max A/C Rate	2.00 AC/h

Rooms using this template

Room ID	Name
[L01B0010]	L01 Bedroom
[L01B0001]	L01 Bedroom
[L01B0003]	L01 Bedroom
[L01B0004]	L01 Bedroom
[L01B0007]	L01 Bedroom
[L01B0006]	L01 Bedroom
[L01B0000]	L01 Bedroom
[L01B0009]	L01 Bedroom
[L01L0000]	L01 Living Room
[L01L0002]	L01 Living Room
[L01L0003]	L01 Living Room
[L01L0001]	L01 Living Room

Table C3 Thermal Conditions Input in IES Baseline Model for Corridor Thermal Template

Thermal Template: Corridor

Room Conditions	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	8 - 6 weekday working (no lunch)
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
Systems	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	unlimited
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	
Min. % Saturation	30 %
Max. % Saturation	70 %
• System outside air supply	
Min. Flow Rate	0.80 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
Internal Gains	
• Fluorescent Lighting : Fluorescent Lighting Corridor	
Max Sensible Gain	13.00 W/m²
Max Power Consumption	13.00 W/m²
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Dimming Profile	on continuously
Air Exchanges	
• Infiltration	
Type	Infiltration
Variation Profile	on continuously
Adjacent Condition	External Air
Max A/C Rate	0.25 AC/h
• Auxiliary ventilation	
Type	Auxiliary Ventilation
Variation Profile	8 - 6 weekday working (no lunch)
Adjacent Condition	External Air
Max A/C Rate	2.00 AC/h

Rooms using this template

Room ID	**Name**
[L01C0000]	L01 Corridor
[L01C0001]	L01 Corridor
[L01C0003]	L01 Corridor
[L01C0002]	L01 Corridor
[L01C0005]	L01 Corridor
[L01C0006]	L01 Corridor
[L01C0007]	L01 Corridor
[L01C0008]	L01 Corridor
[MZNN0000]	Mezanine offices

Rooms using this template

Room ID	Name
[MZNN0001]	Mezanine offices
[MZNN0002]	Mezanine offices
[MZNN0003]	Mezanine offices
[MZNN0004]	Mezanine offices
[MZNN0005]	Mezanine offices
[MZNN0006]	Mezanine offices
[MZNN0007]	Mezanine offices
[MZNN0008]	Mezanine offices
[MZNN0009]	Mezanine offices
[MZNN0010]	Mezanine offices
[MZNN0011]	Mezanine offices
[MZNN0012]	Mezanine offices
[MZNN0013]	Mezanine offices
[MZNN0014]	Mezanine offices
[MZNN0015]	Mezanine offices
[L01C0009]	L01 Corridor
[L01C0010]	L01 Corridor
[L01C0011]	L01 Corridor
[L01C0012]	L01 Corridor
[GRND0000]	Ground Retail
[GRND0002]	Ground Retail
[GRND0003]	Ground Retail
[GRND0005]	Ground Retail
[GRND0006]	Ground Retail
[GRND0007]	Ground Retail
[GRND0010]	Ground Retail
[GRND0011]	Ground Retail

Table C4 Thermal Conditions Input in IES Baseline Model for Kitchen Thermal Template

Thermal Template: Kitchen

Room Conditions	
• Heating	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• Cooling	
Profile	8 - 6 weekday working (no lunch)
Setpoint: Constant	23 °C
• Model Settings	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
Systems	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• Heating	
Radiant Fraction	0.20
Capacity	unlimited
• Cooling	
Radiant Fraction	0.00
Capacity	unlimited
• Humidity Control	

Min. % Saturation	30 %
Max. % Saturation	70 %
• System outside air supply	
Min. Flow Rate	0.80 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
Internal Gains	
• Fluorescent Lighting : Fluorescent Lighting Kitchen	
Max Sensible Gain	9.00 W/m²
Max Power Consumption	9.00 W/m²
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Dimming Profile	on continuously
• Cooking : Cooking	
Max Sensible Gain	10.00 W/m²
Max Latent Gain	0.00 W/m²
Max Power Consumption	10.00 W/m²
Radiant Fraction	0.60
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Air Exchanges	
• Infiltration	
Type	Infiltration
Variation Profile	on continuously
Adjacent Condition	External Air
Max A/C Rate	0.25 AC/h
• Auxiliary ventilation	
Type	Auxiliary Ventilation
Variation Profile	8 - 6 weekday working (no lunch)
Adjacent Condition	External Air
Max A/C Rate	2.00 AC/h

Rooms using this template

Room ID	Name
[L01K0003]	L01 Kitchen
[L01K0001]	L01 Kitchen
[L01K0002]	L01 Kitchen
[L01K0000]	L01 Kitchen

Table C5 Thermal Conditions Input in IES Baseline Model for Lobby Thermal Template

Thermal Template: Lobby

Room Conditions	
• *Heating*	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• *Cooling*	
Profile	8 - 6 weekday working (no lunch)
Setpoint: Constant	23 °C
• *Model Settings*	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
Systems	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• *Heating*	
Radiant Fraction	0.20
Capacity	unlimited
• *Cooling*	
Radiant Fraction	0.00
Capacity	unlimited
• *Humidity Control*	
Min. % Saturation	30 %
Max. % Saturation	70 %
• *System outside air supply*	
Min. Flow Rate	0.80 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
Internal Gains	
• *Fluorescent Lighting : Fluorescent Lighting Lobby*	
Max Sensible Gain	12.00 W/m²
Max Power Consumption	12.00 W/m²
Radiant Fraction	0.45
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Dimming Profile	on continuously
• *Miscellaneous : Miscellaneous Lift*	
Max Sensible Gain	5.00 W/m²
Max Latent Gain	0.00 W/m²
Max Power Consumption	5.00 W/m²
Radiant Fraction	0.22
Fuel	Electricity
Variation Profile	8 - 6 weekday working (no lunch)
Air Exchanges	
• *Infiltration*	
Type	Infiltration
Variation Profile	on continuously
Adjacent Condition	External Air
Max A/C Rate	0.25 AC/h
• *Auxiliary ventilation*	
Type	Auxiliary Ventilation
Variation Profile	8 - 6 weekday working (no lunch)
Adjacent Condition	External Air
Max A/C Rate	2.00 AC/h

Rooms using this template

Room ID	**Name**
[L01C0004]	L01 Lobby
[L01L0004]	L01 Lobby
[L01L0005]	L01 Lobby

Table C6 Thermal Conditions Input in IES Baseline Model for Void Zone

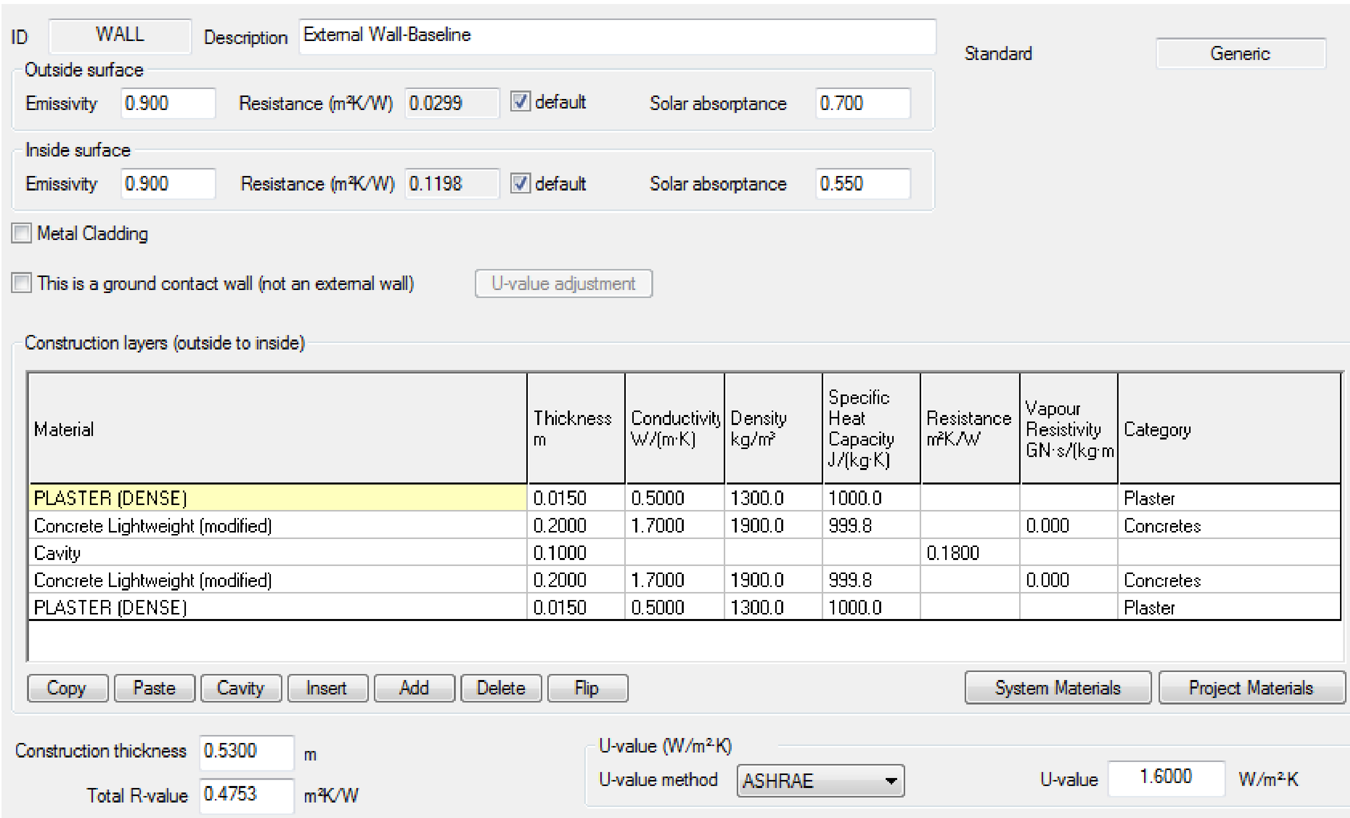
Thermal Template: Void

Room Conditions	
• *Heating*	
Profile	off continuously
Setpoint: Constant	19 °C
Hot Water consumption	0.00 l/(h·pers)
• *Cooling*	
Profile	off continuously
Setpoint: Constant	23 °C
• *Model Settings*	
Solar Reflected Fraction	0.05
Furniture Mass Factor	1.00
Systems	
HVAC System	Main system
Auxilliary vent. system	Main system
DHW system	Main system
• *Heating*	
Radiant Fraction	0.20
Capacity	unlimited
• *Cooling*	
Radiant Fraction	0.00
Capacity	unlimited
• *Humidity Control*	
Min. % Saturation	0 %
Max. % Saturation	100 %
• *System outside air supply*	
Min. Flow Rate	0.80 l/(s·m²)
Add. Free Cooling Capacity	0.00 AC/h
Variation Profile	off continuously
Internal Gains	
	None
Air Exchanges	
• *Natural ventilation*	
Type	Natural Ventilation
Variation Profile	on continuously
Adjacent Condition	External Air
Max A/C Rate	6.00 AC/h

Rooms using this template

Room ID	**Name**
[VOID0001]	Void
[VOID0000]	Void

APPENDIX D – SIMULATION INPUT DATA



ID WALL Description External Wall-Baseline

Standard Generic

Outside surface

Emissivity 0.900 Resistance (m²K/W) 0.0299 default Solar absorptance 0.700

Inside surface

Emissivity 0.900 Resistance (m²K/W) 0.1198 default Solar absorptance 0.550

Metal Cladding

This is a ground contact wall (not an external wall) U-value adjustment

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster
Concrete Lightweight (modified)	0.2000	1.7000	1900.0	999.8		0.000	Concretes
Cavity	0.1000				0.1800		
Concrete Lightweight (modified)	0.2000	1.7000	1900.0	999.8		0.000	Concretes
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

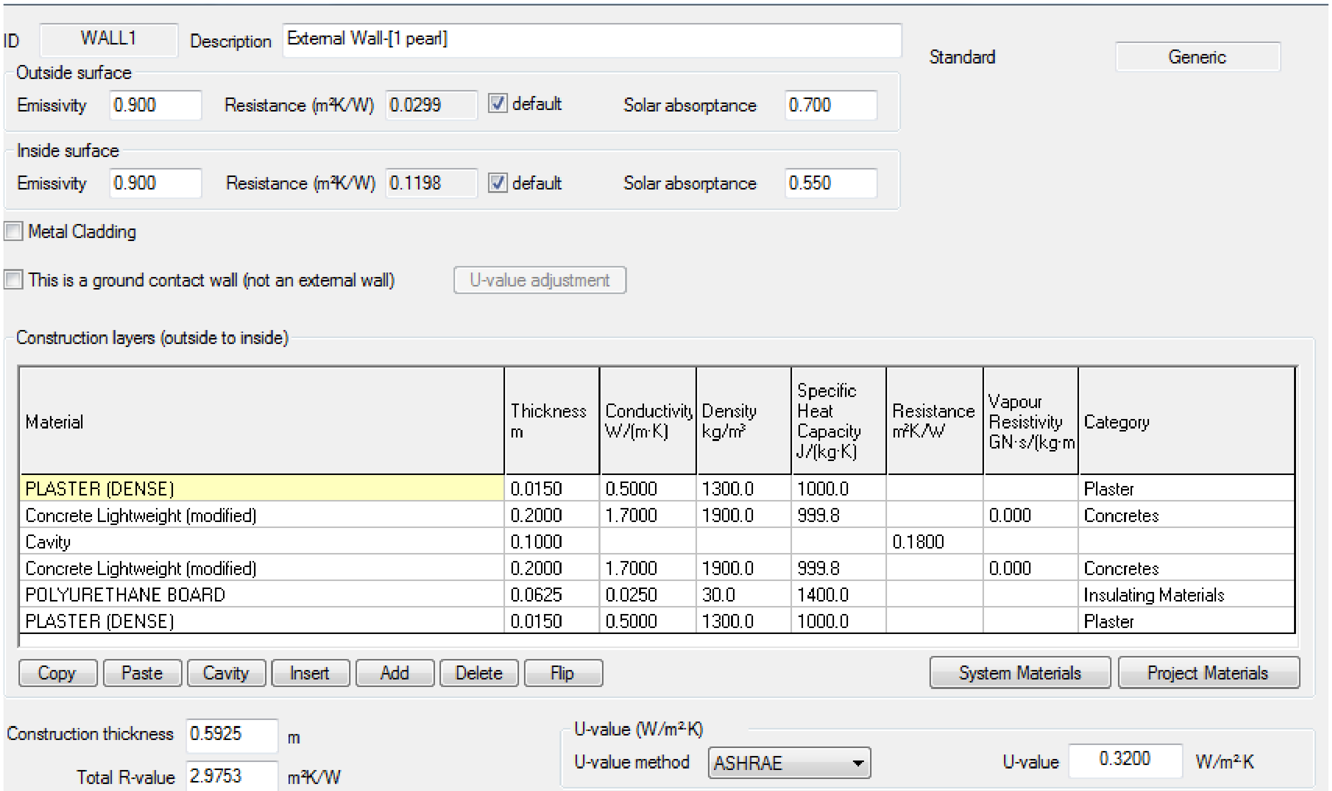
Construction thickness 0.5300 m

Total R-value 0.4753 m²K/W

U-value (W/m²K)

U-value method ASHRAE U-value 1.6000 W/m²K

Figure D 35 Wall construction details for baseline model.



ID WALL1 Description External Wall-[1 pearl] Standard Generic

Outside surface
Emissivity 0.900 Resistance (m²K/W) 0.0299 default Solar absorptance 0.700

Inside surface
Emissivity 0.900 Resistance (m²K/W) 0.1198 default Solar absorptance 0.550

Metal Cladding

This is a ground contact wall (not an external wall) U-value adjustment

Construction layers (outside to inside)

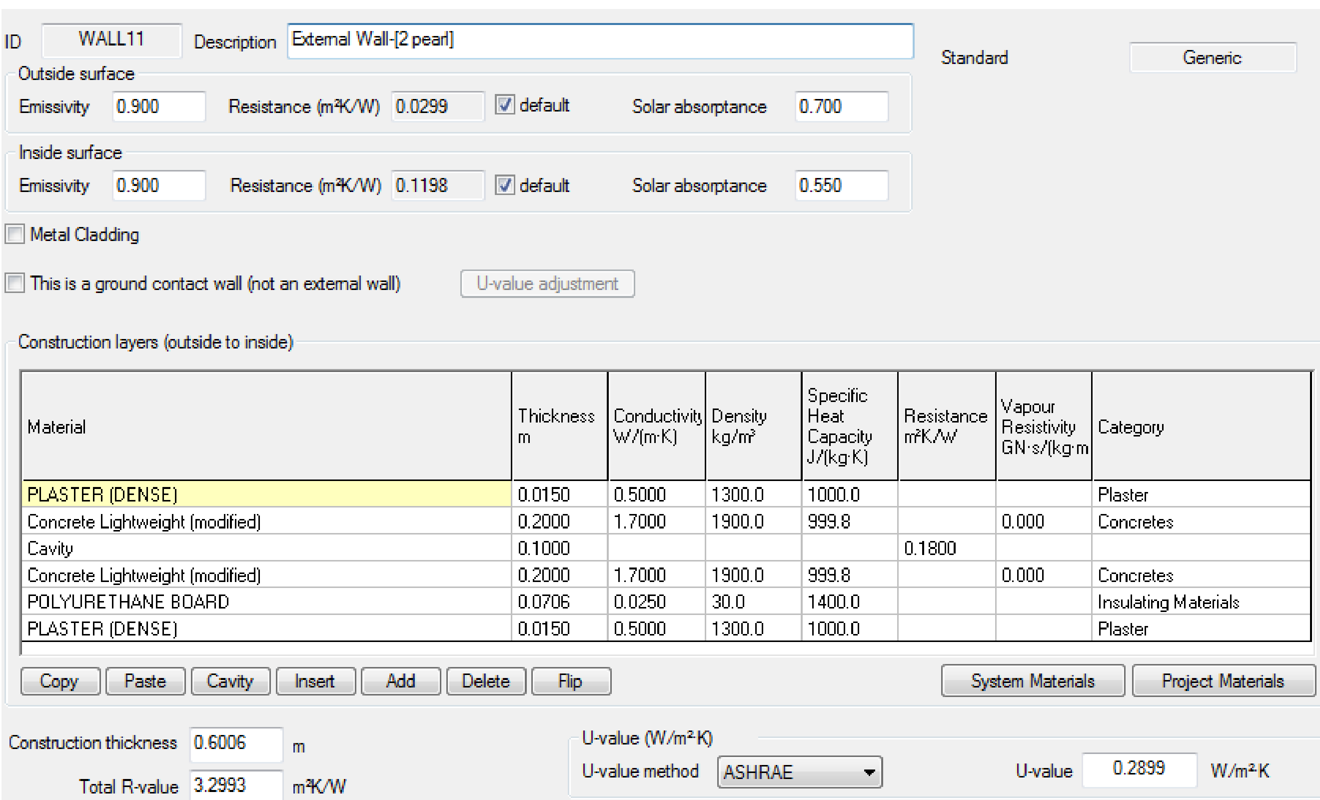
Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster
Concrete Lightweight (modified)	0.2000	1.7000	1900.0	999.8		0.000	Concretes
Cavity	0.1000				0.1800		
Concrete Lightweight (modified)	0.2000	1.7000	1900.0	999.8		0.000	Concretes
POLYURETHANE BOARD	0.0625	0.0250	30.0	1400.0			Insulating Materials
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.5925 m
Total R-value 2.9753 m²K/W

U-value (W/m²K)
U-value method ASHRAE U-value 0.3200 W/m²K

Figure D 36 Wall construction details for Pearl 1 model.



ID WALL11 Description External Wall-[2 pearl] Standard Generic

Outside surface
Emissivity 0.900 Resistance (m²K/W) 0.0299 default Solar absorptance 0.700

Inside surface
Emissivity 0.900 Resistance (m²K/W) 0.1198 default Solar absorptance 0.550

Metal Cladding

This is a ground contact wall (not an external wall) U-value adjustment

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster
Concrete Lightweight (modified)	0.2000	1.7000	1900.0	999.8		0.000	Concretes
Cavity	0.1000				0.1800		
Concrete Lightweight (modified)	0.2000	1.7000	1900.0	999.8		0.000	Concretes
POLYURETHANE BOARD	0.0706	0.0250	30.0	1400.0			Insulating Materials
PLASTER (DENSE)	0.0150	0.5000	1300.0	1000.0			Plaster

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.6006 m
Total R-value 3.2993 m²K/W

U-value (W/m²K)
U-value method ASHRAE U-value 0.2899 W/m²K

Figure D 37 Wall construction details for Pearl 2-5 model.

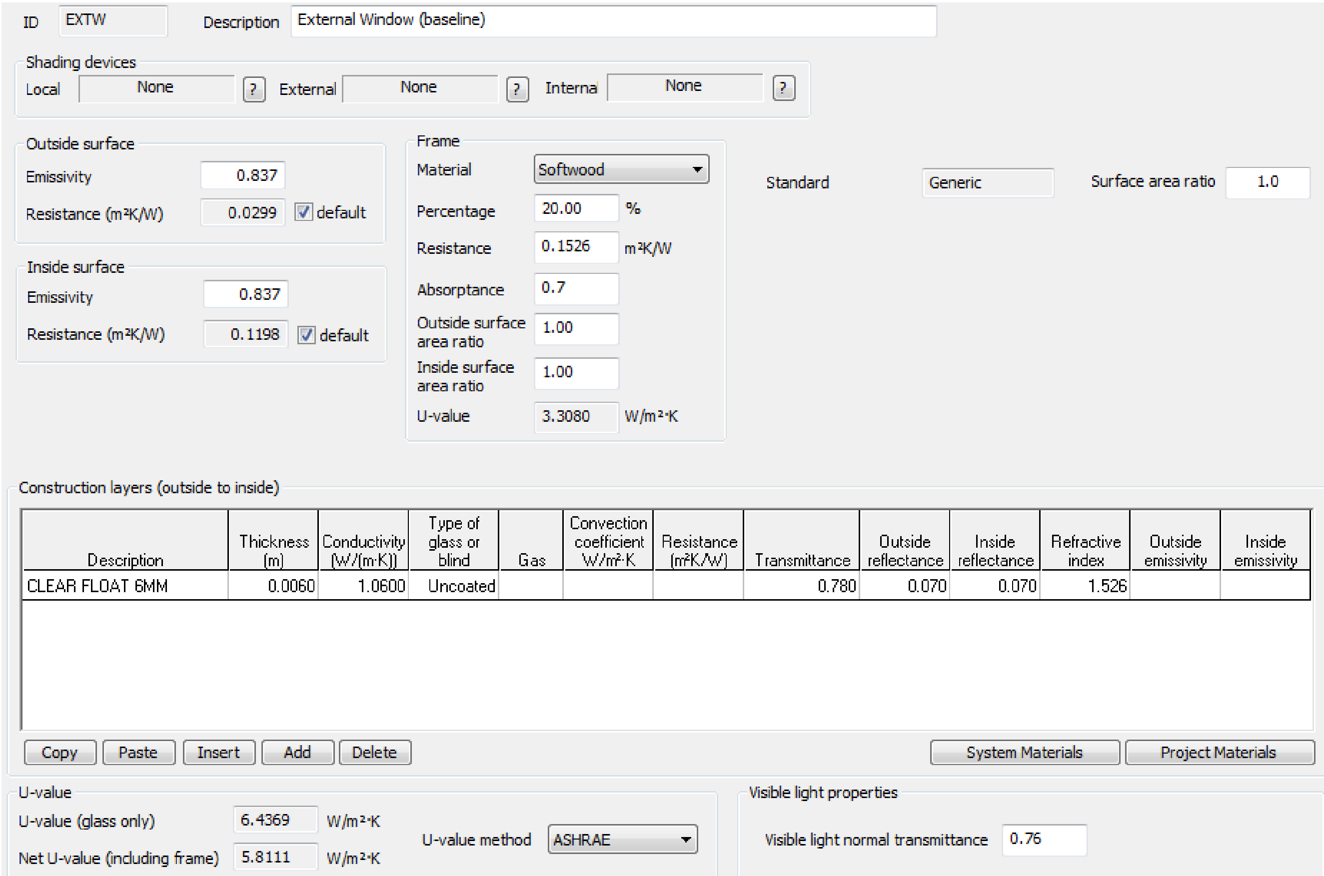


Figure D 38 External Glazing construction details for Baseline model.

Table D 37 External Glazing construction details for Baseline model.

External Window [Baseline]	
U-value (glass only)	6.4369 W/m²·K
Net U-value (including frame*)	5.8111 W/m²·K
Outside surface air-film resistance	0.0299 m²K/W
Inside surface air-film resistance	0.1198 m²K/W

THETA	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
T(D)	0.780	0.779	0.776	0.770	0.759	0.736	0.688	0.581	0.348	0.000
T(R)	0.032	0.032	0.032	0.033	0.035	0.036	0.037	0.038	0.036	0.000

Short-wave shading coefficient	*0.8966*
Long-wave shading coefficient	0.0364
Total shading coefficient	0.9329
SHGC (center-pane)	0.8116

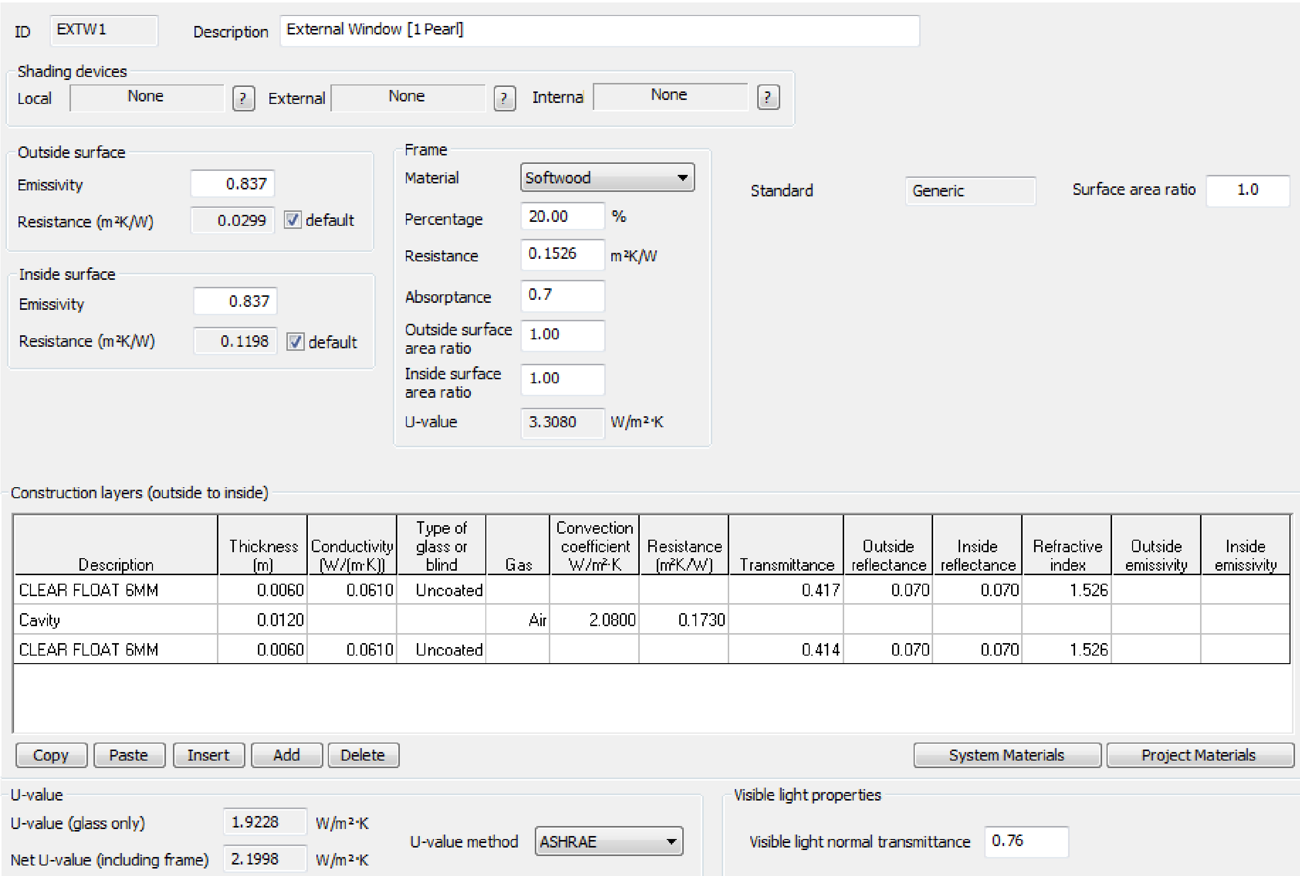


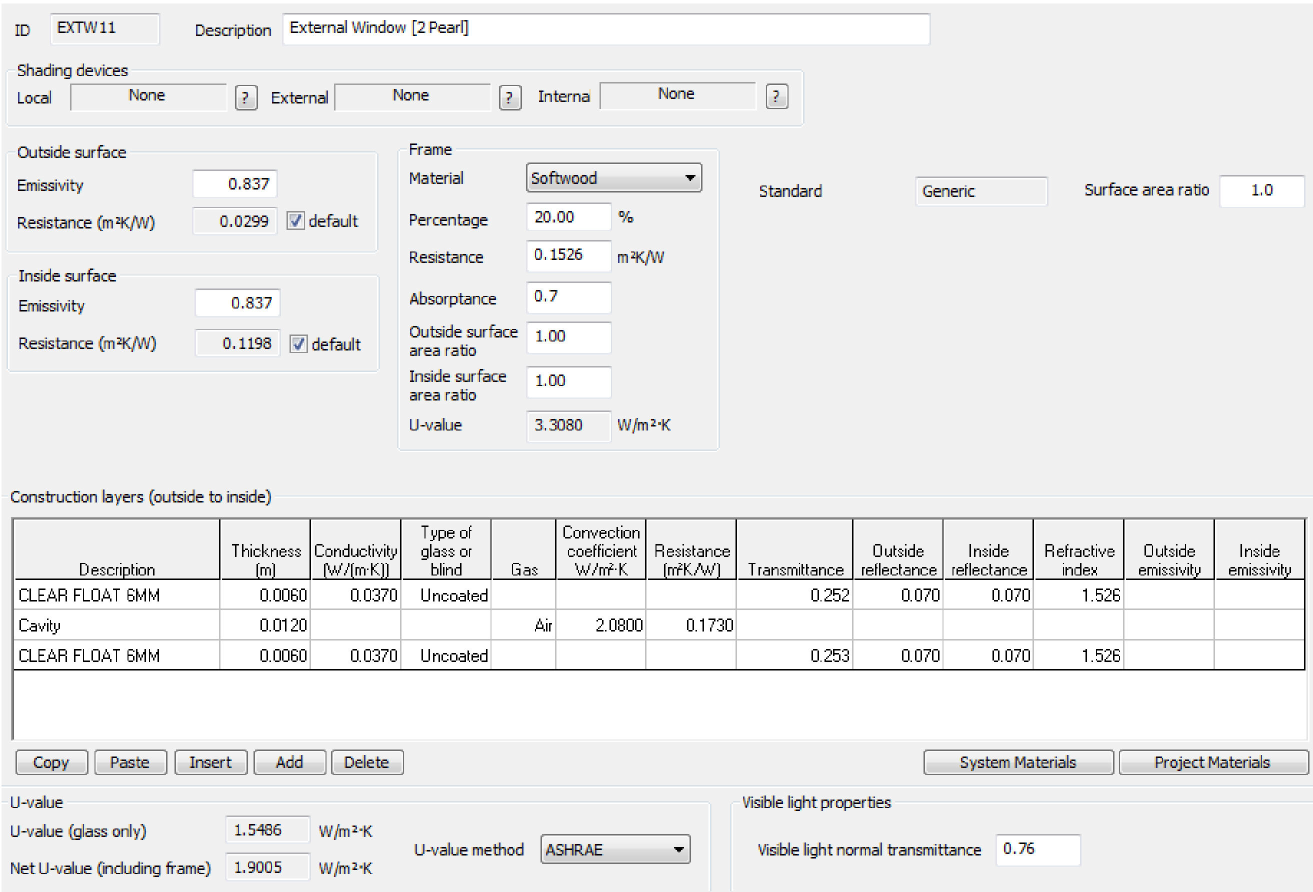
Figure D 39 External Glazing construction details for Pearl 1 model.

Table D 38 External Glazing construction details for Pearl 1 model.

External Window [1 Pearl]	
U-value (glass only)	1.9228 W/m²·K
Net U-value (including frame*)	2.1998 W/m²·K
Outside surface air-film resistance	0.0299 m²K/W
Inside surface air-film resistance	0.1198 m²K/W

THETA	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
T(D)	0.173	0.172	0.167	0.158	0.146	0.130	0.108	0.076	0.028	0.000
T(R)	0.227	0.227	0.227	0.228	0.227	0.224	0.214	0.187	0.124	0.000

Short-wave shading coefficient	*0.1994*
Long-wave shading coefficient	0.2604
Total shading coefficient	0.4598
SHGC (center-pane)	0.4000


ID EXTW11 Description External Window [2 Pearl]

Shading devices: Local None ? External None ? Interna None ?

Outside surface
Emissivity 0.837
Resistance (m²K/W) 0.0299 default

Inside surface
Emissivity 0.837
Resistance (m²K/W) 0.1198 default

Frame
Material Softwood
Percentage 20.00 %
Resistance 0.1526 m²K/W
Absorptance 0.7
Outside surface area ratio 1.00
Inside surface area ratio 1.00
U-value 3.3080 W/m²·K

Standard Generic Surface area ratio 1.0

Construction layers (outside to inside)

Description	Thickness (m)	Conductivity (W/(m·K))	Type of glass or blind	Gas	Convection coefficient W/m²·K	Resistance (m²K/W)	Transmittance	Outside reflectance	Inside reflectance	Refractive index	Outside emissivity	Inside emissivity
CLEAR FLOAT 6MM	0.0060	0.0370	Uncoated				0.252	0.070	0.070	1.526		
Cavity	0.0120			Air	2.0800	0.1730						
CLEAR FLOAT 6MM	0.0060	0.0370	Uncoated				0.253	0.070	0.070	1.526		

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U-value
U-value (glass only) 1.5486 W/m²·K
Net U-value (including frame) 1.9005 W/m²·K
U-value method ASHRAE

Visible light properties
Visible light normal transmittance 0.76

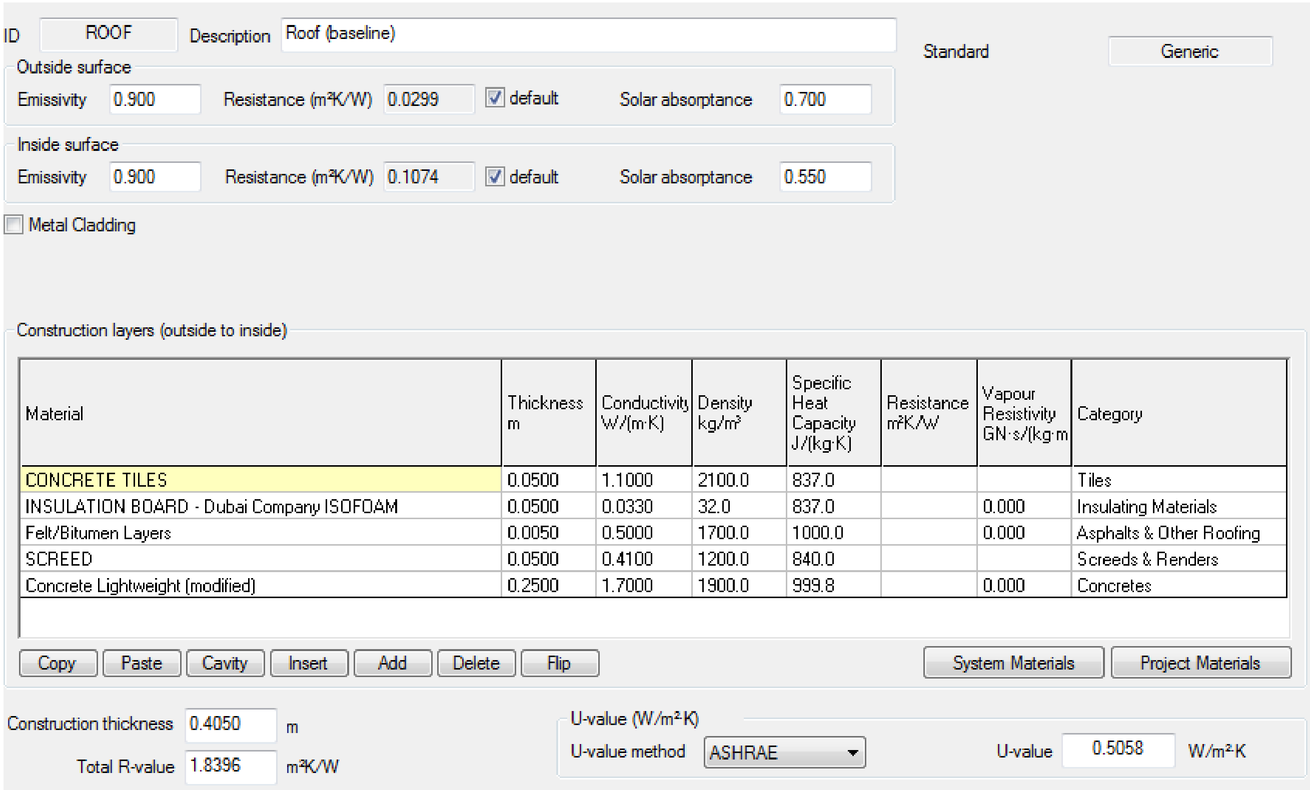
Figure D 40 External Glazing construction details for Pearl 2-5 model.

Table D 39 External Glazing construction details for Pearl 2-5 model.

External Window [2 Pearl]	
U-value (glass only) Net U-value (including frame*) Outside surface air-film resistance Inside surface air-film resistance	1.5486 W/m²·K 1.9005 W/m²·K 0.0299 m²K/W 0.1198 m²K/W

THETA	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
T(D)	0.064	0.063	0.060	0.055	0.049	0.041	0.032	0.021	0.008	0.000
T(R)	0.236	0.236	0.235	0.233	0.230	0.223	0.211	0.184	0.124	0.000

Short-wave shading coefficient	*0.0736*
Long-wave shading coefficient	0.2713
Total shading coefficient	0.3450
SHGC (center-pane)	0.3000



ID ROOF Description Roof (baseline) Standard Generic

Outside surface

Emissivity 0.900 Resistance (m²K/W) 0.0299 default Solar absorptance 0.700

Inside surface

Emissivity 0.900 Resistance (m²K/W) 0.1074 default Solar absorptance 0.550

Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
CONCRETE TILES	0.0500	1.1000	2100.0	837.0			Tiles
INSULATION BOARD - Dubai Company ISOFOAM	0.0500	0.0330	32.0	837.0		0.000	Insulating Materials
Felt/Bitumen Layers	0.0050	0.5000	1700.0	1000.0		0.000	Asphalts & Other Roofing
SCREED	0.0500	0.4100	1200.0	840.0			Screeds & Renders
Concrete Lightweight (modified)	0.2500	1.7000	1900.0	999.8		0.000	Concretes

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

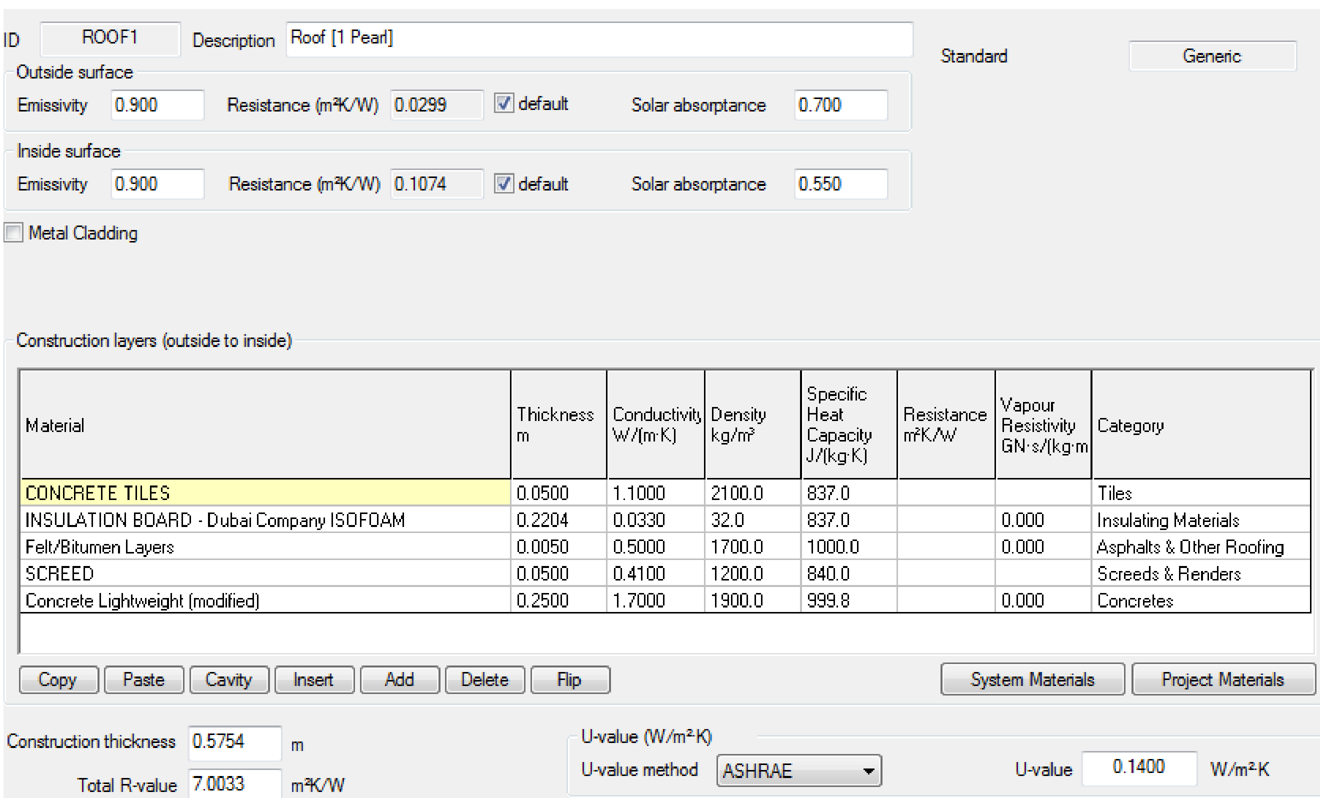
Construction thickness 0.4050 m

Total R-value 1.8396 m²K/W

U-value (W/m²·K)

U-value method ASHRAE U-value 0.5058 W/m²·K

Figure D 41 Roof construction details for Baseline model.



ID ROOF1 Description Roof [1 Pearl] Standard Generic

Outside surface

Emissivity 0.900 Resistance (m²K/W) 0.0299 default Solar absorptance 0.700

Inside surface

Emissivity 0.900 Resistance (m²K/W) 0.1074 default Solar absorptance 0.550

Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
CONCRETE TILES	0.0500	1.1000	2100.0	837.0			Tiles
INSULATION BOARD - Dubai Company ISOFOAM	0.2204	0.0330	32.0	837.0		0.000	Insulating Materials
Felt/Bitumen Layers	0.0050	0.5000	1700.0	1000.0		0.000	Asphalts & Other Roofing
SCREED	0.0500	0.4100	1200.0	840.0			Screeds & Renders
Concrete Lightweight (modified)	0.2500	1.7000	1900.0	999.8		0.000	Concretes

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

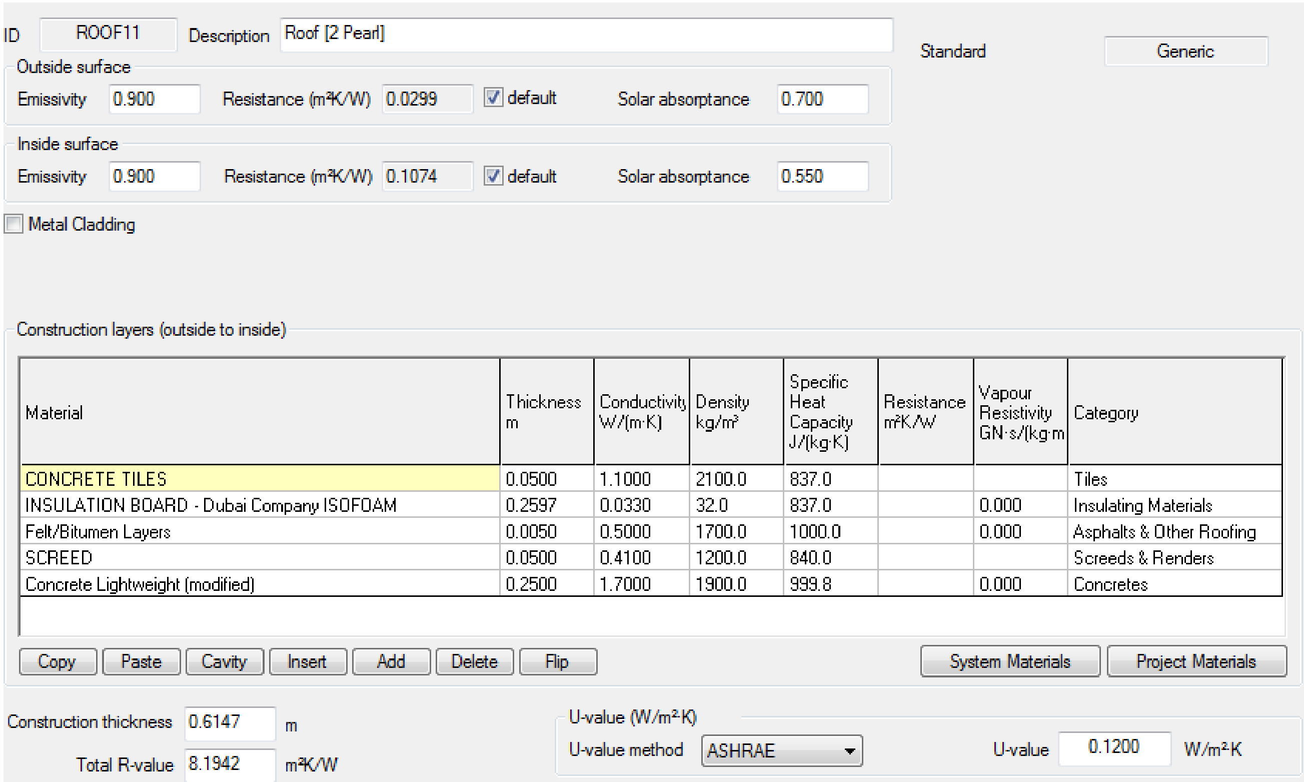
Construction thickness 0.5754 m

Total R-value 7.0033 m²K/W

U-value (W/m²·K)

U-value method ASHRAE U-value 0.1400 W/m²·K

Figure D 42 Roof construction details for Pearl 1 model.



ID ROOF11 Description Roof [2 Pearl]

Standard Generic

Outside surface

Emissivity 0.900 Resistance (m²K/W) 0.0299 default Solar absorptance 0.700

Inside surface

Emissivity 0.900 Resistance (m²K/W) 0.1074 default Solar absorptance 0.550

Metal Cladding

Construction layers (outside to inside)

Material	Thickness m	Conductivity W/(m·K)	Density kg/m³	Specific Heat Capacity J/(kg·K)	Resistance m²K/W	Vapour Resistivity GN·s/(kg·m	Category
CONCRETE TILES	0.0500	1.1000	2100.0	837.0			Tiles
INSULATION BOARD - Dubai Company ISOFOAM	0.2597	0.0330	32.0	837.0		0.000	Insulating Materials
Felt/Bitumen Layers	0.0050	0.5000	1700.0	1000.0		0.000	Asphalts & Other Roofing
SCREED	0.0500	0.4100	1200.0	840.0			Screeds & Renders
Concrete Lightweight (modified)	0.2500	1.7000	1900.0	999.8		0.000	Concretes

Copy Paste Cavity Insert Add Delete Flip System Materials Project Materials

Construction thickness 0.6147 m

Total R-value 8.1942 m²K/W

U-value (W/m²K)

U-value method ASHRAE U-value 0.1200 W/m²K

Figure D 43 Roof construction details for Pearl 2-5 model.

APPENDIX E IES RESULTS

Table E1 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for Baseline Model

/ Room cooling plant sens. load (MW			Total CE (kgCO2)
Date		Date	
Jan 01-31	0.9059	Jan 01-31	1627
Feb 01-28	1.8522	Feb 01-28	1817
Mar 01-31	4.8052	Mar 01-31	2938
Apr 01-30	9.6783	Apr 01-30	4124
May 01-31	14.0266	May 01-31	5307
Jun 01-30	17.2003	Jun 01-30	6621
Jul 01-31	18.6062	Jul 01-31	7254
Aug 01-31	19.5397	Aug 01-31	7455
Sep 01-30	16.8354	Sep 01-30	6789
Oct 01-31	11.9635	Oct 01-31	4927
Nov 01-30	7.5186	Nov 01-30	3654
Dec 01-31	2.5366	Dec 01-31	2211
Summed total	**125.4686**	**Summed total**	**54723**

	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Date						
Jan 01-31	0.39	0.39	0.117	1.3244	3.1459	3.1469
Feb 01-28	0.7601	0.7601	0.228	1.8169	3.4943	3.5456
Mar 01-31	2.165	2.165	0.6495	3.7086	5.6837	5.6837
Apr 01-30	4.0051	4.0051	1.2015	6.0666	7.9757	7.9803
May 01-31	5.8512	5.8512	1.7554	8.4347	10.2598	10.2715
Jun 01-30	7.6953	7.6953	2.3086	10.8642	12.8037	12.8087
Jul 01-31	8.6786	8.6786	2.6036	12.1375	14.0311	14.0311
Aug 01-31	8.9828	8.9828	2.6948	12.5329	14.4188	14.4188
Sep 01-30	7.9639	7.9639	2.3892	11.2143	13.1299	13.1359
Oct 01-31	5.2899	5.2899	1.587	7.6932	9.5295	9.5295
Nov 01-30	3.3013	3.3013	0.9904	5.147	7.0674	7.0674
Dec 01-31	1.0593	1.0593	0.3178	2.2731	4.2758	4.2777
Total	**56.1426**	**56.1426**	**16.8428**	**83.2134**	**105.8156**	**105.897**

Table E2 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for 1 Pearl Wall Scenario

Date	Pearl 1 - Wall Room cooling plant sens. load (MWh)
Jan 01-31	1.0853
Feb 01-28	2.017
Mar 01-31	4.7584
Apr 01-30	9.2074
May 01-31	13.1215
Jun 01-30	15.9749
Jul 01-31	17.2209
Aug 01-31	18.1011
Sep 01-30	15.6486
Oct 01-31	11.2546
Nov 01-30	7.2578
Dec 01-31	2.7053
Summed total	**118.3528**

Date	Total CE (kgCO2)
Jan 01-31	1673
Feb 01-28	1861
Mar 01-31	2926
Apr 01-30	3996
May 01-31	5060
Jun 01-30	6287
Jul 01-31	6877
Aug 01-31	7063
Sep 01-30	6467
Oct 01-31	4734
Nov 01-30	3583
Dec 01-31	2257
Summed total	**52783**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.4588	0.4588	0.1377	1.4141	3.2354	3.2366
Feb 01-28	0.8253	0.8253	0.2476	1.9026	3.5791	3.6313
Mar 01-31	2.1457	2.1457	0.6437	3.6836	5.6587	5.6587
Apr 01-30	3.8145	3.8145	1.1443	5.8187	7.7278	7.7325
May 01-31	5.4848	5.4848	1.6454	7.9583	9.7835	9.7951
Jun 01-30	7.1993	7.1993	2.1598	10.2193	12.1588	12.1638
Jul 01-31	8.1179	8.1179	2.4354	11.4085	13.3022	13.3022
Aug 01-31	8.4005	8.4005	2.5201	11.7759	13.6617	13.6617
Sep 01-30	7.4835	7.4835	2.2451	10.5898	12.5055	12.5114
Oct 01-31	5.0029	5.0029	1.5009	7.3201	9.1564	9.1564
Nov 01-30	3.1958	3.1958	0.9587	5.0098	6.9302	6.9302
Dec 01-31	1.1275	1.1275	0.3383	2.362	4.3645	4.3666
total	**53.2564**	**53.2564**	**15.9769**	**79.4628**	**102.0636**	**102.1464**

Table E3 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for 2 Pearl Wall Scenario

Date	Pearl 2 - Wall Room cooling plant sens. load (MWh)
Jan 01-31	1.0882
Feb 01-28	2.0195
Mar 01-31	4.7571
Apr 01-30	9.196
May 01-31	13.1014
Jun 01-30	15.9473
Jul 01-31	17.1898
Aug 01-31	18.0687
Sep 01-30	15.6213
Oct 01-31	11.2376
Nov 01-30	7.2507
Dec 01-31	2.7077
Summed total	**118.1854**

Date	Total CE (kgCO2)
Jan 01-31	1674
Feb 01-28	1861
Mar 01-31	2925
Apr 01-30	3993
May 01-31	5055
Jun 01-30	6280
Jul 01-31	6869
Aug 01-31	7054
Sep 01-30	6459
Oct 01-31	4729
Nov 01-30	3581
Dec 01-31	2257
Summed total	**52738**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.4599	0.4599	0.138	1.4155	3.2368	3.238
Feb 01-28	0.8263	0.8263	0.2479	1.9039	3.5804	3.6326
Mar 01-31	2.1451	2.1451	0.6435	3.6828	5.6579	5.6579
Apr 01-30	3.8099	3.8099	1.143	5.8128	7.7218	7.7265
May 01-31	5.4767	5.4767	1.643	7.9478	9.7729	9.7846
Jun 01-30	7.1881	7.1881	2.1564	10.2048	12.1443	12.1493
Jul 01-31	8.1053	8.1053	2.4316	11.3922	13.2858	13.2858
Aug 01-31	8.3874	8.3874	2.5162	11.7588	13.6447	13.6447
Sep 01-30	7.4725	7.4725	2.2417	10.5755	12.4911	12.4971
Oct 01-31	4.996	4.996	1.4988	7.3112	9.1474	9.1474
Nov 01-30	3.1929	3.1929	0.9579	5.006	6.9264	6.9264
Dec 01-31	1.1285	1.1285	0.3385	2.3633	4.3657	4.3678
Summed total	**53.1885**	**53.1885**	**15.9566**	**79.3745**	**101.9753**	**102.0581**

Table E 4 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for 1 Pearl Glazing Scenario

Date	Pearl 1 - Glazing Room cooling plant sens. load (MWh)	Date	Total CE (kgCO2)
Jan 01-31	0.6054	Jan 01-31	1547
Feb 01-28	1.3424	Feb 01-28	1679
Mar 01-31	3.9517	Mar 01-31	2707
Apr 01-30	8.5225	Apr 01-30	3810
May 01-31	12.524	May 01-31	4898
Jun 01-30	15.5056	Jun 01-30	6159
Jul 01-31	16.8337	Jul 01-31	6772
Aug 01-31	17.7432	Aug 01-31	6966
Sep 01-30	15.2474	Sep 01-30	6357
Oct 01-31	10.7449	Oct 01-31	4595
Nov 01-30	6.5906	Nov 01-30	3401
Dec 01-31	2.025	Dec 01-31	2072
Summed total	**111.6365**	**Summed total**	**50963**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.2714	0.2714	0.0814	1.17	2.9917	2.9924
Feb 01-28	0.5558	0.5558	0.1667	1.55	3.2288	3.2787
Mar 01-31	1.8202	1.8202	0.546	3.2603	5.2355	5.2355
Apr 01-30	3.5372	3.5372	1.0612	5.4583	7.3673	7.372
May 01-31	5.2429	5.2429	1.5729	7.6439	9.469	9.4807
Jun 01-30	7.0093	7.0093	2.1028	9.9723	11.9118	11.9168
Jul 01-31	7.9611	7.9611	2.3883	11.2047	13.0983	13.0983
Aug 01-31	8.2556	8.2556	2.4767	11.5876	13.4734	13.4734
Sep 01-30	7.3211	7.3211	2.1963	10.3787	12.2943	12.3003
Oct 01-31	4.7965	4.7965	1.439	7.0519	8.8881	8.8881
Nov 01-30	2.9256	2.9256	0.8777	4.6586	6.579	6.579
Dec 01-31	0.8526	0.8526	0.2558	2.0042	4.0071	4.0088
Summed total	**50.5493**	**50.5493**	**15.1648**	**75.9404**	**98.5444**	**98.624**

Table E 5 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for 2 Pearl Glazing Scenario

Date	Pearl 2 - Glazing Room cooling plant sens. load (MWh)
Jan 01-31	0.4897
Feb 01-28	1.1675
Mar 01-31	3.7043
Apr 01-30	8.2494
May 01-31	12.2262
Jun 01-30	15.1881
Jul 01-31	16.5098
Aug 01-31	17.4131
Sep 01-30	14.9362
Oct 01-31	10.4725
Nov 01-30	6.3365
Dec 01-31	1.8371
Summed total	**108.5303**

Date	Total CE (kgCO2)
Jan 01-31	1517
Feb 01-28	1632
Mar 01-31	2640
Apr 01-30	3736
May 01-31	4817
Jun 01-30	6073
Jul 01-31	6684
Aug 01-31	6876
Sep 01-30	6273
Oct 01-31	4521
Nov 01-30	3332
Dec 01-31	2021
Summed total	**50120**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.2265	0.2265	0.068	1.1116	2.9334	2.9341
Feb 01-28	0.4861	0.4861	0.1458	1.4589	3.1382	3.1877
Mar 01-31	1.7203	1.7203	0.5161	3.1305	5.1056	5.1056
Apr 01-30	3.4266	3.4266	1.028	5.3145	7.2236	7.2283
May 01-31	5.1224	5.1224	1.5367	7.4872	9.3123	9.324
Jun 01-30	6.8808	6.8808	2.0642	9.8052	11.7447	11.7497
Jul 01-31	7.83	7.83	2.349	11.0343	12.9279	12.9279
Aug 01-31	8.122	8.122	2.4366	11.4138	13.2997	13.2997
Sep 01-30	7.1952	7.1952	2.1585	10.2149	12.1306	12.1365
Oct 01-31	4.6862	4.6862	1.4059	6.9085	8.7447	8.7447
Nov 01-30	2.8228	2.8228	0.8468	4.5249	6.4452	6.4452
Dec 01-31	0.7767	0.7767	0.233	1.9055	3.9084	3.91
Summed total	**49.2955**	**49.2955**	**14.7887**	**74.3098**	**96.9144**	**96.9934**

Table E 6 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for 1 Pearl Combined Scenario

Date	Pearl 1 Combined Room cooling plant sens. load (MWh)
Jan 01-31	0.7344
Feb 01-28	1.4428
Mar 01-31	3.8108
Apr 01-30	7.9265
May 01-31	11.4585
Jun 01-30	14.0964
Jul 01-31	15.2558
Aug 01-31	16.104
Sep 01-30	13.8825
Oct 01-31	9.901
Nov 01-30	6.2288
Dec 01-31	2.1311
Summed total	**102.9726**

Date	Total CE (kgCO2)
Jan 01-31	1579
Feb 01-28	1706
Mar 01-31	2668
Apr 01-30	3648
May 01-31	4608
Jun 01-30	5776
Jul 01-31	6343
Aug 01-31	6520
Sep 01-30	5986
Oct 01-31	4366
Nov 01-30	3303
Dec 01-31	2101
Summed total	**48602**

Date	Chillers energy (MV	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.3196	0.3196	0.0959	1.2328	3.0543	3.0552
Feb 01-28	0.5949	0.5949	0.1785	1.6017	3.2796	3.3305
Mar 01-31	1.7629	1.7629	0.5289	3.186	5.1611	5.1611
Apr 01-30	3.2959	3.2959	0.9888	5.1446	7.0537	7.0583
May 01-31	4.8116	4.8116	1.4435	7.0831	8.9082	8.9199
Jun 01-30	6.4388	6.4388	1.9316	9.2307	11.1703	11.1752
Jul 01-31	7.3225	7.3225	2.1967	10.3745	12.2681	12.2681
Aug 01-31	7.5921	7.5921	2.2776	10.725	12.6108	12.6108
Sep 01-30	6.7687	6.7687	2.0306	9.6605	11.5762	11.5821
Oct 01-31	4.4549	4.4549	1.3365	6.6077	8.444	8.444
Nov 01-30	2.7791	2.7791	0.8337	4.4682	6.3885	6.3885
Dec 01-31	0.8955	0.8955	0.2686	2.0602	4.0628	4.0648
Summed total	**47.0364**	**47.0364**	**14.1109**	**71.3749**	**93.9775**	**94.0586**

Table E 7 IES Monthly Results for Cooling Loads, Energy and Carbon for Typical Floor for 2 Pearl Combined Scenario

Date	Pearl 2 Combined Room cooling plant sens. load (MWh)
Jan 01-31	0.6001
Feb 01-28	1.252
Mar 01-31	3.5373
Apr 01-30	7.6138
May 01-31	11.1075
Jun 01-30	13.7149
Jul 01-31	14.8636
Aug 01-31	15.7025
Sep 01-30	13.5086
Oct 01-31	9.5823
Nov 01-30	5.9424
Dec 01-31	1.9258
Summed total	**99.3509**

Date	Total CE (kgCO2)
Jan 01-31	1544
Feb 01-28	1654
Mar 01-31	2594
Apr 01-30	3563
May 01-31	4512
Jun 01-30	5672
Jul 01-31	6236
Aug 01-31	6411
Sep 01-30	5884
Oct 01-31	4279
Nov 01-30	3225
Dec 01-31	2045
Summed total	**47619**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.2671	0.2671	0.0801	1.1645	2.9861	2.987
Feb 01-28	0.5188	0.5188	0.1556	1.5023	3.1807	3.231
Mar 01-31	1.6526	1.6526	0.4958	3.0425	5.0176	5.0176
Apr 01-30	3.1693	3.1693	0.9508	4.9801	6.8891	6.8938
May 01-31	4.6695	4.6695	1.4009	6.8984	8.7235	8.7352
Jun 01-30	6.2844	6.2844	1.8853	9.03	10.9695	10.9745
Jul 01-31	7.1637	7.1637	2.1491	10.1681	12.0617	12.0617
Aug 01-31	7.4295	7.4295	2.2289	10.5137	12.3995	12.3995
Sep 01-30	6.6173	6.6173	1.9852	9.4637	11.3794	11.3853
Oct 01-31	4.3259	4.3259	1.2978	6.44	8.2763	8.2763
Nov 01-30	2.6632	2.6632	0.799	4.3174	6.2378	6.2378
Dec 01-31	0.8125	0.8125	0.2438	1.9523	3.955	3.9569
Summed total	**45.5739**	**45.5739**	**13.6722**	**69.4731**	**92.0763**	**92.1567**

Table E 8 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for Baseline Model

PW Room cooling plant sens. load (MWh)	
Date	
Jan 01-31	1.167
Feb 01-28	2.3083
Mar 01-31	5.3366
Apr 01-30	9.9375
May 01-31	14.0887
Jun 01-30	17.1648
Jul 01-31	18.4735
Aug 01-31	19.3478
Sep 01-30	16.7773
Oct 01-31	12.0334
Nov 01-30	7.7868
Dec 01-31	2.9138
Summed total	**127.3355**

Total CE (kgCO2)	
Date	
Jan 01-31	1692
Feb 01-28	1938
Mar 01-31	3082
Apr 01-30	4195
May 01-31	5324
Jun 01-30	6611
Jul 01-31	7218
Aug 01-31	7402
Sep 01-30	6774
Oct 01-31	4946
Nov 01-30	3727
Dec 01-31	2313
Summed total	**55222**

	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Date						
Jan 01-31	0.4876	0.4876	0.1463	1.4516	3.2728	3.2741
Feb 01-28	0.9403	0.9403	0.2821	2.0538	3.7286	3.7825
Mar 01-31	2.3791	2.3791	0.7137	3.9869	5.962	5.962
Apr 01-30	4.11	4.11	1.233	6.203	8.1121	8.1167
May 01-31	5.8764	5.8764	1.7629	8.4674	10.2925	10.3042
Jun 01-30	7.681	7.681	2.3043	10.8455	12.785	12.79
Jul 01-31	8.6249	8.6249	2.5875	12.0676	13.9612	13.9612
Aug 01-31	8.9052	8.9052	2.6715	12.432	14.3178	14.3178
Sep 01-30	7.9404	7.9404	2.3821	11.1837	13.0994	13.1053
Oct 01-31	5.3181	5.3181	1.5954	7.73	9.5662	9.5662
Nov 01-30	3.4099	3.4099	1.023	5.2882	7.2085	7.2085
Dec 01-31	1.2116	1.2116	0.3635	2.4714	4.4738	4.476
Summed total	**56.8844**	**56.8844**	**17.0653**	**84.1811**	**106.78**	**106.8647**

Table E 9 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 1 Pearl Wall Scenario

. - Wall Room cooling plant sens. load (			Total CE (kgCO2)
Date		Date	
Jan 01-31	1.3934	Jan 01-31	1752
Feb 01-28	2.525	Feb 01-28	1996
Mar 01-31	5.3094	Mar 01-31	3075
Apr 01-30	9.4332	Apr 01-30	4058
May 01-31	13.1231	May 01-31	5061
Jun 01-30	15.8496	Jun 01-30	6253
Jul 01-31	16.9862	Jul 01-31	6813
Aug 01-31	17.7932	Aug 01-31	6979
Sep 01-30	15.4897	Sep 01-30	6423
Oct 01-31	11.2562	Oct 01-31	4734
Nov 01-30	7.4945	Nov 01-30	3647
Dec 01-31	3.1132	Dec 01-31	2368
Summed total	**119.7668**	**Summed total**	**53160**

	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Date						
Jan 01-31	0.5757	0.5757	0.1727	1.5664	3.3873	3.3889
Feb 01-28	1.0266	1.0266	0.308	2.1666	3.8408	3.8953
Mar 01-31	2.3679	2.3679	0.7104	3.9724	5.9475	5.9475
Apr 01-30	3.9059	3.9059	1.1718	5.9376	7.8467	7.8513
May 01-31	5.4855	5.4855	1.6456	7.9592	9.7843	9.796
Jun 01-30	7.1486	7.1486	2.1446	10.1534	12.0929	12.0979
Jul 01-31	8.0229	8.0229	2.4069	11.285	13.1787	13.1787
Aug 01-31	8.2758	8.2758	2.4828	11.6139	13.4997	13.4997
Sep 01-30	7.4193	7.4193	2.2258	10.5062	12.4219	12.4278
Oct 01-31	5.0035	5.0035	1.5011	7.321	9.1572	9.1572
Nov 01-30	3.2916	3.2916	0.9875	5.1343	7.0547	7.0547
Dec 01-31	1.2923	1.2923	0.3877	2.5766	4.5787	4.5812
Summed total	**53.8155**	**53.8155**	**16.1447**	**80.1926**	**102.7904**	**102.8762**

Table E 10 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 2 Pearl Wall Scenario

Date	Pearl 2 - Wall Room cooling plant sens. load (MWh)
Jan 01-31	1.3978
Feb 01-28	2.5293
Mar 01-31	5.3089
Apr 01-30	9.4209
May 01-31	13.1012
Jun 01-30	15.8192
Jul 01-31	16.952
Aug 01-31	17.757
Sep 01-30	15.4593
Oct 01-31	11.2372
Nov 01-30	7.4866
Dec 01-31	3.1168
Summed total	**119.5863**

Date	Total CE (kgCO2)
Jan 01-31	1753
Feb 01-28	1998
Mar 01-31	3075
Apr 01-30	4054
May 01-31	5055
Jun 01-30	6245
Jul 01-31	6804
Aug 01-31	6969
Sep 01-30	6415
Oct 01-31	4729
Nov 01-30	3645
Dec 01-31	2369
Summed total	**53110**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.5774	0.5774	0.1732	1.5686	3.3895	3.3911
Feb 01-28	1.0284	1.0284	0.3085	2.1689	3.8431	3.8976
Mar 01-31	2.3677	2.3677	0.7103	3.9721	5.9472	5.9472
Apr 01-30	3.9009	3.9009	1.1703	5.9312	7.8402	7.8449
May 01-31	5.4766	5.4766	1.643	7.9477	9.7728	9.7845
Jun 01-30	7.1363	7.1363	2.1409	10.1374	12.0769	12.0819
Jul 01-31	8.009	8.009	2.4027	11.267	13.1606	13.1606
Aug 01-31	8.2612	8.2612	2.4784	11.5948	13.4806	13.4806
Sep 01-30	7.4069	7.4069	2.2221	10.4902	12.4059	12.4118
Oct 01-31	4.9958	4.9958	1.4987	7.3109	9.1472	9.1472
Nov 01-30	3.2884	3.2884	0.9865	5.1301	7.0505	7.0505
Dec 01-31	1.2937	1.2937	0.3881	2.5785	4.5806	4.5831
Summed total	**53.7423**	**53.7423**	**16.1227**	**80.0975**	**102.6952**	**102.781**

Table E 11 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 1 Pearl Glazing Scenario

Date	Pearl 1 - Glazing Room cooling plant sens. load (MWh)
Jan 01-31	0.8382
Feb 01-28	1.7601
Mar 01-31	4.4395
Apr 01-30	8.719
May 01-31	12.4942
Jun 01-30	15.3592
Jul 01-31	16.5814
Aug 01-31	17.4201
Sep 01-30	15.0777
Oct 01-31	10.7339
Nov 01-30	6.8079
Dec 01-31	2.376
Summed total	**112.6073**

Date	Total CE (kgCO2)
Jan 01-31	1604
Feb 01-28	1790
Mar 01-31	2838
Apr 01-30	3863
May 01-31	4890
Jun 01-30	6120
Jul 01-31	6703
Aug 01-31	6878
Sep 01-30	6311
Oct 01-31	4592
Nov 01-30	3460
Dec 01-31	2167
Summed total	**51216**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.3559	0.3559	0.1068	1.2802	3.1016	3.1027
Feb 01-28	0.7193	0.7193	0.2158	1.7657	3.4414	3.4945
Mar 01-31	2.0161	2.0161	0.6048	3.5151	5.4902	5.4902
Apr 01-30	3.6168	3.6168	1.085	5.5617	7.4708	7.4755
May 01-31	5.2309	5.2309	1.5693	7.6282	9.4533	9.465
Jun 01-30	6.95	6.95	2.085	9.8953	11.8348	11.8398
Jul 01-31	7.859	7.859	2.3577	11.072	12.9656	12.9656
Aug 01-31	8.1248	8.1248	2.4375	11.4176	13.3034	13.3034
Sep 01-30	7.2524	7.2524	2.1757	10.2894	12.205	12.211
Oct 01-31	4.792	4.792	1.4376	7.0461	8.8823	8.8823
Nov 01-30	3.0136	3.0136	0.9041	4.7729	6.6933	6.6933
Dec 01-31	0.9941	0.9941	0.2982	2.1884	4.191	4.193
Summed total	**50.925**	**50.925**	**15.2775**	**76.4326**	**99.0327**	**99.1162**

Table E 12 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 2 Pearl Glazing Scenario

Date	Pearl 2 - Glazing Room cooling plant sens. load (MWh)
Jan 01-31	0.6995
Feb 01-28	1.5615
Mar 01-31	4.1722
Apr 01-30	8.4287
May 01-31	12.1762
Jun 01-30	15.0194
Jul 01-31	16.2347
Aug 01-31	17.0655
Sep 01-30	14.744
Oct 01-31	10.4425
Nov 01-30	6.5377
Dec 01-31	2.1702
Summed total	**109.2521**

Date	Total CE (kgCO2)
Jan 01-31	1567
Feb 01-28	1736
Mar 01-31	2766
Apr 01-30	3784
May 01-31	4803
Jun 01-30	6027
Jul 01-31	6609
Aug 01-31	6781
Sep 01-30	6220
Oct 01-31	4513
Nov 01-30	3387
Dec 01-31	2111
Summed total	**50305**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.3013	0.3013	0.0904	1.2092	3.0306	3.0317
Feb 01-28	0.6396	0.6396	0.1919	1.6617	3.3378	3.3905
Mar 01-31	1.908	1.908	0.5724	3.3745	5.3496	5.3496
Apr 01-30	3.4992	3.4992	1.0498	5.4089	7.318	7.3227
May 01-31	5.1021	5.1021	1.5306	7.4609	9.286	9.2977
Jun 01-30	6.8125	6.8125	2.0437	9.7165	11.656	11.661
Jul 01-31	7.7187	7.7187	2.3156	10.8895	12.7832	12.7832
Aug 01-31	7.9813	7.9813	2.3944	11.231	13.1168	13.1168
Sep 01-30	7.1174	7.1174	2.1352	10.1138	12.0295	12.0354
Oct 01-31	4.6741	4.6741	1.4022	6.8927	8.729	8.729
Nov 01-30	2.9042	2.9042	0.8713	4.6307	6.5511	6.5511
Dec 01-31	0.9108	0.9108	0.2732	2.0802	4.0828	4.0847
Summed total	**49.5692**	**49.5692**	**14.8708**	**74.6696**	**97.2702**	**97.3532**

Table E 13 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 1 Pearl Roof Scenario

Date	Pearl 1 - Roof Room cooling plant sens. load (MWh)
Jan 01-31	1.2513
Feb 01-28	2.3366
Mar 01-31	5.2117
Apr 01-30	9.6118
May 01-31	13.5508
Jun 01-30	16.4546
Jul 01-31	17.6706
Aug 01-31	18.535
Sep 01-30	16.0898
Oct 01-31	11.6279
Nov 01-30	7.6285
Dec 01-31	2.9838
Summed total	**122.9523**

Date	Total CE (kgCO2)
Jan 01-31	1714
Feb 01-28	1946
Mar 01-31	3048
Apr 01-30	4106
May 01-31	5177
Jun 01-30	6418
Jul 01-31	7000
Aug 01-31	7181
Sep 01-30	6587
Oct 01-31	4835
Nov 01-30	3684
Dec 01-31	2332
Summed total	**54029**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.5204	0.5204	0.1561	1.4943	3.3154	3.3168
Feb 01-28	0.9515	0.9515	0.2855	2.0684	3.7432	3.7971
Mar 01-31	2.3285	2.3285	0.6985	3.9212	5.8963	5.8963
Apr 01-30	3.9782	3.9782	1.1935	6.0316	7.9407	7.9453
May 01-31	5.6587	5.6587	1.6976	8.1843	10.0094	10.0211
Jun 01-30	7.3935	7.3935	2.218	10.4718	12.4113	12.4163
Jul 01-31	8.3	8.3	2.49	11.6452	13.5388	13.5388
Aug 01-31	8.5762	8.5762	2.5729	12.0043	13.8901	13.8901
Sep 01-30	7.6622	7.6622	2.2986	10.822	12.7377	12.7436
Oct 01-31	5.154	5.154	1.5462	7.5166	9.3528	9.3528
Nov 01-30	3.3458	3.3458	1.0037	5.2049	7.1252	7.1252
Dec 01-31	1.24	1.24	0.372	2.5084	4.5107	4.5129
Summed total	**55.1088**	**55.1088**	**16.5326**	**81.8729**	**104.4717**	**104.5565**

Table E 14 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 2 Pearl Roof Scenario

Date	Pearl 2 - Roof Room cooling plant sens. load (MWh)
Jan 01-31	1.2564
Feb 01-28	2.3385
Mar 01-31	5.2049
Apr 01-30	9.5933
May 01-31	13.5202
Jun 01-30	16.414
Jul 01-31	17.6247
Aug 01-31	18.4884
Sep 01-30	16.0504
Oct 01-31	11.6047
Nov 01-30	7.6196
Dec 01-31	2.988
Summed total	**122.7032**

Date	Total CE (kgCO2)
Jan 01-31	1716
Feb 01-28	1946
Mar 01-31	3047
Apr 01-30	4101
May 01-31	5169
Jun 01-30	6407
Jul 01-31	6987
Aug 01-31	7169
Sep 01-30	6576
Oct 01-31	4829
Nov 01-30	3681
Dec 01-31	2334
Summed total	**53961**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.5224	0.5224	0.1567	1.4969	3.318	3.3194
Feb 01-28	0.9523	0.9523	0.2857	2.0694	3.7442	3.7981
Mar 01-31	2.3257	2.3257	0.6977	3.9176	5.8927	5.8927
Apr 01-30	3.9707	3.9707	1.1912	6.0219	7.931	7.9356
May 01-31	5.6463	5.6463	1.6939	8.1682	9.9933	10.005
Jun 01-30	7.3771	7.3771	2.2131	10.4504	12.3899	12.3949
Jul 01-31	8.2814	8.2814	2.4844	11.6211	13.5147	13.5147
Aug 01-31	8.5573	8.5573	2.5672	11.9798	13.8656	13.8656
Sep 01-30	7.6462	7.6462	2.2939	10.8013	12.7169	12.7229
Oct 01-31	5.1446	5.1446	1.5434	7.5044	9.3406	9.3406
Nov 01-30	3.3422	3.3422	1.0027	5.2001	7.1205	7.1205
Dec 01-31	1.2417	1.2417	0.3725	2.5106	4.5129	4.5152
Summed total	**55.0079**	**55.0079**	**16.5024**	**81.7417**	**104.3404**	**104.4252**

Table E 15 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 1 Pearl Combined Scenario

	Pearl 1 Combined Room cooling plant sens. load (MWh)
Date	
Jan 01-31	1.1086
Feb 01-28	1.9213
Mar 01-31	4.127
Apr 01-30	7.6222
May 01-31	10.621
Jun 01-30	12.8833
Jul 01-31	13.8119
Aug 01-31	14.5427
Sep 01-30	12.6582
Oct 01-31	9.2372
Nov 01-30	6.1532
Dec 01-31	2.5666
Summed total	**97.2532**

	Total CE (kgCO2)
Date	
Jan 01-31	1674
Feb 01-28	1832
Mar 01-31	2753
Apr 01-30	3565
May 01-31	4380
Jun 01-30	5446
Jul 01-31	5950
Aug 01-31	6095
Sep 01-30	5653
Oct 01-31	4185
Nov 01-30	3282
Dec 01-31	2219
Summed total	**47034**

	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Date						
Jan 01-31	0.4597	0.4597	0.1379	1.4154	3.2365	3.2379
Feb 01-28	0.7826	0.7826	0.2348	1.8488	3.5236	3.5775
Mar 01-31	1.8894	1.8894	0.5668	3.3504	5.3255	5.3255
Apr 01-30	3.1727	3.1727	0.9518	4.9844	6.8935	6.8982
May 01-31	4.4726	4.4726	1.3418	6.6424	8.4675	8.4792
Jun 01-30	5.9478	5.9478	1.7843	8.5924	10.5319	10.5369
Jul 01-31	6.7379	6.7379	2.0214	9.6146	11.5082	11.5082
Aug 01-31	6.9597	6.9597	2.0879	9.9028	11.7887	11.7887
Sep 01-30	6.273	6.273	1.8819	9.0161	10.9317	10.9377
Oct 01-31	4.1862	4.1862	1.2559	6.2584	8.0947	8.0947
Nov 01-30	2.7485	2.7485	0.8246	4.4284	6.3488	6.3488
Dec 01-31	1.0711	1.0711	0.3213	2.2891	4.2912	4.2937
Summed total	**44.7012**	**44.7012**	**13.4104**	**68.3432**	**90.9418**	**91.0268**

Table E 16 IES Monthly Results for Cooling Loads, Energy and Carbon for Roof Floor for 2 Pearl Combined Scenario

Date	Pearl 2 Combined Room cooling plant sens. load (MWh)
Jan 01-31	0.9447
Feb 01-28	1.6936
Mar 01-31	3.8046
Apr 01-30	7.2414
May 01-31	10.1765
Jun 01-30	12.3865
Jul 01-31	13.2956
Aug 01-31	14.0105
Sep 01-30	12.1697
Oct 01-31	8.8378
Nov 01-30	5.8148
Dec 01-31	2.333
Summed total	**92.7087**

Date	Total CE (kgCO2)
Jan 01-31	1630
Feb 01-28	1771
Mar 01-31	2666
Apr 01-30	3461
May 01-31	4259
Jun 01-30	5311
Jul 01-31	5809
Aug 01-31	5950
Sep 01-30	5520
Oct 01-31	4076
Nov 01-30	3190
Dec 01-31	2156
Summed total	**45798**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	0.3943	0.3943	0.1183	1.3303	3.1515	3.1528
Feb 01-28	0.6909	0.6909	0.2073	1.7293	3.4044	3.458
Mar 01-31	1.759	1.759	0.5277	3.1809	5.156	5.156
Apr 01-30	3.0185	3.0185	0.9056	4.784	6.6931	6.6978
May 01-31	4.2926	4.2926	1.2878	6.4084	8.2335	8.2452
Jun 01-30	5.7467	5.7467	1.724	8.331	10.2705	10.2755
Jul 01-31	6.5289	6.5289	1.9587	9.3429	11.2365	11.2365
Aug 01-31	6.7441	6.7441	2.0232	9.6226	11.5084	11.5084
Sep 01-30	6.0751	6.0751	1.8225	8.7589	10.6745	10.6805
Oct 01-31	4.0245	4.0245	1.2074	6.0483	7.8845	7.8845
Nov 01-30	2.6116	2.6116	0.7835	4.2503	6.1707	6.1707
Dec 01-31	0.9766	0.9766	0.293	2.1662	4.1683	4.1708
Summed total	**42.8629**	**42.8629**	**12.8589**	**65.9531**	**88.552**	**88.6367**

Table E 17 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for Baseline Model

Date	PW Room cooling plant sens. load (MWh)
Jan 01-31	4.8277
Feb 01-28	7.1878
Mar 01-31	12.3987
Apr 01-30	19.5385
May 01-31	26.0515
Jun 01-30	30.8737
Jul 01-31	32.9321
Aug 01-31	34.3809
Sep 01-30	30.1718
Oct 01-31	22.7376
Nov 01-30	16.3251
Dec 01-31	8.2974
Summed total	**245.7228**

Date	Total CE (kgCO2)
Jan 01-31	3745
Feb 01-28	4283
Mar 01-31	6256
Apr 01-30	7945
May 01-31	9696
Jun 01-30	11719
Jul 01-31	12720
Aug 01-31	13036
Sep 01-30	11973
Oct 01-31	9083
Nov 01-30	7249
Dec 01-31	4944
Summed total	**102649**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	1.969	1.969	0.5907	3.7585	7.2432	7.2457
Feb 01-28	2.9151	2.9151	0.8745	5.0179	8.2502	8.339
Mar 01-31	5.3629	5.3629	1.6089	8.282	12.1014	12.1014
Apr 01-30	8.0453	8.0453	2.4136	11.7196	15.3654	15.3729
May 01-31	10.8182	10.8182	3.2455	15.2792	18.7473	18.7664
Jun 01-30	13.6593	13.6593	4.0978	19.0186	22.6637	22.6718
Jul 01-31	15.1512	15.1512	4.5453	20.9498	24.6031	24.6031
Aug 01-31	15.6213	15.6213	4.6864	21.5609	25.2142	25.2142
Sep 01-30	14.0371	14.0371	4.2111	19.5113	23.1548	23.1646
Oct 01-31	9.9111	9.9111	2.9733	14.0808	17.568	17.568
Nov 01-30	7.0113	7.0113	2.1034	10.3681	14.0213	14.0213
Dec 01-31	3.4085	3.4085	1.0226	5.7451	9.5607	9.5644
Summed total	**107.9103**	**107.9103**	**32.3731**	**155.2918**	**198.4932**	**198.6329**

Table E 18 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for 1 Pearl Wall Scenario

Date	Pearl 1 - Wall Room cooling plant sens. load (MWh)
Jan 01-31	5.3563
Feb 01-28	7.6822
Mar 01-31	12.5156
Apr 01-30	18.9078
May 01-31	24.7172
Jun 01-30	29.0255
Jul 01-31	30.8381
Aug 01-31	32.1874
Sep 01-30	28.3966
Oct 01-31	21.7249
Nov 01-30	16.059
Dec 01-31	8.7731
Summed total	**236.1836**

Date	Total CE (kgCO2)
Jan 01-31	3886
Feb 01-28	4417
Mar 01-31	6288
Apr 01-30	7774
May 01-31	9333
Jun 01-30	11216
Jul 01-31	12150
Aug 01-31	12439
Sep 01-30	11490
Oct 01-31	8807
Nov 01-30	7177
Dec 01-31	5073
Summed total	**100049**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	2.1786	2.1786	0.6536	4.0313	7.5157	7.5185
Feb 01-28	3.1137	3.1137	0.9341	5.2769	8.5083	8.598
Mar 01-31	5.41	5.41	1.623	8.3433	12.1626	12.1626
Apr 01-30	7.7899	7.7899	2.337	11.3877	15.0334	15.041
May 01-31	10.2781	10.2781	3.0834	14.5769	18.045	18.0641
Jun 01-30	12.9112	12.9112	3.8733	18.046	21.6911	21.6993
Jul 01-31	14.3035	14.3035	4.2911	19.8479	23.5012	23.5012
Aug 01-31	14.7331	14.7331	4.4199	20.4063	24.0596	24.0596
Sep 01-30	13.3184	13.3184	3.9955	18.577	22.2205	22.2303
Oct 01-31	9.5012	9.5012	2.8503	13.5478	17.0351	17.035
Nov 01-30	6.9036	6.9036	2.0711	10.228	13.8813	13.8813
Dec 01-31	3.601	3.601	1.0803	5.9957	9.8109	9.815
Summed total	**104.0423**	**104.0423**	**31.2127**	**150.2647**	**193.4648**	**193.6059**

Table E 19 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for 2 Pearl Wall Scenario

Date	Pearl 2 - Wall Room cooling plant sens. load (MWh)
Jan 01-31	5.3686
Feb 01-28	7.6938
Mar 01-31	12.519
Apr 01-30	18.892
May 01-31	24.686
Jun 01-30	28.9814
Jul 01-31	30.7884
Aug 01-31	32.1343
Sep 01-30	28.3532
Oct 01-31	21.6993
Nov 01-30	16.0512
Dec 01-31	8.7834
Summed total	**235.9506**

Date	Total CE (kgCO2)
Jan 01-31	3889
Feb 01-28	4420
Mar 01-31	6289
Apr 01-30	7769
May 01-31	9325
Jun 01-30	11204
Jul 01-31	12137
Aug 01-31	12424
Sep 01-30	11478
Oct 01-31	8800
Nov 01-30	7175
Dec 01-31	5076
Summed total	**99986**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	2.1835	2.1835	0.655	4.0376	7.5221	7.5249
Feb 01-28	3.1183	3.1183	0.9355	5.2829	8.5144	8.6041
Mar 01-31	5.4114	5.4114	1.6234	8.3451	12.1644	12.1644
Apr 01-30	7.7835	7.7835	2.3351	11.3794	15.0252	15.0327
May 01-31	10.2654	10.2654	3.0796	14.5605	18.0286	18.0477
Jun 01-30	12.8933	12.8933	3.868	18.0227	21.6678	21.676
Jul 01-31	14.2834	14.2834	4.285	19.8217	23.475	23.475
Aug 01-31	14.7116	14.7116	4.4135	20.3784	24.0317	24.0317
Sep 01-30	13.3008	13.3008	3.9903	18.5542	22.1977	22.2074
Oct 01-31	9.4908	9.4908	2.8472	13.5343	17.0216	17.0216
Nov 01-30	6.9005	6.9005	2.0701	10.2239	13.8772	13.8772
Dec 01-31	3.6052	3.6052	1.0816	6.0011	9.8164	9.8205
Summed total	**103.9478**	**103.9478**	**31.1843**	**150.142**	**193.342**	**193.4831**

Table E 20 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for 1 Pearl Glazing Scenario

Date	Pearl 1 - Glazing Room cooling plant sens. load (MWh)
Jan 01-31	3.9118
Feb 01-28	5.6525
Mar 01-31	9.8998
Apr 01-30	15.8946
May 01-31	21.227
Jun 01-30	25.2645
Jul 01-31	26.9905
Aug 01-31	28.3108
Sep 01-30	24.8183
Oct 01-31	18.6616
Nov 01-30	13.3182
Dec 01-31	6.7517
Summed total	**200.7012**

Date	Total CE (kgCO2)
Jan 01-31	3496
Feb 01-28	3865
Mar 01-31	5577
Apr 01-30	6954
May 01-31	8383
Jun 01-30	10193
Jul 01-31	11103
Aug 01-31	11384
Sep 01-30	10516
Oct 01-31	7974
Nov 01-30	6431
Dec 01-31	4523
Summed total	**90399**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	1.5982	1.5982	0.4795	3.2763	6.7612	6.7635
Feb 01-28	2.2939	2.2939	0.6882	4.2096	7.4426	7.5308
Mar 01-31	4.3515	4.3515	1.3054	6.9672	10.7865	10.7865
Apr 01-30	6.57	6.57	1.971	9.8018	13.4476	13.4551
May 01-31	8.8651	8.8651	2.6595	12.7401	16.2081	16.2273
Jun 01-30	11.3886	11.3886	3.4166	16.0666	19.7117	19.7199
Jul 01-31	12.746	12.746	3.8238	17.8231	21.4764	21.4764
Aug 01-31	13.1639	13.1639	3.9492	18.3664	22.0196	22.0196
Sep 01-30	11.8699	11.8699	3.561	16.694	20.3375	20.3473
Oct 01-31	8.261	8.261	2.4783	11.9356	15.4228	15.4228
Nov 01-30	5.794	5.794	1.7382	8.7855	12.4387	12.4387
Dec 01-31	2.7828	2.7828	0.8348	4.9316	8.7472	8.7509
Summed total	**89.6848**	**89.6848**	**26.9054**	**131.5977**	**174.8001**	**174.9389**

Table E 21 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for 2 Pearl Glazing Scenario

Date	Pearl 2 - GlazingRoom cooling plant sens. load (MWh)
Jan 01-31	3.3067
Feb 01-28	4.907
Mar 01-31	8.9546
Apr 01-30	14.875
May 01-31	20.1106
Jun 01-30	24.0566
Jul 01-31	25.7521
Aug 01-31	27.0394
Sep 01-30	23.6206
Oct 01-31	17.607
Nov 01-30	12.3339
Dec 01-31	5.978
Summed total	**188.5416**

Date	Total CE (kgCO2)
Jan 01-31	3332
Feb 01-28	3663
Mar 01-31	5320
Apr 01-30	6676
May 01-31	8080
Jun 01-30	9864
Jul 01-31	10766
Aug 01-31	11038
Sep 01-30	10191
Oct 01-31	7687
Nov 01-30	6163
Dec 01-31	4313
Summed total	**87092**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	1.3547	1.3547	0.4064	2.9597	6.4447	6.4469
Feb 01-28	1.9929	1.9929	0.5979	3.8178	7.0513	7.1389
Mar 01-31	3.969	3.969	1.1907	6.4699	10.2893	10.2893
Apr 01-30	6.1572	6.1572	1.8472	9.2652	12.911	12.9185
May 01-31	8.4131	8.4131	2.5239	12.1525	15.6206	15.6397
Jun 01-30	10.8996	10.8996	3.2699	15.431	19.0761	19.0843
Jul 01-31	12.2447	12.2447	3.6734	17.1714	20.8247	20.8247
Aug 01-31	12.6492	12.6492	3.7948	17.6973	21.3506	21.3506
Sep 01-30	11.3851	11.3851	3.4155	16.0637	19.7072	19.717
Oct 01-31	7.8341	7.8341	2.3502	11.3806	14.8678	14.8678
Nov 01-30	5.3955	5.3955	1.6186	8.2674	11.9207	11.9207
Dec 01-31	2.4696	2.4696	0.7409	4.5244	8.3401	8.3437
Summed total	84.7648	84.7648	25.4294	125.201	168.4041	168.5421

Table E 22 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for 1 Pearl Combined Scenario

Date	Pearl 1 Room cooling plant sens. load (MWh)
Jan 01-31	4.4063
Feb 01-28	6.0783
Mar 01-31	9.8843
Apr 01-30	15.0318
May 01-31	19.5664
Jun 01-30	23.0208
Jul 01-31	24.4762
Aug 01-31	25.6658
Sep 01-30	22.657
Oct 01-31	17.3721
Nov 01-30	12.8696
Dec 01-31	7.1506
Summed total	**188.179**

Date	Total CE (kgCO2)
Jan 01-31	3627
Feb 01-28	3980
Mar 01-31	5572
Apr 01-30	6719
May 01-31	7932
Jun 01-30	9582
Jul 01-31	10419
Aug 01-31	10664
Sep 01-30	9928
Oct 01-31	7623
Nov 01-30	6309
Dec 01-31	4632
Summed total	**86986**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	1.7935	1.7935	0.538	3.5305	7.015	7.0177
Feb 01-28	2.4642	2.4642	0.7393	4.4322	7.664	7.7534
Mar 01-31	4.3448	4.3448	1.3035	6.9586	10.7779	10.7779
Apr 01-30	6.2207	6.2207	1.8662	9.3477	12.9935	13.001
May 01-31	8.1928	8.1928	2.4578	11.8661	15.3342	15.3533
Jun 01-30	10.4803	10.4803	3.1441	14.8859	18.531	18.5392
Jul 01-31	11.7278	11.7278	3.5183	16.4994	20.1527	20.1527
Aug 01-31	12.0921	12.0921	3.6276	16.9731	20.6264	20.6264
Sep 01-30	10.9944	10.9944	3.2983	15.5558	19.1993	19.209
Oct 01-31	7.739	7.739	2.3217	11.257	14.7442	14.7442
Nov 01-30	5.6124	5.6124	1.6837	8.5494	12.2027	12.2027
Dec 01-31	2.9442	2.9442	0.8833	5.1418	8.957	8.9611
Summed total	**84.6061**	**84.6061**	**25.3818**	**124.9974**	**168.1977**	**168.3385**

Table E 23 IES Monthly Results for Cooling Loads, Energy and Carbon for GF + Mezz Floor for 2 Pearl Combined Scenario

Date	Pearl 2 Combined Room cooling plant sens. load (MWh)
Jan 01-31	3.7678
Feb 01-28	5.2969
Mar 01-31	8.8893
Apr 01-30	13.9327
May 01-31	18.3389
Jun 01-30	21.6775
Jul 01-31	23.0938
Aug 01-31	24.2402
Sep 01-30	21.3267
Oct 01-31	16.2209
Nov 01-30	11.82
Dec 01-31	6.3421
Summed total	**174.9468**

Date	Total CE (kgCO2)
Jan 01-31	3454
Feb 01-28	3768
Mar 01-31	5301
Apr 01-30	6420
May 01-31	7598
Jun 01-30	9217
Jul 01-31	10043
Aug 01-31	10276
Sep 01-30	9566
Oct 01-31	7310
Nov 01-30	6023
Dec 01-31	4412
Summed total	**83386**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	1.5358	1.5358	0.4607	3.1954	6.6801	6.6826
Feb 01-28	2.1482	2.1482	0.6445	4.0212	7.2532	7.3424
Mar 01-31	3.9421	3.9421	1.1826	6.435	10.2543	10.2543
Apr 01-30	5.7757	5.7757	1.7327	8.7692	12.415	12.4225
May 01-31	7.6959	7.6959	2.3088	11.2201	14.6882	14.7073
Jun 01-30	9.9366	9.9366	2.981	14.179	17.8241	17.8323
Jul 01-31	11.168	11.168	3.3504	15.7717	19.4249	19.4249
Aug 01-31	11.5145	11.5145	3.4544	16.2222	19.8754	19.8754
Sep 01-30	10.4556	10.4556	3.1367	14.8554	18.4989	18.5086
Oct 01-31	7.273	7.273	2.1819	10.6512	14.1384	14.1384
Nov 01-30	5.1874	5.1874	1.5562	7.997	11.6503	11.6503
Dec 01-31	2.6169	2.6169	0.7851	4.7162	8.5315	8.5356
Summed total	**79.2497**	**79.2497**	**23.7749**	**118.0336**	**161.2344**	**161.3748**

Table E 24 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for Baseline Model

/ Room cooling plant sens. load (MW	
Date	
Jan 01-31	18.6773
Feb 01-28	35.4269
Mar 01-31	85.0081
Apr 01-30	164.9722
May 01-31	236.5126
Jun 01-30	288.8427
Jul 01-31	311.8924
Aug 01-31	327.2845
Sep 01-30	282.6447
Oct 01-31	202.26
Nov 01-30	129.3723
Dec 01-31	46.7236
Summed total	**2129.6187**

	Total CE (kgCO2)
Date	
Jan 01-31	28215
Feb 01-28	31659
Mar 01-31	50470
Apr 01-30	69876
May 01-31	89318
Jun 01-30	111024
Jul 01-31	121494
Aug 01-31	124808
Sep 01-30	113793
Oct 01-31	83007
Nov 01-30	62132
Dec 01-31	38211
Summed total	**923993**

	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Date						
Jan 01-31	7.9166	7.9166	2.375	23.7517	54.5586	54.5764
Feb 01-28	14.4968	14.4968	4.3486	32.5083	60.899	61.7599
Mar 01-31	38.052	38.052	11.4156	64.1893	97.6352	97.6352
Apr 01-30	68.2267	68.2267	20.4676	102.855	135.1373	135.2138
May 01-31	98.6114	98.6114	29.584	141.8324	172.677	172.8716
Jun 01-30	129.0745	129.0745	38.7225	181.9629	214.7005	214.7836
Jul 01-31	145.2765	145.2765	43.5832	202.9424	234.9997	234.9997
Aug 01-31	150.2857	150.2857	45.0851	209.4535	241.3952	241.3952
Sep 01-30	133.4721	133.4721	40.042	187.6952	220.0728	220.1725
Oct 01-31	89.2878	89.2878	26.7867	129.5156	160.5472	160.5472
Nov 01-30	56.6394	56.6394	16.992	87.7143	120.1734	120.1734
Dec 01-31	19.4503	19.4503	5.8353	40.0399	73.8957	73.9282
Summed total	**950.7911**	**950.7911**	**285.2376**	**1404.4605**	**1786.6916**	**1788.0556**

Table E 25 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 1 Pearl Wall Scenario

Date	Pearl 1 - WallRoom cooling plant sens. load (MWh)
Jan 01-31	21.7175
Feb 01-28	38.2285
Mar 01-31	84.4698
Apr 01-30	157.7489
May 01-31	222.5069
Jun 01-30	269.8389
Jul 01-31	290.4042
Aug 01-31	304.9506
Sep 01-30	264.2543
Oct 01-31	191.3227
Nov 01-30	125.455
Dec 01-31	49.5611
Summed total	**2020.4583**

Date	Total CE (kgCO2)
Jan 01-31	29000
Feb 01-28	32409
Mar 01-31	50334
Apr 01-30	67913
May 01-31	85497
Jun 01-30	105845
Jul 01-31	115646
Aug 01-31	118723
Sep 01-30	108802
Oct 01-31	80029
Nov 01-30	61066
Dec 01-31	38984
Summed total	**894233**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	9.1775	9.1775	2.7541	25.3951	56.1986	56.2198
Feb 01-28	15.6945	15.6945	4.7085	34.0799	62.4565	63.3315
Mar 01-31	37.8177	37.8177	11.3452	63.8861	97.3319	97.3319
Apr 01-30	65.0988	65.0988	19.529	98.7871	131.0693	131.1473
May 01-31	92.5508	92.5508	27.7646	133.9523	164.7983	164.9915
Jun 01-30	120.85	120.85	36.2551	171.2696	204.0072	204.0904
Jul 01-31	135.977	135.977	40.7936	190.8519	222.9107	222.9107
Aug 01-31	140.6159	140.6159	42.1841	196.8828	228.8231	228.8231
Sep 01-30	125.5067	125.5067	37.6527	177.3404	209.7194	209.8177
Oct 01-31	84.5453	84.5453	25.364	123.3502	154.3819	154.3818
Nov 01-30	54.9364	54.9364	16.4804	85.4995	117.9588	117.9588
Dec 01-31	20.6783	20.6783	6.2042	41.6403	75.4926	75.5286
Summed total	**903.4474**	**903.4474**	**271.034**	**1342.9365**	**1725.1456**	**1726.5317**

Table E 26 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 2 Pearl Wall Scenario

Date	Pearl 2- Wall Room cooling plant sens. load (MWh)
Jan 01-31	22.0012
Feb 01-28	38.4961
Mar 01-31	84.4273
Apr 01-30	157.0569
May 01-31	221.2068
Jun 01-30	268.0628
Jul 01-31	288.3976
Aug 01-31	302.8531
Sep 01-30	262.5107
Oct 01-31	190.2629
Nov 01-30	125.0476
Dec 01-31	49.808
Summed total	**2010.1325**

Date	Total CE (kgCO2)
Jan 01-31	29078
Feb 01-28	32472
Mar 01-31	50314
Apr 01-30	67725
May 01-31	85150
Jun 01-30	105369
Jul 01-31	115107
Aug 01-31	118149
Sep 01-30	108319
Oct 01-31	79735
Nov 01-30	60954
Dec 01-31	39043
Summed total	**891428**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	9.1995	9.1995	2.7602	25.4232	56.2268	56.248
Feb 01-28	15.7149	15.7149	4.7146	34.1064	62.4831	63.3581
Mar 01-31	37.8105	37.8105	11.3427	63.8764	97.3222	97.3222
Apr 01-30	65.023	65.023	19.5074	98.6898	130.9706	131.0486
May 01-31	92.4158	92.4158	27.7246	133.7774	164.622	164.8166
Jun 01-30	120.663	120.663	36.1985	171.0273	203.7649	203.8481
Jul 01-31	135.7666	135.7666	40.7301	190.5795	222.6368	222.6368
Aug 01-31	140.3964	140.3964	42.1187	196.5964	228.5381	228.5381
Sep 01-30	125.3227	125.3227	37.5962	177.1014	209.479	209.5786
Oct 01-31	84.4306	84.4306	25.3291	123.202	154.2324	154.2324
Nov 01-30	54.8895	54.8895	16.4672	85.438	117.8973	117.8973
Dec 01-31	20.6979	20.6979	6.2087	41.6658	75.5168	75.5528
Summed total	**902.3291**	**902.3291**	**270.6994**	**1341.4825**	**1723.6914**	**1725.0775**

Table E27 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 1 Pearl Glazing Scenario

Date	Pearl 1 - Glazing Room cooling plant sens. load (MWh)
Jan 01-31	13.2256
Feb 01-28	26.2062
Mar 01-31	69.6631
Apr 01-30	143.9286
May 01-31	209.0572
Jun 01-30	257.7021
Jul 01-31	279.2437
Aug 01-31	294.1357
Sep 01-30	253.3596
Oct 01-31	179.8241
Nov 01-30	112.3945
Dec 01-31	37.4777
Summed total	**1876.2195**

Date	Total CE (kgCO2)
Jan 01-31	26758
Feb 01-28	29161
Mar 01-31	46313
Apr 01-30	64157
May 01-31	81845
Jun 01-30	102539
Jul 01-31	112614
Aug 01-31	115786
Sep 01-30	105825
Oct 01-31	76896
Nov 01-30	57505
Dec 01-31	35698
Summed total	**855097**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	5.7537	5.7537	1.7259	20.9365	51.7466	51.7598
Feb 01-28	10.7944	10.7944	3.2378	27.6753	56.0872	56.9271
Mar 01-31	31.8504	31.8504	9.5542	56.1265	89.5737	89.5737
Apr 01-30	59.7076	59.7076	17.9128	91.7797	124.0606	124.1386
May 01-31	87.4966	87.4966	26.2494	127.3829	158.2274	158.4221
Jun 01-30	116.4688	116.4688	34.9408	165.5741	198.3117	198.3949
Jul 01-31	132.0604	132.0604	39.6177	185.7609	217.8182	217.8182
Aug 01-31	136.8671	136.8671	41.0605	192.0104	223.9506	223.9506
Sep 01-30	121.6177	121.6177	36.4849	172.2852	204.6627	204.7625
Oct 01-31	80.204	80.204	24.0619	117.7083	148.7385	148.7385
Nov 01-30	49.766	49.766	14.9301	78.7788	111.238	111.238
Dec 01-31	15.7133	15.7133	4.7142	35.1788	69.0376	69.0671
Summed total	**848.3**	**848.3**	**254.4901**	**1271.1959**	**1653.4544**	**1654.7911**

Table E 28 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 2 Pearl Wall Scenario

Date	Pearl 2 Glazing Room cooling plant sens. load (MWh)
Jan 01-31	10.862
Feb 01-28	22.8135
Mar 01-31	64.987
Apr 01-30	138.7953
May 01-31	203.4536
Jun 01-30	251.7094
Jul 01-31	273.124
Aug 01-31	287.8883
Sep 01-30	247.4714
Oct 01-31	174.6645
Nov 01-30	107.5826
Dec 01-31	33.8676
Summed total	**1817.2179**

Date	Total CE (kgCO2)
Jan 01-31	26137
Feb 01-28	28247
Mar 01-31	45046
Apr 01-30	62764
May 01-31	80321
Jun 01-30	100913
Jul 01-31	110951
Aug 01-31	114083
Sep 01-30	104233
Oct 01-31	75494
Nov 01-30	56198
Dec 01-31	34718
Summed total	**839077**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	4.827	4.827	1.4488	19.7313	50.5429	50.556
Feb 01-28	9.4379	9.4379	2.831	25.9041	54.3239	55.1572
Mar 01-31	29.9612	29.9612	8.9885	53.6714	87.1173	87.1173
Apr 01-30	57.6288	57.6288	17.289	89.0771	121.3594	121.4374
May 01-31	85.2288	85.2288	25.5683	124.4342	155.2788	155.4734
Jun 01-30	114.0433	114.0433	34.2124	162.4203	195.1579	195.2411
Jul 01-31	129.5834	129.5834	38.875	182.5411	214.5985	214.5985
Aug 01-31	134.3385	134.3385	40.3016	188.7215	220.6632	220.6632
Sep 01-30	119.2353	119.2353	35.7697	169.1861	201.5651	201.6634
Oct 01-31	78.115	78.115	23.435	114.9923	146.0226	146.0226
Nov 01-30	47.8189	47.8189	14.3451	76.2467	108.7046	108.7046
Dec 01-31	14.2542	14.2542	4.2761	33.2816	67.1405	67.1684
Summed total	**824.471**	**824.471**	**247.342**	**1240.2078**	**1622.4759**	**1623.8029**

Table E 29 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 1 Pearl Roof Scenario

	Pearl 1 Roof - Room cooling plant sens. load (MWh)
Date	
Jan 01-31	18.7616
Feb 01-28	35.4552
Mar 01-31	84.8832
Apr 01-30	164.6465
May 01-31	235.9747
Jun 01-30	288.1325
Jul 01-31	311.0895
Aug 01-31	326.4717
Sep 01-30	281.9572
Oct 01-31	201.8545
Nov 01-30	129.214
Dec 01-31	46.7936
Summed total	**2125.2355**

	Total CE (kgCO2)
Date	
Jan 01-31	28237
Feb 01-28	31667
Mar 01-31	50436
Apr 01-30	69787
May 01-31	89171
Jun 01-30	110831
Jul 01-31	121276
Aug 01-31	124587
Sep 01-30	113606
Oct 01-31	82896
Nov 01-30	62089
Dec 01-31	38230
Summed total	**922800**

	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Date						
Jan 01-31	7.9494	7.9494	2.3848	23.7944	54.6012	54.6191
Feb 01-28	14.508	14.508	4.352	32.5229	60.9136	61.7745
Mar 01-31	38.0014	38.0014	11.4004	64.1236	97.5695	97.5695
Apr 01-30	68.0949	68.0949	20.4281	102.6836	134.9659	135.0424
May 01-31	98.3937	98.3937	29.5187	141.5493	172.3939	172.5885
Jun 01-30	128.787	128.787	38.6362	181.5892	214.3268	214.4099
Jul 01-31	144.9516	144.9516	43.4857	202.52	234.5773	234.5773
Aug 01-31	149.9567	149.9567	44.9865	209.0258	240.9675	240.9675
Sep 01-30	133.1939	133.1939	39.9585	187.3335	219.7111	219.8108
Oct 01-31	89.1237	89.1237	26.7375	129.3022	160.3338	160.3338
Nov 01-30	56.5753	56.5753	16.9727	87.631	120.0901	120.0901
Dec 01-31	19.4787	19.4787	5.8438	40.0769	73.9326	73.9651
Summed total	**949.0155**	**949.0155**	**284.7049**	**1402.1523**	**1784.3833**	**1785.7474**

Table E 30 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 2 Pearl Roof Scenario

Date	Pearl 2 Roof Room cooling plant sens. load (MWh)
Jan 01-31	18.7667
Feb 01-28	35.4571
Mar 01-31	84.8764
Apr 01-30	164.628
May 01-31	235.9441
Jun 01-30	288.0919
Jul 01-31	311.0436
Aug 01-31	326.4251
Sep 01-30	281.9178
Oct 01-31	201.8313
Nov 01-30	129.2051
Dec 01-31	46.7978
Summed total	**2124.9864**

Date	Total CE (kgCO2)
Jan 01-31	28239
Feb 01-28	31667
Mar 01-31	50435
Apr 01-30	69782
May 01-31	89163
Jun 01-30	110820
Jul 01-31	121263
Aug 01-31	124575
Sep 01-30	113595
Oct 01-31	82890
Nov 01-30	62086
Dec 01-31	38232
Summed total	**922732**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	7.9514	7.9514	2.3854	23.797	54.6038	54.6217
Feb 01-28	14.5088	14.5088	4.3522	32.5239	60.9146	61.7755
Mar 01-31	37.9986	37.9986	11.3996	64.12	97.5659	97.5659
Apr 01-30	68.0874	68.0874	20.4258	102.6739	134.9562	135.0327
May 01-31	98.3813	98.3813	29.515	141.5332	172.3778	172.5724
Jun 01-30	128.7706	128.7706	38.6313	181.5678	214.3054	214.3885
Jul 01-31	144.933	144.933	43.4801	202.4959	234.5532	234.5532
Aug 01-31	149.9378	149.9378	44.9808	209.0013	240.943	240.943
Sep 01-30	133.1779	133.1779	39.9538	187.3128	219.6903	219.7901
Oct 01-31	89.1143	89.1143	26.7347	129.29	160.3216	160.3216
Nov 01-30	56.5717	56.5717	16.9717	87.6262	120.0854	120.0854
Dec 01-31	19.4804	19.4804	5.8443	40.0791	73.9348	73.9674
Summed total	**948.9146**	**948.9146**	**284.6747**	**1402.0211**	**1784.252**	**1785.6161**

Table E 31 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 1 Pearl Combined Scenario

Date	Pearl 1 Combined Room cooling plant sens. load (MWh)
Jan 01-31	15.7965
Feb 01-28	28.1988
Mar 01-31	67.3625
Apr 01-30	133.625
May 01-31	190.6064
Jun 01-30	233.2537
Jul 01-31	251.8693
Aug 01-31	265.6645
Sep 01-30	229.6702
Oct 01-31	165.2233
Nov 01-30	106.226
Dec 01-31	39.5526
Summed total	**1727.0486**

Date	Total CE (kgCO2)
Jan 01-31	27407
Feb 01-28	29696
Mar 01-31	45677
Apr 01-30	61356
May 01-31	76824
Jun 01-30	95892
Jul 01-31	105171
Aug 01-31	108039
Sep 01-30	99385
Oct 01-31	72932
Nov 01-30	55833
Dec 01-31	36265
Summed total	**814448**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	6.7276	6.7276	2.0185	22.2051	53.0117	53.0284
Feb 01-28	11.5754	11.5754	3.4731	28.7048	57.102	57.9579
Mar 01-31	30.9148	30.9148	9.2749	54.913	88.3588	88.3588
Apr 01-30	55.536	55.536	16.6612	86.3565	118.6388	118.7154
May 01-31	80.0278	80.0278	24.0086	117.6719	148.5165	148.7111
Jun 01-30	106.5713	106.5713	31.9708	152.7081	185.4471	185.5289
Jul 01-31	120.9807	120.9807	36.2935	171.357	203.4143	203.4143
Aug 01-31	125.3412	125.3412	37.6019	177.0259	208.9663	208.9663
Sep 01-30	112.0292	112.0292	33.6086	159.8189	192.1978	192.2961
Oct 01-31	74.2938	74.2938	22.2886	110.0232	141.0549	141.0549
Nov 01-30	47.2683	47.2683	14.1801	75.5326	107.9905	107.9905
Dec 01-31	16.5523	16.5523	4.965	36.2737	70.1274	70.162
Summed total	**787.8169**	**787.8169**	**236.3448**	**1192.5892**	**1574.8245**	**1576.1857**

Table E 32 IES Monthly Results for Cooling Loads, Energy and Carbon for All Building for 2 Pearl Combined Scenario

Date	Pearl 2 CombinedRoom cooling plant sens. load (MWh)
Jan 01-31	13.1139
Feb 01-28	24.5185
Mar 01-31	62.2161
Apr 01-30	127.7673
May 01-31	184.0204
Jun 01-30	226.0726
Jul 01-31	244.4798
Aug 01-31	258.0857
Sep 01-30	222.6168
Oct 01-31	159.2109
Nov 01-30	100.8284
Dec 01-31	35.6363
Summed total	**1658.5681**

Date	Total CE (kgCO2)
Jan 01-31	26700
Feb 01-28	28695
Mar 01-31	44283
Apr 01-30	59763
May 01-31	75025
Jun 01-30	93936
Jul 01-31	103156
Aug 01-31	105980
Sep 01-30	97462
Oct 01-31	71292
Nov 01-30	54363
Dec 01-31	35198
Summed total	**795850**

Date	Chillers energy (MWh)	Ap Sys chillers energy (MWh)	Ap Sys heat rej fans/pumps energy (MWh)	Total system energy (MWh)	Total electricity (MWh)	Total energy (MWh)
Jan 01-31	5.6695	5.6695	1.7004	20.8287	51.637	51.6534
Feb 01-28	10.1023	10.1023	3.0302	26.7827	55.1874	56.0344
Mar 01-31	28.8375	28.8375	8.6515	52.2109	85.6567	85.6567
Apr 01-30	53.1644	53.1644	15.9495	83.2746	115.5555	115.6335
May 01-31	77.3615	77.3615	23.2092	114.2061	145.0507	145.2453
Jun 01-30	103.6649	103.6649	31.0992	148.93	181.6676	181.7508
Jul 01-31	117.9887	117.9887	35.3965	167.468	199.5252	199.5252
Aug 01-31	122.2716	122.2716	36.6822	173.0366	204.9768	204.9768
Sep 01-30	109.1729	109.1729	32.752	156.1061	188.485	188.5833
Oct 01-31	71.8601	71.8601	21.5585	106.8595	137.8911	137.8911
Nov 01-30	45.0838	45.0838	13.5257	72.6909	105.1502	105.1502
Dec 01-31	14.9685	14.9685	4.4913	34.2146	68.0698	68.103
Summed total	**760.1472**	**760.1472**	**228.0446**	**1156.6101**	**1538.8546**	**1540.2053**