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# Improving the Estidama Rating for New ADEC Prototype Schools by Renewable Energy Integration Joud Abdalla Al Jumaa Al Dakheel

Joud Abdalla Al Jumaa Al Dakheel

جامعة الإمارات العربيـة المتحدة
United Arab Emirates University

United Arab Emirates University

College of Engineering

Department of Architectural Engineering

# IMPROVING THE *ESTIDAMA* RATING FOR NEW *ADEC* PROTOTYPE SCHOOLS BY RENEWABLE ENERGY INTEGRATION

Joud Abdalla Al Jumaa Al Dakheel

This thesis is submitted in partial fulfillment of the requirements for the degree of Master of Science in Architectural Engineering

Under the Supervision of Professor Kheira Anissa Tabet Aoul

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**Declaration of Original Work**

I, Joud Abdalla Al Jumaa Al Dakheel, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Improving the Estidama Rating for New ADEC Prototype Schools by Renewable Energy Integration*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Professor Kheira Anissa Tabet Aoul, in the College of Engineering at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

Student's Signature: ____________ Date: 21-6-2017

# Approval of the Master Thesis

This Master Thesis is approved by the following Examining Committee Members:

1) Advisor: Professor Kheira Anissa Tabet Aoul
   Title: Professor
   Department of Architecture
   College of Engineering

   Signature ______________________ Date 26-05-2017

2) Member: Dr. Rashed K. Al Shaali
   Title: Assistant Professor
   Department of Architecture
   College of Engineering

   Signature ______________________ Date 31-5-2017

3) Member (External Examiner): Professor Moncef Krarti
   Title: Professor
   Department of Civil, Environmental and Architectural Engineering
   Institution: University of Colorado at Boulder, USA

   Signature ______________________ Date 21-5-2017

   on behalf of Prof. Moncef

This Master Thesis is accepted by:

Dean of the College of Engineering: Professor Sabah Alkass

Signature ____________________ Date 21/6/2017

Dean of the College of Graduate Studies: Professor Nagi T. Wakim

Signature ____________________ Date 2/7/2017

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# Abstract

The building sector in the United Arab Emirates (UAE) has experienced a tremendous expansion in the last forty years due to population growth and economic development. Presently, the UAE has one of the world's largest energy consumption per capita, with the building sector accounting for 70% of the consumed energy. In the last decade, the government intensified its efforts to implement stringent environmental regulations and schemes by mandating environmental policies and regulations. It introduced "*Estidama*"; the local sustainability framework, and the Pearl Building Rating System (PBRS) to promote the development of sustainable buildings. All governmental buildings must achieve a minimum of 2 out of a maximum of 5 Pearls. Among these, schools are dominant in numbers and target the dual intent to create a sustainable as well as a healthy learning environment. In this regard, Abu Dhabi Educational Council (ADEC) has targeted all new schools to go beyond the requirement and reach 3 Pearls by planning to build 100 new schools from 2010 to 2020. Presently, 53 schools had been built. However, only 10 of the built schools have achieved the desired target.

The objective of this research is to investigate the opportunities of enhancing the performance of ADEC schools that did not achieve the targeted *Estidama* level through a representative school prototype. Hence, an analysis of the *Estidama* performance of the school was carried out to identify the opportunities of enhancement which showed a gap within the renewable energy systems. Next, a transient simulation tool TRNSYS, was used to assess and predict the performance of three renewable energy systems namely Photovoltaic System (PV), Solar Powered Absorption Chiller and Geothermal System. These systems were selected based on a literature review done to show their effective performances. Several parameters were optimized in each system to reach optimal performances. The photovoltaic system was sized to achieve 10% of the annual energy consumption and the solar absorption chiller targeted a cooling demand reduction of 10%. The geothermal system was sized to reach optimum values of delivered energy and outlet temperature of the ground heat exchanger. Finally, a simple payback period was done on the three systems to determine the economic feasibility of renewable energy in ADEC schools.

Key findings revealed that the PV panels achieved the targeted 10% of the annual energy consumption producing 208849.32 kWh annually. The optimized solar absorption chiller system showed 19% annual cooling savings and 7.2% savings from the overall energy consumption of the school. The geothermal system findings implied 2.2% from the total energy consumption and 5.8% from the annual cooling consumption. The three renewable energy systems have shown collectively 19% savings of the annual energy consumption. The simple payback period for PV and solar absorption chiller was 3.5 years and for the geothermal system was 8 years. The proposed school design increased the credits of the school by 14 additional credit points and reached the targeted 3 Pearls. Finally, these results augur a great potential in integrating renewable energy systems in future ADEC schools for an improved energy performance.

**Keywords**: Abu Dhabi Educational Council Schools, *Estidama*, Pearl Building Rating System, Enhance Energy Performance, Renewable Energy, Photovoltaic, Solar Absorption Chiller, Geothermal, TRNSYS.

## Title and Abstract (in Arabic)

# تحسين مستوى استدامة لمدارس مجلس أبوظبي للتعليم من خلال إضافة أنظمة الطاقة المتجددة


### *الملخص*

شَهِد قطاع البناء في دولة الإمارات العربية المتحدة توسعاً هائلا في السنوات الأربعين الماضية بسبب النمو السكاني والتنمية الاقتصادية. وفي الوقت الحاضر، تعد الإمارات واحدة من أكثر دول العالم استهلاكاً للطاقة حيث أن وزارة الطاقة قد أفادت بأن معدل استهلاك الفرد من الكهرباء يعد من بين الأعلى على المستوى العالمي في حين أن قطاع البناء يستهلك 70% من الطاقة الكهربائية. في العقد الأخير، كثّفت الحكومة جهودها لتطبيق أنظمة ومخططات بيئية صارمة عن طريق فرض سياسات وأنظمة جديدة لترشيد استهلاك الطاقة و جعلها أكثر كفاءة. و بناء على ذلك كانت انطلاقة برنامج "استدامة" في عام 2008 ، و هو برنامج قائم على تحسين قطاع البناء من خلال تبني اسلوب المباني الخضراء و المستدامة. و في هذا الصدد تم انشاء نظام تقييم المباني بدرجات اللؤلؤ (The Pearl Building Rating System) لتعزيز تطوير المباني المستدامة و يعد هذا النظام إطار عمل لبناء واستخدام مستدام للمجمعات العمرانية والمباني. و لقد توجب على جميع المباني الحكومية تحقيق ما لا يقل عن 2 من الحد الأقصى من 5 درجات من المقياس. و مما هو جدير بالذكر أن من بين هذه المباني، تهيمن المدارس على أعداد كبيرة وتستهدف النية المزدوجة لخلق بيئة تعليمية مستدامة وصحية. وفي هذا الصدد استهدف مجلس أبوظبي للتعليم جميع المدارس الجديدة لتجاوز متطلبات "استدامة" والوصول إلى 3 لآلئ من خلال التخطيط لبناء 100 مدرسة جديدة بين عامي 2010 إلى 2020. حتى يومنا هذا قد تم بناء 53 مدرسة, ولكن لم تحقق سوى 10 من المدارس المبنية الهدف المنشود.

الهدف من هذا البحث هو دراسة فرص تعزيز أداء مدارس مجلس أبوظبي للتعليم التي لم تحقق مستوى الإستدامة المستهدف من خلال دراسة نموذج أولي من المدارس. و بناءً على ذلك فقد تم إجراء دراسة و تحليل لأداء استدامة للمدرسة المختارة للدراسة و ذلك لتحديد فرص التحسين والتي أظهرت وجود فجوة في أنظمة الطاقة المتجددة. من ثَمّ تم استخدام برنامج محاكاة (Simulation) يسمى (TRNSYS) لتقييم وتوقع أداء ثلاثة أنظمة للطاقة المتجددة: الأول هو نظام الطاقة الكهروضوئية (Photovoltaic System)، الثاني هو مبرد الامتصاص

المعتمد على الطاقة الشمسية (Solar Absorption Chiller) والثالث هو الطاقة الحرارية الأرضية (Geothermal System).

لقد تم اختيار هذه الأنظمة استنادا إلى ما تم ايجاده اثناء مراجعة البحوث و الاختبارات السابقة التي أجريت لإظهار أدائها الفعال. و قد تم تحسين العديد من الاعدادت في كل نظام للوصول إلى الأداء الأمثل. وتم تحديد حجم النظام الكهروضوئي (Photovoltaic) لتحقيق 10٪ من الاستهلاك السنوي للطاقة ,و تحديد 10% كنسبة لخفض معدل كهرباء التبريد السنوي من خلال مبرد الامتصاص المعتمد على الطاقة الشمسية (Solar Absorption Chiller), وحساب نظام الطاقة الحرارية الأرضية (Geothermal System) للوصول إلى القيمة الأمثل للطاقة ودرجة حرارة مناسبة للتبريد. و في النهاية قد تمّ حساب فترة استردادا القيمة المادية (Simple Payback Period) للأنظمة الثلاثة للطاقة المتجددة في المدرسة.

أظهرت النتائج الرئيسية أن الألواح الكهروضوئية حققت ال10٪ المستهدفة من الاستهلاك السنوي للطاقة المنتجة 208849.32 (kWh). بينما أظهرت نتائج نظام تبريد الامتصاص المعتمد على الطاقة الشمسية توفيراً وصل إلى 19٪ من التبريد السنوي و 7.2٪ من إجمالي استهلاك الطاقة من المدرسة. وقد أشارت نتائج نظام الطاقة الحرارية الأرضية إلى توفير يعادل فقط 2.2٪ من إجمالي استهلاك الطاقة و 5.8٪ من استهلاك التبريد السنوي. وقد أظهرت محاكاة أنظمة الطاقة المتجددة الثلاثة معاً توفير بنسبة 19٪ من الاستهلاك السنوي للطاقة. و قد أشارت النتائج أن فترة الاسترداد للألواح الكهروضوئية و نظام تبريد الامتصاص المعتمد على الطاقة الشمسية هي ثلاثة سنوات و نصف أما نظام الطاقة الحرارية الأرضية فقد أشار إلى أن قيمة الاسترداد هي ثمانية سنوات. وازدادت نقاط تقييم المدرسة بمقدار 14 نقطة إضافية نسبة لنظام "استدامة" ووصلت إلى 3 درجات من الآلئ (المقياس المعتمد).و في الختام, إن هذه النتائج تبشر بإمكانيات كبيرة في دمج أنظمة الطاقة المتجددة في مدارس مجلس أبوظبي للتعليم المستقبلية لتحسين أداء الطاقة.

**مفاهيم البحث الرئيسية**: مدارس مجلس أبوظبي للتعليم ،استدامة،نظام تقييم اللؤلؤة للمباني، تعزيز أداء الطاقة، الطاقة المتجددة، النظام الكهروضوئي،مبرد الامتصاص المعتمد على الطاقة الشمسية، الطاقة الحرارية الأرضية،TRNSYS.

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My final words go to my role model my father who supported me all the way and believed in me and my capabilities, my dear mother, who was behind my success in my life, and my sisters and brother who have always been there for me.

# Dedication

*To my beloved parents and family*

*To my friends*

*To my Advisors*

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## List of Abbreviations

| | |
|---|---|
| ADEC | Abu Dhabi Educational Council |
| ADWEA | Abu Dhabi Water and Energy Authority |
| DEWA | Dubai Electricity and Water Authority |
| GDP | Gross Domestic Product |
| PBRS | Pearl Building Rating System |
| PRS | Pearl Rating System |
| TWh | Terawatt Hours |
| UNFCCC | United Nation Framework Convention on Climate Change |
| ADCED | Abu Dhabi Council for Economic Development |
| AGEDI | Abu Dhabi Global Environment Data Initiative |
| a-Si | Amorphous Silicon |
| C1 | Cycle 1 |
| C2 | Cycle 2 |
| C3 | Cycle 3 |
| CIS | Copper Indium Disulfide |
| COP | Conference of the Parties |
| CSC | Complete Sustainable Communities |
| c-Si | Crystalline Silicon |
| DC | Direct Current |
| EAD | Environment Agency - Abu Dhabi |
| EESs | Earth-Energy Systems |
| EFI | Ecological Footprint Initiative |
| EWS-WWF | Emirates Wildlife Society - World Wildlife Fund |

| | |
|---|---|
| GEs | Geo-Exchange Systems |
| GFN | Global Footprint Network |
| GHA | Global Hectares |
| GSHPs | Ground-Source Heat Pumps |
| GWP | Global Warming Potential |
| HIT | Hetero-Junction Incorporating Thin |
| HTG | High Temperature Generator |
| ICAO | International Civil Aviation Organization |
| IDP | Integrated Development Process |
| IP | Innovating Practice |
| KG | Kindergarten |
| kW | Kilo-Watts |
| kWh | Kilo-Watt Hours |
| LB | Livable Buildings |
| LTG | Low Temperature Generator |
| mc-Si | Mono-Crystalline |
| MOE | Ministry of Education |
| MOEW | Ministry of Environment and Water |
| m-Si | Multi-Crystalline Silicon |
| NS | Natural Systems |
| ODP | Ozone Depletion Potential |
| pc-Si | Poly-Crystalline |
| PV | Photovoltaic |
| PW | Precious Water |

| | |
|---|---|
| RE | Resourceful Energy |
| SHC | Solar Heating and Cooling Systems |
| SM | Stewarding Materials |
| TRNSYS | Transient Systems Simulation Program |
| UAE | United Arab Emirates |
| UPC | Urban Planning Council |

# Chapter 1: Introduction

## 1.1 Overview

Energy efficiency is a growing challenge in the United Arab Emirates (UAE), due to population growth, urbanization, economic activity, and high electric consumption. The building sector in the UAE, one of the leading sectors in economic development, has experienced a tremendous growth in the last 40 years. Buildings consume more energy than any other sector in the UAE, accounting for 80 percent of the electrical energy consumed (Ministry-of-Energy, 2015). To address this challenge, the UAE embraced comprehensive energy efficiency, similar to the global agenda set by international protocols and the United Nation Framework Convention on Climate Change (UNFCCC). For this purpose the UAE adhered to the international protocols with a clear understanding of the need to tackle the increasing energy consumption.

At a local level, in 2007, the UAE started initiating its own sustainability frameworks to comply with their future visions. Energy efficiency and conservation are important pillars in the UAE sustainability plans. Abu Dhabi Emirate, the capital of the UAE, has driven the efforts to make buildings more efficient; in that regard they established "*Estidama";* the local sustainability framework (Estidama, 2010a). In 2010, the Pearl Building Rating System (PBRS) was developed by "*Estidama"* as the UAE's building rating system which aimed at promoting the development of sustainable buildings. The highest weight in the guideline is attributed to the energy and water categories, due to the scarcity of water and extreme climate conditions that required substantial amount of cooling. The rest of the categories similar to most rating systems include consideration of site, building management strategies, and indoor and outdoor building environment. The system rates buildings on a ranking of 1 Pearl being the lowest to 5 Pearls being the highest.

Starting from 2010 onwards, new villas and communities are required by the UAE government to meet the minimum rating of one Pearl. However, governmental buildings have more stringent requirements to meet higher level performance since they are obliged to achieve a minimum of two Pearls. Schools are a corpus of governmental buildings and should abide by these requirements. Education in the UAE was challenged in the provision of new schools that meets the ongoing population growth demand and green buildings standards. As a response, Abu Dhabi Educational Council (ADEC) was established by the government to improve the built environment of existing schools by complying with the PBRS of "*Estidama"* and to build new schools in order to overcome the population growth. ADEC has targeted a higher performance standard of achieving three Pearls rating based on "*Estidama"* requirements. They initiated a plan to build new sustainable designed schools with an aim to build a hundred new schools between 2010 and 2020 (ADEC, 2012).

## 1.2 Problem Statement

ADEC developed the "Future Schools Program" initiative aiming to build 100 new sustainable public schools. The program intends to go beyond the minimum required rating for governmental buildings targeting a higher performance reaching 3 Pearls based on the PBRS. Presently, fifty-three new schools have been built. However, only 20% of the built schools reached the target (3 pearls). The remaining schools have only achieved the mandated 2 Pearls.

### 1.3 Research Objectives and Questions

This research aims to investigate the opportunities of enhancing the performance level on *Estidama* rating for ADEC schools using a school prototype that achieved two Pearls. For this purpose, an assessment of the performance was carried out in order to explore potential areas of improvement.

This research seeks to answer the following major question:

- What are the possible opportunities for ADEC prototype school with 2 Pearls to achieve a higher performance and reach 3 Pearls rating?

To answer this question, the research aimed to critically:

1. Assess the attained and un-attained credits of / on *Estidama* PBRS.
2. Determine the performance gaps in the PBRS performance of the school.
3. Identify the credit performance enhancement technical and economical feasibility.

### 1.4 Research Methodology

The target of the research was based on qualitative critical analysis and quantitative analysis for the performance enhancement. The qualitative critical analysis assessed *Estidama* performance of the prototypical school and determined the gaps and opportunities of improvement. The critical analysis revealed a gap in adopting renewable energy in the prototype school. As a result, three renewable energy systems namely photovoltaic system, solar thermal absorption chiller and geothermal system were selected based on a thorough literature review. The systems were examined to test the opportunity of their application in ADEC schools in the

UAE context. Thus, quantitative analysis was done using e-QUEST for its strong features for building modeling simulations where it was used to predict the monthly energy consumption of the school. Then a transient simulation program TRNSYS was used for its strong capabilities in systems analysis and has allows more flexibility of changing variables and parameters where it tested the energy performance of the three renewable energy systems. Finally, simple payback period economic analysis has been carried out on the three systems to evaluate the feasibility of their application in the school. The structure of the work and the steps approaching the research problem are illustrated in Figure 1.1.

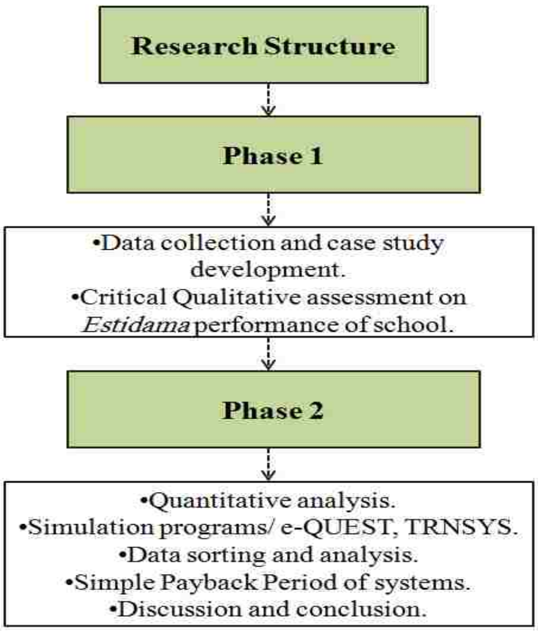


Figure 1.1: Research Design

Expected results will improve the energy performance of the school, increase the Pearl ratings and enhance the future of ADEC public schools in Abu Dhabi Emirate.

## 1.5 Thesis Organization

This work is structured in six chapters and is summarized as follows:

**Chapter One** introduces the problem, sets the objective of the thesis and outlines the research questions and methodology.

**Chapter Two** presents an extensive review of the energy status of the UAE, the increase in electricity demand and the environmental initiatives and regulations that were initiated by the UAE government as a response action to these challenges. Additionally, the chapter investigates "*Estidama*" the local sustainability framework and the green building rating system the "Pearl Building Rating System" established in Abu Dhabi Emirate.

**Chapter Three** identifies the development of the built environment of the schools in Abu Dhabi Emirate and the establishment of ADEC to promote a healthy educational environment for public schools. Additionally, the chapter describes the case study by providing a detailed demonstration of a representative prototype of ADEC schools for performance enhancement.

**Chapter Four** describes the research methodology adopted and shows the critical assessment done on "*Estidama*" performance of the case study.

**Chapter Five** discusses the optimization process of enhancing the energy performance of the school through presenting the simulation model setup, then the results and discussion of the work and finally showing the economic analysis used to evaluate the feasibility of the systems.

**Chapter Six** assess if the objective of this study are met, discusses the limitations of the work with a series of recommendations and conclude with suggested future work suggestions.

# Chapter 2: The United Arab Emirates Move towards Sustainability

## 2.1 Introduction

Economic development, population growth rates and a fairly low energy cost in the UAE, has led to vast increase in the country's energy consumption, making it one of the highest energy consumers per capita in the world (Kazim, 2007). Consequently, environmental pollution and carbon emissions have increased in a dramatic way. Since 2007, the government has intensified its efforts to implement stringent environmental regulations, and schemes on various sectors and mandate tough environmental policies to enlighten the public about energy conservation (Ministry-of-Energy, 2015).

In light of the above, this chapter gives a general overview of the UAE, with a focus on Abu Dhabi Emirate. Electric and energy consumption growth are discussed and the mitigation strategies undertaken to control these issues are laid out. In this context, the newly established local sustainability framework "*Estidama*" and its building rating system are presented.

## 2.2 Overview of the United Arab Emirates

### 2.2.1 Geography and Climate Conditions of the UAE

The United Arab Emirates is located in Southwest Asia between latitudes 22.0° and 26.5° N and 51° and 56.5° E (MOE, 2006). The UAE was established in 1971 as a federation of seven Emirates – Abu Dhabi, Dubai, Sharjah, Umm al-Quwain, Ajman, Ras Al Khaimah and, Fujairah - that span approximately 83,600 square kilometers (Figure 2.1) (MOE, 2006). The UAE shares borders with Qatar to the west, Saudi Arabia to the south and west, the Sultanate of Oman to the east and south and the Arabian Gulf and the Gulf of Oman to the north.

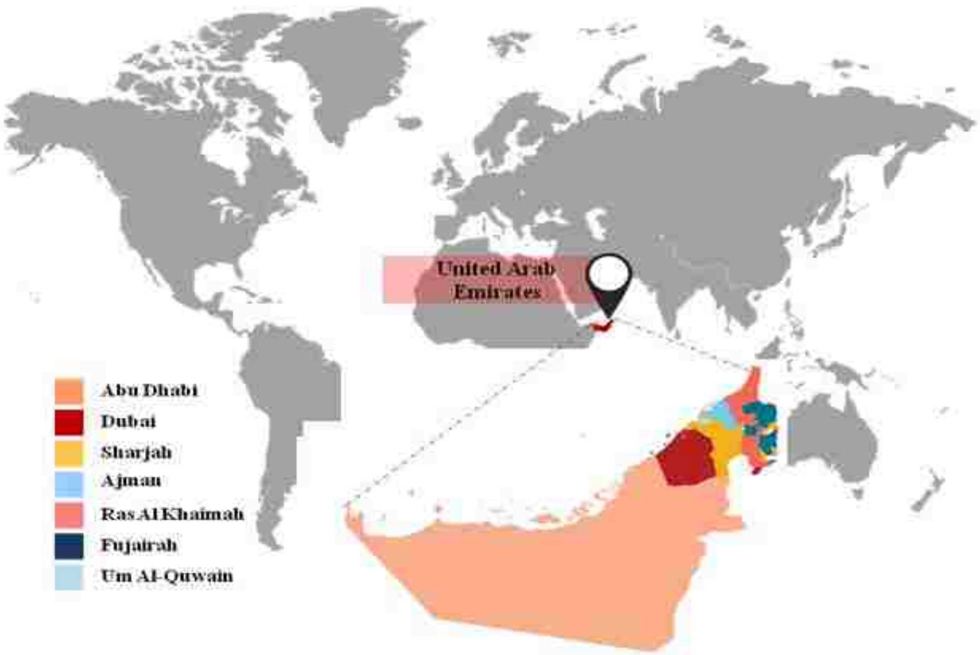


Figure 2.1: United Arab Emirates Map (Worldmap, 2016)

The UAE can be divided into 3 major ecological areas: coastal, mountainous and desert areas. Over four-fifths of the UAE is desert, especially the western part of the country (MOE, 2006).

The UAE has a hot arid climate that is subject to ocean effects (MOE, 2006). It is characterized by two main seasons; a mild winter which lasts from November to March, and summer which lasts from April through October. The winter temperature in Abu Dhabi ranges between 14 and 23 degrees Centigrade, while summers are very hot and humid with temperature ranging from 35 to 48 degrees Centigrade, while humidity levels can often reach 90% (World-Weather, 2016). Humidity averages between 50% and 60% in coastal areas, and declines sharply inland where its annual average reaches 45%. Most of the country is subject to violent dust storms with rare rainfall. Average annual weather characteristics including precipitation, high and low temperatures and rainfall days are presented in Figure 2.2 (World-Weather, 2016).

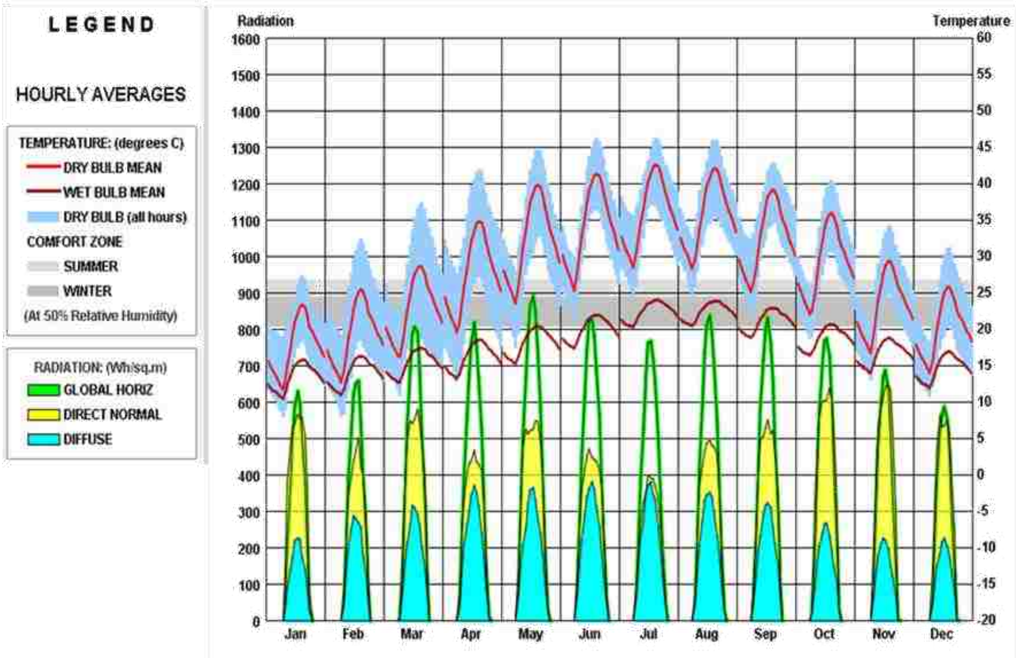


Figure 2.2: Climate of Abu Dhabi (Climate-Consultant, 2017a)

### 2.2.2 Population and Urbanization

During the last 10 years, the UAE has experienced high rates of population growth due to urbanization, immigration and economic growth. The population has been estimated in the last census of 2014 at 9.45 million in which it has increased by 50% since 2006 (Figure 2.3) (World-Bank, 2015).

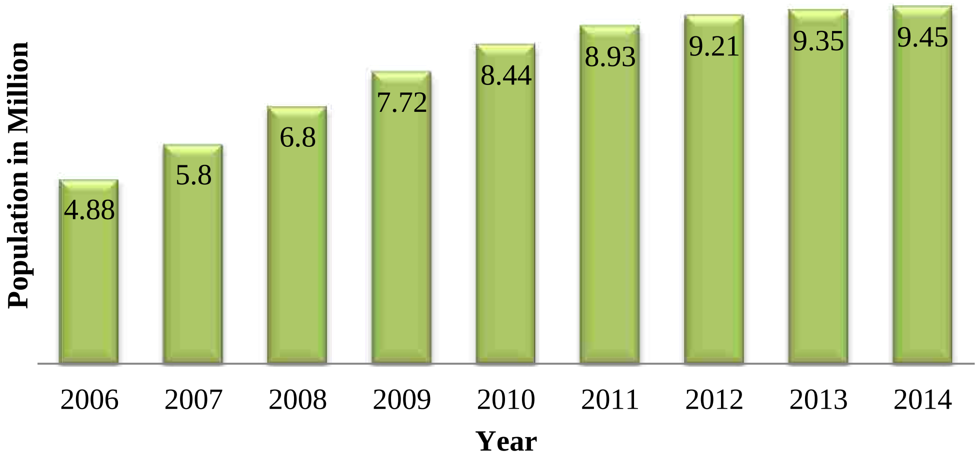


Figure 2.3: Population in the United Arab Emirates (World-Bank, 2015)

Immigration has been the primary driver of population growth in the UAE, with immigrants making up the vast majority of the total population. As the composition of the UAE population is 11% nationals and the rest are expats. However, Abu Dhabi Emirate houses the highest ratio of UAE nationals (Figure 2.4).

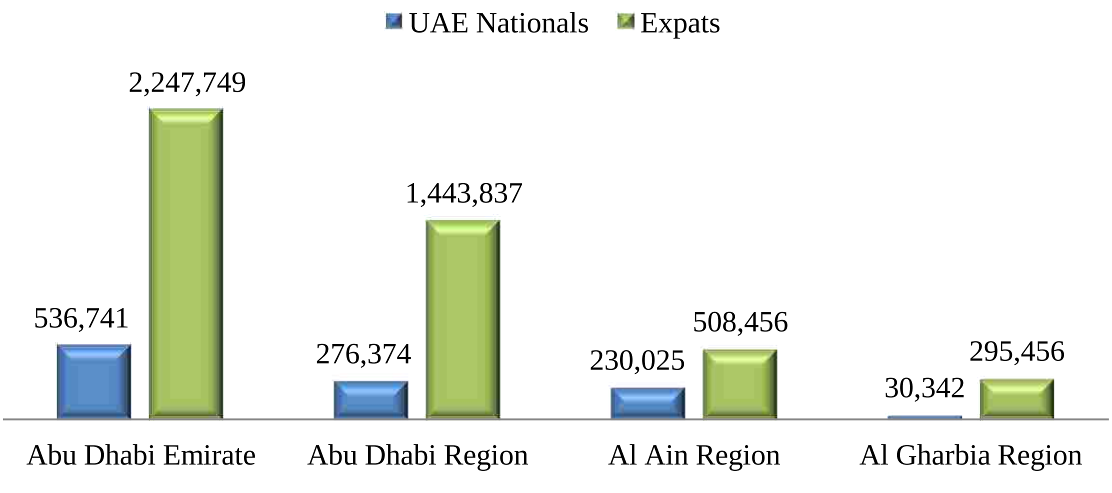


Figure 2.4: Population in Abu Dhabi Emirate by Region (SCAD, 2016)

### 2.2.3 Energy Status in the UAE

Population growth and urbanization has led to increased energy consumption in the UAE. The Gross Domestic Product (GDP) has also experienced a tremendous growth; by which it was almost 100 USD Billion in 2000 increased to 370 USD Billion in 2016 (Figure 2.5) (World-Bank, 2016).

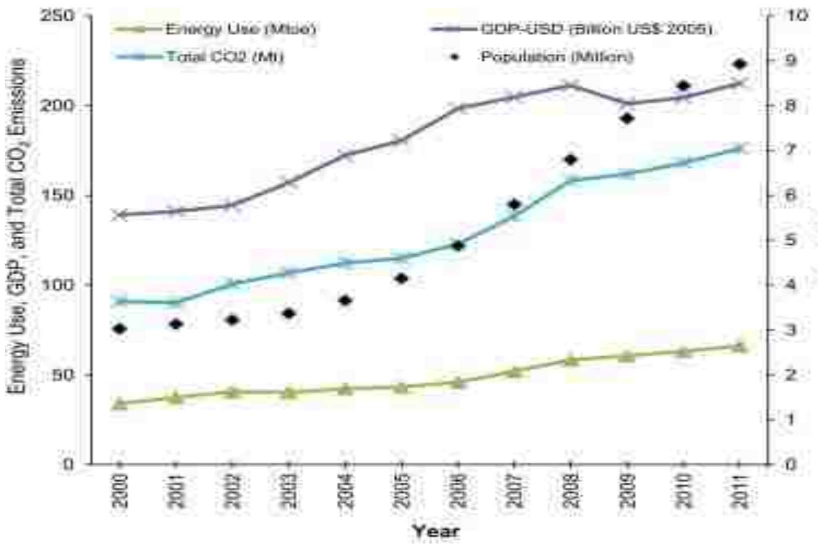


Figure 2.5: Energy and GDP Use in Relation to Population Growth in the UAE (Khondaker et al., 2016)

The UAE is a rich gas and oil resource country. Its estimated oil reserves are about 100 billion barrels of oil, close to 10% of the world's reserves. Whereas its natural gas reserves, ranks the UAE fifth worldwide, with about 200 trillion cubic feet (Ministry-of-Energy, 2015). In 2014 the UAE consumed 112 terawatt hours (TWh) electricity, an increase of 56% from 2004 where 49 TWh was consumed (Ministry-of-Energy, 2015). As a result, carbon emissions has increased by around 50% from 2004 (103 Metric tons) to 2013 (168 Metric tons) (IEA, 2016). Energy demand has significantly increased, in accordance with the gross domestic product (GDP) - 49.7% for Abu Dhabi Water and Energy Authority (ADWEA) and 25.8%

for Dubai Electricity and Water Authority (DEWA) between 2008 and 2012 (Ministry-of-Energy, 2015).

### 2.2.4 Ecological Footprint of the UAE

The environmental impacts resulting from the high population, economic, urbanization and intensive energy increase were significant; by which the UAE had the highest ecological footprint in the world in 2006 (Emirates-Wildlife-Society, 2011). The ecological footprint per capita in the UAE in 2006 was 11.68 global hectares per person (gha) compared to 2.7 (gha) worldwide global hectares (Emirates-Wildlife-Society, 2011). This high ecological footprint is a result of very harsh climate and limited resources that require substantial quantities of energy for cooling and seawater desalination; where the building sector is the most dominant contributor. The UAE has witnessed a dramatic expansion in the building sector in a short period of time, which can be seen in Abu Dhabi and Dubai Skyline (Figure 2.6). However, buildings prior to 2007 were built without energy efficiency codes and standards consideration making an intensive energy demand.

Figure 2.6: Abu Dhabi and Dubai Skyline (left, (Dacat, 2013), right, (Wikipedia Commons, 2010))

As a result, Ecological Footprint Initiative (EFI) was initiated in 2007. It is a partnership, between the Ministry of Environment and Water (MOEW); Abu Dhabi Global Environment Data Initiative (AGEDI), a UAE Government initiative championed by Environment Agency - Abu Dhabi (EAD); the Emirates Wildlife Society in association with World Wildlife Fund (EWS-WWF); and the Global Footprint Network (GFN) (Emirates-Wildlife-Society, 2011). This initiative has helped UAE governmental institutions to spread awareness between people to take actions to reduce the country's EF. In 2009-2010, a scientific tool was developed by the EFI to track the power and water sector's and forecast the carbon dioxide emissions reduction by 2030 if mitigation strategies were enforced. Predictions has shown that up to 40% CO2 emissions can be reduced by 2030, and the UAE's overall per capita Footprint could be reduced by 1 gha/person (Emirates-Wildlife-Society, 2011).

## 2.3 Energy Consumption and Mitigation Strategies in Buildings

### 2.3.1 Energy Consumption Challenges in Buildings

Studies have shown that the building sector accounts for 40% of the total energy consumption and over one third of the total greenhouse gas emissions and waste generation in the world (U.N.E.P, 2009). Whereas the building sector in the UAE accounts for almost 80% of electricity consumption which is twofold the energy consumed worldwide (Hanan and Yasser, 2014). The electricity consumption in built environment is distributed among residential, commercial, governmental and schools and industrial sectors Figure 2.7. The largest electricity is consumed in residential sector, while the third largest electricity consumption is attributed to governmental buildings including schools (Taleb and Al-Saleh, 2014).

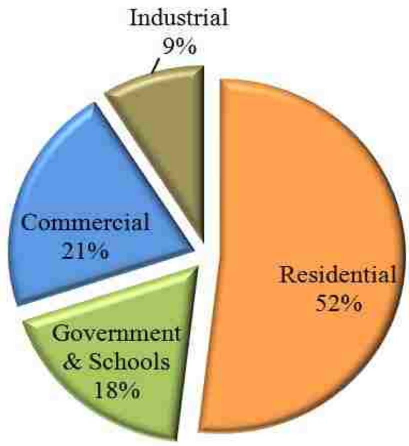


Figure 2.7: Electricity Consumption by Sector in the UAE (Taleb and Al-Saleh, 2014)

Due to the harsh climate in the UAE, about 60–75% of the total building electricity is needed for cooling (Radhi, 2009). The highest electricity is consumed by the chillers and air conditioning systems due to the harsh summer climates in the UAE (Figure 2.8) (Afshari et al., 2014).

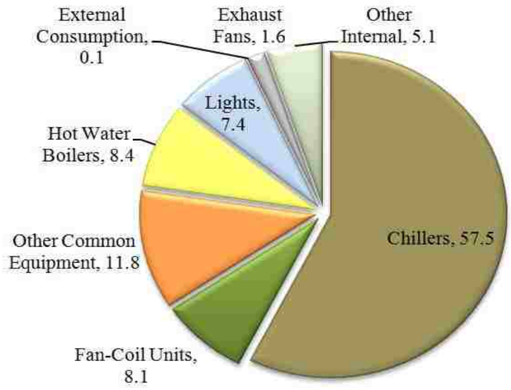


Figure 2.8: Electricity Consumption per End-use Break-down (Afshari et al., 2014)

The energy consumption in the UAE had been increasing at an annual rate of 4% over the past six years (Ministry-of-Energy, 2015). It is predicted that this increase will reach up to 5% through 2020 (EIA, 2014). Due to the increasing rate of population, rapid urbanization and low cost of energy, the UAE has become one of the highest per capita energy consumers in the world (Li and Lam, 2001). The UAE were the 12th world's largest consumer of electricity per capita during 2006, 2008 and 2010 (Mokri et al., 2013). Due to the population increase in the UAE, the electricity consumption has dramatically increased since the 2000 (Figure 2.9) (Central-Intelligence-Agency, 2015).

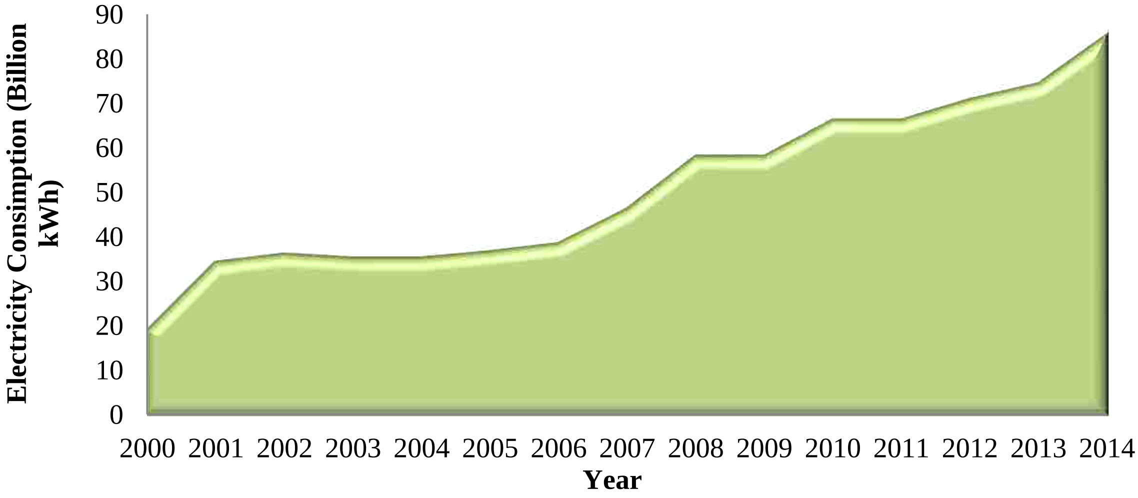


Figure 2.9: Electricity Consumption in the UAE (Central-Intelligence-Agency, 2015)

In light of the above identified rapid energy usage growth, a line of actions has been initiated and is addressed in the following sections to show the UAE's mitigation strategies that were done in order to overcome those problems.

### 2.3.2 UAE and Environmental International Protocols

The UAE joined the international driven initiatives for climate change, in which it collaborated with the United Nations Framework Convention on Climate Change (UNFCCC). The UAE participated in the negotiations of the UNFCCC with a clear recognition of the urgent need to tackle climate change (Ministry-of-Energy, 2015). Additionally, the country has joined Conference of the Parties (COP 21) in Paris in 2015 with the aim to work constructively towards limiting global average temperature rise to 2°C (Climate-Action, 2015). The UAE also joined several institutions that works on climate issues in the world such as; the Cartagena Group, OPEC, League of Arab States, The Clean Energy Ministerial and the International Civil Aviation Organization (ICAO) (Ministry-of-Energy, 2015). Furthermore, the UAE started acting as a major player in this issue by hosting Abu Dhabi Ascent in 2014 in support of Climate Summit 2014 and by hosting the World Future Energy Summit in Abu Dhabi in 2016 and 2017 (Ministry-of-Energy, 2015).

In addition to joining international protocols, the UAE has undertaken numerous actions domestically to mitigate climate change.

### 2.3.3 UAE Green Buildings Initiatives

The UAE initiated several initiatives and building guidelines in order to address short term and long term environmental problems. The UAE is striving to achieve sustainability at economic, social and environmental levels.

The timeline of these initiatives as presented in Figure 2.10 illustrates the different steps undertaken in several emirates to promote green buildings.

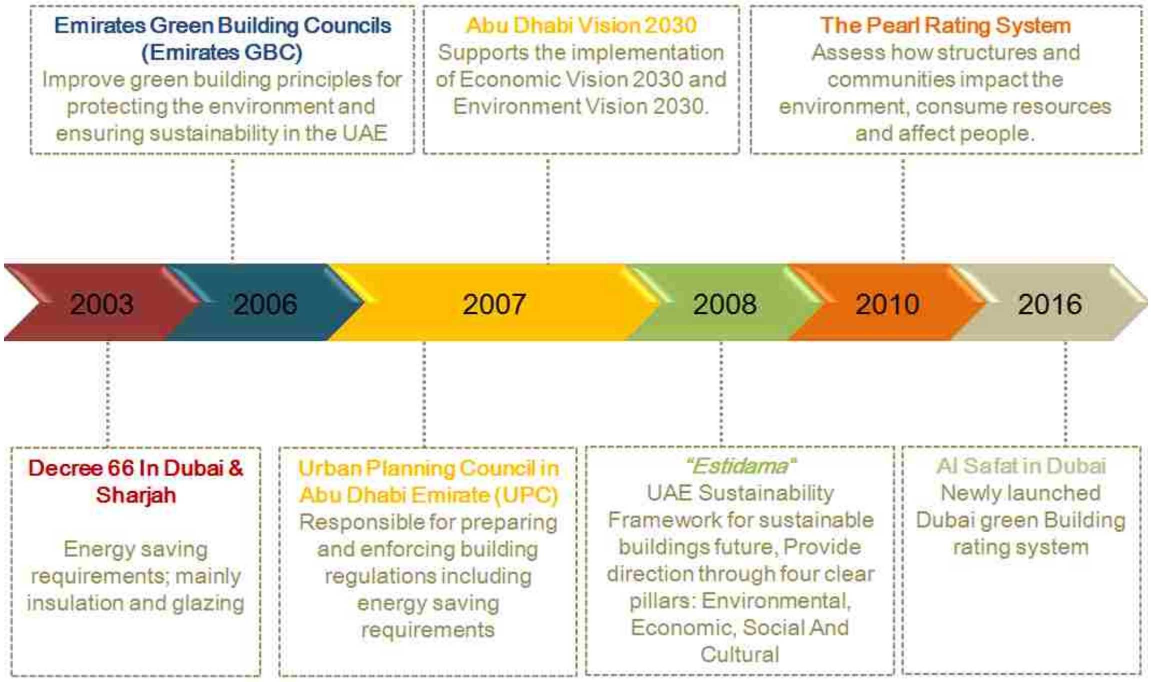


Figure 2.10: Timeline of UAE Green Building Initiatives

The following section details the initiatives and guideline established in Abu Dhabi Emirate, the location of our case study; the Urban Planning Council (UPC), Abu Dhabi Vision 2030, *Estidama* Rating System and The Pearl Rating System.

## 2.4 Sustainability in the Emirate of Abu Dhabi; Actions and Stakeholders

### 2.4.1 Overview

Abu Dhabi Urban Planning Council (UPC) was created by Decree number 23, to be responsible for the future of Abu Dhabi's urban environments and the visionary Plan Abu Dhabi 2030 urban structure framework (UPC, 2009). The UPC focuses on both; economic activities and the development of a professionally designed and well-managed urban environment in the Emirate. It ensures best practice in planning for both new and existing urban areas. The main mission of the UPC is to develop the urban environment of Abu Dhabi according to the Vision 2030 as well as existing urban areas, by providing and managing the supporting initiatives (UPC, 2009). One of the main priorities is developing the infrastructure with sustainable concepts and environmentally friendly approaches (UPC, 2009). In order to be able to transfer the 2030 Vision into a physical setting, UPC developed strategic plans and guiding principles for the influential projects that have a major effect on shaping the Emirate. A holistic analysis was carried out for the urban fabric, the land available and its best use, environmental, mobility, infrastructure and urban services to be integrated in the City Development Strategy. Sustainability policies in Abu Dhabi are grounded by three basic elements: the natural environment, economic development and cultural heritage (UPC, 2009).

The UPC made a plan for the whole of Abu Dhabi Emirate and has therefore re-branded Plan Abu Dhabi 2030 as 'Capital 2030'.This plan supported all the regions within Abu Dhabi Emirate including; Abu Dhabi region, Al Ain, Al Gharbia and the Marine area (UPC, 2009).

The UPC is dedicated to; develop plans for neighborhoods and blocks in Abu Dhabi, work with other governmental bodies, develop regulations and guidelines and incorporate *Estidama* principles of sustainability into the built environment (UPC, 2011).

### 2.4.2 Abu Dhabi 2030

Abu Dhabi 2030 was developed in 2007 by the UPC for optimizing the development of the Emirate through a 25 year program (UPC, 2009). Vision 2030 focuses on ensuring economically sustainable community that is socially consistent while preserving the Emirate's cultural heritage. The vision lays out the framework for development of the Emirate through guidelines for all new projects. The main principles of the vision are; ensuring sustainable economy, preserving natural environment of its coastal and desert ecologies, manifesting its role and stature as a capital city, protecting and enhancing the Emirate's culture and values (UPC, 2009).

Abu Dhabi Vision 2030 consists of two plans; the "Urban Development" and "Economic Development" of the Emirate, called Urban Planning Vision 2030 and Economic Vision 2030. The UPC communicates with other government departments to maintain a productive sustainability process from all aspects, such as; the Department of Transport, the Environment Agency, municipalities and utility providers (UPC, 2009). The UPC also collaborates with Abu Dhabi council for Economic Development (ADCED) to work on the economical part of the vision. The Urban Planning Vision 2030 that deals with the built environment is shown in Appendix A.

#### 2.4.2.1 Urban Planning Vision 2030

The Urban Planning Vision 2030 encompasses the need for measured and controlled growth throughout the Emirate and addressing the needs of its people. The Vision also promotes the development of the capital to ensure sustainable growth and a high quality of living. Abu Dhabi Island and the surrounding mainland are covered (UPC, 2016). The plan focuses first on the livability within the city, second, the provision of growth centers in downtown Abu Dhabi and within Capital District, third, the revitalization of existing locations across the metropolitan area and the importance of capturing culture and last, heritage through planning and design.

#### 2.4.2.2 Supporting Initiatives

The UPC developed several supporting manuals in plan 2030, in which each manual is dedicated to serve a purpose. The manuals are based on the Complete Sustainable Communities (CSC) initiative, which meets the diverse need of existing and future residents, their children and other users, and contribute to a high quality life by offering opportunity and choice. It is achieved by strategies that make effective use of natural resources, enhance the environment, promote social cohesion and inclusion, and strengthen economic prosperity (UPC, 2013). The CSC is divided into 4 main pillars of sustainability; Social Environmental, Economic and Cultural.

The UPC has launched several guidelines manuals; *Estidama* Sustainability Framework for Buildings, the Pearl Rating Systems for different building uses, the Public Realm Design Manual and the Urban Street Design Manual (UPC, 2013). These manuals have been launched in order to serve for all types of projects developed in Abu Dhabi, and assigned by organizing agencies to each manual in order to guide consultants to know which coordination is required with which agency. The relationship between the manuals, their use and benefits are illustrated in Figure 2.11 (UPC, 2013).


Figure 2.11: UPC Design Manuals Summary (UPC, 2013)

### 2.4.3 "*Estidama*" Sustainability Framework

#### 2.4.3.1 Vision and Mission

"*Estidama*" is the Arabic word for sustainability. *Estidama* is an initiative developed and promoted by the UPC in 2008. It is a demonstration of visionary governance promoting thoughtful and responsible development (Estidama, 2010a). *Estidama* is focused on the rapidly changing built environment to reduce the use of natural resources, to ensure less impact on the environment, to ensure better quality of life, and to achieve energy and water savings (Estidama, 2010b). The system emerged from the need to properly plan, design, construct and operate sustainable developments by overcoming the harsh climatic conditions and also maintaining the traditions embedded within the rich local culture. The main goal of *Estidama* is to preserve and enrich Abu Dhabi's physical and cultural identity, while always improving the quality of life for its residents (Estidama, 2010a).

*Estidama* is based on the integrated process of the four pillars: Environment, Economy, Society and Culture (Estidama, 2010a).

### 2.4.3.2 The Four Pillars of "*Estidama*"

*Estidama* is organized under four pillars that set the main principles of the urban planning vision:

- **Environment**

The principle of this pillar is to follow sustainable development to protect and enhance the ecology and natural resources for current and future generations. Planning in response to the desert climate and harsh weather and respecting the water and energy demand are the main objectives of this pillar (Estidama, 2010b). Additionally, protecting, preserving the environmental assets and limiting urban sprawl are important aspects that are considered.

- **Economy**

This pillar supports and empowers the growth of the economy of Abu Dhabi to transform the city into a global capital providing better opportunities. Transforming Abu Dhabi into a leading Emirate that attracts people and enterprises to its high quality of life, high-quality buildings, public realm and world-class transportation system is the main aim of this pillar (Estidama, 2010b).

- **Society**

The principle of this pillar is to raise the standards of living for residents and visitors of the Emirate by forming mixed-use communities and providing housing for all ranges of income. Creating communities that enable people to live, work and play in attractive, vibrant surroundings, providing a wide range of housing choices that meets with different range of income levels, Renovating communities with high-quality amenities and transportation and ensuring safety for people are the ultimate purpose of this pillar (Estidama, 2010b).

- **Culture**

The principle of this pillar is to protect and enrich Arab and Emirati traditions and culture, at the same time provide contemporary living respecting the diverse cultures residing and visiting Abu Dhabi. Furthermore, the pillar is responsible for ensuring that Emirati culture and local heritage are protected and enhanced through traditional living patterns and sustainable high quality Emirati architecture.

The Pearl Rating System similar to LEED and BREEAM (USGBC, 2017, BREEAM, 2017), has the specifics of recognizing the harsh weather climate of the Emirate, low water availability and unique Emirati culture.

### 2.4.4 The Pearl Rating System (PRS)

#### 2.4.4.1 Scope and Objectives

The Pearl Rating System (PRS) is an initiatives developed by the UPC to act as a rating system to assess the impact of buildings and communities to the environment, resources consumption and people (Estidama, 2010b). The PRS aims to address the sustainability of buildings and structures throughout its lifecycle from design through construction to operation. It provides design guidance and detailed requirements for rating a project's potential performance in relation to the four pillars of *Estidama*. It has been designed and published for communities, villas and buildings as a mandatory assessment tool in Abu Dhabi Emirate (Estidama, 2010b). The building certification covers offices, retail, schools, residential and mixed use buildings. The system aims to increase quality to achieve healthier working and living environments with lower operation and maintenance costs. This guideline help architects, developers and contractors to choose the most suitable materials in buildings (Estidama, 2010b).

The PBRS is categorized into seven parts that are essential for sustainable development, they form the heart of the Pearl Rating System (Estidama, 2010b):

1. **Integrated Development Process**: Encouraging cross-disciplinary teamwork to deliver environmental and quality management throughout the life of the project.
2. **Natural Systems**: Conserving, preserving and restoring the region's critical natural environments and habitats.
3. **Livable Buildings:** Improving the quality and connectivity of outdoor and indoor spaces.
4. **Precious Water:** Reducing water demand and encouraging efficient distribution and alternative water sources.
5. **Resourceful Energy:** Targeting energy conservation through passive design measures, reduced demand, energy efficiency and renewable sources.
6. **Stewarding Materials:** Ensuring consideration of the 'whole-of-life' cycle when selecting and specifying materials.

7. **Innovating Practice:** encouraging innovation in building design and construction to facilitate market and industry transformation.

### 2.4.4.2 The Pearl Building Rating System Levels and Weighting

The number of credit points might vary among several building types; offices, retail stores, villas and schools. This is done to reinforce the critical issues that should be addressed for a particular building use (Estidama, 2010b). The maximum credit points for each section in the PBRS are shown in Table 2.1.

| Credit Section | Maximum Credit Points |
|---|---|
| IDP – Integrated Development Process | 13 |
| NS – Natural Systems | 12 |
| LB - Livable Buildings | 37* |
| PW – Precious Water | 43* |
| RE – Resourceful Energy | 44 |
| SM – Stewarding Materials | 28 |
| IP – Innovating Practice | 3 |
| Total | 177* |

Table 2.1: Maximum Credit Points for PBRS Sections (Estidama, 2010b)

*LB: Maximum of 36 credit points available for offices and 30 credit points for retail.

*PW: Maximum of 45 credit points available for Schools.

*Total: Excludes Innovating Practice credit points which are offered as bonus credits.

In the seven categories of the PBRS there are both mandatory and optional credits and credit points are awarded for each optional credit achieved. The pearl rating system rates buildings based on the credits they achieve ranging from 1 Pearl being the minimum and 5 Pearls being the maximum (similar to LEED certifications ranging from Basic Certification to Platinum). The credit allowance for each Pearl Rating is shown in Table 2.2 (Estidama, 2010b).

| Requirement | Pearl Rating Achieved |
|---|---|
| All mandatory credits | 1 Pearl |
| All mandatory credits + 60 credit points | 2 Pearls |
| All mandatory credits + 85 credit points | 3 Pearls |
| All mandatory credits + 115 credit points | 4 Pearls |
| All mandatory credits + 140 credit points | 5 Pearls |

Table 2.2: PBRS Levels (Estidama, 2010b)

#### 2.4.4.3 The Pearl Rating Stages

The Pearl Rating System has three rating stages; Design, Construction and Operational (Estidama, 2010b):

**Pearl Design Rating:** The Design Rating rewards measures during the design development of the project that meet the intent and requirements of each credit, in which the Pearl Design Rating is valid only until construction is complete, where the project is identified as a Pearl Design Rated project.

**Pearl Construction Rating:** The Construction Rating ensures that the responsibilities made for the Design Rating have been achieved.

**Pearl Operational Rating:** The operational rating defines the built-in features and operational performance of a building and ensures that it is operating sustainably. This rating can be achieved after construction by a minimum of two years and when the building has reached a minimum occupancy of 80%.

The initiatives done by *Estidama*, the UPC and other related government sectors show the efforts for creating integrated processes aiming to change the behavior of residents, developers, designers and the government to embrace the evolving concepts of sustainability.

## 2.5 Summary

This chapter has covered the energy consumption challenges of the built environment in the UAE and the mitigation strategies that were done to overcome those issues. "*Estidama"* sustainability framework was initiated by the UPC to protect the built environment and set codes for buildings. The Pearl Building Rating system which is the official building rating system in Abu Dhabi Emirate was developed to guide buildings starting from construction stage to operation stage. The rating system rates buildings according to several criteria defined previously.

Since the educational sector is an important area of interest among the built environment in the UAE, next chapter will explore the educational development in Abu Dhabi Emirate. The chapter will also discuss the formation of Abu Dhabi Educational Council that had the vision of converting the schools in the UAE to sustainable, healthy environment following the Pearl Building Rating System criteria.

# Chapter 3: Educational Environment in Abu Dhabi Emirate

## 3.1 Introduction

The educational sector in the UAE is considered as a critical strategic sector and represents a stepping-stone in the country's ongoing development aims. From the onset of the United Arab Emirates in 1971, investing in its human capital has been recognized and targeted as often illustrated by the quote of the visionary leadership, the late President of the UAE '*Sheikh Zayed Bin Sultan Al Nahyan'*; "*The greatest use that can be made of wealth is to invest it in creating generations of educated and trained people*" (UAE-Embassy, 2015). Since then, Abu Dhabi government has paid particular attention to education and established a dedicated authority for leading the education in the UAE; the Ministry of Education (MOE). The MOE was established in 1971 and is responsible for all the stages of public education in Abu Dhabi Emirate. The focus on education was reinforced by generous spending from Abu Dhabi Government (SCAD, 2015).

In 2005, under the pressure of massive population growth in a short period of time from 3 million in 2004 to around 5 million in 2005 the government realized the necessity to provide new schools that meets both population growth and meeting international standards. For this purpose a specific body, ADEC has been established to address these challenges.

## 3.2 Historical Development of Educational Sector

### 3.2.1 Ministry of Education

The Ministry Of Education was developed in 1971 to ensure inclusive quality education, good governance of educational and institutional performance as well as establishing a culture of innovation (Ministry-Of-Education, 2017). The MOE aims for promoting Abu Dhabi Emirate educational system, investing in human capital to build a knowledge-based society while enriching citizenship values. It had been interested in adopting a plan to introduce advanced education techniques, improve innovative skills, and focus more on the self learning abilities of students.

The public schools in Abu Dhabi Emirate are managed by the MOE, and follow the Arabic curriculum whereas the private schools follow 15 different curricula ranging from Arabic to international curricula. The MOE education is provided for all UAE citizens and is free. The existing educational structure is a four tier system covering 14 years of education as per the following; Kindergarten enrolls students from 4 to 5 years old (1-2 years program), Primary or Cycle 1 which enrolls students from 6 to 12 years old (6 years program), Preparatory or Cycle 2 which enrolls students from 12 to 15 years old (3 years program) and Secondary or Cycle 3 which enrolls students from 15 to 18 years old (3 years program) (Ministry-Of-Education, 2017).

The public schools receive considerable support by allocating 24% of the federal budget from Abu Dhabi government (Ministry-Of-Education, 2017). The MOE is responsible for public schools in the three regions of Abu Dhabi Emirate; Abu Dhabi, Al Ain and Al Gharbia, while the number of public schools in Abu Dhabi region is the highest among the other regions due to the fact that it has the highest number of UAE nationals (Figure 3.1) (Al Daheri, 2016a).

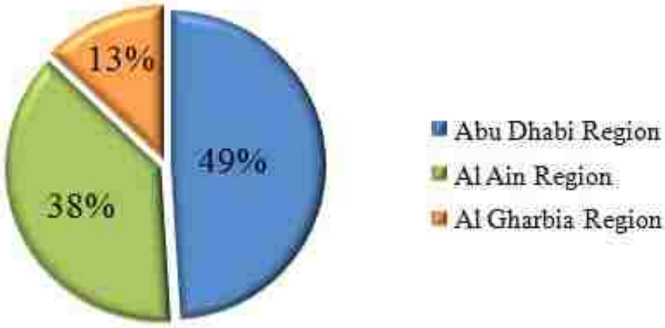


Figure 3.1: Abu Dhabi Emirate Public Schools (Al Daheri, 2016a)

Several public schools in the UAE were established in houses and villas. In 2005, the UAE was challenged by the need for elevating the educational level to reach international standards, replace all villa schools by new buildings to improve the built environment of schools and built more schools to accommodate the massive population growth that went from 3 million in 2000 to about 5 million in 2005 (Central-Intelligence-Agency, 2015). As a result, the UAE started initiating plans to overcome those challenges. “Education 2020” has been initiated by the Ministry of Education, in which it is a series of 10-year plan designed to enhance the curriculum, improve education techniques and innovative skills. It was developed mainly to bring the curriculum of education in the UAE to international standards (Ministry-Of-Education, 2017).

On another level, the educational sector in the UAE has experienced development it its building guidelines and codes which was inspired by the movement of the UAE towards sustainability and supporting Abu Dhabi vision 2030. New initiatives have been introduced at all educational levels in order to convert the existing school buildings into sustainable buildings that can follow the new vision of the UAE and “*Estidama*” guidelines. This transformation expands through all areas of education including the physical environment, curriculum, assessment, teaching methods, health and well-being (Ministry-Of-Education, 2017). Abu Dhabi government has undertaken the enormous actions of overhauling the school system; for that in 2005 ADEC was formed in order to achieve these goals in public schools.

### 3.2.2 Abu Dhabi Educational Council (ADEC)

ADEC was established in 2005 as an independent Abu Dhabi-based corporate body created to develop education throughout the UAE (ADEC, 2010). It is the regulatory body that provides licensing and accreditation to public and private schools in Abu Dhabi Emirate and sets the minimum standards for educational outcomes, health, safety, building and site requirements. ADEC works closely with the MOE in formulating the emirate's education plan. Since September 2008, all private schools are required by law to register with ADEC (ADEC, 2010). The main role of ADEC encompasses several responsibilities including: managing, guiding, adopting and implementing various educational development strategies and initiatives in the Emirate of Abu Dhabi.

ADEC has developed a 10-Year Strategic Plan as part of the Educational Policy Agenda to addresses challenges facing all levels of school education from KG to Grade 12. It represents a 10-year period forecast of student growth lined to the UAE national and expatriate population growth across the emirate. The 10-Year Strategic Plan aims to drive tangible improvements on four main categories: elevating school quality, improving access to K-12 education, providing affordable options of high-quality private and public education, and focusing on national identity and career development (ADEC, 2010). The plan has focused on identifying the demand and supply gaps in public schools in the emirate of Abu Dhabi, where it provides a road map to build new public schools ensuring a sustainable development in the education sector. ADEC sets up some expectations that must be met within all school facilities; as the schools must be effective educationally, stimulating and vibrant, healthy and productive, cost effective, sustainable, community centered and culturally appropriate (ADEC, 2010). The 10-Year strategic plan aimed at building 100 new schools in Abu Dhabi Emirate under a program called the "Future Schools program" from 2010 till 2020.

### 3.3 ADEC Future Schools Program

The "Future Schools Program" was initiated by ADEC in 2009 with the aim to build 100 new public schools during the 2010-2020 time frames. The schools are built based on demand and national population growth in the Emirates of Abu Dhabi (ADEC, 2011). The "Future Schools Program" focuses on understanding educational needs and community expectations, achieving the highest international standards and creating a new Master Plan for new schools design. The program is also responsible for replacing all villa schools by new buildings and producing sustainable safe designs that are appropriate for learning, well built, easy maintenance, attractive and stimulating for students and teachers (ADEC, 2010).

The program is responsible for all educational levels from Kindergarten to Cycle 3, catering for approximately more than 20,000 students in the 100 new schools (ADEC, 2010). The process of the establishment of schools follow a very systematic approach that includes the understanding of the educational needs and the high international standards needs. The planning and implementation of this strategy that was developed in 2009 is indicated in a timeline for each cycle of schools in Figure 3.2.

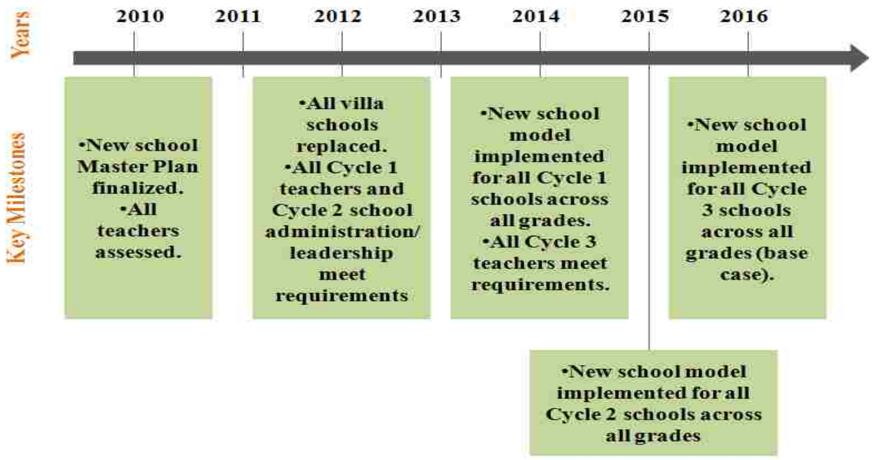


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Figure 3.2: Timeline of Key Milestones of ADEC Schools Cycles (Al Daheri, 2016b)

### 3.3.1 Status of ADEC Future Schools Program

Prior to the establishment of ADEC, 202 public schools were built by the MOE in Abu Dhabi Emirate. After the establishment of ADEC, 53 additional public schools out of the 100 "Future Schools Program" had been built. The number of schools based on the educational levels managed by the MOE and ADEC are shown in Table 3.1 (Al Daheri, 2016a). The remaining schools will be assigned based on specific needs in each region as per population growth and demand. (The data is retrieved based on personal communication with ADEC representatives).

(Note: KG= Kindergarten, Cycle 1=C1, Cycle 2=C2, Cycle 3=C3)

| Authority Name | School Types by educational level | Number of Built schools |
|---|---|---|
| Ministry of Education Schools (Prior to ADEC) | KG + C1 | 1 |
| | C1 + C2 | 4 |
| | C1 + C2 + C3 | 10 |
| | KG + C1 + C2 + C3 | 10 |
| | C2 + C3 | 25 |

| | | |
|---|---|---|
| | C3 | 25 |
| | KG | 39 |
| | C2 | 40 |
| | C1 | 48 |
| **Total** | | 202 |
| **ADEC Future Schools Program** | KG+C1+C2 | 1 |
| | C3 | 1 |
| | KG+C1+C2+C3 | 2 |
| | C2 | 2 |
| | KG+C1 | 8 |
| | C2+C3 | 10 |
| | C1 | 13 |
| | KG | 16 |
| **Total** | | 53 |
| **Grand Total** | | **255** |

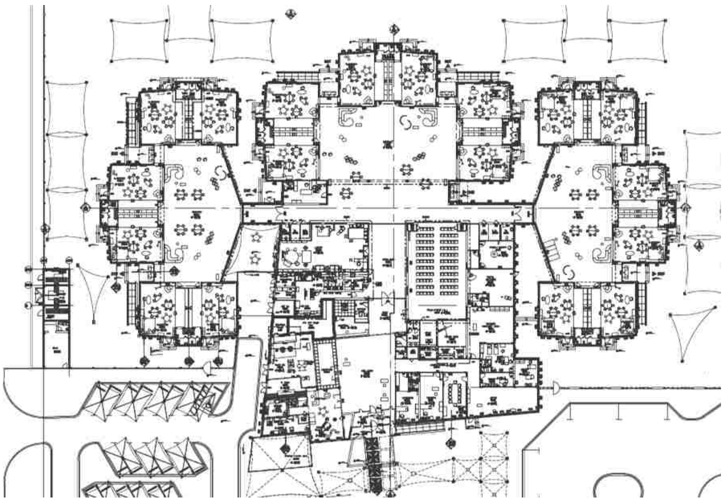
Table 3.1: Number of Public schools in Abu Dhabi Emirate (Al Daheri, 2016a)

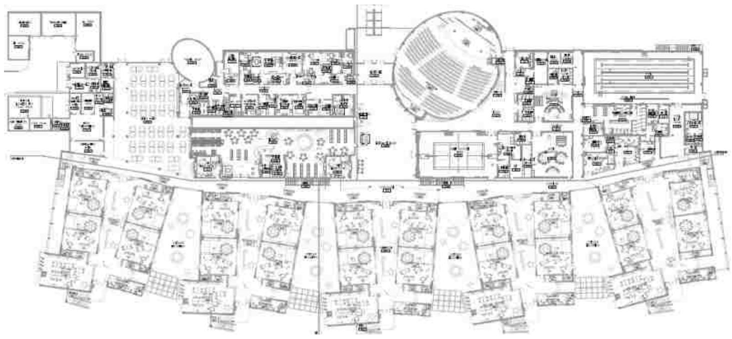
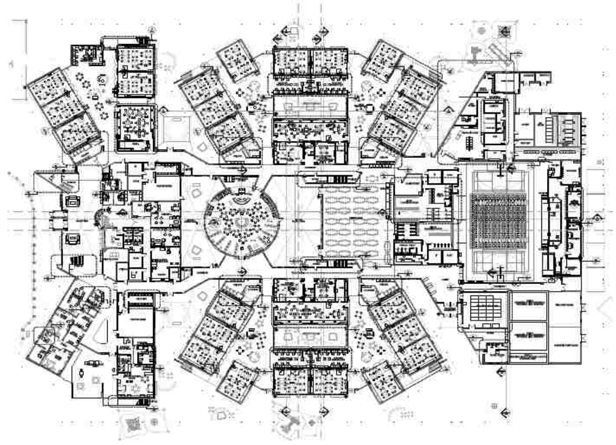
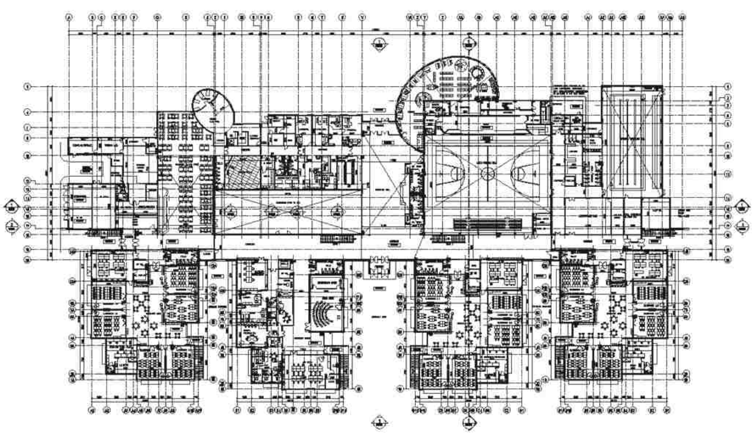
The number of public schools built in each region of Abu Dhabi Emirate depends on the population of the UAE citizens. Abu Dhabi region has the largest number of public schools since it has the highest population of UAE citizens as was noted previously in chapter 2 in Figure 2.4. The number of public schools including schools governed by the MOE and by ADEC in each region of Abu Dhabi Emirate are presented in Table 3.2 (Al Daheri, 2016a).

| **Region** | **Abu Dhabi** | **Al Ain** | **Al Gharbia** |
|---|---|---|---|
| **MOE Schools** | 99 | 77 | 26 |
| **ADEC Schools** | 20 | 27 | 6 |
| **Total** | 119 | 104 | 32 |

Table 3.2: Public Schools Number by Region (Al Daheri, 2016a)

Prior to the establishment of ADEC, public schools consisted of seven prototype model designs that were built without any energy efficiency code consideration. However, after the establishment of ADEC, new school prototypes were targeted covering all cycles that were built as sustainable high performing buildings based on the guidelines of the PBRS. The new schools consisted of five design prototypes that tend to serve the purpose and function of the school level. The five public schools designs prototypes are for KG, KG and Cycle 1, Cycle 1, Cycle 2 and 3 and a model covering KG to Cycle 3 (Al Daheri, 2016b). The prototypes of the schools can be modified according to the gender type, numbers of students, or the land size available for the school. The five prototypes were selected based on a competitive procedure by which several consultant offices designed several designs and entered tender, then ADEC selected the designs to represent each prototype. The five school prototypes plans are presented in Table 3.3(Al Daheri, 2016a).

| Type | Prototype Model |
|---|---|
| **KG** |  |

| | |
|---|---|
| **KG + Cycle 1** |  |
| **Cycle 1** |  |
| **Cycle 2 and 3** |  |

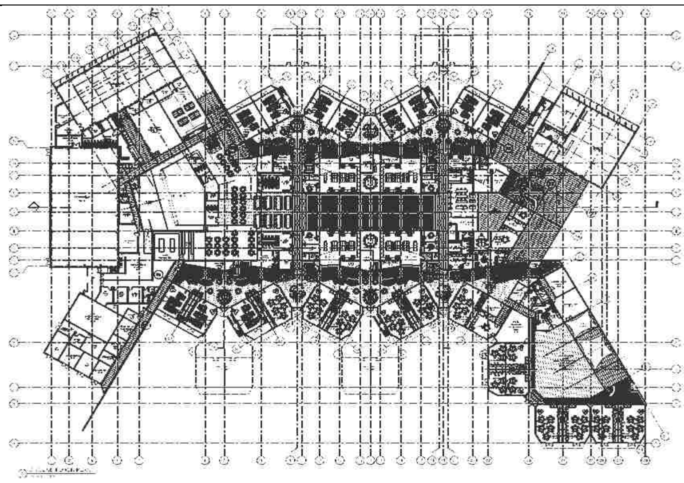
| | |
|---|---|
| **KG to Cycle 3** |  |

Table 3.3: ADEC School Prototypes Plans (Al Daheri, 2016a)

### 3.3.2 Design Strategy of Future Schools Program

One of the common targeted strategies is to design green sustainable school prototypes. ADEC schools were the first schools in the emirate to comply with the UPC's *Estidama* standard. *Estidama* has mandated that all governmental buildings including ADEC public schools should achieve a minimum of two Pearl *Estidama* ratings. Meanwhile, ADEC expressed a desire to achieve Three Pearl *Estidama* rating for the school projects. ADEC developed a design manual that details the design requirements and guidelines of schools, the green design strategies incorporated and the performance standards of the schools (ADEC, 2010).

ADEC encourages implementation of both passive and active design strategies in the schools. The passive strategies incorporate siting, orientation and shading; in which detailed shading studies are done to prevent direct incidence of sun into the learning areas, prevent heat gain and reduce glare, improve student comfort and concentration. In addition to the use of shade incorporated within landscape design to reduce solar impact on students and the environmental fabric (ADEC, 2012). There are also shaded drop off areas and walkways to provide outdoor thermal comfort and protection.

On the other hand, in terms of the active design strategies; the HVAC systems have been designed to maximize energy performance. Heat recovery facilities such as heat exchangers have been incorporated in supply air systems to ensure that the maximum available energy is recovered for cooling the incoming ambient air (ADEC, 2010). Solar hot water heating system is used as an on-site renewable energy source to provide domestic hot water for showers and swimming pools. The schools are built using recycled and recyclable materials that are procured within 500 km. Moreover, high performance windows and glazing with shading are used to save energy and provide environmental friendly atmosphere. The school designs also focus on daylighting, where light tubes are used to provide ambient natural daylight for interior spaces (ADEC, 2010). Moreover, high efficacy luminaries with low wattage lamps and high frequency control to optimize light output and reduce switching losses are used. Since the UAE has one of the highest per capita water consumption rates in the world and due to the extensive use of desalination with high costs and energy requirements, the design of ADEC schools focused on water saving strategies (ADEC, 2010). Native and adaptive species, careful plant selection, artificial turf for fields and balancing of hard and soft landscaped areas was used to reduce water consumption. Additionally, low flow fixtures, low flush and low flow fixture units were used to reduce potable water usage and reduce domestic water consumption. The design of some schools focused on providing social sustainability by incorporating eco-courtyard with living wall and eco-tree to provide daylight and ventilation plus additional benefit of sustainability education to create student interest in science and math (ADEC, 2010).

The previous design strategies set by ADEC are summarized as 5 main goals for sustainability to be achieved in schools design; 25% lower water demand, 25% lower energy consumption, outdoor thermal comfort, materials specification and waste reduction and indoor environmental quality (Figure 3.3) (ADEC, 2012).

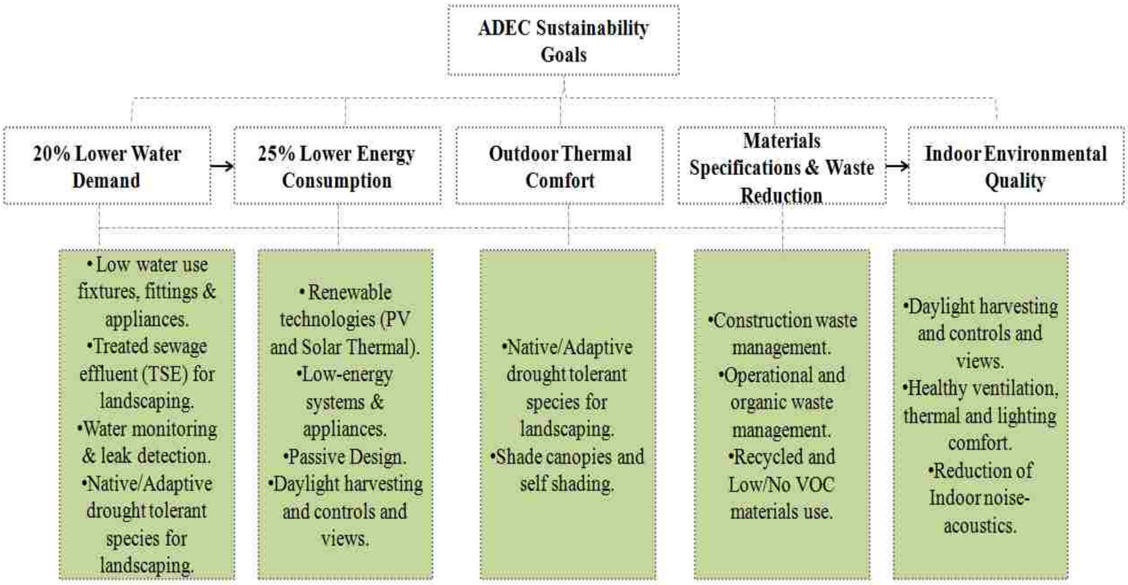



Figure 3.3: ADEC Sustainability Goals (ADEC, 2012)

### 3.3.3 Future Schools Program Rating

Although ADEC has planned to achieve 3 Pearls rating in all the schools, only 10 schools out of the 53 already built schools had achieved the target of 3 Pearl Ratings representing about 20% of ADEC schools. The ten schools were awarded by the UPC, since they achieved 3 Pearl Design and Construction Ratings from the *Estidama* Pearl Building Rating System (PBRS). The achievement was based on using integrated design process, energy saving strategies, water consumption reduction and recycling (Masdar, 2013). Sustainable materials were also used to reduce energy and water consumption, improve indoor air quality conditions for students and incorporate better waste management practices.

On the other hand, around 80% of the built schools did not achieve ADEC's target of 3 Pearl *Estidama* ratings. One of the schools that achieved two Pearls ratings representing one of the prototypes shown previously will present the case study that will be explored in order to identify the opportunities of implementing additional credits from "*Estidama*" PBRS systems to increase the energy efficiency and hence increase the Pearl ratings. The case study was chosen because access of all required documents was provided by a representative from ADEC.

### 3.4 Sheikha Bint Suroor Public School; Case Study General Overview

"Sheikha Bint Suroor Public School" is one of the "Future Schools Program" representing prototype of Cycle 2 and 3 that achieved 2 Pearl Design Rating. The school is a female school located in Al Ain region. It is designed by KEO consultant design team. KEO consultant is a creative enterprise and had designed different types of projects including many educational facilities. KEO was appointed to design models for the 'Future Schools Program' of ADEC. The main task of the KEO was to help ADEC accomplish its vision of new sustainable educational schools. It also strives to maintain the essence of ADEC's vision through complying with standards in ADEC's design manual, PBRS and International Building Code 2009 standards. The KEO had designed three prototypes of ADEC schools including; KG, C2+C3, and KG+C1. The general architectural data of the school are presented in Table 3.4.

| **Project Name** | **Sheikha Bint Suroor School** |
|---|---|
| **Site** | Al Ain |
| **Construction Completion Year** | 2013 |
| **Design Team** | KEO |
| **Students Capacity** | 1000 |
| **Gender** | Female |
| **Number of Floors** | 2 Floors |
| **Area** | 14694 $m^2$ |
| **Orientation** | North-West |
| **Number of Class rooms** | 35 |
| **Number of Learning Communities** | 7 |
| **Facilities** | ICT/science labs, a four lane 25 meter swimming pool, outdoor sports fields, a library, a cafeteria with seating for 205 people, a multi-purpose gymnasium with staged seating capacity of 425, a music room, and an art room. |
| **Cycles** | Cycles 2 & 3 |
| **Awards** | 2 Pearl Ratings |

Table 3.4: General Architectural Data of Case Study (Shwehna, 2016, KEO, 2017)

The exterior images of the school are shown in Figures 3.4 and 3.5 (KEO, 2017), and the architectural drawings of the school including plan and elevations are presented from Figures 3.6 till 3.8 (Shwehna, 2016).

Figure 3.4: Front Entrance of Sheikha Bint Suroor Public School (KEO, 2017)

Figure 3.5: Arial view of Sheikha Bint Suroor Public School (Shwehna, 2016)

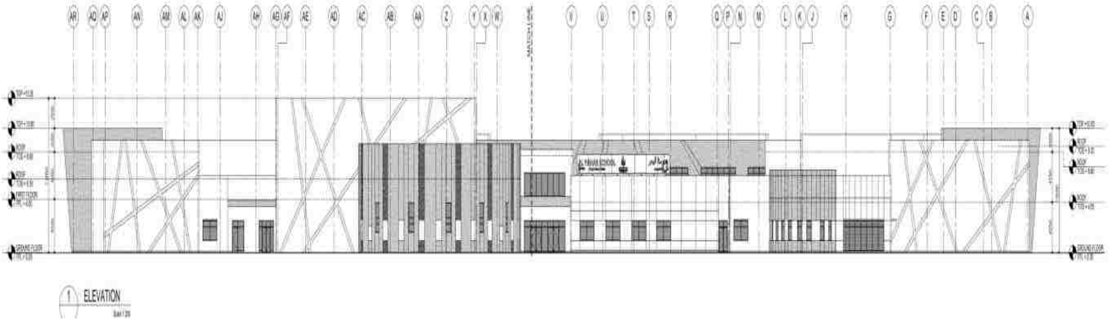



Figure 3.6: Front Side Elevation (Shwehna, 2016)

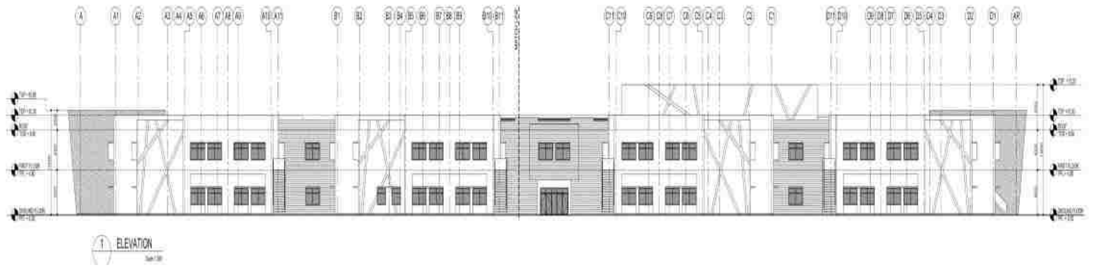



Figure 3.7: Back Side Elevation (Shwehna, 2016)

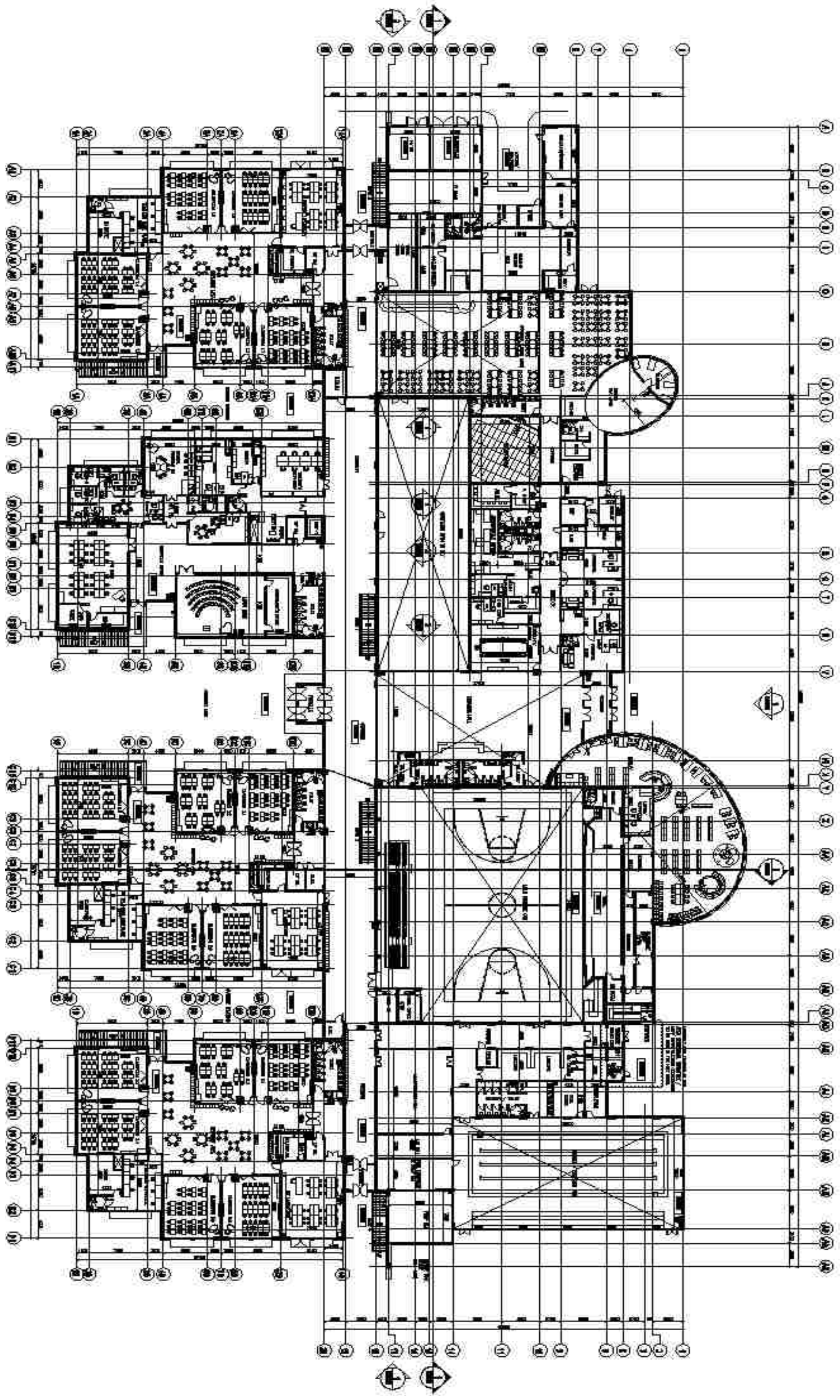


Figure 3.8: Ground Floor Plan (Shwehna, 2016)

The design strategies implemented in the school were based on the PBRS requirements. The building envelope performance is summarized in Table 3.5.

| Building Envelope | Value |
|---|---|
| **Roof** | U-Value 0.22 W/m$^2$K |
| **Walls** | U – 0.32 W/m$^2$K |
| **Floor** | U – 1.0 W/m$^2$K |
| **Windows** | U – 2.2 W/m$^2$K<br>Fenestration Assembly SHGC - 0.25<br>Vertical Glazing Ratio (gross window-to-wall) 10%<br>Vertical Glazing Light Transmittance 40% |

Table 3.5: Sheikha Bint Suroor Public School Building Envelope Performance (Shwehna, 2016)

The school has implemented green building design strategies in order to reduce energy consumption. The sustainable key features applied in the school are summarized in Table 3.6. By applying those strategies, the school achieved 2 Pearls rating from *Estidama*.

| System | Sustainable Key Features |
|---|---|
| **Building Materials** | • 100% of all adhesives and sealants used do not exceed the prescribed VOC limits.<br>• All internal construction materials do not exceed formaldehyde VOC content class E1 levels.<br>• All thermal insulation materials used have an Ozone Depletion Potential (ODP) of zero and a (Global Warming Potential) of less than 5.<br>• Regionally transported materials travelled a maximum distance of 500 km from point of origin to the project site.<br>• 70% proportion (by cost) of the timber and composite wood used in the project is FSC certified or reused. |
| **Water Conservation** | • 28% reduction for the interior potable water consumption. |

| | |
|---|---|
| | • Low-flow and water efficient fixtures.<br>• Low irrigation demand plant selection.<br>• Efficient irrigation system.<br>• Irrigation system management |
| **Individual Controls** | • Occupancy Sensors.<br>• $CO_2$ sensor controls.<br>• Thermostat controls. |
| **Landscaping** | • 70% of plants selected are native species<br>• Artificial turf playgrounds. |
| **Lighting** | • No incandescent lamps installed in the internal environment.<br>• LED lights use. |
| **Views** | • 65% of all occupied spaces have a direct line of sight to the outside through vision glazing. |
| **Renewable Energy Systems** | Solar hot water system to meet heating requirements of swimming pool, kitchen and showers that yields 4.5% saving. |
| **Equipments** | Energy Star accreditation |

Table 3.6: Sustainable Key Features of School (Shwehna, 2016)

The overall building energy performance of the school based on the provided simulation data is shown in Table 3.7.

| Criteria | Value |
|---|---|
| **Proposed Building Annual Energy Consumption (kWh)** | 2,206,253 |
| **Peak Demand (kW)** | 1,392.9 |
| **Annual Renewable Energy Generation (kWh)** | 117,760.0 |
| **Percentage of Energy from Renewables** | 5.3% |
| **Occupied Hours Per Day (hrs)** | 9 |

Table 3.7: Energy Performance of School (Shwehna, 2016)

*Estidama* PBRS has a total of 182 credit points to be achieved in order to gain the 5 Pearl Ratings; whereas “Sheikha Bint Suroor School” has achieved 81 credit points which corresponds to 2 Pearl Ratings. The gap between the 2 pearls and the next level (3 Pearls) seems to be within easy reach as only 4 points were needed to reach the next level, hence the focus of this research. Due to this, a thorough investigation is being made to identify the opportunity of enhancing the performance of the school and increase the credit points in order to gain more *Estidama* Pearl ratings.

### 3.5 Summary

This chapter has documented the educational sector in the context of the UAE development. Due to the massive population growth that took place in the UAE in the last 20 years, a development in the educational sector had taken place. In that sense, Abu Dhabi Educational Council (ADEC) was the body initiated to overcome the challenges in education. ADEC has targeted sustainable environment and launched 100 new schools “Future program” of which 52 schools have been built. All governmental buildings including schools are mandated to meet 2 Pearls rating on the PBRS. One of the main drivers of ADEC schools is to achieve the most sustainable educational environment with a target going beyond the required governmental rating to achieve 3 Pearls. However, only 20% of the 52 schools already built achieved the targeted Pearls.

Thus, the objective of the thesis is to explore the opportunities through a representative case study school. This has been carried out through one case study which represents one typology of ADEC schools that achieved 2 Pearls rating in which data access was provided, where architectural data has been presented in this chapter. The next chapter will critically analyze the performance in relation to *Estidama*, in order to identify potentialities for enhancement performance that improves to the Three Pearls.

# Chapter 4: Case Study Performance; Methodology and Analysis

## 4.1 Introduction

This chapter explains the methodological approach adopted in the thesis. The purpose of the thesis being enhancing the performance of the school to meet higher rating of *Estidama* PBRS requires a thorough investigation of the level of attainment in each category to identify the opportunities. Thus, the first step of the methodology is a critical qualitative analysis. The potential area based on the PBRS is identified as the renewable energy and cooling systems which is the least targeted criteria in the school. The second part of the study evaluates the performance of the renewable energy systems based on quantitative simulation testing programs. This chapter summarizes the description, working principles, performance parameters and simulation set up for the intended systems namely geothermal cooling, absorption cooling and photovoltaic systems.

## 4.2 Research Design

### 4.2.1 Methodological Approach

The study starts with a critical analysis of *Estidama* performance of the school in an attempt to identify achieved and un-achieved credits through applied measures. After identifying the unattained credits, the preliminary targets are defined to achieve the remaining credits by selecting potential systems to be integrated into building. The energy saving target is primarily established to help design the system capacity required to earn the needed credits.

In the following section, the data collection of ADEC prototype case study is discussed.

### 4.2.2 Data Collection

The school was selected based on its credit rating with *Estidama* (2 Pearls) along with availability of data from ADEC. The data collection required certain formal procedures from ADEC along with several stake holders resulting in prolonged date collection phase from March 2016 until August 2016. The practice provided fruitful yet challenging experience in conducting such research involving several meetings. The documentation obtained included ADEC schools and information about "Sheikha Bint Suroor Public School" including architectural drawings, design strategy, technical specifications and the simulated data of the school performance including building loads, electricity consumption, operational schedules, and used systems. The collected data also included details of *Estidama* PBRS credits application in the school which showed the attained and un-attained credits and ADEC's comments on the reasons for achieving and not achieving the credits. The data were analyzed in three steps; first stage analysis that showed an analysis of the overall performance of the school, the second stage analysis which identified the gaps within *Estidama* performance and the third stage analysis that assessed the opportunities of systems integration in the school. The detailed subsequent sub points of the analysis are presented in Figure 4.1.

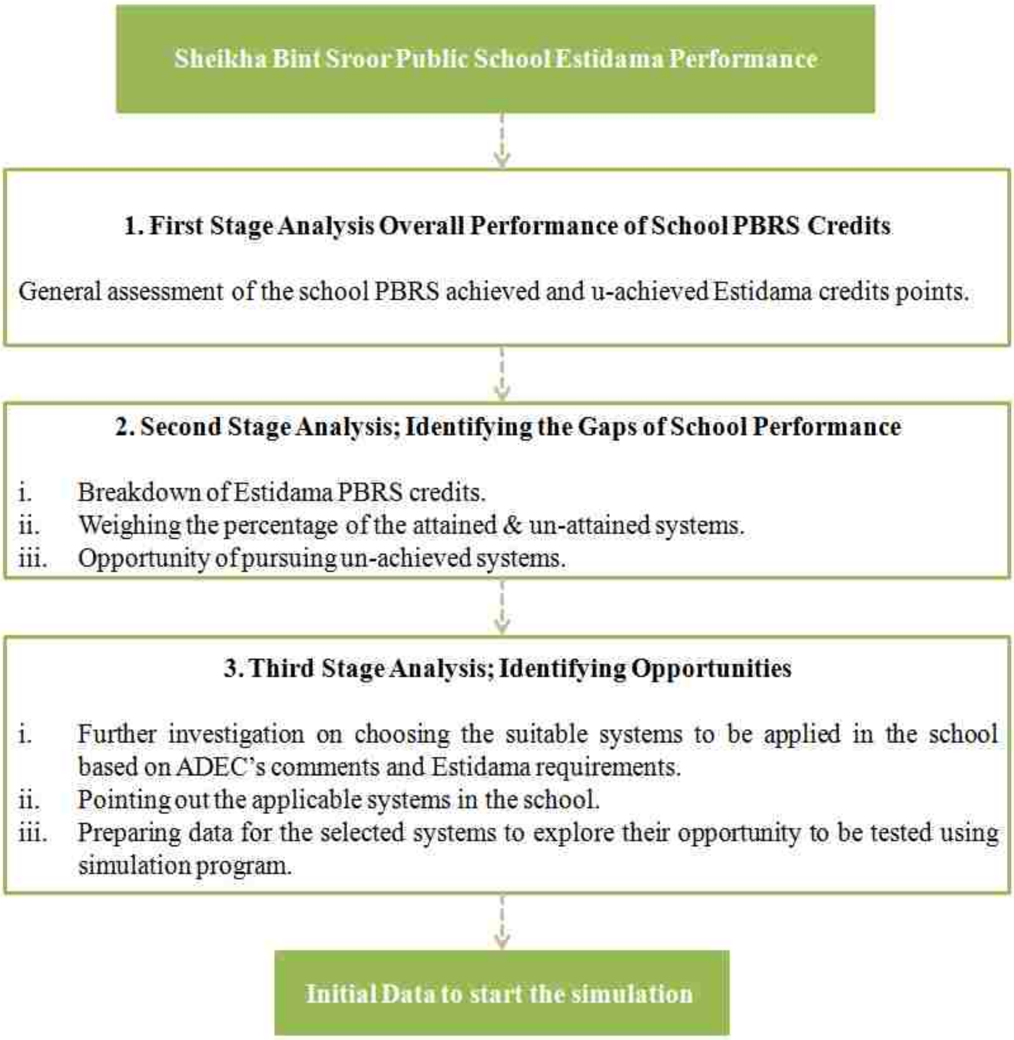



Figure 4.1: Three Stage Analysis of the Case Study

### 4.3 Critical Qualitative Analysis of the School *Estidama* Performance

The performance of the school is critically analyzed in a three stage analysis for the purpose of investigating the opportunities of the applicable credits to be integrated to the school in the UAE context.

#### 4.3.1 First Stage Analysis; Overall Performance of School PBRS Credits

The Pearl Building Rating System has seven credits sections that have a total of 182 credits points which translates to 5 Pearls ratings. However, the school has achieved 81 credits equivalent to 2 Pearls ratings. The achieved PBRS credits of ‘Shiekha Bint Suroor Public School” are listed in Table 4.1.

| Credit Section | Credit Points Available | Design Credit Points Achieved By School |
|---|---|---|
| **IDP - Integrated Development Process** | 13 | 5 |
| **NS - Natural Systems** | 12 | 2 |
| **LB - Livable Buildings** | 37 | 18 |
| **PW - Precious Water** | 45 | 29 |
| **RE - Resourceful Energy** | 44 | 13 |
| **SM - Stewarding Materials** | 28 | 14 |
| **IP - Innovating Practice** | 3 | 0 |
| **Total** | **182** | **81** |

Table 4.1: Summary of School Achieved Credit Points (Shwehna, 2016)

Some credits based on *Estidama* PBRS were achieved in the school, while some credits were not attained. The un-attained credits by the school with the number of credits are listed in Table 4.2 in order to identify the opportunity to achieve more credits. The detailed table of attained, un-attained credits and listed as maybe credits by ADEC are shown in Appendix B.

| Systems | Un-Attained Credits Name/ (Credits Weight) |
|---|---|
| **Integrated Development Process (IDP)** | IDP-1 Life cycle cost (4)<br>IDP-2 Guest worker accommodation (2)<br>IDP-3 Construction environmental management (1)<br>IDP-4 Building envelope verification (1) |

| | |
|---|---|
| **Natural Systems (NS)** | NS-1 Reuse of land (2)<br><br>NS-2 Remediation of contaminated land (2)<br><br>NS-4 Habitat creation & restoration (6) |
| **Livable Buildings : Outdoors (LBo)** | LBo-1 Improved outdoor thermal comfort (2)<br><br>LBo-2 Pearl rated communities (1)<br><br>LBo-6 Public transport (3)<br><br>LBo-7 Bicycle facilities (2)<br><br>LBo-8 Preferred car parking spaces (1)<br><br>LBo-9 Travel plan (1)<br><br>LBo-10 Light pollution reduction (1) |
| **Livable Buildings Indoors (LBi)** | LBi-10 Safe & secure environment (2)<br><br>LBi-1 Ventilation quality (1)<br><br>LBi-5.3 Thermal comfort & controls: thermal comfort modeling (2)<br><br>LBi-7 Daylight & glare (2)<br><br>LBi-9 Indoor noise pollution (1) |
| **Precious Water (PW)** | PW-1 Improved interior water use reduction (8)<br><br>PW-2.1 Exterior water use reduction: landscaping (2)<br><br>PW-3 Water monitoring & leak detection (2)<br><br>PW-4 Storm-water management detection (4) |
| **Resourceful Energy (RE)** | RE-1 Improved energy performance (14)<br><br>RE-2 Cool building strategies (3)<br><br>RE-4 Vertical transportation (1)<br><br>RE-5 Peak load reduction (4)<br><br>RE-6 Renewable energy (6)<br><br>RE-7 Global warming impacts of refrigerants & fire suppression systems (3) |
| **Stewarding Materials (SM)** | SM-1 Non-polluting materials (2) |

| | |
|---|---|
| | SM-2 Design for materials reduction (1)<br><br>SM-3 Design for flexibility & adaptability (1)<br><br>SM-4 Design for disassembly (1)<br><br>SM-5 Modular flooring systems (1)<br><br>SM -7 Building reuse (2)<br><br>SM-8 Material reuse (1)<br><br>SM-10 Recycled materials (4)<br><br>SM-11 Rapidly renewable materials (1) |

Table 4.2: *Estidama* PBRS School Un-Attained Credits

### 4.3.2 Second Stage Analysis; Identifying the Gaps

Based on the first stage analysis, it is shown that the weight and objective of each un-attained credit within each section varied. The un-achieved credits were assessed in terms of the potentiality of performance enhancement. Based on ADEC comments, the credits that were related to context, site, transportation, project management, recycling as identified in Figure 4.2 were not considered for further analysis since they are not dealing with the building performance and are out of the research scope.

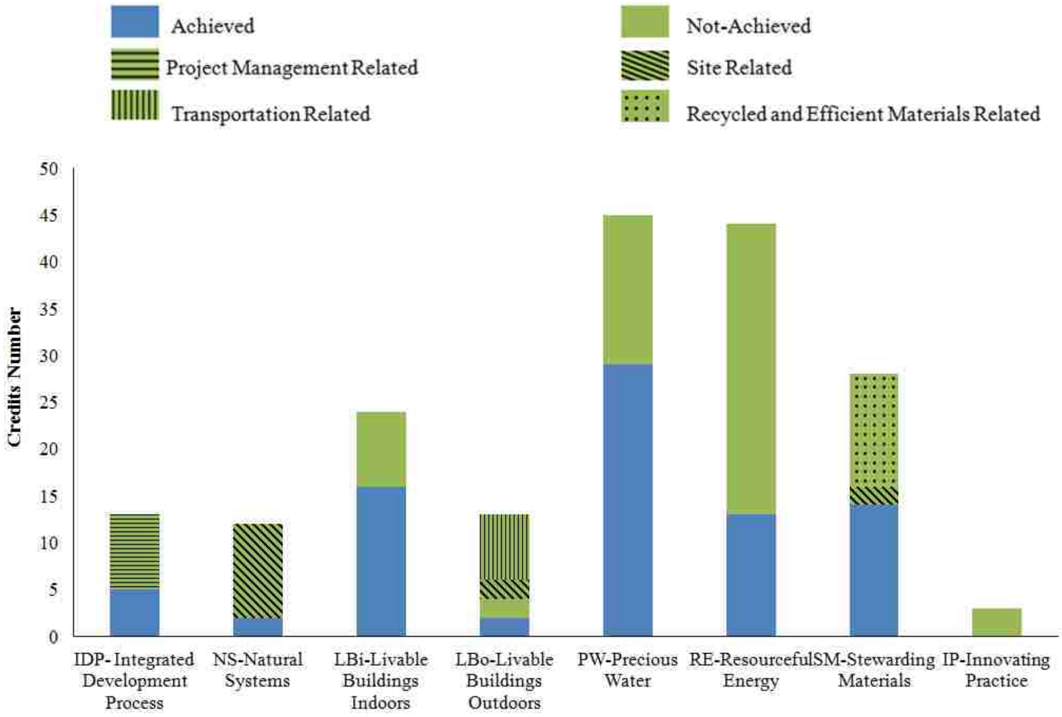



Figure 4.2: Gaps of *Esitdama* PBRS in School

The analysis has shown that the school had achieved the credits responsible for the building envelope such as insulation, roof and glazing systems which had complying U-values to Estidama requirements. Additionally, electrical systems such as LED lighting, sensors and controls were installed and were claimed in Estidama credits.

The credits that were not fulfilled in the Livable Building Indoors (LBi) section has an opportunity to be explored since they are related to the building performance including, daylight, ventilation and acoustics, therefore are investigated in this study. The Precious Water (PW) was the highest implemented system in the school of all the other systems. This achievement supports the initial goal of ADEC schools and *Estidama* PBRS to focus on reducing water consumption. Some of the credits that were not applied in the PW are related to storm water management, water monitoring and leak detection which needs high level of expertise and therefore they are not studied in this thesis. The other un-attained credits of the PW focused on water recycling and landscaping which are known and applicable, however, implementation of this system have been already highly implemented in the school and improving their performance will result in limited additional credits and therefore they are not pursued in the study. The Resourceful Energy (RE) system has the highest gap in un-attained credits by which 70% of the credits were not pursued, although *Estidama* has dedicated one quarter of the weight of credits on energy conservation and ADEC has aimed on reducing energy consumption in schools by 25%. Thus, is an intriguing fact and an investigation is done on the RE system to look at its possible opportunities in this thesis.

The following section presents the third stage analysis which is done on the LBi and RE systems in order to investigate their opportunities and applicability in the thesis.

### 4.3.3 Third Stage Analysis; Identifying Opportunities

The un-achieved credits for Livable Building Indoors are analyzed in Table 4.3. The reasons for not pursuing some credits were specified by ADEC in the provided documents. Thus, the analysis in this stage considers the comments of ADEC and the requirements and methodology of each credit from the PBRS manual to specify the applicability of credits.

| Livable Buildings Indoors (LBi) | | |
|---|---|---|
| **Un-attained credits** | **Reasons for not achieving credits (based on ADEC's comments)** | **Critical Assessment of Technical Feasibility** |
| LBi-1 Ventilation quality (1 credit) | The additional credit point is achieved if the HVAC and ventilation design falls under 'mixed mode ventilation'. Achievement of this additional point will require undertaking of dynamic simulation modeling for natural ventilation. | This credit is not applicable; since it requires doing onsite testing during the operation of the school. However, the school did not provide access to visit or to perform tests, thus, this credits was not implemented. |
| LBi-5.3 Thermal comfort & controls: thermal comfort modeling (2 credits) | Not prioritized. | Based on PBRS requirements, this credit requires Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) of the systems in which 1 year of period of operation testing is required. Thus, it is not applicable in this study. |
| LBi-7 Daylight & glare (2 credits unachieved) | Not targeted. Daylighting thresholds are not anticipated to comply with credit thresholds. | The daylighting credit is an applicable credit due to the easiness of applying it and its availability in the UAE context. Whereas, in order to be studied in this thesis, on-site visit to the school is required to do measurements of the daylight. However, ADEC did not permit the school visit and testing. Therefore, this credit was not studied. |
| LBi-9 Indoor noise pollution (1 credit) | Not targeted. Will require engagement in a contract with a third-party acoustics professional. | Requires experts in acoustics which is not available, therefore; out of scope. |

| | | |
|---|---|---|
| LBi-10 Safe & secure environment (2 credits) | Not prioritized. | This credit is not pursued in this study since it deals with the environment and safety within the building, therefore, not prioritized in the study. |

Table 4.3: Livable Building Indoors Section Analysis

The analysis in the previous table has shown that the credits are not applicable in this study since some require on-site measurements which were not applicable since permission was not given to visit the school. Additionally, some of the credits required experience that is not available or related to the site and outdoor environment of the building which is not the scope of this research. Thus, the LBi system is eliminated from further exploration in this research. The un-attained credits in the Resourceful Energy system is analyzed in Table 4.4 and the opportunities of pursuing additional credits based on *Estidama* requirements and ADECs' comments are explored.

| **Resourceful Energy (RE)** | | |
|---|---|---|
| **Un-attained credits** | **Reasons for not achieving credits (based on ADEC comments)** | **Critical Assessment of Technical Feasibility** |
| Re-1 improved energy performance (14 credits) | Energy saving achieved is 15.2% which corresponds to 1 point in re-1 | Based on PBRS requirements this credit is applicable by improving the energy performance. Therefore there is an opportunity of this credit. |
| RE-2 Cool building strategies (3 credits) | Further reductions contributing to additional points will depend on energy modeling results. | This credit requires the application of passive cooling design strategies. However application of the credit based on PBRS requires testing of infiltration gain and external conduction gain which is not possible in the thesis. |

| | | |
|---|---|---|
| RE-4 Vertical transportation (1 credit) | 1 additional credit is achieved if 'Energy efficient escalators' is applied, however, it is not applicable to the project. | 'Energy efficient escalators' is not applicable to the project since the school is a low rise building. |
| RE-5 Peak load reduction (4 credits) | Not targeted. | Peak load reduction can be achieved by applying renewable energy systems such as Photovoltaic (PV). Therefore there is an opportunity of this credit. |
| RE-6 Renewable energy (6 credits) | 4.5% savings achieved via solar hot water contributing to 2 points. | There is an opportunity within this credit, since there are number of renewable energy systems that depend on solar radiation due to its availability in the UAE. The systems are integrated to enhance the energy performance of the school. |
| RE-7 Global warming impacts of refrigerants & fire suppression systems (3 credits) | Demonstrate compliance during construction. | This credit is out of scope of this study. |

Table 4.4: Resourceful Energy Section Analysis

The hierarchy of building energy efficiency includes maximizing passive design strategies, which are design based and does not lie within the research scope. The second level of enhancement is within the building envelope and systems; in this consideration all of ADEC school prototypes are meeting Estidama requirements and U-values which show a marginal benefit in improving them. The room in terms of performance enhancement in regard to the rating system which is target of the study seems to lay way more in the un-achieved ones which are in the renewable energy credits. The renewable energy systems offer the dual benefit of being systems that can be considered in new to be build schools and as a potential retrofit. The analysis in Table 4.4 has shown that the opportunity lies within the application of renewable energy in the building due to its applicability in the study and the fact that 70% of the credits were not achieved by ADEC in this field.

### 4.3.4 Opportunities for Further Improvement

The opportunity of exploring the "Resourceful Energy System" had been identified. The applicability for the credits is determined based on the PBRS requirements and methodologies investigated in Table 4.5.

<table>
<tr><th>Credit name</th><th>RE-1 Improved Energy Performance(15 credits possible, 1 credit achieved)</th></tr>
<tr><td>Estidama requirements</td><td>1-15 credit points: minimum energy performance, demonstrate further percentage reductions in the proposed building energy consumption beyond the baseline building consumption. Points are awarded as follows:<br>
<table>
<tr><th>Points Achieved</th><th>Percentage Reduction</th></tr>
<tr><td>1</td><td>14%</td></tr>
<tr><td>2</td><td>16%</td></tr>
<tr><td>3</td><td>18%</td></tr>
<tr><td>4</td><td>20%</td></tr>
<tr><td>5</td><td>22.5%</td></tr>
<tr><td>6</td><td>25%</td></tr>
<tr><td>7</td><td>27.5%</td></tr>
<tr><td>8</td><td>30%</td></tr>
<tr><td>9</td><td>32.5%</td></tr>
<tr><td>10</td><td>35%</td></tr>
<tr><td>11</td><td>40%</td></tr>
<tr><td>12</td><td>45%</td></tr>
<tr><td>13</td><td>50%</td></tr>
<tr><td>14</td><td>55%</td></tr>
<tr><td>15</td><td>60%</td></tr>
</table></td></tr>
<tr><td>Estidama methodology</td><td>$$\text{Percentage improvement} = \frac{100 * \text{Baseline Building Performance}\left(\frac{kWh}{yrh}\right) - \text{Proposed Building Performance}\left(\frac{kW}{yrh}\right)}{\text{Baseline Building Performance}\left(\frac{kWh}{yr}\right)}$$</td></tr>
<tr><td>Application in thesis</td><td>Application of this credit in the thesis will be done through applying renewable energy systems.</td></tr>
</table>

<table>
<tr><td>Credit name</td><td>RE-5 Peak Load Reduction (4 unachieved credits)</td></tr>
<tr><td>Estidama requirements</td><td><ul><li>2 credit points: peak electrical load is less than 80% than the project design annual average electrical load.</li><li>4 credit points: peak electrical load is less than 60% than the project design annual average electrical load.</li></ul></td></tr>
<tr><td>Estidama methodology</td><td><ul><li>The electrical loads must include all energy conservation and peak load reduction measures (e.g. Renewable technologies, energy storage systems etc)</li></ul></td></tr>
<tr><td>Application in thesis</td><td>Renewable energy systems are studied in this thesis in order to test their performance enhancement and their applicability.</td></tr>
<tr><td>Credit name</td><td>RE-6 Renewable Energy (9 credits possible, 3 credits achieved, 6 credits unachieved)</td></tr>
<tr><td>Estidama requirements</td><td>Demonstrate that a percentage of the developments total energy demand is supplied through renewable energy.<br><br>Onsite systems:<ul><li>1-8 credit points: demonstrate that a percentage of the proposed buildings energy consumption is supplied through onsite renewable energy. Points are awarded as follows:</li></ul>
<table>
<tr><th>Points Achieved</th><th>Required Percentage</th></tr>
<tr><td>1</td><td>1%</td></tr>
<tr><td>2</td><td>3%</td></tr>
<tr><td>3</td><td>5%</td></tr>
<tr><td>4</td><td>7%</td></tr>
<tr><td>5</td><td>10%</td></tr>
<tr><td>6</td><td>13%</td></tr>
<tr><td>7</td><td>16%</td></tr>
<tr><td>8</td><td>20%</td></tr>
</table>
<ul><li>1 additional credit point for offsite systems.</li></ul></td></tr>
<tr><td>Estidama methodology</td><td>$$\text{Percentage Onsite Renewable Energy} = \frac{100 * \sum \text{Annual Energy Generated from Onsite Renewable Technologies (kWh)}}{\text{Proposed Building Energy Consumption (kWh)}}$$</td></tr>
<tr><td>Application in thesis</td><td>Application of this credit in the thesis will be done through the implementation of onsite renewable energy systems.</td></tr>
</table>

Table 4.5: PBRS Requirements for Resourceful Energy Credits (Estidama, 2010b)

In summary, the critical performance analysis has demonstrated opportunities in the renewable energy. On site renewable energy systems are to be applied in the school in order to reduce the cooling load consumption and supply energy. Examples of the renewable energy systems that can be integrated into buildings can range from solar electric, or photovoltaic (PV), solar thermal, including solar hot water (domestic water heating), solar cooling and ventilation systems, geothermal heat pump and wind turbines (Hayter and Kandt, 2011). The applied systems are selected based on a selection criterion shown in Table 4.6.

| System/ Criteria | Source | Payback Period versus life span | Advantage | Limitation |
|---|---|---|---|---|
| **Wind turbine (Bonou et al., 2016)** | Wind. | • Average payback period ranges between 10 to 25 years.<br>• Lifespan ranges between 20-30 years. | • Clean energy source.<br>• Lower cost than other renewable energy resources. | • Used in larger scale projects.<br>• Requires on-site testing and measurements of wind. |
| **Photovoltaic System (Walwil et al., 2017)** | Solar radiation. | • Average payback period ranges between 1 to 5 years.<br>• Lifespan ranges between 25-30 years. | Solar radiation is highly available in the UAE and free. | • Dust which results in radiation reduction on panel.<br>• High temperature which results in power losses. |
| **Solar Cooling (Solar absorption chiller) (Shirazi et al., 2017, Bellos et al., 2017)** | Solar radiation. | • Average payback period ranges between 3 to 13 years.<br>• Lifespan ranges between 25-35 years. | Solar radiation is highly available in the UAE and free. | • High initial cost.<br>• Dust on collectors which results in radiation reduction.<br>• High temperature which results in power losses. |
| **Geothermal System (Climate-Consultant, 2017b, Fong et al., 2017)** | Ground temperature. | • Average payback period ranges between 4 to 10 years according to the system size.<br>• Lifespan a minimum of 50 years. | • Difference between ambient and ground temperature can reach up to 20 °C.<br>• Minimal maintenance throughout life of the system. | • High initial costs.<br>• Installation expertise and special requirements. |

Table 4.6: Renewable Energy Systems Selection

Based on the comparison between renewable energy systems done in Table 4.6 it is concluded that the wind turbines cannot be evaluated since the system is applicable to larger scale projects. The solar radiation in the UAE is highly available, therefore; the optical properties from the sun are used by applying photovoltaic systems in order to produce electricity for the school, while the thermal properties of the radiation are used through the application of solar absorption chiller in order to produce cooling. The geothermal system has an opportunity to be further explored since the difference between ambient and ground temperatures can reach up to 20 °C and the system has a long lifespan and little payback period. Thus, the performance of three renewable energy systems will be explored to be optimized under the UAE climatic conditions. The systems tend to provide alternative sources of cooling to reduce the peak load of the school. Further information prior to optimization needed to be established; hence a literature review of the three systems is presented in the following section.

## 4.4 Renewable Energy Systems; Types and Applications

The potential of the systems stands out to be explored in the following order starting from photovoltaic system, then solar absorption chiller and finally the geothermal system. The PV system, solar absorption chiller and geothermal system had been studied in the UAE and in hot climatic conditions and has shown reductions in energy consumption. Therefore, there is a potential of testing the application of the three systems in the school.

### 4.4.1 Photovoltaic System (PV)

#### 4.4.1.1 Description of System

Photovoltaic (PV) is a semiconductor device known to convert sunlight into direct current (DC) electrical energy (Good et al., 2015). One of the most promising markets in the field of renewable energy is capturing solar energy through photovoltaic panels to produce electricity due to the abundant amount of solar radiation all over the world. The main types of solar PV cells available in market are based on silicon categorized as mono-crystalline silicon (Edalati et al., 2015, Congedo et al., 2013), multi-crystalline silicon (Wu et al., 2008), and amorphous silicon (Elbaset et al., 2016).

Based on application, the PV are categorized as building integrated photovoltaic (BiPV) (Baljit et al., 2016), rooftop PV systems (Peng and Lu, 2013), ground mounted PV systems and grid connected PV systems (Aste and Del Pero, 2010).

#### 4.4.1.2 System Performance

Field investigation was done in Abu Dhabi to test the performance of several roof-top PV systems employing multi-crystalline silicon (m-Si) and single-crystalline silicon (c-Si). The results showed that the final yield was 6.2 kWh/kWp/day with a capacity factor as high as 21% (Emziane and Al Ali, 2015). Evaluation of rooftop PV installations at 2 Kuwaiti schools was carried out (Al-Otaibi et al., 2015). The results showed that the performance ratio was maintained between 0.74 and 0.85, the minimum monthly energy yield was 104 kWh/kWp and the annual yields was 4.5 kWh/kWp (Al-Otaibi et al., 2015).

Building integrated photovoltaic systems (BiPV) as a wall cladding system was applied to a commercial building in the UAE (Radhi, 2010) concluding the pay-back period range 12–13 years with subsidized and 3.0–3.2 years for unsubsidized energy rates (Radhi, 2010). The performance of seven roof mounted grid connected PV systems installed in Abu Dhabi was analyzed using PVsysts Project Design (Al Ali and Emziane, 2013). The study showed that the total installed capacity of 1,023.08 kWp can save up to 1,500 tons of $CO_2$ emissions annually as well as 1725 kWh energy savings yearly showing 5% performance improvement. The PV systems analyzed in Al Ali and Emziane study showed a good energy performance which indicates that roof mounted PV systems in Abu Dubai are viable, reliable and can provide significant environmental benefits compared to conventional power plants (Al Ali and Emziane, 2013). The technical, economic and environmental aspects of PV were tested in UAE buildings. Results showed that each single watt generated or saved by the PV technology significantly reduces the amount of $CO_2$ emissions from ordinary central power plants. The study also suggested that BiPV systems offer more cost reductions in both energy and economic terms over centralized PV plants, especially if the costs of saved operating energy and avoided building materials are taken into account. To be a cost-effective option, therefore, subsidies for PV investments and reasonable electricity tariff must be implemented (Radhi, 2012).

#### 4.4.1.3 System Variables

Several performance parameters of the PV systems have been studied in literature. The performance of different types of PV including mono-crystalline, polycrystalline and amorphous silicon is important to determines the efficiency of the system and can contribute in cost reductions (Elibol et al., 2017). The tilt angle of PV is also an important variable in the design of the system that contributes to the system performance (Kaddoura et al., 2016). The photovoltaic system variables identified above are evaluated in order to find the optimum design of the system in the school.

### 4.4.2 Solar Absorption Cooling System

#### 4.4.2.1 Description of the System

Electrically driven air-conditioning systems require high energy and electricity consumption which contributes to almost 40% of greenhouse gas emissions (Qi et al., 2014). The cooling demand of buildings in summer is accompanied with the availability of high solar energy, which offers an opportunity to benefit from the solar energy for cooling. Solar cooling technology contributes to economical and ecological energy supply. Solar-powered absorption systems provide summer comfort conditions in buildings at low primary energy consumption.

The most common fluids in absorption chillers are either lithium bromide-water (LiBr/ H2O) or ammonia-water (NH3H2O) systems. The lithium bromide-water system uses lithium bromide as the absorber and water as the refrigerant, while the ammonia-water system uses water as the absorber and ammonia as the refrigerant (Li and Sumathy, 2000). The main components of solar absorption chillers are; solar collector, evaporator, absorber, generator and heat exchanger (Assilzadeh et al., 2005). The solar collector collects energy from sunlight and transfers it to refrigeration system through a high temperature reservoir. Heat is taken in the absorption system from the evaporator that evaporates the refrigerant as water vapor. Then, the water vapor passes into the absorber and gets absorbed by the fluid to create a weak solution, which is then pumped into the generator. The generator requires heat from the solar collector system to detach the water vapor from the solution. The water vapor produced is at high temperature and pressure, which passes to the condenser so that heat is removed and the vapor cools down to form a liquid. High pressure liquid water then goes through the expansion valve to the low-pressure area in the evaporator where the water is changed into vapor again in the tube heat exchanger. The strong solution from the generator is pumped through a heat exchanger to the absorber and the weak solution from the absorber goes through the same heat exchanger to the generator. Finally, heat is removed from the system by cooling water, which passes through the condenser and the absorber to a cooling tower where heat is dissipated to the environment (Assilzadeh et al., 2005). The process of solar absorption chiller system is presented in Figure 4.3 (Lubis et al., 2016).

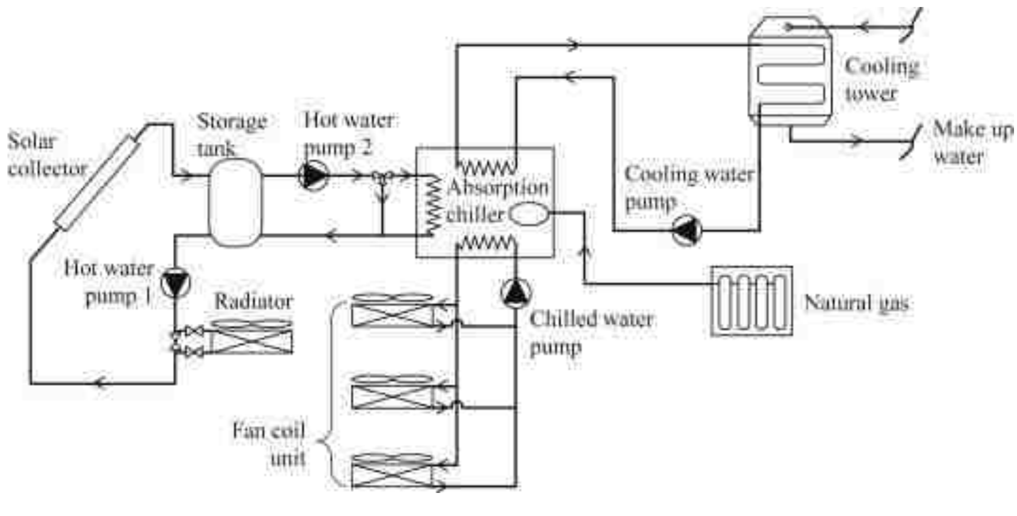



Figure 4.3: Solar Absorption Chiller Cooling System (Lubis et al., 2016)

Absorption chillers are categorized as single-effect chillers, double-effect chillers and triple-effect chillers. In the single effect absorption chillers the refrigerant and the absorbent are regenerated in a single step using a lower grade heat source using one generator (Ochoa et al., 2016). In double effect absorption chillers the refrigerant and the absorbent are regenerated in two steps using a medium grade heat source, and two generators namely High Temperature Generator (HTG) & Low Temperature Generator (LTG) (Shin et al., 2009). The triple effect absorption chiller-heaters have three generators and refrigerant solution is generated in three steps (Matsushima et al., 2010). It was claimed that single-effect lithium bromide-water (LiBr–$H_2O$) chiller is the most popular machine in solar cooling due to its low temperature operability (Ketfi et al., 2015).

The following section reviews the performance of the solar absorption cooling systems based on relevant literature.

#### 4.4.2.2 System Performance

The performance of an adsorption cooling system driven by solar thermal energy was evaluated under different climatic conditions in Australia and Jordan (Alahmer et al., 2016). The effects of solar collector area, collector slope, hot water temperature and flow rate on the system performance were investigated using the real-time weather data of the two cities. The performance of the systems was tested using TRNSYS Simulation software. The results showed that the two cities had similar solar radiation during the summer and that the solar adsorption chiller could reliably provide cooling at a reasonably higher system COP. An economic analysis showed that the solar driven adsorption cooling system could reduce the electricity consumption in Australia and Amman cities by 34% and 28% respectively (Alahmer et al., 2016). A study tested the performance of single effect absorption chiller driven by a dual-heat source that combines gas and solar energy in Indonesia (Lubis et al., 2016). Validated mathematical model predicted a coefficient of performance between 1.4 and 3.3, and a potential energy saving up to 58% when compared to a double-effect absorption chiller driven by gas (Lubis et al., 2016). A mini-type solar absorption cooling system was installed in Shanghai consisting of a 96 $m^2$ solar collector arrays, an absorption chiller of 8 kW and a heat storage water tank of 3 $m^3$. It was found that for the fan coil cooling mode, the average cooling output reached 4.27 kW during 9 h of operation under typical weather conditions. Comparing with the experimental results of the fan coil cooling mode, the average cooling output increased by 23.5% (Yin et al., 2012).

A dynamic model that couples the solar cooling system with the building was developed in TRNSYS to assess its performance in an office building in Tunisia (Soussi et al., 2017). The model predicted a primary energy savings up to 82.3% compared to a classic air conditioning system resulting $CO_2$ emissions savings of 2947 kg (Soussi et al., 2017). A solar cooling system installed in the University of California comprised of a solar field of 54 $m^2$compound parabolic concentrators (XCPC) coupled with a 23 kW double effect absorption chiller. The system achieved collector efficiency up to 39%, and chiller *COP* up to 1.02 (Hang et al., 2014). The performance of solar-assisted air-conditioning system with two chilled water storage tanks was tested in the Solar Energy Research Center building in Spain (Rosiek and Garrido, 2012). The system consisted of a solar field of 160 $m^2$ of selective absorption coated flat plate collectors, a 70 kW single effect LiBr-$H_2O$ absorption chiller, two hot water storage tanks, a cooling tower and an auxiliary heater. The results showed that the integration of two chilled water tanks saved 20% energy consumption compared to the conventional chilled water system, 30% of water consumption and 1.7 tons of $CO_2$ emissions (Rosiek and Garrido, 2012).

The thermal performance and environmental aspects of solar heating and cooling (SHC) systems in two residential buildings in UAE were investigated. The results showed that the maximum solar penetration of 20% was found to be optimum as it reduced energy consumption by 175, 648 kWh and $CO_2$ emissions by 140 ton/year with a payback period of 4 years (Ghaith and Abusitta, 2014). In another study, a solar powered absorption cycle was modeled in TRNSYS employing evacuated tube collectors coupled with a 10 kW ammonia–water absorption chiller. The results show that a cost and energy saving of up to 24.5% and 35.3%, respectively, (Al-Alili et al., 2010). In a similar study the solar absorption cycle reduces the annual electricity consumption by 60% compared to a vapor compression cycle in Abu Dhabi (Al-Alili et al., 2012). It was concluded that the solar powered absorption cooling can make potential replacement of 2/3 rd capacity of the conventional compression based air-conditioning systems (Ssembatya et al., 2014).

**4.4.2.3 System Variables**

Several performance parameters of the absorption chiller system have been studied in literature. The type and properties of the solar collector are important factors that determine the efficiency of the system and can contribute in cost reductions (Kadja et al., 2016, Choudhury et al., 2013). Studies have shown that concentrated collectors are more efficient in absorption cooling (Kadja et al., 2016, Guinard et al., 2016). The concentration ratio of collectors affects the performance of the absorption cooling system (Guinard et al., 2016, Hang et al., 2014). The temperatures and flow rates of chilled, cooling and hot water in the absorption chiller had also been indicated as important variables of the system (Budania et al., 2013, Al-Alili et al., 2012). The solar-powered absorption chiller system variables identified above are considered in the research to find the optimum design of the system in the school.

### 4.4.3 Geothermal Cooling System

#### 4.4.3.1 Description of System

Geothermal cooling systems (also called Earth-Energy systems (EESs), Ground-Source Heat Pumps (GSHPs), or Geo-Exchange systems (GEs)) are heat pumps that transfer heat between the building and the earth where the cooler ground absorbs the excess heat in the case of cooling (Omer, 2008). Uniform ground temperature is exploited to provide one of the most energy-efficient strategies of cooling buildings. In general, the initial installation cost for geothermal is higher than conventional systems; however, the operational and maintenance costs are very low and can be expected to provide reliable and environmentally friendly cooling for more than 20 years. They are quiet, pollution free and do not detract from the surrounding landscape.

Ground temperature below a particular depth remains relatively constant throughout the year; due to the high thermal inertia of the soil (Lee, 2013). At a sufficient depth, the ground temperature is always lower than the outside air in summer. When GSHP is used, the temperature difference between the outside air and the ground is utilized to dump heat into the ground in summer to provide cooling. There are two general types of GSHP, open and closed loop systems (Luo et al., 2016). In an open loop, ambient air passes through pipes buried in the ground for pre-cooling or pre-heating. In closed loop system, heat exchangers are located underground, either in horizontal, vertical or oblique position. The heat carrier medium is circulated within the heat exchanger, transferring the heat from a heat pump to the ground or vice versa (Florides and Kalogirou, 2007).

The GSHP consists of three main elements (Figure 4.4) (Florides and Kalogirou, 2007, Omer, 2008):

1. Ground loop; comprised of pipe buried in the ground, either in a borehole or a horizontal trench. The pipe is a closed circuit and is filled with a mixture of water and antifreeze, which is pumped around the pipe to transfer the heat to the ground.
2. Heat pump; consists of three main parts namely evaporator, compressor and a condenser. The evaporator releases heat to the fluid in the ground loop, the compressor moves the refrigerant round the heat pump and compresses to achieve the desired temperature and the condenser regenerates the refrigerant to its low boiling point, liquid state.
3. Heat distribution system; comprised of under floor heating or radiators for space cooling and in some cases water storage for water supply.

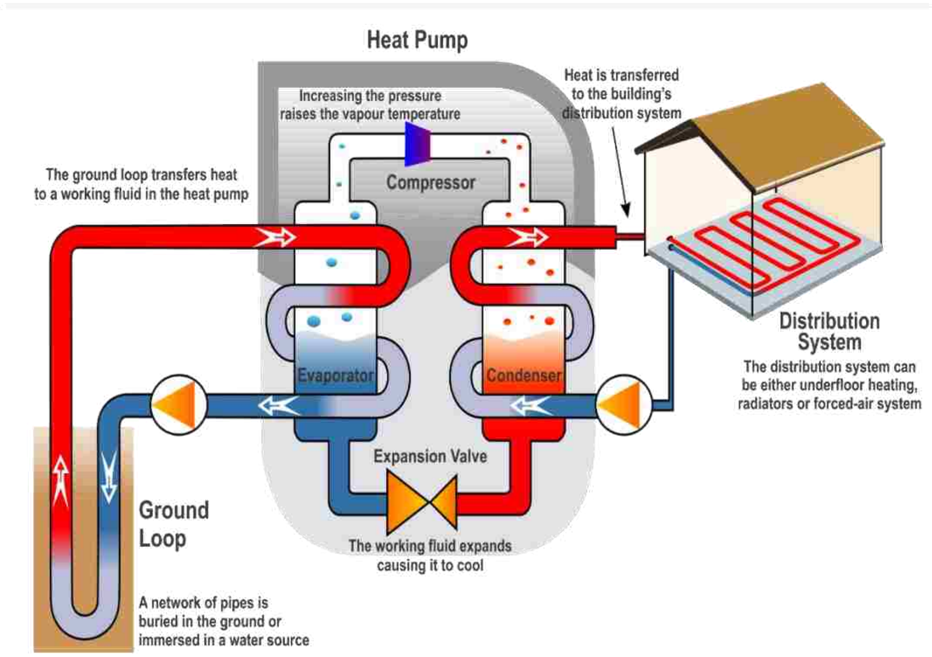



Figure 4.4: Geothermal Cooling System (Tidewater-Mechanical, 2016)

The materials of the loop of the heat exchanger are generally polyethylene, copper and aluminum. High-density polyethylene is the most common pipe material in the configuration of the GSHP (Zeng et al., 2003). Water or an environmentally safe antifreeze solution can be used as fluids in the loop. The loop length depends on number of elements, namely; type of loop configuration used, the building heating and air conditioning load, soil conditions, local climate and many more.

The geothermal system had been widely studied in literature and has been proven to be efficient and contribute to energy savings. Next section reviews relevant literature on the system.

#### 4.4.3.2 System Performance

Geothermal cooling system is effective and can reduce energy consumption by up to 44% compared to air-source heat pumps and up to 72% compared to conventional electrical heating and air conditioning in tropical climates (Omer, 2008, Yang et al., 2015). A desiccant cooling system and geothermal heat pump together in a solar hybrid desiccant air conditioning system were tested using TRNSYS software in Shanghai. Under typical weather condition, the solar driven desiccant cooling unit achieved an average cooling capacity of 70 kW contributing up to 31.4 % of the cooling capacity of the system (Dai et al., 2015). A mathematical model was developed and validated experimentally coupling the Solar Cooling System (SCS) with a Geothermal Heat Exchanger (GHX) in California, USA (Acuña et al., 2017a). The results show that a 12.30 kW cooling capacity SCS would be necessary to satisfy the maximum cooling load requirement during the summer. Additionally, between 10-23% of the energy demand was met by the systems. A numerical analysis has been done on heating and cooling by geothermal heat pumps with energy piles on residential buildings in two climatic zones in Italy, Naples and Milan (Biagio et al., 2014). The Calculated Primary Energy Saving (PES) was 40% for Naples for cooling, whereas it was about 53% for Milan for heating. While the GHG emission saving in Naples reached 20% that remained only 5% in Milan. A desiccant-based air handling unit is coupled with a geothermal source in a study in Italy. A TRNSYS model is developed to simulate both winter and summer period. Results showed that using the systems reduced the payback from 14 years to 1.2 years with the Primary Energy Savings of about 90% (Angrisani et al., 2016). Experiments were conducted in a test facility in Nebraska in the summer to evaluate the performance of Earth-to-Air Heat Exchanger (EAHE) and solar chimney (Li et al., 2014). The EAHE provided a maximum of 3308 W cooling capacity during the day time. The results show that the coupled system can maintain the indoor thermal environmental comfort conditions at a favorable range that complies with ASHRAE standard for thermal comfort (Li et al., 2014). In a similar study, the EAHE system has been developed in Fluent and validated experimentally to predict the thermal performance of the system in India during summer (Bansal et al., 2010). Effects of the operating parameters (i.e. the pipe material, air velocity) on the thermal performance of earth–air–pipe heat exchanger systems are studied. Results shows that the 23.42 m long EPAHE system gives cooling in the range of 8.0–12.7 °C for the flow velocities 2–5 m/s. The COP of the EPAHE system varies from 1.9 to 2.9 for increase in velocity from 2.0 to 5.0 m/s (Bansal et al., 2010).

At a local level, a study was done to test geothermal cooling system application in Dubai Oasis Silicon headquarters commercial building in Dubai (Salem and Hashim, 2010). The study showed that there is a potential for the efficient use of GCHP leading to significant savings up to 198 million kWh in energy usage and $27 million in operating cost. Total savings of more than $14 million were achieved with a simple payback period less than 8 years with reduction of 148,448 ton and 545 ton in CO2 and NOx respectively (Salem and Hashim, 2010). Another study tested the energy savings by using GSHP systems in the residential buildings sector in Qatar by studying a common type of houses as a case study (Kharseh et al., 2015). Two considered air conditioning systems were studied including the conventional air source heat pump system (reference system) and the ground source heat pump system. The results showed that reduction in the prime energy demand and the greenhouse gas emissions for the GSHP was 19% when compared to the conventional air source heat pump system. In addition, the analyses show that for the local conditions in Qatar the payback time of GSHP is 9 years (Kharseh et al., 2015). The implementation of GSHP was tested in residential buildings in Saudi Arabia. It showed that the implementation of GSHP systems could result in energy 14–20% compared to conventional A/C systems (Said et al., 2010).

The reviewed studies have shown that the ground heat exchanger has effective performance in reducing the temperature inside buildings during summer period in hot climatic conditions and have major contributions in energy reduction.

#### 4.4.3.3 System Variables

Several design variables that affect the performance of the geothermal system have been investigated in literature. Pipe length had been discussed as a main variable in the geothermal system (Florides and Kalogirou, 2007, Omer, 2008, Luo et al., 2016). Thermal conductivity, $\lambda$, (W/m K) and thermal capacity, cρ, $m^2/s^2$ K of the material have been studied as a parameter of the GSHP (Abuel-Naga et al., 2009, Florides and Kalogirou, 2007). Pipe flow rate and flow velocity were studied (Luo et al., 2016, Usowicz et al., 2006). Also, thermal properties of the ground including; thermal conductivity of the soil, $\lambda_{eff}$, and borehole thermal resistance, $R_{b,}$ have been studied (Ozyurt and Ekinci, 2011, Michopoulos et al., 2007). Pipe spacing and pipe diameter has been studied and proven to have effect on the performance of the GSHP (Pu et al., 2017, Yang et al., 2015). Few of the geothermal variables mentioned are going to be optimized in this study in order to design an optimal system.

The ground temperatures in Abu Dhabi Emirate at several depths retrieved from Climate Consultant program are shown in Figure 4.5. It is shown that in summer months, as the depth increases the ground temperature decreases, where at depth of 4 meters the temperature of the ground ranges between 22 °C and 32 °C, while in winter months, the ground temperatures increases at deeper ground levels.

The ground temperatures help in selecting the suitable depth of ground loop system for the geothermal.

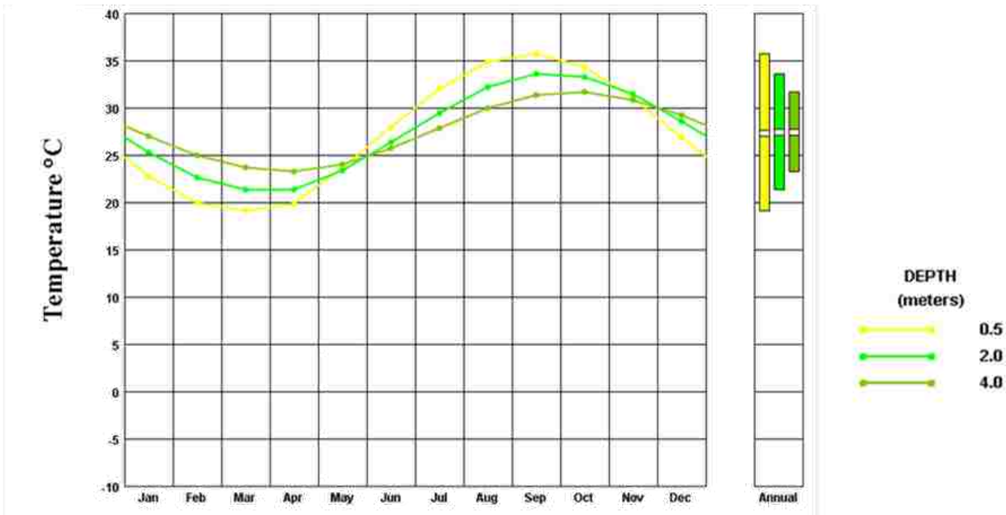



Figure 4.5: Ground Temperatures in Abu Dhabi (Climate-Consultant, 2017b)

The methodology adopted to test the performance of the three renewable energy systems is discussed in the following section.

### 4.5 Quantitative Analysis

The performances of the selected systems were optimized through a quantitative method. Quantitative research is testing objective theories by examining the relationship between variables that can be measured, usually by instruments, in which numerical data can be analyzed using statistical procedures (Creswell, 2013). Quantitative methodology is a formal, objective, systematic process for obtaining information and it is used to describe, test relationships, and examine cause and effect relationships. It is useful for testing the results gained by a series of qualitative analysis, which leads to a final answer and a narrowing down of possible directions for follow up research to take (Creswell, 2013). There are two main approaches within the quantitative research; experimental and simulation approaches (Creswell, 2013). The approach in this study requires testing several variables within each system which makes experimental analysis difficult to implement due to time and cost constraints of building models. Hence, the suitable method is simulation analysis due to availability of software.

Simulation modeling approach is used to test the opportunity of integrating systems to enhance the energy performance of the school. Simulation performance data by the school was collected and it showed the annual energy performance of the school. The first simulation program used is e-QUEST, in order to get the monthly energy and cooling consumption of the school. Whereas the second simulation program is the TRNSYS Simulation Program to test the performance of the systems. TRNSYS simulation program has been widely used in literature and has been proven as an effective program for simulating geothermal system (Chargui et al., 2012, Cocchi et al., 2013, Safa et al., 2015), absorption cooling (Florides et al., 2002, Kim and Park, 2007, Asim et al., 2016) and photovoltaic system (Li and Jing, 2017, Vuong et al., 2015, Quesada et al., 2011).

The following section describes E-QUEST and TRNSYS software and their use in the thesis.

### 4.5.1 Simulation Programs

#### 4.5.1.1 E-QUEST Energy Modeling Software

- **General Information of Software**

E-QUEST which stands for Quick Energy Simulation Tool, is a building energy analysis tool which provides professional-level results without much effort

(Energy-Design-Resources, 2017). The program is designed to allow performing detailed analysis of the state-of-the-art building design technologies using the most recent sophisticated building energy simulation techniques without requiring extensive experience in the building performance modeling. E-QUEST has a building creation "wizard" that allows the user to create an effective building energy model through several steps. This wizard has some series of steps that helps the user to describe the features of the design that would impact energy use, such as: architectural design, HVAC equipment, building type and size, floor plan layout, construction materials, area usage and occupancy, lighting system (Energy-Design-Resources, 2017).

The e-QUEST building creation wizard requests the most general information about the building design, and then goes into more details. After completing the building description, e-QUEST produces a detailed simulation of the building, as well as an estimate of the energy amount it would use. Heating or cooling loads are calculated for each hour of the year, based on the factors such as: walls, windows, glass, people, plug loads and ventilation. Additionally, the performance of fans, pumps, chillers, boilers and other energy-consuming devices is simulated (Energy-Design-Resources, 2017).

The results of e-QUEST appear in several graphical formats for viewing simulation results. Comparisons can be made over the performance of alternative building designs in which multiple simulations can be done and therefore view the alternative results in side-by-side graphics. The results offers: energy cost estimating, daylighting and lighting system control and automatic implementation of common energy efficiency measures (by selecting preferred measures from a list) (Energy-Design-Resources, 2017).

- **E-QUEST Monthly Energy Simulation**

E-quest is used to perform monthly simulation for the school building. The data collected from ADEC shows an annual performance of the prototype school that includes the annual energy consumption, annual cooling load and annual electric consumption. However, it does not show the monthly energy and cooling consumption. Thus, e-QUEST is used to simulate the monthly energy performance for the school. There are several reasons for choosing e-QUEST simulation over other programs in which it is a free program that can be downloaded easily from the internet. E-QUEST also allows importing building geometry from architectural AutoCAD plans. Additionally, E-QUEST's wizard is very simple and does not require experience in energy analysis to use the program. Moreover, results are accurate and detailed where the user can find a list of results that appear in a report that are represented at a monthly basis (Energy-Design-Resources, 2017, Energy-Models, 2013).

E-QUEST Version 3.64 is used to simulate the energy performance of the school. First, the AutoCAD file of the school is imported to the program and all the dimensions are fixed. Then the parameters applied for the building wizard are based on the documents given by ADEC that specifies the building materials and U-values used in the school. The windows, doors and glazing materials are also specified in the wizard based on the data retrieved from the collected documents. The model is ready for simulation after filling all the required data. The simulation takes only few minutes and the result is ready for analysis. The output file appears as a report representing the monthly electric consumption and the breakdown of all the systems that contribute to the electricity consumption such as; space cooling, ventilation and fans, space heating, lighting and other types of load. The output of this program sets the baseline case for the school. The baseline will be used to compare the results of the renewable energy systems that will be studied using TRNSYS Simulation Program.

#### 4.5.1.2 TRNSYS Simulation Program

- **General Information of Software**

Transient System Simulation Program TRNSYS is graphically based software used to simulate the behavior of transient systems. TRNSYS is a simulation program is mainly used in the fields of renewable energy engineering and building simulation for passive and active solar design. TRNSYS is a commercial software package developed by the University of Wisconsin (University-of-Wisconsin-System, 2013). TRNSYS consists of two parts; the first part is an engine called the kernel which reads and processes the input file, repetitively solves the system, determines convergence, and plots system variables. The kernel also has some utilities that determine invert matrices, thermo-physical properties, interpolate external data files and performs linear regressions. The second part of TRNSYS is the library of components, which models the performance of one part of the system (TRNSYS, 2017b). There are two libraries; the standard library and the TESS library. The standard library includes approximately 150 models which have pumps, wind turbines, multizone buildings, weather data processors, economics routines, and basic HVAC equipment. Models are constructed in a way that users can modify existing components or write their own, extending the capabilities of the environment. The TESS library has over 90 new models (TRNSYS, 2017a). The components in this library represent advanced systems and models. The components are useful for creating daily, weekly, monthly schedules, normalized occupancy, lighting, or equipment schedules, and set points for thermostats. The TESS Library contains numerous controllers for practically any TRNSYS simulation. It also contains electrical components with many kinds of solar photovoltaic (PV), solar thermal, lighting controls, geothermal heat pump components, ground coupling components, advanced HVAC components, Hydronics, loads and structures components, solar collector components, storage tank components and other systems (TRNSYS, 2017a).

During setting up the model in TRNSYS, the user defines the parameters and variables in each component; after that the user connects between the components and set the input parameters of each component. The user can have variety of output files that are selected from the wide range available in the library. The output files can be shown as numerical data presented in Notepad and graphical simulations. The user can choose any desired time interval for the simulations.

- **TRNSYS Renewable Energy Simulation**

TRNSYS 17 is used in the thesis to simulate renewable energy systems and to explore the opportunity of integrating those systems to schools in the UAE. This software requires learning, where I have spent 3 months learning about the software, using it, building models, simulate them, get results and analyze them.

TRNSYS Simulation Program has been chosen over other programs since it is known for its strong simulation capabilities for passive and active solar systems and was claimed to be the most comprehensive energy simulation software (Sousa, 2012). The output devices of TRNSYS allow the user great flexibility in integrating, printing, and reporting any component output value. Additionally, the results of TRNSYS are very accurate (Sousa, 2012, TRNSYS, 2017b). TRNSYS is used to simulate the renewable energy systems; photovoltaic, absorption chiller system and geothermal system and will be discussed in details in Chapter 5.

## 4.6 Summary

This chapter presents the methodologies used to meet the study objectives. The process went through two main stages; first, a critical analysis of *Estidama* performance of “Sheikha Bint Suroor Public School” was carried out. The analysis has gone through three main stages. The first stage pointed out the achieved and un-achieved credits from *Estidama* PBRS. The second stage analyzed and weighted the un-achieved credits in order to find the opportunities of applying additional credits. The third stage investigated the applicability of the un-achieved credits based on the credits requirement and the applicability of the credits in the school context. The conclusion from the critical analysis showed that the ‘Resourceful Energy’ System from Estidama PBRS had the highest gap and has an opportunity for integration in the case study. Three renewable energy systems are selected; geothermal, absorption chiller and photovoltaic. The literature review done on the systems has shown the effectiveness and energy improvement yield by them. E-QUEST software is used to calculate the monthly energy consumption of the school, while TRNSYS Simulation Software is used to test the performance and feasibility of the three systems since it gives variety of variables and parameters that can be controlled. The application of the systems is examined in the next chapter to see the potential of the three renewable energy systems integration to enhance the energy performance of the prototype school.

# Chapter 5: Case Study Application; School Energy Performance Enhancement

## 5.1 Introduction

This chapter is dedicated to energy performance of the three renewable energy systems introduced in chapter 4. The first part of the chapter describes the baseline energy consumption of the school calculated from e-Quest simulation program and compared with the data provided by the school. The simulation models are generated in TRNSYS for the three renewable energy systems, namely; geothermal, absorption chiller and photovoltaic. The models are simulated to predict energy savings and the resulting credits achieved from *"Estidama"* from the three systems. Finally, cost estimation analysis is carried out on the three systems to determine the feasibility of their application in the school.

## 5.2 Energy Data for Case Study School

### 5.2.1 Baseline Energy Performance of School

Simulated data was collected from ADEC showing Typical Meteorological Year (TMY) annual energy consumption by systems of “Sheikha Bint Suroor Public School” presented in Table 5.1 where it is treated as a baseline case.

| System | Peak Demand in kW | Annual Consumption in kWh |
|---|---|---|
| Space Cooling | 360.5 | 777,607.7 |
| Heat Rejection | 49.4 | 151,257.6 |
| Space Heating | 79.7 | 66.0 |

| | | |
|---|---|---|
| Pumps | 42.8 | 105,742.8 |
| Fans – Interior | 304.6 | 276,997.0 |
| Interior Lighting | 188.3 | 410,262.4 |
| Service Water Heating | 200.0 | 231,840.0 |
| Receptacle/Process Equipment | 167.5 | 252,479.7 |
| Total | 1,392.9 | 2,206,253.2 |

Table 5.1: Simulated TMY Annual Peak Demand and Energy Consumption of School (ADEC, 2016b)

The school uses chilled water cooling system which operates for 24 hours a day. The school uses Solar Thermal Panels to meet hot water demand for a swimming pool and the showers. The solar thermal system yielded an annual energy savings of 117760.00 kWh representing an annual energy savings by 5.3% of the total annual energy consumption, 2,088,493.2 kWh of the school

The provided documents by ADEC showed the annual energy and cooling consumption however, the peak cooling demand was missing which was predicted by e-QUEST model validated through the collected school data.

### 5.2.2 E-QUEST Model for Energy Consumption

The building energy performance evaluated through e-QUEST relied on the following data:

- The weather data of Abu Dhabi, the school area, number of floors and type of cooling system.

- The floor plan can be imported from AutoCAD and the orientation can be adjusted.
- The building envelope specifications including the roof, walls and floor materials and U-values.
- The windows and doors materials, U values and SHGF where applicable.
- Occupancy schedules.
- The HVAC system involving cooling and heating demands.

The monthly total energy consumption and space cooling demand are presented in Figures 5.1 and 5.2, respectively. Since, the peak energy and cooling consumption occurs from May to August, the proposed alternative cooling system (geothermal and absorption chiller) are simulated in the same peak months.

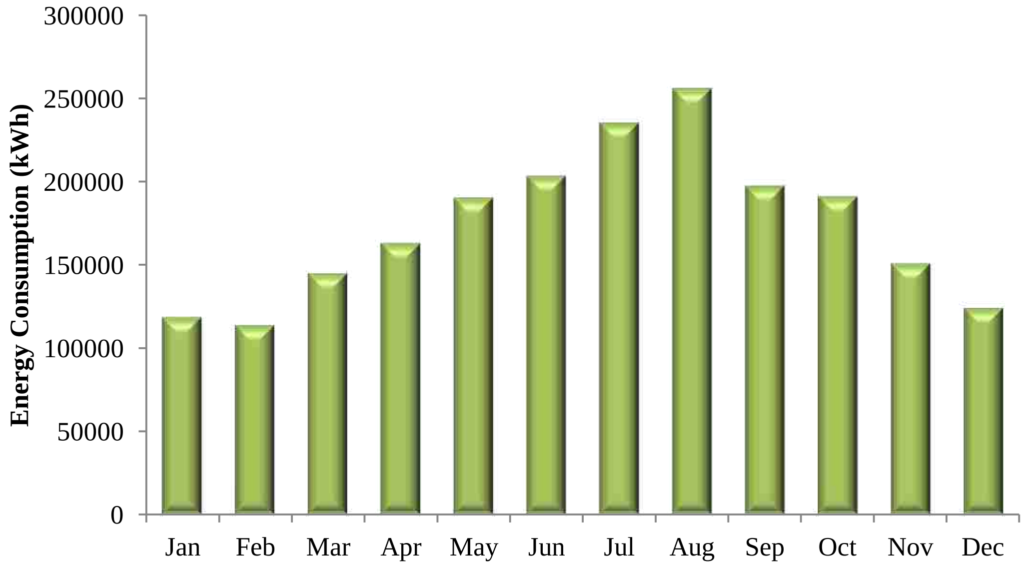



Figure 5.1: Monthly Energy Consumption of School in kWh

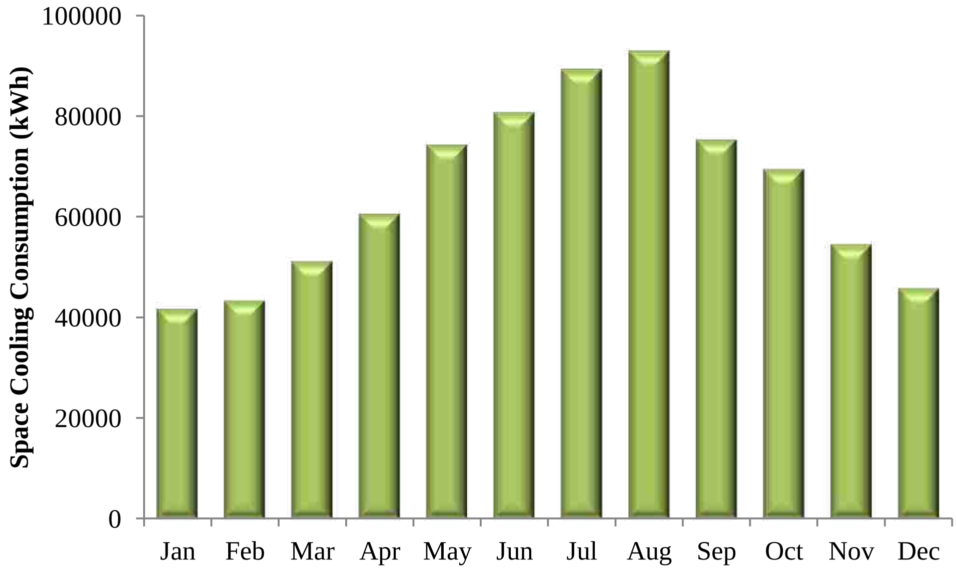



Figure 5.2: Monthly Space Cooling Consumption of School in kWh by e-QUEST

The simulated net annual electric consumption for the school given by ADEC is comparable with that simulated in e-QUEST. Therefore the monthly electricity data given by the software was trusted to be true. Since ADEC did not provide detailed monthly cooling consumption in the peak months, the validated e-Quest model is used to predict it. The predicted cooling load from May to August through e-Quest is used as base line to predict cooling load saving by geothermal and solar absorption cooling system through TRNSYS.

### 5.3 Numerical Model Setup

#### 5.3.1 Photovoltaic Model Setup in TRNSYS

A transient photovoltaic system model was developed in TRNSYS 17. The design of the model consists of two main components; the weather data and the photovoltaic panel as shown in Appendix C. The target of the PV system is to provide 10% (208849.32 kWh) of the total energy consumption (2,088,493.20 kWh). The main component of the photovoltaic is explained below:

**Type 562e: Simple Glazed Photovoltaic Panel**

Type562 model is a component in TRNSYS TESS library representing glazed photovoltaic array (TRNSYS, 2017a). Efficiency of the panel is provided by the user based on selected panel as a constant value or a variable. The constant parameters used to model the photovoltaic system are shown in Table 5.2. The input weather data of solar radiation, wind speed and ambient temperature is provided by Abu Dhabi weather file. The model outputs PV temperature, temperature based power loss and net power production.

| Parameter | Value | Unit |
|---|---|---|
| Area | 1.6 | $m^2$ |
| PV Efficiency | 17.2 | % |
| Ambient Temperature | Based on Weather Data of Abu Dhabi | C |
| Back Radiant Temperature | 45 | C |
| Top Heat Loss Coefficient | 15 | C |
| Bottom Heat Loss Coefficient | 12 | C |
| Incident Solar Radiation | Based on Weather Data of Abu Dhabi | $W/m^2$ |

Table 5.2: Constant Parameters for Photovoltaic System Component

### 5.3.2 Solar Absorption Chiller Model Setup in TRNSYS

A transient solar absorption chiller model was developed in TRNSYS 17. The model consists of four main components; the weather data, solar thermal concentrator and single effect absorption chiller. The solar cooling system is run by concentrated solar collectors. It exploits the absorption process to convert the collected solar thermal energy into the required cooling load. The components of the absorption cooling model are shown in Appendix C.

The target is to reduce 10% of the peak cooling peak demand from the solar absorption cooling system. The concentrated collector acts as a thermal engine to provide work from high temperature followed by high pressure that eventually produces cooling. In order to achieve the targeted cooling demand, the system needed to be sized. There are two separate systems working; the absorption chiller and the solar concentrator. The absorption chiller worked as a thermal engine in which a sterling engine is assumed to be used (Kong et al., 2004). The thermal energy hitting the collector is transformed to cooling. The efficiency of the sterling engine based on literature is 40% therefore; this efficiency was used to calculate the size of the collector (Ernst and Shaltens, 1997, Kong et al., 2004, Wikipedia, 2017). The system is designed to deliver 10% reduction (36.05 kW) from the peak cooling demand of 360.05 kW. The size of one collector is selected as 3 $m^2$ and the peak radiation being 1 $kW/m^2$. The equation used to calculate the load on one collector is:

$$\text{Collector output} = \eta_c \times \text{peak load} \times \text{collector size} \tag{5-1}$$

$$\text{Collector output} = 0.4 \times 1\ kW/m^2 \times 3\ m^2$$

$$\text{Collector output} = 1.2\ kW$$

Considering 1.2 kW cooling power produced from one collector, 30 collectors representing 90 $m^2$ aperture area are needed  produce 36 kW cooling capacity. The collectors are assumed to be connected in parallel with a fixed flow rate that heats up the fluid independently to attain required temperature through an optimal fluid flow rate.

These input parameters and variables are considered in TRNSYS model as collector size, number of panels, tilt angle, fluid flow rate and chiller capacity. The output is recorded as the useful energy gain. The model was iterated until the useful energy gain approached the target output of 36 kW validating the initial assumptions.

TRNSYS Simulations are carried out to optimize the parameters of collector area, concentration ratio, inlet fluid flow rate, absorption chiller capacity, cooling, heating and chilled water inlet temperatures and flow rates. The useful energy gain for the peak months between May and August is determined. The main components of the absorption chiller are explained below:

**Type 1245: Generic Concentrator Solar Collector**

This type is a component from TESS Library. It is a generic concentrating solar collector where the collector efficiency and off-normal performance are modeled with curve-fits found from collector tests. The collector has an external reflective concentrator located behind an evacuated tube which houses the absorber and heat transfer fluid (TRNSYS, 2017a). The parameters that were considered during the simulation were; total aperture area, concentration ratio (aperture area: receiver surface area); collector efficiency as a function of the mean receiver temperature, and the inlet fluid flow rate (Table 5.3). The weather data of Abu Dhabi is fed into the concentrated collector.

| Parameter | Value | Unit |
|---|---|---|
| Total aperture area | 3 | $m^2$ |
| Concentration ratio | 1, 5, 10, 15, 20, 25 | - |
| Collector efficiency | 0.7 | - |
| Inlet fluid flow rate | 200 | kg/hr |

Table 5.3: Parameters for Solar Collector Component

**Type 107: Absorption Chiller (Hot-Water Fired, Single Effect)**

Type107 is a built-in component for modeling single effect absorption chillers. It uses an external absorption chiller performance data file for predicting the chiller performance at the prevailing conditions of hot water supply, cooling water, and chilled water inlet temperature. This model requires knowledge of the effect of the factors on the performance of the absorption chiller involving chilled water inlet temperature, cooling water inlet temperature, hot water inlet temperature and part load ratio. This component enables the determination of the maximum thermal output obtainable from the solar collector field (TRNSYS, 2010). The flow rates and temperatures of the absorption chiller were based on guess values to get optimal output (Table 5.4).

| Parameter | Value | Unit |
|---|---|---|
| Rated capacity | 1.2 | kW |
| Rated C.O.P. | 0.6 | - |
| Chilled water flow rate | 250 | kg/hr |

| | | |
|---|---|---|
| Cooling water inlet temperature | 24 | C |
| Cooling water flow rate | 250 | kg/hr |
| Hot water inlet temperature | 85 | C |
| Hot water flow rate | 25 | kg/hr |

Table 5.4: Constant Parameters for Absorption Chiller Component

### 5.3.3 Geothermal System Model Setup in TRNSYS

A transient geothermal model was used in TRNSYS 17. The design of the model is shown in Appendix C. The model consists of two main components; the weather data and the horizontal ground heat exchanger to provide alternative cooling source for the building. The system used the actual ground temperatures based on Abu Dhabi weather file as the heat sink to transfer heat from building to the ground through horizontal loop heat exchanger. The heat exchanger consists of a network of buried pipes installed in horizontal trenches using water as heat transfer fluid. The heat exchange is controlled by surface temperature of the ground, the distance between the pipes, number and material of pipes, diameter of pipes, type of fluid (water in the present case), fluid flow rate, loop length and depth of loop. Evaluation is made on the spacing between earth and loop, and total area needed to install the loop while keeping number of loops in parallel and series constant. The design of the geothermal system is done based on the four peak months of the year between May and August. The output is monitored in terms of inlet and outlet fluid temperatures, fluid to ground heat transfer rate (the rate at which energy is transferred from the fluid to the soil) and the delivered energy rate (cooling produced). The parametric influence of the pipe depth, pipe material, pipe length, pipe spacing, pipe diameter and pipe flow rate are determined.

The role of each component used in the model simulation is explained below:

**Type 15-6, Weather Data of Abu Dhabi City**

This component serves the purpose of reading data at regular time intervals from the selected weather data; in this model Abu Dhabi weather data file, interpolating the data (including solar radiation for tilted surfaces). Simulation takes place at time steps of less than one hour, and makes it available to other TRNSYS components. The model also calculates sky diffused and ground reflected radiation, the angle of incidence of beam solar radiation and the slope and azimuth of surfaces. It outputs heating and cooling seasons and monthly and annual maximum, minimum and average temperature (TRNSYS, 2010).

**Type 997, Horizontal Ground Heat Exchanger**

This type is a component from TESS Library. A series of horizontal pipes are buried in the ground to transfer heat from/to the ground. The impact of energy storage in the ground is included where pipes are surrounded by a fully 3-D rectangular conduction model of the ground (TRNSYS, 2017a). This component models a series of fluid-filled, parallel, horizontal pipes buried in the earth. This model allows the specification of groundwater flow through a horizontal layer of soil and multiple soil layers. The fluid properties, pipe material properties and soil properties, flow rate and temperature of the fluid are specified in this component.

## 5.4 Numerical Results and Discussion

### 5.4.1 Photovoltaic Simulation Results

Several parameters are considered in the Photovoltaic system analysis with the range of tested values presented in Table 5.5. Three parameters have been tested in order to find out the optimum values that will produce higher energy savings.

| **Parameters** | **Variables** |
|---|---|
| Type of PV | Multi-Crystalline, Single Crystalline, Amorphous Silicon |
| Slope of PV | 0 degrees, 24 degrees, 45 degrees, 90 degrees |
| Azimuth of PV | 0 degrees, 45 degrees, -45 degrees, 90 degrees, -90 degrees |

Table 5.5: Parameters and Variables of Photovoltaic System

The simulations results are presented in terms of power production of the PV from incident solar radiation and the PV temperature that determines power losses. The PV is simulated for 1 year; however the results are presented as 12 selective days one from each month that produces the highest power and associated PV temperature.

Monthly variation for the ambient temperature retrieved from Abu Dhabi weather file during a year is shown in Figure 5.3. In the figure shows that in summer the ambient reaches up to 46 °C at day time and drops in winter down to 10 °C at night time.

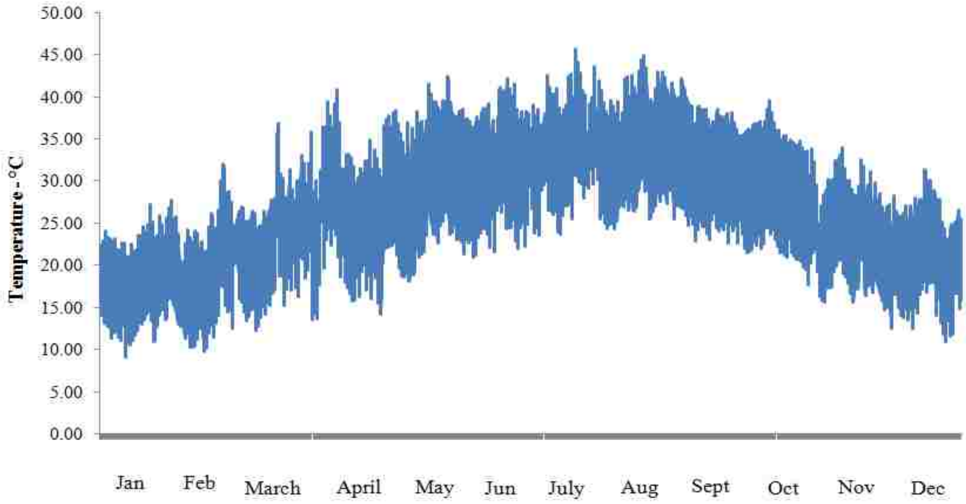



Figure 5.3: Monthly Variation of Ambient Temperature

**Type of PV**

Three different types of PV are analyzed namely, Polycrystalline Silicon (also known as Multi-crystalline), Mono-crystalline Silicon (also known as Single-crystalline Silicon) and Amorphous silicon. A criterion is devised for the performance indicators of the three types in order to choose the optimum and most efficient type presented in Table 5.6.

| Criteria | Polycrystalline Silicon | Mono-Crystalline | Amorphous silicon |
|---|---|---|---|
| Efficiency | 13-16% | 15-24.2% | 7-13% |
| Lowest Temperature coefficient of Pmax | -0.44% | -0.38% | -0.34% |
| Life Span | Up to 25 years | More than 25 Years | Up to 25 years |
| Required Area | Industry standard | Industry standard | May require up to %50 more space for a |

| | | | |
|---|---|---|---|
| | | | given project size |
| Power Production | Less Power Production than Mono-Crystalline | Highest Power Production | Least Power Production |
| Initial Cost | Less installation cost. | Highest installation cost | Cheapest among the other types. |

Table 5.6: Comparison of Different PV Types (Alchemie, 2013)

Based on the comparison carried in Table 5.6, it is shown that the most suitable PV type is the Mono-crystalline PV due to highest efficiency and moderate power loss coefficient. A Mono-crystalline PV product is selected from SUNTECH Company to simulate in TRNSYS model (SUNTECH, 2016). The specifications of the product are laid out in Table 5.7.

| **Type** | **Mono-Crystalline Solar Module** |
|---|---|
| Company | SUNTECH |
| Diagram |  |
| Dimension | Dimensions:1640 × 992 × 35 mm |
| Maximum Power at STC (Pmax) | 280 W |
| Optimum Operating Voltage (Vmp) | 31.5 V |
| Optimum Operating Current (Imp) | 8.89 A |

| | |
|---|---|
| Open Circuit Voltage (Voc) | 39.4 V |
| Module Efficiency | 17.2% |
| Operating Module Temperature | -40 °C to +85 °C |
| Temperature Coefficient of Pmax | -0.41 %/°C |

Table 5.7: Mono-Crystalline PV Specifications (SUNTECH, 2016)

The analysis done is based on the performance of one panel rated at 280 W noted in Table 5.7 above. The results of PV are reported in the following ways:

- Transient Temperatures; plots the highest day temperature in each month for a year in order to predict the power losses at the peak time of each month and during overall time.
- Transient power; presents the day with the peak power for each month in the year.
- Monthly power produced.
- Annual Power Production (Gross Power).
- Transient power losses based on temperature; shows the power losses based on the transient power and temperatures of the peak days in each month.
- Annual Power Loss and net power, the net power is calculated by subtracting annual power loss from annual gross power.

**Slope of PV**

The simulation at four slopes is conducted in TRNSYS being 0, 24, 45 and 90 degrees, to find the optimal slope degree for the PV.

- **Transient Temperatures**

The transient temperature of the four slopes was tested by selecting the days of each month in the year with the peak temperatures (Figure 5.4).

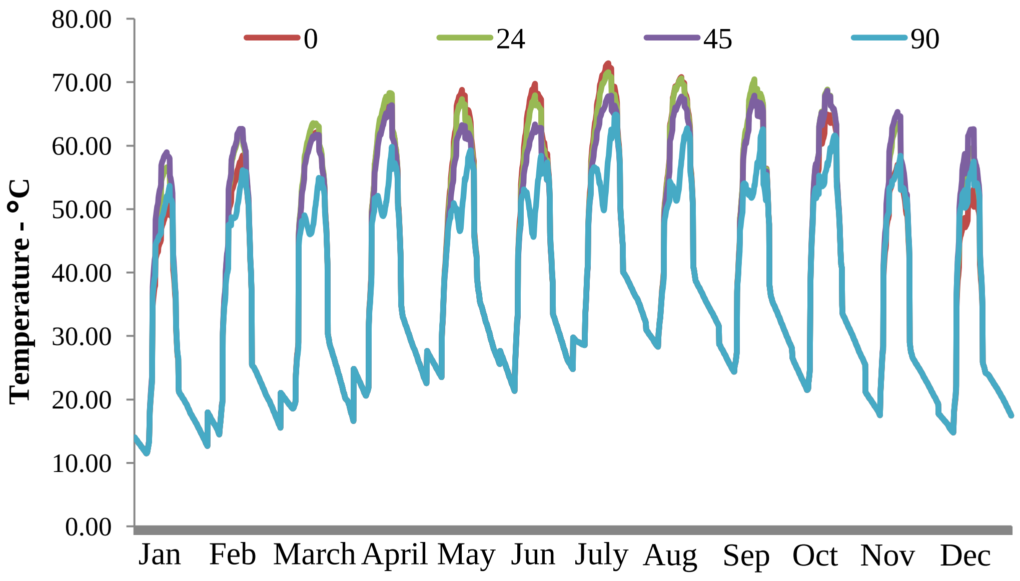



Figure 5.4: Temperatures of Different PV Slopes during Peak Days of Each Month

The plot shows that the temperature of the PV panels increases during summer and decreases during the winter in line with the ambient temperature of the UAE. Results imply that during winter (November, December, January and February) the 45 degrees slope yields that highest temperature, this is due to the low angle of sun in winter where the 45 slope became an optimal angle. During summer (May, June July and August), the 0 degrees slope gains more solar radiation at the peak time during the day which yields higher PV temperature on the panel and will affect the performance more and yield higher losses. In the shoulder months (March, April, September and October); 24 degrees slope yields the highest temperature, as it gains higher direct solar radiation.

- **Transient Power**

The transient power of the four slopes was predicted by selecting the days of each month in the year with the highest peak time temperatures (Figure 5.5).

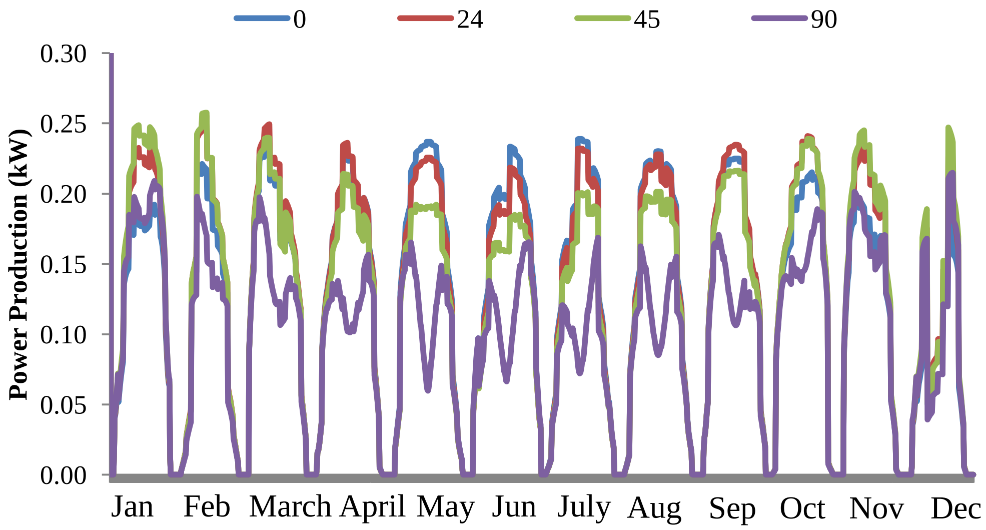



Figure 5.5: Power Produced at Different PV Slopes for Peak Days in Each Month

The power produced shows similar trend as of the solar radiation. Peak power produced in winter is higher than summer due to higher solar radiation of the sky and lower ambient temperature which produces fewer losses. The plot also demonstrates that the height of the curves is higher in winter than summer representing peak radiation; however, width of each curve is larger in summer representing the day length. Consequently, the summer has less peak power but lasts over longer time than in winter resulting in higher overall energy production.

Based on the results in Figure 5.5 representing one day selected for each month, it is shown that during summer, panel slope of 90 degrees experiences a drop in peak power at noon time. This is justified by the fact that at noon time, the solar radiation is directly parallel over the vertical panel; which provides no direct radiation over the panel. On the other hand, at noon time during winter, the sun is at lower angle which allows some radiation on the panel, while for the panel slope of 0 degrees, the peak power is showing an opposite behavior, since the direct solar radiation hits the panel on summer and produces the maximum power. The power output of the panels is in line with the temperature trend of each panel slope explained in Figure 5.4. The slope of 0 degrees experiences the highest power during summer due to the sun position nearly perpendicular to the plane of the PV panel. While for slope of 24 degrees, the power is the maximum during shoulder months between summer and winter because the sun is at optimal angle with the panel resulting in higher temperature and power production. Moreover, for the slope of 45, the maximum power is witnessed during winter due to the optimal angle between sun at peak time and the panel slope.

- **Monthly Power Produced**

The total power produced during each month for the four different slopes is plotted in Figure 5.6.

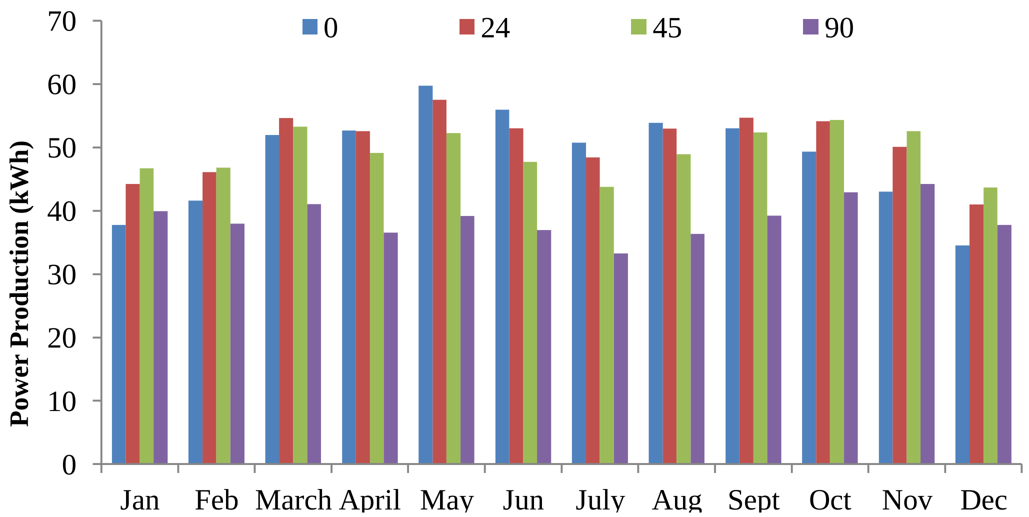



Figure 5.6: Total Monthly Power of Different PV Slopes per Panel

Results implies that the power during the peak summer months of June, July, August and winter peak months of December, January and February, is lower than shoulder months. Several reasons tend to explain this trend; the peak summer months experiences very high temperatures that over heats the panels and decreases the PV cell efficiency. Additionally, summer months in the UAE tend to have dust accumulated in the atmosphere that reduces the radiation reaching the panel, and therefore reduces the power produced. On the other hand, during winter; the sky tends to be clear and little dust is present in the atmosphere; however, the day hours are less during winter which reduces the net amount of radiation on the panel resulting in reduced power production.

- **Annual Power Production (Gross Power)**

The annual power production for each panel slope is aggregated to choose the most optimum slope for the PV (Figure 5.7).

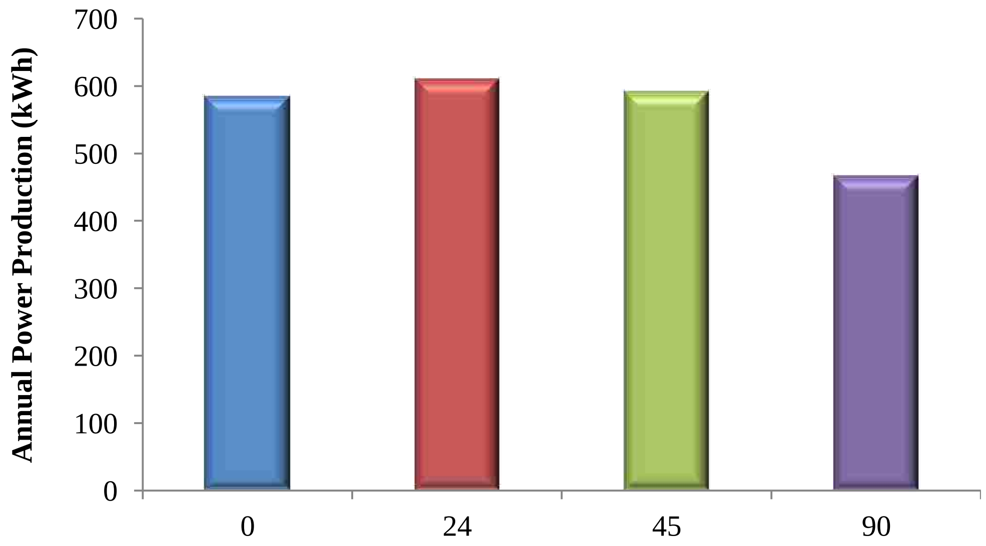



Figure 5.7: Annual Power Production per Panel for Different Slopes in kWh

The annual power production for the 0°, 24° and 45° slopes are close to each other, however 24° slope yields highest of all being 609.27 kWh annually which is consistent and confirm the basic rule of optimal tilt angles for PV systems (tilt = latitude angle of the location) (Gunerhan and Hepbasli, 2007, Jafarkazemi and Saadabadi, 2013). While the 90 slope yields the lowest power production of 465.28 kWh annually. The 24 degrees slope produces the highest annual power since the monthly total shoulder months (March, April, September and October) are higher than peak summer and winter months. During peak summer months, the 0° slope produces the highest power. Thus, the suitable angle can be either 0 or 24 degrees. The 0 degree panel has more flexibility of installation, and integration with the building. Additionally, the cost of resources is less for the 0 degree panel since no support structures needed for that angle, unlike the 24 slope which needs support structures to install the panel at that angle. However, there is a trade-off between the 0 and 24 panels slope; where the 0 degrees slope is exposed to dust which cannot be cleaned easily since it is horizontal, however, the 24 degree experiences less accumulation of dust because the dust can drop off the panel easily however the true effect of dust accumulation with various angles is unknown. Therefore, based on the previous analysis, the selected angle for the PV panel is 24 degrees (Jafarkazemi and Saadabadi, 2013, Radhi, 2010).

- **Transient Power Losses**

The power losses are calculated for each slope by using the peak days in each month. It is calculated based on the transient power shown in Figure 5.5. The power losses based on temperature for the peak day in each month for the four slopes are shown in Figure 5.8.

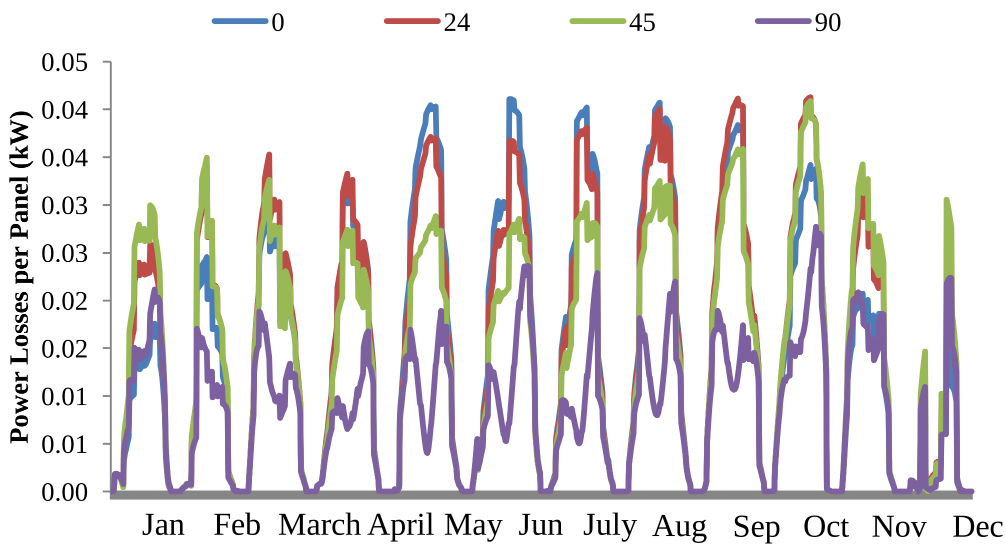



Figure 5.8: Power Losses per Panel for Different Slopes in kW

The power losses follow in trend the transient temperatures and transient powers shown previously. The 90 degree panel slope has the lowest power losses since it experiences the lowest temperature over the whole year, while the 45 angle panel slope has the highest power losses during winter months due to the high temperature. The 0 slope experiences the highest power losses during peak summer months since the temperature is the highest in these months. The 24 angle panel slope has the highest power losses during shoulder months due to the sun position that yields the highest temperature for these months.

- **Monthly Power Losses**

The monthly power losses are calculated for the 24 degrees optimal slope angle for one panel (Figure 5.9). The plot shows the trend of power loss based on temperature and power for each month.

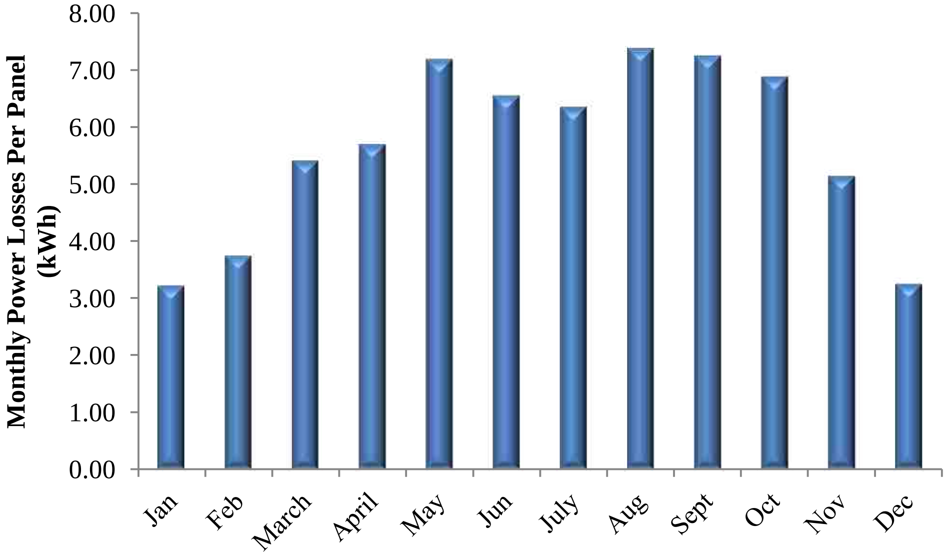



Figure 5.9: Monthly Power Losses for 24 Degrees Panel Slope in kWh

- **Annual Power Losses and Net Power**

The annual power losses and net power are calculated for the selected slope of 24 degrees for one panel (Figure 5.10).

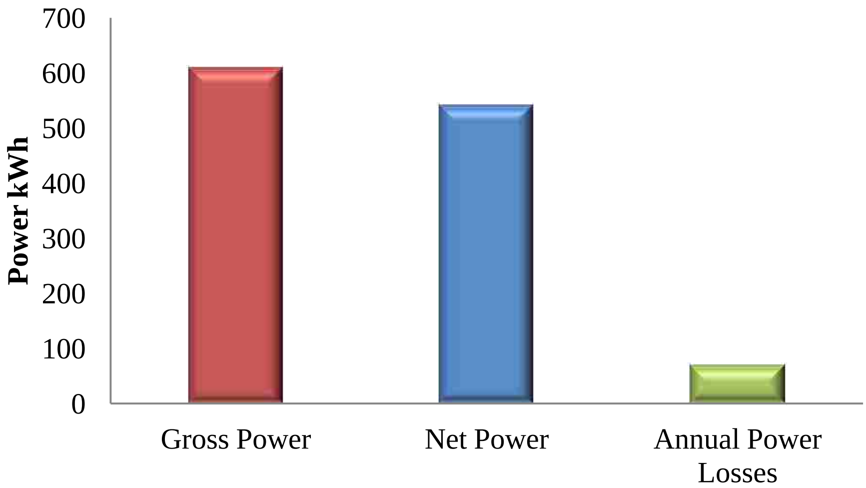



Figure 5.10: Net, Gross Power and Annual Losses for 24 Degrees Slope

The net power of one panel with slope 24 is 541.36 kWh/year. The previous analysis had been conducted for one panel. The number of panels is calculated to produce 10% of the annual energy consumption. The gross power of one panel is 609.277 kWh, while in order to reduce 10% of the energy consumption (208849.32 kWh) 342 panels must be installed which seems quite practical considering the scale of the school.

The covered area by the array of PV panels is 555 $m^2$ where each panel has a 1.62 $m^2$ area. The panels are separated by 1.6 meters for services and maintenance, therefore the total required area for the panels is 1110.6 $m^2$. The roof of the school has an area of 14694 $m^2$, thus there is an adequate space to install the PV panels. There is no net metering system used in the PV system since there is no excess power produced as shown in Figure 5.11 which shows the school electric demand compared to the 10% power produced by the PV panels.

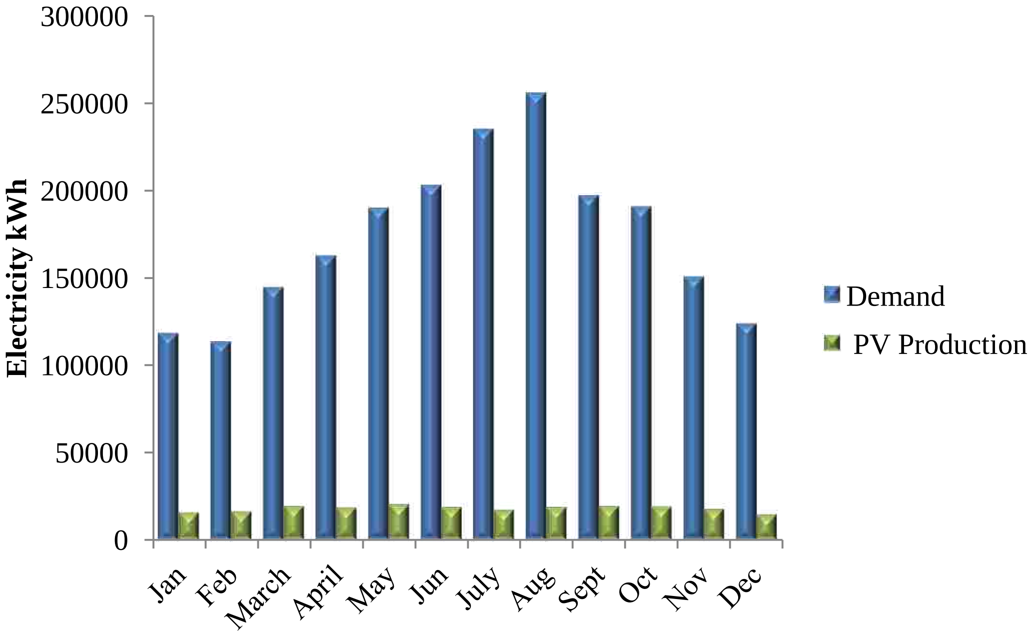



Figure 5.11: School Electric Demand versus PV Production in kWh

Next part discusses the effect of azimuth on power PV production and identifies the optimum azimuth angle of the PV.

**Azimuth Angle**

Azimuth angle is simulated in order to evaluate the power production of each angle and show their power losses. It is well known that the optimum angle that produces the highest power is towards the south orientation representing 0 degrees (Assi et al., 2008), however, the power loss incurred by deviating from the optimum is azimuth  is not well known. The building configuration varies from one building to another, where sometimes architects have to select an off the optimal azimuth in order to align with the building design, facilitate mobility or maintain symmetry. In order to understand off design conditions, the power output from each azimuth angle is simulated in order to let architects know the implications in terms of power losses. Simulations are carried out for five azimuth angles 0°, 45°, -45°, 90° and -90°.

- **Total Power**

The total power during each month for the five different azimuths is plotted in Figure 5.12.

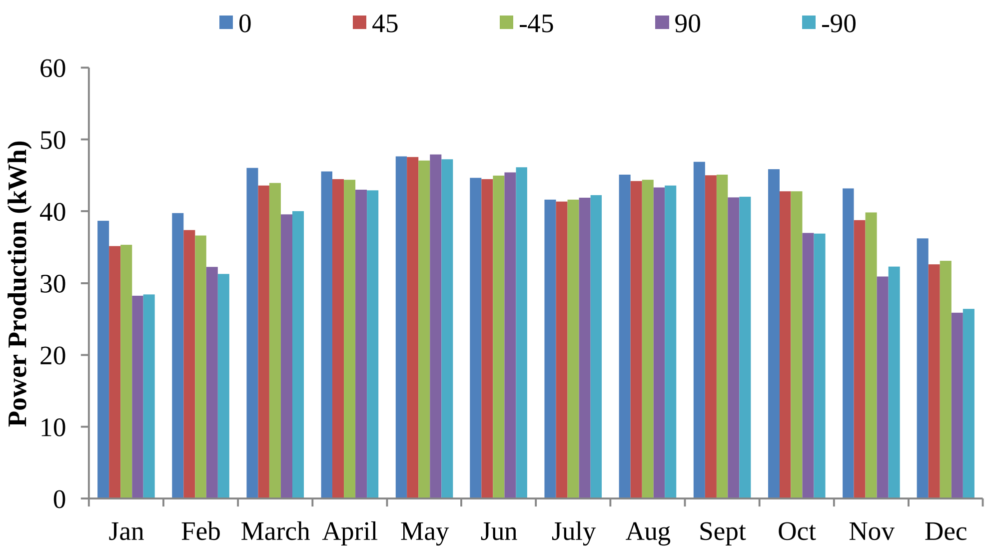



Figure 5.12: Total Monthly Power of Different PV Slopes per Panel in kWh

The 0 azimuth has the highest power during all months except June and July; due to overheated panels that decreases the power in the south direction. Simulation of the different azimuth angles has shown that as the angle deviates from the 0° angle (south which has the highest power production) going to the east (-90°) the power production decreases.

- **Annual Power Production (Gross Power)**

The annual power production for each panel azimuth is aggregated to choose the most optimum angle for the PV (Figure 5.13).

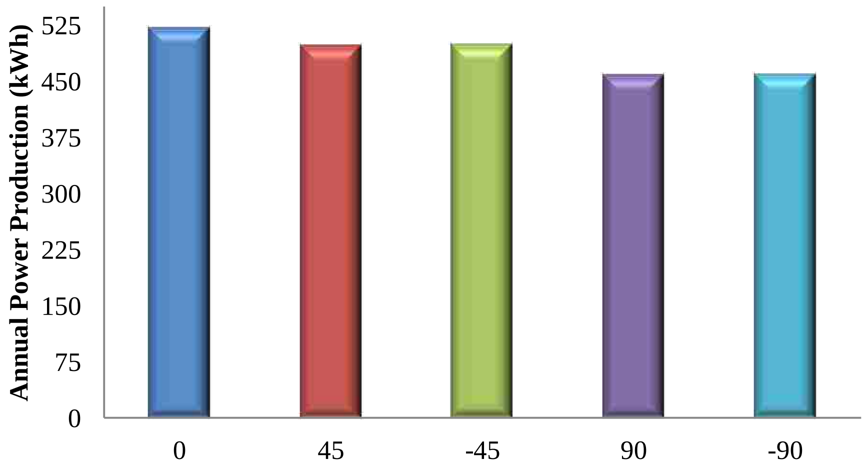



Figure 5.13: Annual Power Production per Panel for Different Azimuths in kWh

The results showed that the 45° (southwest) and -45° (southeast) angles have almost the same annual power production and power losses by which they lose about 24 kWh as they go off the optimal angle. The 90° (west) and -90° (east) angles also have the same power production and power losses where they experience higher power losses of 65 kWh as they deviate from the 0° azimuth. In this study the 0° angle is selected since it yields the highest power production.

The previous simulation analysis has shown the optimal PV type, slope and azimuth to be used in the school under the UAE climate. Results have shown that 342 panels are needed with slope 24° and azimuth of 0° to produce 208849.32 kWh of the total energy consumption.

### 5.4.2 Solar Absorption Chiller Simulation Results

Several parameters are tested in the Absorption Chiller system to determine optimum value for each parameter as shown in table 5.8.

| Parameters | Values |
|---|---|
| Concentration Ratio | 1, 5, 10, 15, 20, 25 |
| Water Flow rate | 2 kg/hr, 4 kg/hr , 6 kg/hr, 8 kg/hr |

Table 5.8: Parameters of Absorption Chiller System

The simulation results for the concentration ratio and the water flow rate in terms fluid outlet temperature of the collector during 9 representative days are plotted.

**Concentration ratio**

The first parameter tested in the absorption chiller cooling system is the concentration ratio of the solar collector meant to increase the intensity of the incident solar radiation at the receiver surface. The geometric concentration ratio is applied in the TRNSYS model as illustrated in Figure 5.14.

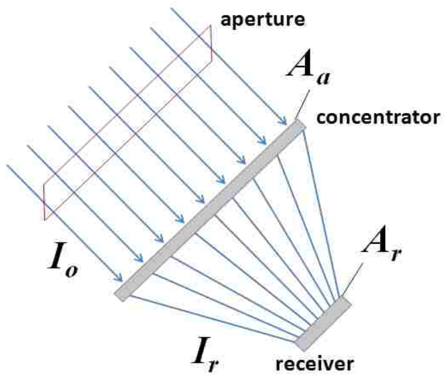



Figure 5.14: Solar Concentrator (PennState, 2014)

In TRNSYS the concentration is entered in the collector parameters in Type 1245. The target is to reach a collector outlet temperature of around 200 °C. Previous findings suggest that absorption chiller operates optimally at 200 °C collector outlet fluid temperature (Syed et al., 2005). Six different concentration ratios are tested in order to achieve 200 °C fluid outlet temperatures as shown in Figure 5.15.

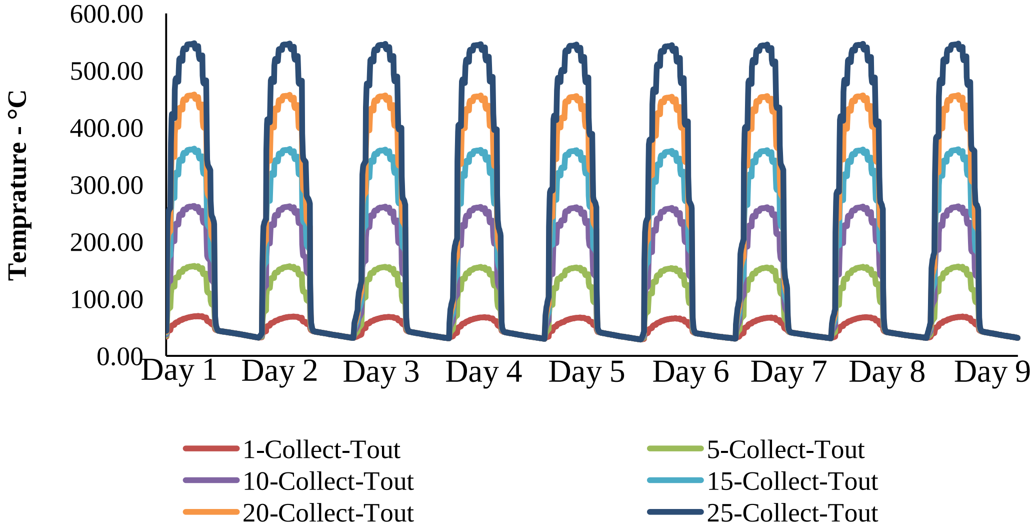



Figure 5.15: Simulation Results of Collector Outlet Temperature at Different Concentration Ratios for Nine Consecutive Peak Summer Days

Results show that as the concentration ratio (x) increases, the outlet temperature of the collector fluid increases from 150 at 5x, to 550 at 25x. Thus, concentration ratio of 10x is considered optimal that achieves substantially higher temperature above 200 °C to ensure the required temperature in all seasons.

**Water Flow rate**

The second parameter tested in the absorption chiller cooling system is the water flow rate of the solar collector which optimizes the chilled water energy or the cooling demand (energy removed to generate required amount of chilled water to produce 10% of the total cooling load) and the useful energy gain or the cooling production (thermal energy of the collector to run the absorption cycle). A right balance between the temperature of the collector, chilled water energy and useful energy gain is indispensable for optimal system operation. The sequential order is to maintain the temperature of collector above 200 °C and assure that the cooling production is higher than the cooling demand. The flow rates are tested to ensure the right balance including 2, 4, 6 and 8 kg/hr. The results are plotted for 7 peak days in July in Figure 5.16.

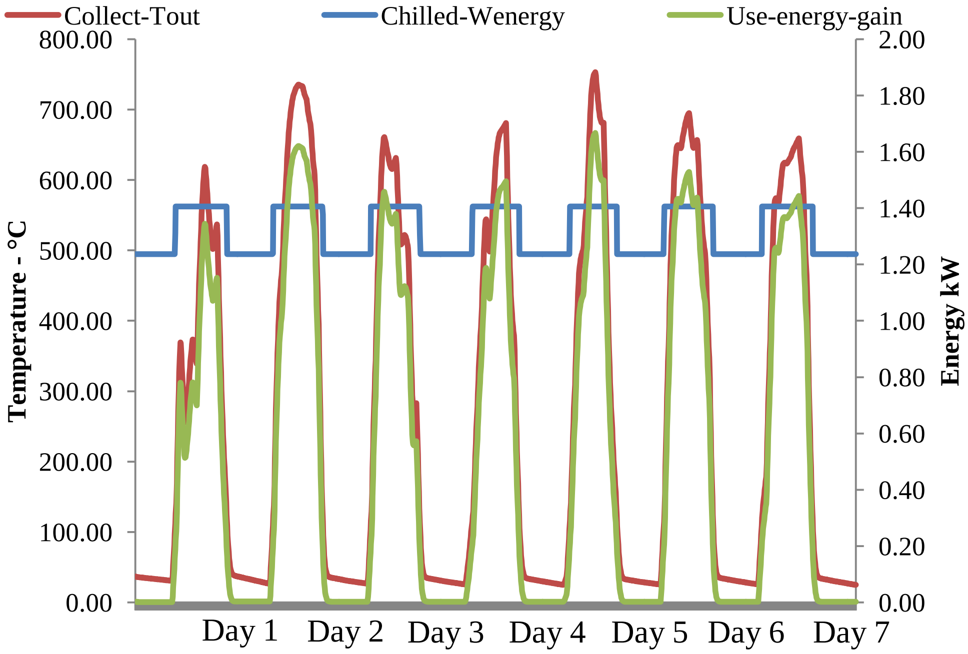



Figure 5.16: Energy and Temperature at 2 Kg/hr Flow-rate

Results show that the collector temperature of 700°C is achieved at 2 Kg/hr being much higher than the optimal value of 200°C. The chilled water energy shows a step change reflecting on/off condition depending on the radiation where it shifts between 1.2 and 1.4 kW. The useful energy gain reaches a maximum of 1.67 kW. However, the chilled water energy is not always lower than the useful energy gain. During the night, the cooling demand (chilled water energy) is higher than the cooling production (useful energy gain), this is due to the fact that the system is designed to meet 10% of the cooling energy and the rest of the energy during the night is supplied by the conventional cooling system. Therefore, the flow rate is raised to 4 Kg/hr in order to optimize the effect on these outputs (Figure 5.17).

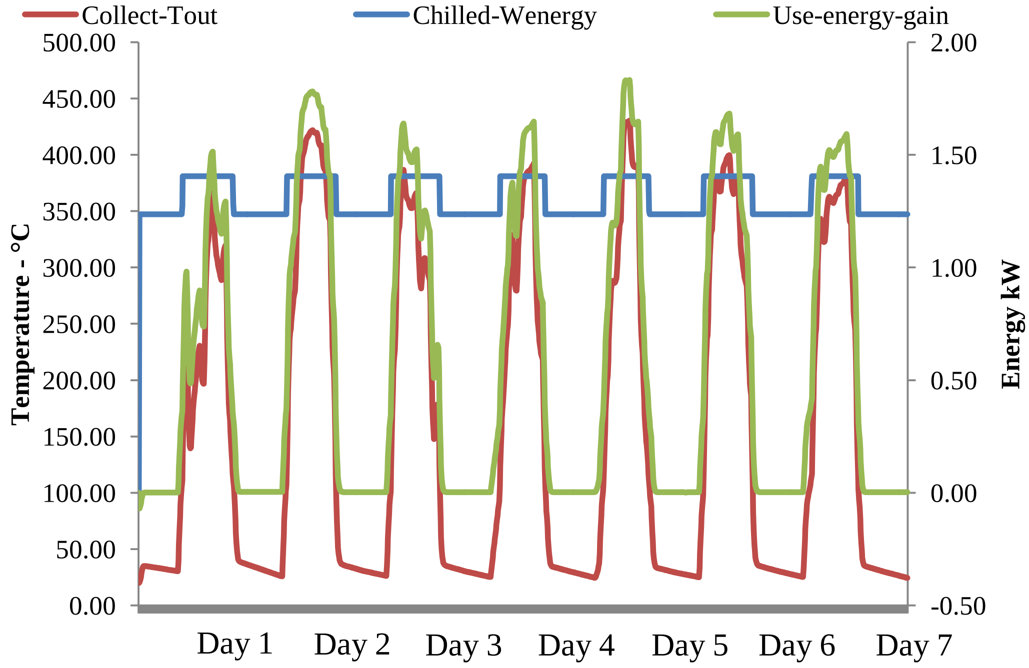



Figure 5.17: Energy and Temperature at 4 Kg/hr Flow-rate

Results imply that at flow rate of 4 Kg/hr the peak collector temperature dropped to 430 °C (still being higher than the targeted 200 °C), the chilled water energy fluctuated between 1.2 and 1.4 kW, and the useful energy gain reached a maximum of 1.82 kW. This trend shows that when the flow rate increases, the collector temperature decreases, the chilled water energy remains the same and the useful energy gain increases slightly. The chilled water energy in this case is lower than the useful energy gain. A higher flow rate of 6 Kg/hr is tested in order to reach to a closer temperature to the targeted 200 °C (Figure 5.18).

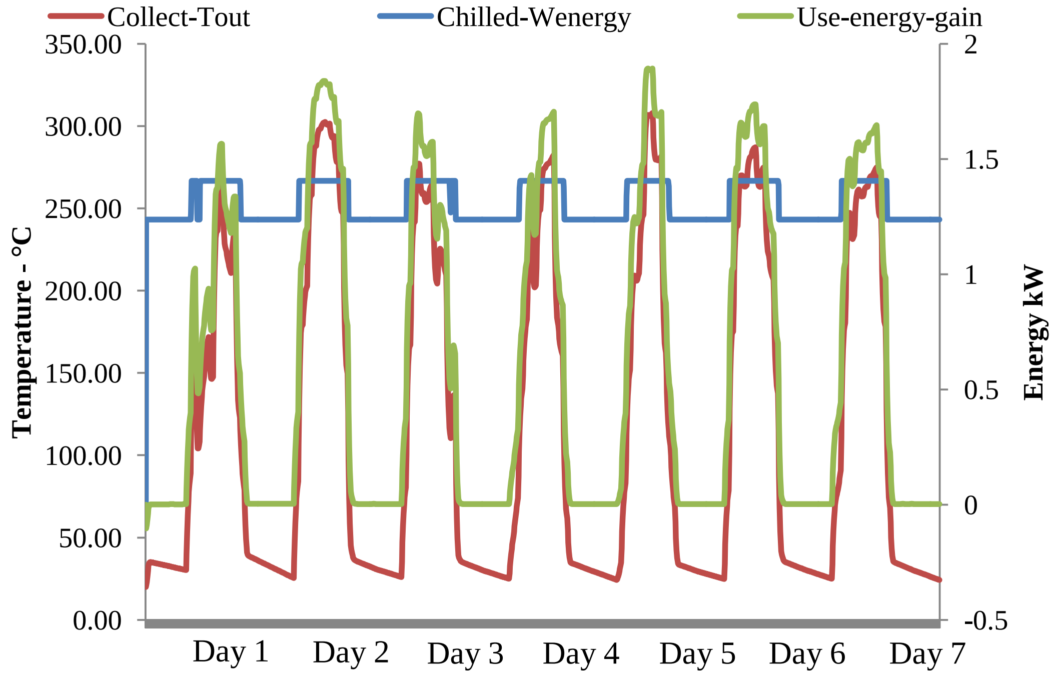



Figure 5.18: Energy and Temperature at 6 Kg/hr Flow-rate

Results show that the highest collector temperature of 310 °C is still higher than the targeted 200 °C. The chilled water energy is fluctuating between 1.2 and 1.4 kW, and the useful energy gain reaches a maximum of 1.89 kW. The chilled water energy is lower than the useful energy gain. A higher flow rate of 8 Kg/hr is tested in order to reach to a closer temperature to the targeted one (Figure 5.19).

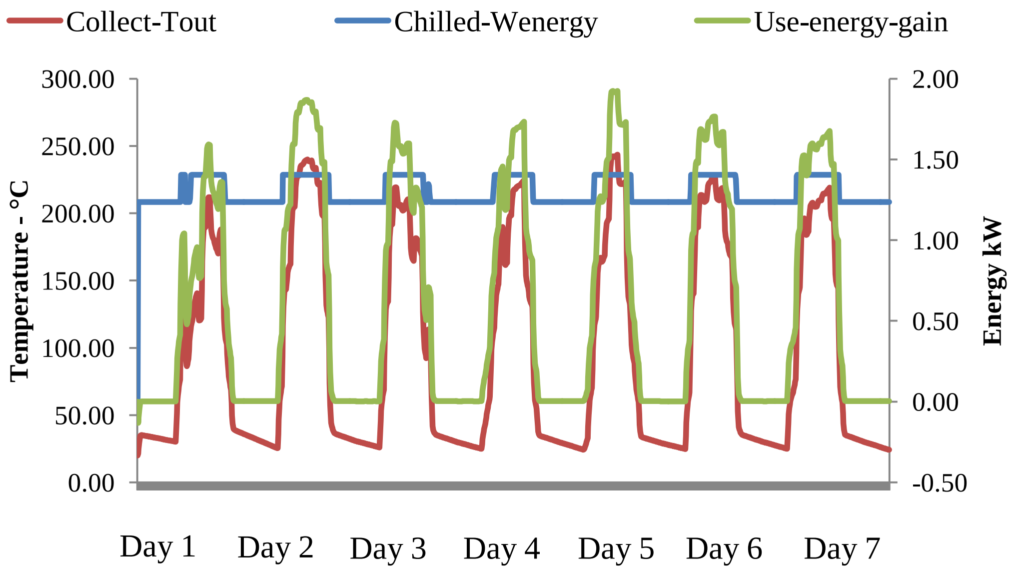



Figure 5.19: Energy and Temperature of 8 Kg/hr Flow-rate

Results reveal that the collector temperature is slightly above 200 °C which is the targeted temperature. The chilled water energy is still the same, while the useful energy gain has a maximum of 1.92 kW showing an increase compared to the previous flow rate. The chilled water energy is lower than the useful energy gain. Therefore, flow rate of 8 Kg/hr is identified to be the flow rate that balances the three conditions.

After optimizing the parameters of the system, the saving in energy is calculated by applying total collector array area 90 $m^2$, 30 collectors, and 240 kg/hr flow rate and chiller capacity of 36 kW in the TRNSYS model.

The annual useful energy gain for the absorption chiller is 150,505 kWh saving 19.35% annual cooling consumption and 7.2% of annual energy consumption of the school summarized in Table 5.9.

| Parameters | Value |
|---|---|
| Number of Collectors | 30 collectors connected in parallel |
| Area Per Collector | 3 $m^2$ |
| Concentration Ratio | 10 x |
| Water Flow rate | 8 Kg/hr |
| Collector Outlet Temperature | 200°C |
| Total Capacity of System | 36 kW |
| Annual Useful Energy Gain | 150,505 kWh |
| Annual Cooling Energy Savings | 19.35% |
| Annual Total Energy Savings | 7.2% |

Table 5.9: Optimized Solar Absorption Chiller Model

### 5.4.3 Geothermal Simulation Results

Different parameters are considered in the geothermal system analysis as indicated in Table 5.10 to optimize output in terms of cooling load reduction. The fluid flow rate and pipe length are the first two parameters tested in order to choose their optimum values and set the reference design of the geothermal system. After fixing the loop flow rate and length, the other parameters are tested to optimize design of the system.

| Parameters | Variables |
|---|---|
| Fluid Flow rate | 400 kg/hr-4400 kg/hr with an increment of 400 kg/hr |
| Pipe Length | 200 m -2800 m with an increment of 200 m |
| Pipe Diameter | 0.75 inch, 1 inch, 1.25 inch, 1.5 inch, 2 inch |
| Pipe Material | Aluminum, Copper, Polyethylene |

| | |
|---|---|
| Pipe Depth | 3m, 4m, 5m, 6m, 7m |
| Pipe Spacing | 0.25m, 0.5m, 0.75m, 1m |

Table 5.10: Parameters and Variables of Geothermal System

The simulation results are expressed as transient outlet fluid temperature and energy produced over 9 consecutive representative days for better readability in July being peak cooling month. The ambient temperature versus ground temperature at 5 meters depth during the four peak cooling months (May, June, July, and August) is shown in Figure 5.20. The overall cooling energy produced is reported for May-August being peak summer months in terms of cooling demand and energy consumption.

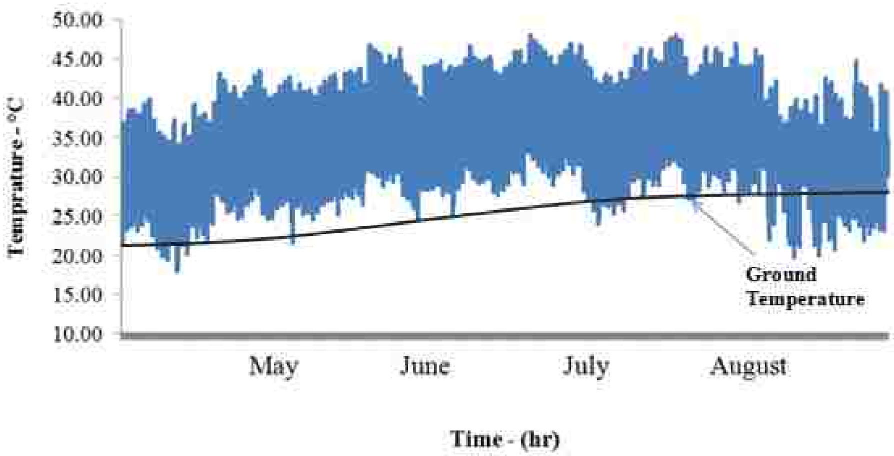



Figure 5.20: Ambient Temperature Versus Ground Temperature at depth of 5 meters During Four Months Period

**Pipe Flow Rate**

The first parameter optimized is the pipe inlet fluid flow rate. The flow rate is tested from 400 kg/hr to 4400 kg/hr with increment of 400 kg/hr. The most optimum is identified based on delivered energy and drop in outlet fluid temperature. The outlet fluid temperature versus the inlet fluid temperature during the 9 representative days of different fluid flow rates is shown in Figure 5.21.

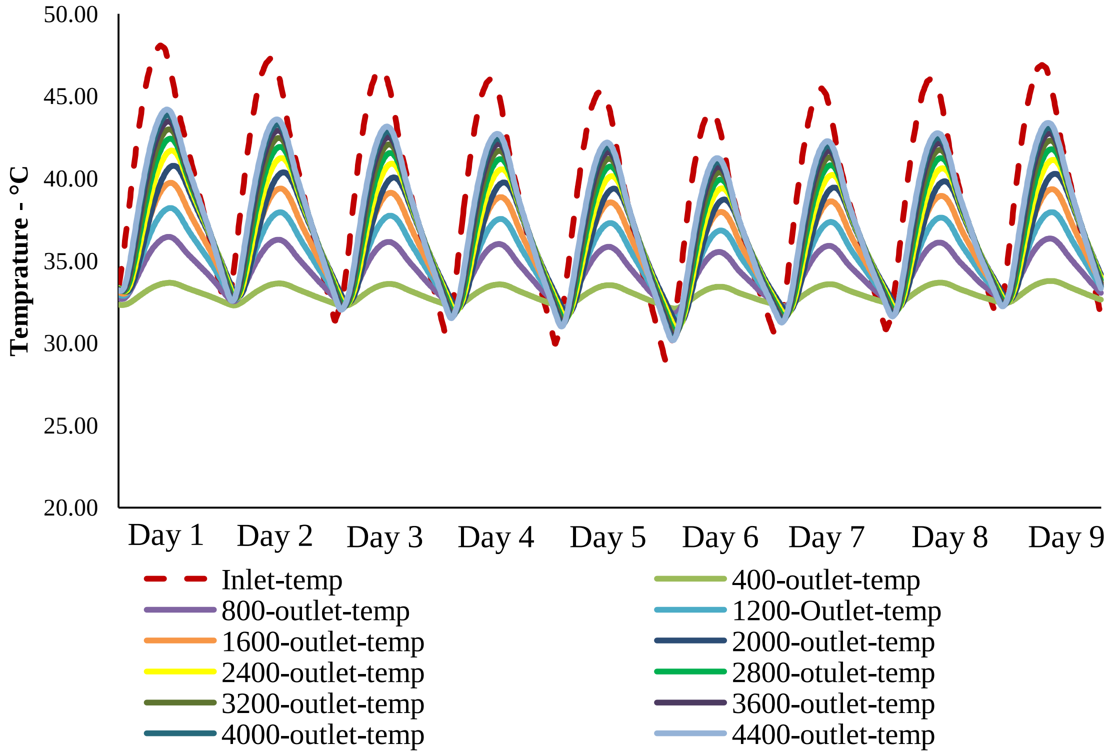



Figure 5.21: Simulation Results for Fluid Inlet and Outlet Temperature at Different Fluid Flow-rates for Nine Consecutive Days in July

The results indicate that the outlet fluid temperature decreases as the fluid flow rate decreases. The highest temperature drop of 14 °C is observed at fluid flow rate of 400 kg/hr yields which reduces to 3 °C peak at 4400 kg/hr.

The delivered energy is plotted against the fluid flow rate for May-August to test to Figure 5.22.

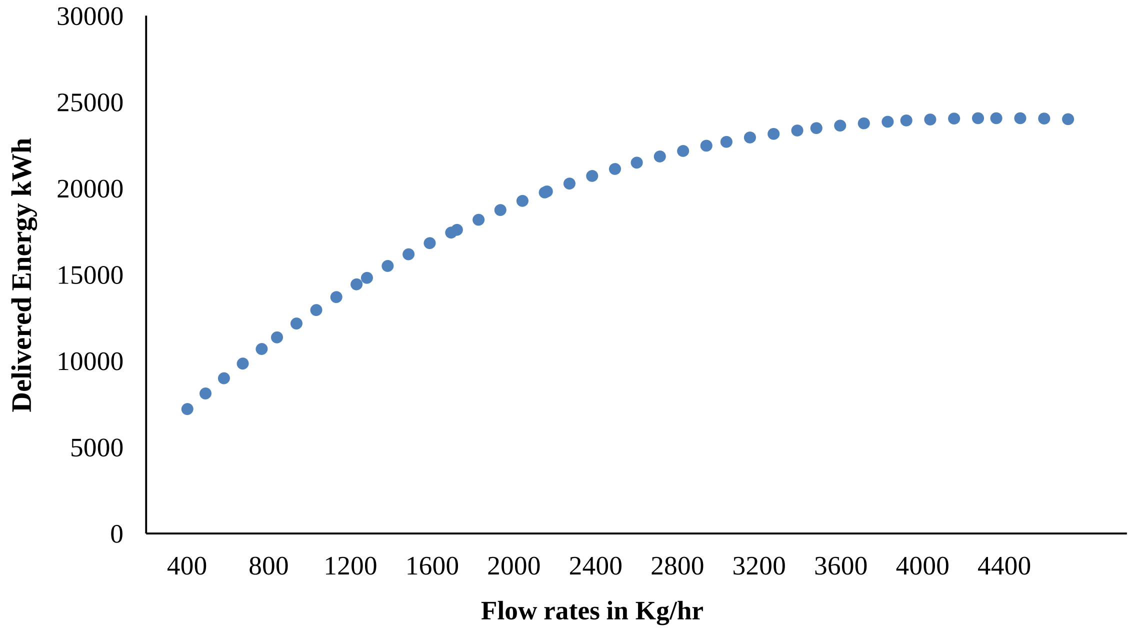



Figure 5.22: Delivered Energy in kWh of the Different Pipe Flow-rates

The results show that the delivered energy increases from 7326 kWh at 400 Kg/hr fluid flow rate to 22081.19 kWh at the 2800 Kg/hr while at higher flow rates, delivered energy stabilizes. Therefore, the optimal flow rate is 2800 Kg/hr. The energy saving at 2800 Kg/hr flow rate is 6.5% of the cooling demand and 2.8% of the total annual energy consumption of the school.

**Pipe Length**

The second parameter tested in the geothermal system is the pipe length of the heat exchanger in order to select the most effective length that yields required cooling demand reduction. The constraint was available land area to install the pipe length. The pipe lengths range from 200 m to 2800 m increasing at increments of 200 m. The outlet fluid temperature versus the inlet fluid temperature during the 9 representative days of different pipe lengths leaving the ground heat exchanger is shown in Figure 5.23.

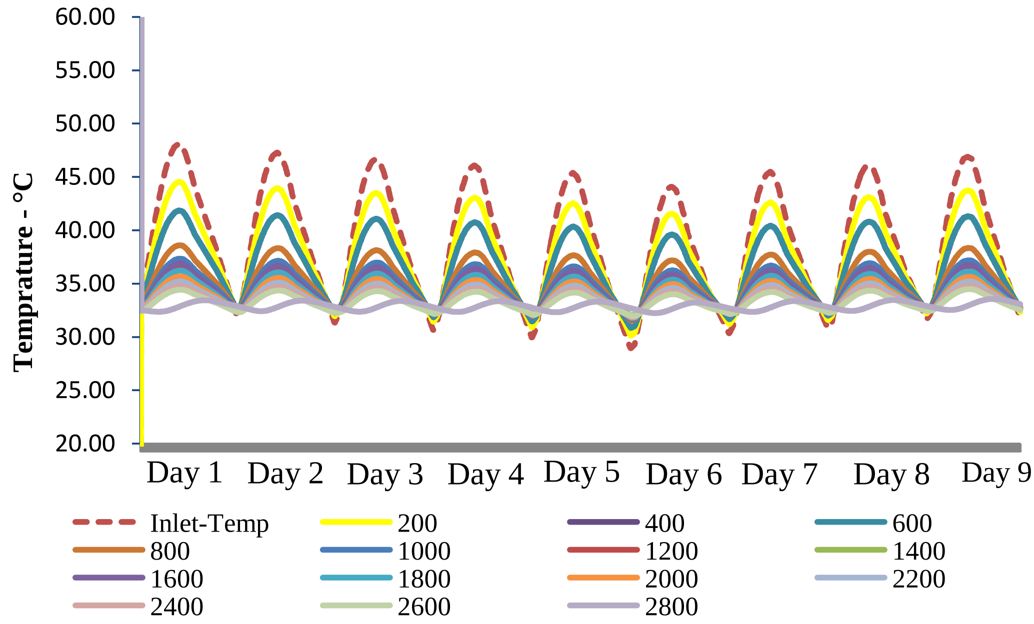



Figure 5.23: Simulation Results for Fluid Inlet and Outlet Temperature at Different Pipe Lengths for Nine Consecutive Days

The result shows that the outlet temperature drops with increasing pipe length. The fluctuation dampens as the pipe length increases that becomes smooth at larger pipe lengths and reaches optimal at 2800 m. The 2800 m pipe length ensures that the fluid in the pipe will have enough time to cool the temperature and is optimal in terms of land area. The temperature shows a drop up to 13 °C.

The simulation is carried out for four months between May and August to determine energy savings at different fluid flow rates (Figure 5.24).

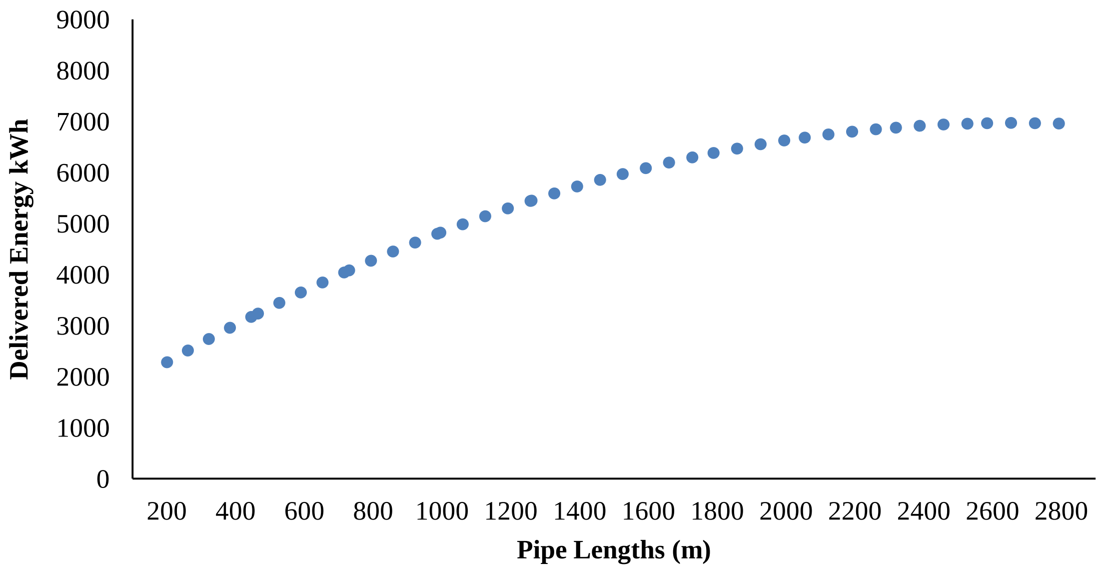



Figure 5.24: Delivered Energy in kWh of the Different Pipe Lengths

The results show that the delivered energy increases from 1661.995 kWh for 200 meters pipe length to 7663.456 kWh for 2800 meters. The cooling energy saving is calculated for the four months period for the different pipe lengths. The results show that the highest saving is for the 2800 pipe being 2.28% of the cooling load and 1% of annual total energy of the school.

The simulations suggest 2800 m heat exchanger pipe length at 2800 Kg/hr fluid flow rate as design parameters.

**Pipe Diameter**

After fixing the previous parameters, the pipe diameter is optimized. Five different pipe diameters were tested from 0.75 inch, to 2 inch. The inlet and outlet fluid temperatures of the different pipe diameters during the selected nine days are shown in Figure 5.25.

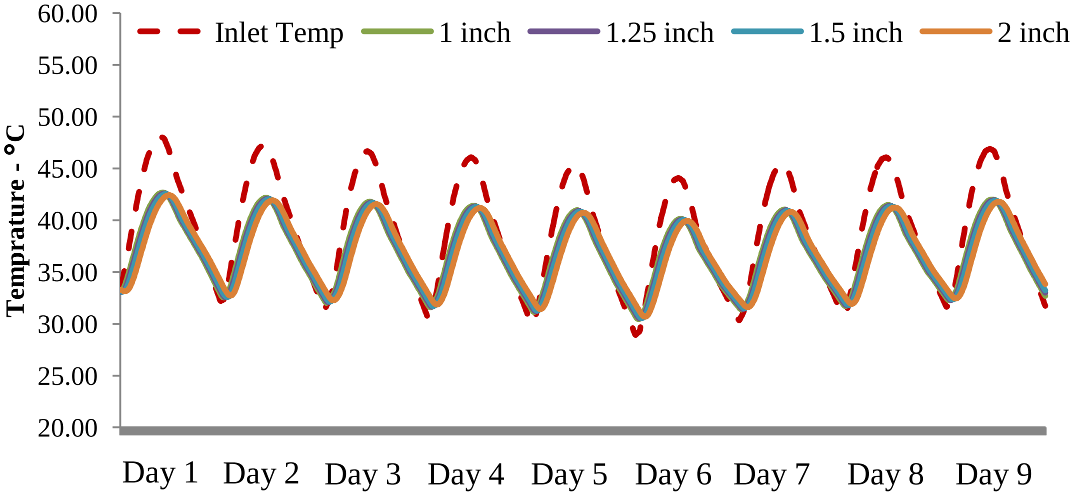



Figure 5.25: Simulation Results for Fluid Inlet and Outlet Temperature at Different Pipe Diameters for Nine Consecutive Days

The results indicate that different diameters of the pipes yields similar fluid outlet temperatures as long as the flow rate is constant which concludes that pipe diameter has minimal impact on fluid outlet temperature. The difference between the inlet fluid temperature and outlet fluid temperature is around 4 °C.

The delivered energy for different pipe diameters during the four months period is shown in Figure 5.26.

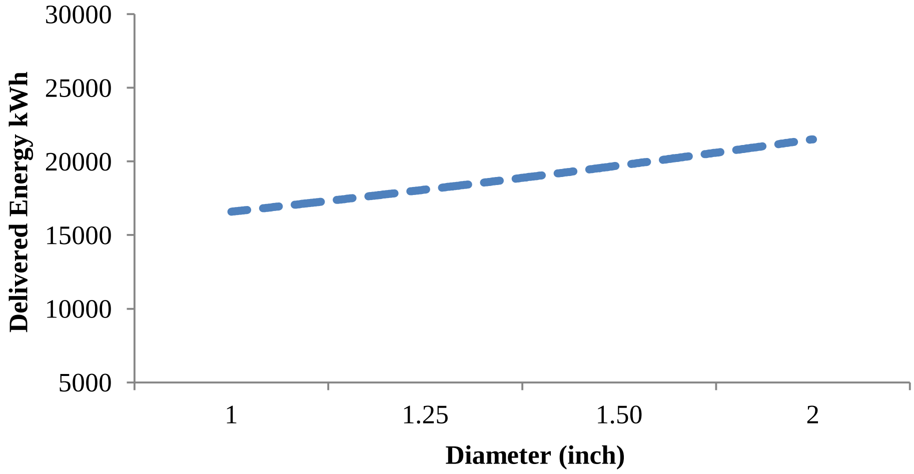



Figure 5.26: Delivered Energy in kWh of the Different Pipe Diameters

The results show that as the pipe diameter increases the delivered energy increases, in which the delivered energy increases from 16867.84 kWh until it reaches 22081.19 kWh. Therefore, the result indicates that 2-inch diameter pipe is the most suitable since it yields the highest delivered energy. The energy saving is calculated for the 2-inch pipe diameter where it shows 6.56% cooling energy saving during the peak four months period, and 2.85% cooling energy saving compared to the annual energy consumption for the school.

**Pipe Material**

The pipe material is tested to select the most suitable material for the heat exchanger. Appropriate selection of piping materials is essential to guarantee the pressure integrity and expected lifetime of the geothermal piping systems. Three main pipe materials are Aluminum, Copper, and Polyethylene. Choosing pipe material with good physical properties is important to conduct and transfer heat efficiently with an extended life. The simulation results of the nine representative days showing the inlet and outlet fluid temperatures of the three pipe materials are shown in Figure 5.27.

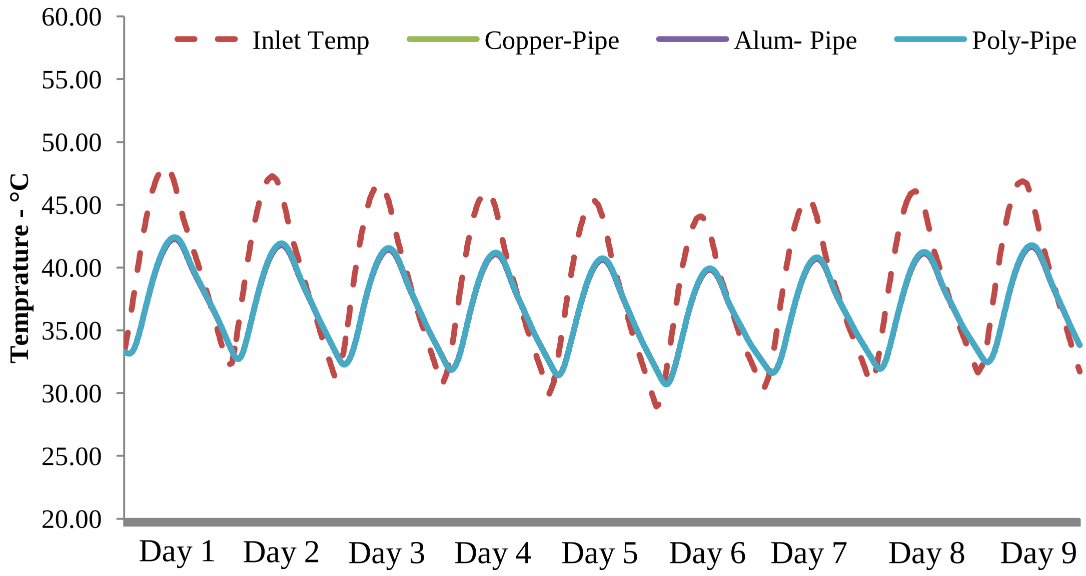



Figure 5.27: Simulation Results for Fluid Inlet and Outlet Temperatures for Nine Consecutive Days of Different Pipe Materials

The results show that the outlet temperature for each of the three materials is the same, showing a drop of 5 °C compared to the inlet temperature. The delivered energy of the different pipe materials during the four months is shown in Figure 5.28.

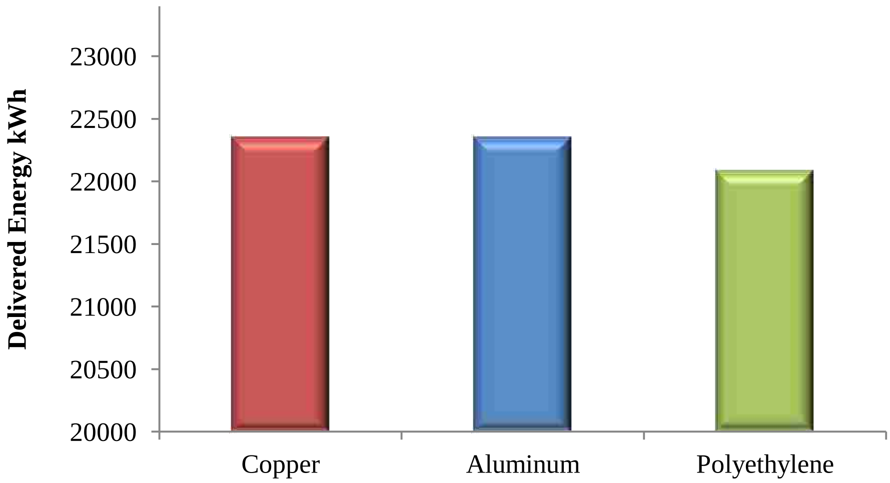



Figure 5.28: Delivered Energy in kWh of the Different Pipe Materials

The result shows that there is a minor difference between the delivered energy of the three materials being 22350.08 kWh, 22349.92 kWh and 22081.19 kWh for copper, Aluminum and Polyethylene respectively.

The results show that the material of the buried heat exchanger pipe does not significantly affect the performance of the geothermal system, however polyethylene pipe may have longer life due to lower corrosion rate thus is recommended as a heat exchanger.

The energy saving obtained by Polyethylene pipe reaches 6.56% of cooling energy during the peak four months period, and 2.85% of annual energy consumption of the school.

**Pipe Depth**

The depth of the pipe is defined as the distance below the ground surface to centerline of pipe axis at which the pipes are buried. The depth of the pipe is studied to optimize the energy efficiency of the heat exchanger. The temperature varies at earth surface with seasons; however the variation dampens as the depth increases. The intention for testing the depth is to determine the depth at which the temperature stabilizes with no variation beyond that depth in various seasons.

The depth was varied from 3 m to 7 m with increment of 1 m (Acuña et al., 2017b). The transient temperature change for 9 representative peak summer days are presented in Figure 5.29.

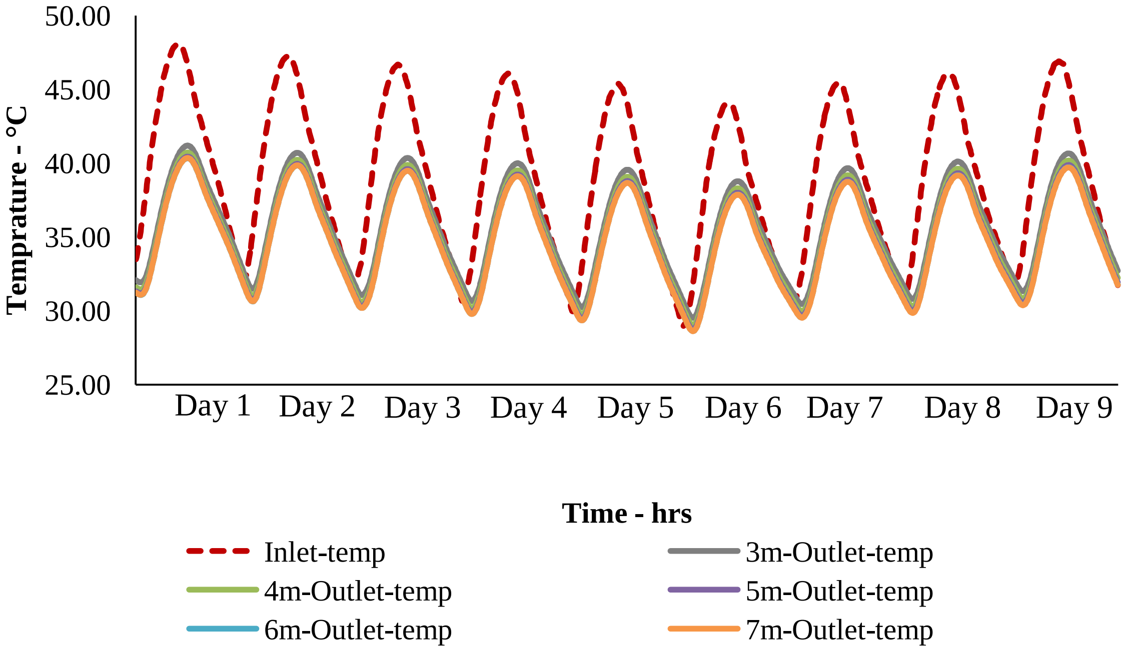



Figure 5.29: Simulation Results for Fluid Inlet and Outlet Temperature at Different Depths for Nine Consecutive Peak Summer Days

The results reveal that at pipe depth of 3m the outlet fluid temperature reduces by 7 °C compared to the ambient temperature. However, as the depth goes down the effect on temperature reduction becomes less with 9 degrees maximum reduction at 7m.

The delivered energy at various depths for peak summer month from May and August is presented in Figure 5.30.

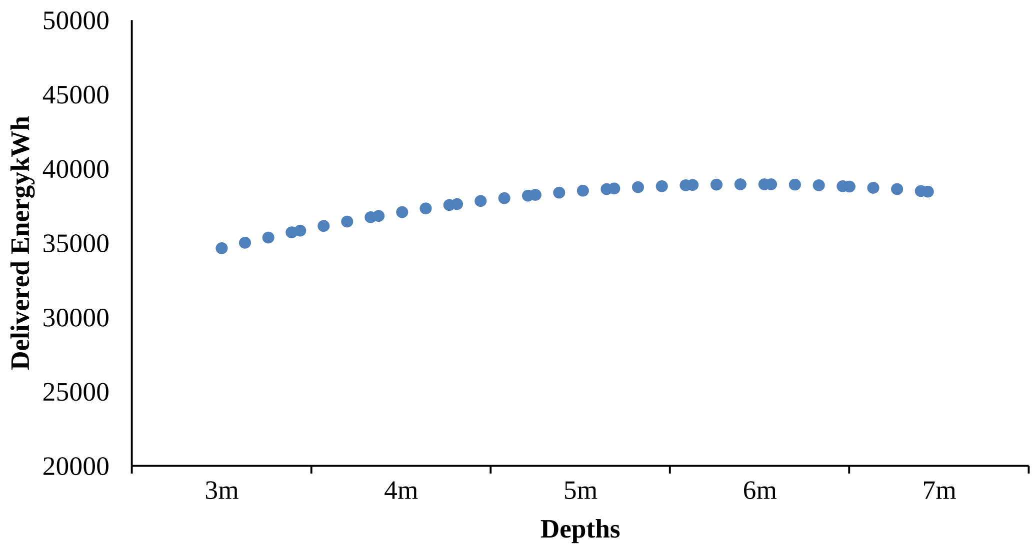



Figure 5.30: Delivered Energy in kWh of the Different Depths

The result shows an increasing delivered energy with increase in pipe depths from 3m (34480.9 kWh) to 5 m (38569.49 kWh) while the impact beyond 5 m is negligible suggesting 5m to be optimal depth. Excavating beyond 5m is not recommendable as the cost of excavation may overcome the benefits of energy savings. The cooling energy saving at 5 m depth is 11.4% compared to the peak four months and 4.9% compared to the annual cooling energy consumption.

**Pipe Spacing**

The spacing between pipes indicates the horizontal distance between parallel pipes. Pipe spacing and pipe length are important parameters to determine the area needed to the ground heat exchanger system. Four different spacing are tested including; 0.25 meters, 0.5 meters, 0.75 meters and 1 meter in order to determine the most appropriate spacing that reduces outlet fluid temperature and delivers higher energy savings. The simulation result of outlet fluid temperature versus the inlet fluid temperature during the nine representative days for several pipe spacing is shown in Figure 5.31.

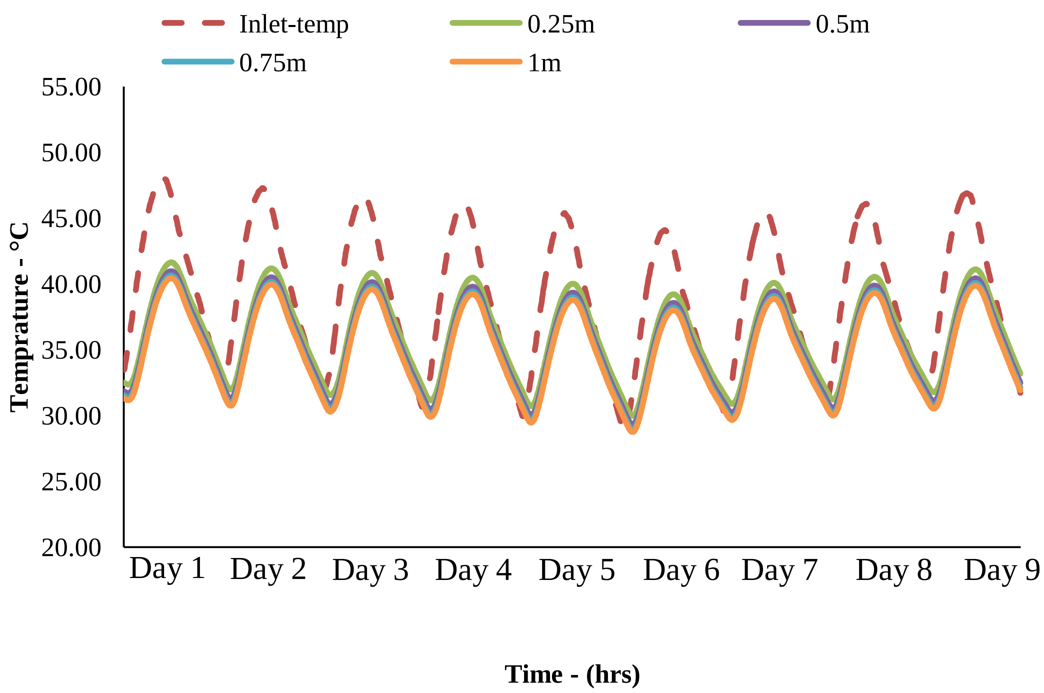



Figure 5.31: Simulation Results of Fluid Inlet and Outlet Temperatures of Different Pipe Spacing for Nine Consecutive Peak Summer Days

The results indicate that as the separation increases the difference between the inlet fluid temperature and outlet fluid temperature increases although with a small temperature differences. The 1 meter spacing gives the highest drop in temperature by 7 °C. The delivered cooling energy for the different pipe spacing during the four months period is shown in Figure 5.32.

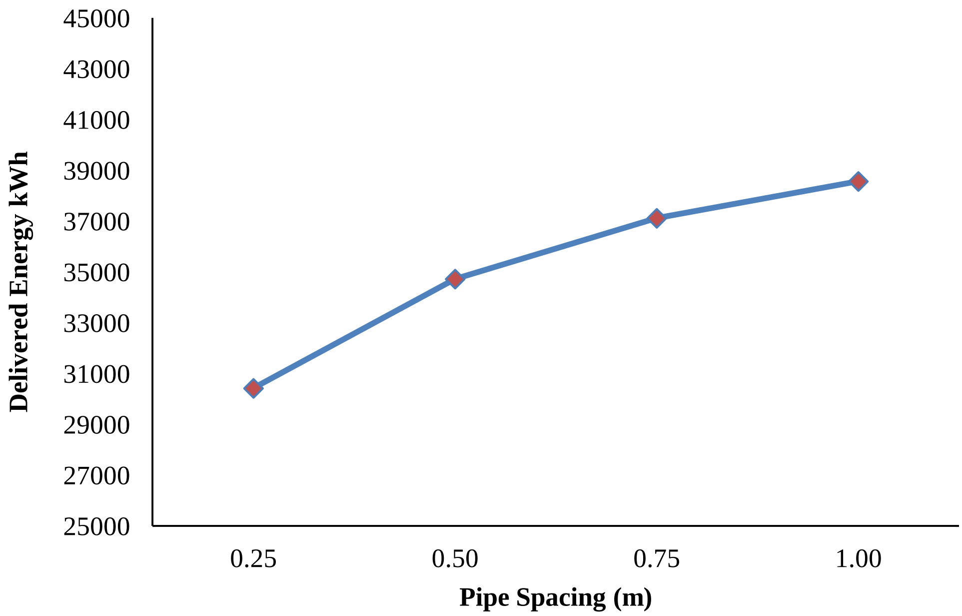



Figure 5.32: Delivered Energy in kWh of the Different Pipe Materials

The results show that as the pipe separation increases the delivered energy increases from 30420.75 kWh at 0.25 m to 38569.49 kWh at 1 m. Eventually, 1 m pipe spacing is considered to be the most suitable resulting in the highest delivered energy and the lowest outlet temperature saving 11.5% cooling energy compared to the peak four months and 5.8% compared to annual cooling energy.

**<u>Annual Simulation of Geothermal System</u>**

After determining the optimized parameters the TRNSYS model simulates geothermal system with optimal parameters. The optimal configuration predicts 10 to 15 °C reduction in the outlet fluid temperature, 5.8% savings in annual cooling energy and 2.8 % savings in total annual energy consumption compared to the base case building (having no geothermal system) summarized in Table 5.11.

| Parameters | Value |
| --- | --- |
| Pipe Flow rate | 2800 Kg/hr |
| Pipe Length | 2800 m |
| Pipe Diameter | 2 inch |
| Pipe Material | Polyethylene |
| Pipe Depth | 5 m |
| Pipe Spacing | 1 m |
| Annual Delivered Energy | 44671.72 kWh |
| Annual Cooling Energy Savings | 5.8% |
| Annual Total Energy Saving | 2.2% |

Table 5.11: Optimized Geothermal Model

The previous simulations had identified the technical feasibility of the systems. However, in order to make the optimum selection of the systems and to determine the most suitable and applicable systems in the school, economical feasibility is carried out through simple payback period of the three systems. The simple payback period will determine the cost and payback period of each system and is detailed in the following section.

### 5.4.4 Simple Payback Period of the Three Systems

A simple payback period of the three systems is calculated in order to determine the applicability of the systems in the study. This is calculated using the following equation:

$$Simple\ Payback\ Period = \frac{Total\ Initial\ Cost}{1st\ Year\ Benefit}$$

The total initial cost is calculated by calculating the following:

1. System initial cost.
2. Installation cost.
3. Maintenance cost.

While the 1st year benefit calculation is calculated by getting the following:

1. Energy saved from each system in kWh.
2. Unsubsidized electricity rate.
3. Convert energy to economic savings:

$$= Unsubsidized\ rate\ \left(\frac{tarrif}{kWh}\right) * \ Total\ kWh\ saved$$

In this thesis the simple payback period is calculated, however, the business as usual scenario including; currency inflation, future energy price and change in demand are ignored and not calculated.

**PV system simple payback period**

The unsubsidized electricity rate is calculated using reference rate of Germany because it gets electricity at unsubsidized rates of 30 c/kWh (Agora-Energiewende, 2017).

The total energy savings from the PV system is 208849.32 kWh, therefore 1st year benefit;

$$= Unsubsidized\ rate\ \left(\frac{tarrif}{kWh}\right) * \ Total\ kWh\ saved$$

= 30 c/kWh x 208849.32 kWh

= 6,265,479.6 c= 62654.79 $

Total Initial Cost of PV is explained in table 5.12.

| **Total Initial Cost** (Chung et al., 2015) | **Unit Cost $** | **Total Cost $** |
|---|---|---|
| **System initial cost** of the Mono-Crystalline PV | 0.6 $/watt | 0.6 $ x 280 watt x 342 panels = 57,456 $ |
| Balance of system (BOS) cost | 1.2 $/watt | 1.2 $/watt x 280 watt= 114,912 $ |
| **Subtotal= 57,456 $ + 114,912 $ = 172,368 $** | | |
| **Installation cost.** | 0.19 $/watt | 0.19 $/ watt x 280 watt =18,194.4 $ |
| **Maintenance cost**<br><br>(Depends on cleaning of the panel due to the dusty climate) Cleaning the panel must be done every 15 days | 20.28 €/$m^2$ year | (342 x 20.28 x 1.6)= 11097.216 € = 12,310.725 $ |
| **Total Cost= 172,368 $ + 18,194.4 $+ 12,310.725 $ = 202,873.125 $** | | |

Table 5.12: Total Initial Cost of PV

Simple payback period is 202,873.125$/ 62654.79 $= 3.23

**PV Payback period= 3.5 Years**

**Solar Absorption Chiller system simple payback period**

The total energy savings from the solar absorption chiller system is 150,505 kWh, therefore 1st year benefit;

= 30 c/kWh x 150,505 kWh *0.40 (Solar absorption chiller efficiency)

= 18,060 $

Total Initial Cost of the solar absorption chiller is explained in table 5.13.

| **Total Initial Cost (Kurup and Turchi, 2015, Buonomano, 2016)** | **Unit Cost $** | **Total Cost $** |
|---|---|---|
| **System initial cost**<br>(Parabolic Trough Collector) | 170$/ $m^2$ | = 170 x 3$m^2$ x 30 collectors = 15,300 $ |

| | | |
|---|---|---|
| **Tracking cost** | 0.36 $/ watt (collectors has 175 watt/m$^2$ with 90 m$^2$ area) | = 175 watt/m$^2$ x 90 m$^2$ x 0.36 $/ watt = 5670 $ |
| **Absorption chiller** | - | = 20,000 $ |
| **BOS** (Balance of the systems; tank, pipes, valves and control system) | 110 $/kW | 110 $/kW x 36 kW= 3960 $ |
| **Subtotal= 15,300 $ + 5670 $ +20,000 $+ 3960$= 24,930 $** | | |
| **Installation cost** | - | 2500 $ |
| **Maintenance cost**<br><br>(Depends on cleaning of the panel due to the dusty climate) Cleaning the panel must be done every 15 days | 20.28 €/m$^2$ year | (342 x 20.28 x 1.6)= 11097.216 € = 12,310.725 $ |
| **Total Cost= 44,930 $ + 2500 + 12,310.725 = 59,740.725 $** | | |

Table 5.13: Total Initial Cost of Solar Absorption Chiller

Simple payback period is 59,740.725 $/18,060 $= 3.3

**Solar absorption chiller Payback period= 3.5 Years**

**<u>Geothermal system simple payback period</u>**

The total energy savings from the solar absorption chiller system is 44671.72 kWh, therefore 1$^{st}$ year benefit;

= 30 c/kWh x 44671.72 kWh

= 1,340,151.6 c = 13401.516 $

Total Initial Cost of the geothermal system is explained in table 5.14.

| **Total Initial Cost** (HDPE-Supply, 2017, Fixr, 2017, Kaushal, 2017) | **Unit Cost $** | **Total Cost $** |
|---|---|---|
| **System initial cost (2 inch polyethylene pipe** | Price = 573.76 $/152.4 m (Pipe length 2800 m / 152.4 | 573.76 $/m x 18.37 m = 10,569.23 $ |

| | | |
|---|---|---|
| **500' coil)** | m =18.37 m) | |
| **Heat Pump** | - | 5000$ |
| **Subtotal = 10,569.23 $ +5000$= 15,569.23$** | | |
| **Installation cost**<br>- **Excavation cost**<br>- **Installation** | **= 60,000$**<br>**= 25,000$** | **Total = 85,000 $** |
| **Maintenance cost** | 1.8 $/m^2$ | 1.8 $/m^2$ x 2800 m^2= 5040$ |
| **Total = 15,569.23$ + 85,000 $ + 5040$= 105,609.23 $** | | |

Table 5.14: Total Initial Cost of Geothermal System

Simple payback period is 105,609.23$/ 13401.516 $ = 7.88

**Geothermal system Payback Period= 8 Years**

The payback period of the three systems shows that their periods lays within acceptable period compared to the lifespan and initial cost of each system. Additionally, the payback periods lays within the range discussed in the previous literature review done in Chapter 4 and therefore are feasible to apply.

### 5.4.5 Overall Systems Performance

The simulations conducted for the three renewable energy systems had shown substantial energy savings each although with magnitudes. The geothermal and absorption cooling systems has shown an annual energy saving of 2.2% and 7.2 % respectively compared to the total energy consumption. The annual cooling decreased from 777,607.7 kWh for the baseline school (without adding renewable energy systems) to 582,430.98 kWh using the geothermal and absorption chiller systems. The simple payback period of the solar absorption chiller is 3.5 years and the geothermal system is 8 years. The photovoltaic system has contributed to the energy production (and savings thereby) by 10% and payback period of 3.5 years. The three systems were designed and sized according to the demand of the school and physical constraint in terms of area occupied and system integration. The geothermal system occupies a ground covered area of 2800 $m^2$. The absorption chiller consists or 30 collectors with net collector area of 90 $m^2$ thus claiming about 200 m2 area of the roof considering area redundancy factor of over 2. The PV panels being 342 cover a total roof area of 1110.6 $m^2$. Higher energy savings can be achieved if the systems were sized bigger; by choosing loner geothermal loop and increasing the number of PV panels and solar collectors. However, over sizing the systems will result in increased initial costs and requirement of bigger roof area.

The baseline school energy performance is compared to the proposed school performance after the application of the three renewable energy systems in Figure 5.33.

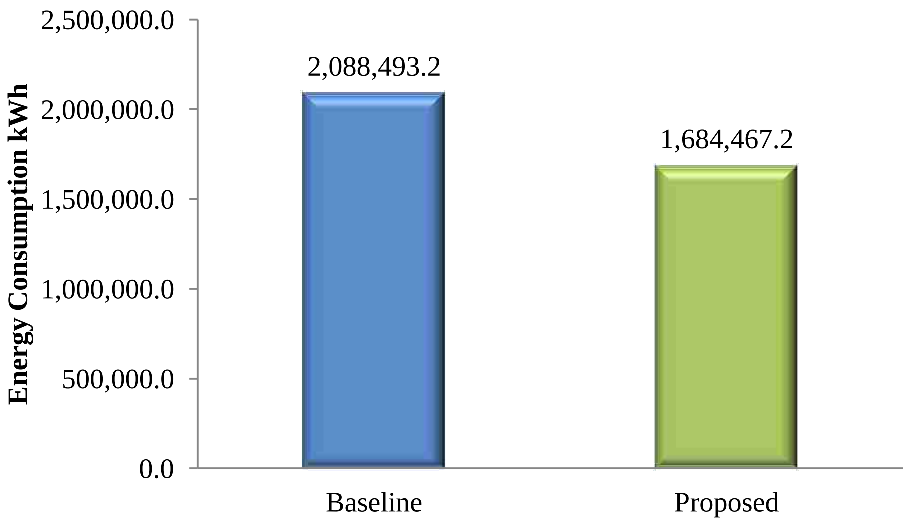



Figure 5.33: Baseline versus Proposed Energy Consumption of the School

## 5.5 School *Estidama* Credits Improvement

The purpose of the study is to increase the credits of "*Estidama"* PBRS in "Sheikha Bint Suroor Public School" through energy performance enhancement. The achievements of energy savings from the three renewable energy systems is transformed into credits from "*Estidama"*. The following paragraphs show the credits achievement after applying the renewable energy systems.

- **RE-1 Improved Energy Performance**

To determine the percentage of improvement from applying the renewable energy systems, the equation in Table 4.5 is used:

$$= \frac{100 * 2{,}088{,}493.2 \left(\frac{kWh}{yrh}\right) - 1{,}684{,}467.2 \left(\frac{kWh}{yrh}\right)}{2{,}088{,}493.2 \left(\frac{kWh}{yr}\right)}$$

Thus, 19.35% is the percentage improvement based on the renewable energy systems added. Based on the PBRS, 19.35% reduction translates into 4 credits points, whereas previously ADEC has achieved 1 credit point because they saved 14%. The proposed system can achieve all the allowable 5 credit points in the area of energy performance.

- **RE-5 Peak Load Reduction (4 Unachieved credits)**

The peak load reduction is achieved by the following equation:

$$\text{Annual Average Electrical Load} = \frac{\text{Cooling Load kWh}}{180 \text{ Days} * 24 \frac{\text{hrs}}{\text{day}}} + \frac{\text{Other Loads kWh}}{180 \text{ Days} * 9 \frac{\text{hrs}}{\text{day}}}$$

$$\text{Annual Average Electrical Load} = \frac{582{,}430.98 \text{ kWh}}{180 \text{ Days} * 24 \frac{\text{hrs}}{\text{day}}} + \frac{1{,}102{,}036.22 \text{ kWh}}{180 \text{ Days} * 9 \frac{\text{hrs}}{\text{day}}} = 815.1 \text{ kW}$$

$$\frac{Peak\ Load}{Average\ Electrical\ Load} = \frac{1{,}392.9}{815.1} = 1.7$$

Since 1.7 < 1.8, therefore, 2 credits are achieved in this section.

- **RE-6 Renewable Energy**

Three onsite renewable energy systems were applied; geothermal system, absorption chiller and photovoltaic. The onsite energy percentage is calculated using the equation in Table 4.5:

$$Percentage\ Onsite\ Renewable\ Energy$$

$$= \frac{100 * \sum Annual\ Energy\ Generated\ from\ Onsite\ Renewable\ Technologies\ (kWh)}{Proposed\ Building\ Energy\ Consumption\ (kWh)}$$

$$= \frac{100 * \ 404026.04\ (kWh)}{2088493.2\ (kWh)} = 19.3\%$$

The school has already achieved 3 credits by saving 5% through adding solar water system. Through the addition of the new systems and achieving 19.35% extra energy reduction, 8 credits points are achieved. The total percentage of renewable energy in the school is around 25%, but the PBRS offers 20% as a maximum reduction percentage offering 8 credits which has been achieved by the proposed systems. The actual performance of the systems might be lower when considering the construction, space organization, inflation cost and future energy prices.

## 5.6 Summary

This chapter presented the application of simulation analysis for the technical and economical performance of the three renewable energy systems. The process went through two main stages. First, e-QUEST Modeling Software was used to calculate the monthly energy consumption of the school and was compared with the energy consumption data provided by the school. The validated e-Quest model was employed to determine detailed monthly energy consumption and cooling load data which was not provided by the school. The monthly data was used to size the renewable energy system in peak summer months, an indispensable condition to design cooling systems. At the second stage, the proposed renewable energy systems of geothermal, solar absorption chiller and photovoltaic were modeled and optimized using TRNSYS Simulation Program.

Several relevant parameters and variables were optimized in each system in order to maximize the energy savings while being grounded to the design conditions and constraints of special requirements and costs though qualitatively. The geothermal system yielded annual cooling energy savings of 5.8% and total energy savings 2.2%. The solar absorption chiller resulted in 19.35% annual cooling energy savings and 7.2% total annual energy savings. The photovoltaic system contributed to 10% total energy production (saving) (Figure 5.34). Finally, a simple payback period was done on the photovoltaic and solar absorption chiller with 3.5 payback years and geothermal system with 8 payback years. The total energy savings from the three systems was 19.35% and led to additional 14 credit points based on "*Estidama"* PBRS. Based on the energy savings, the Pearl ratings of the school improved from 2 Pearls to 3 Pearls.

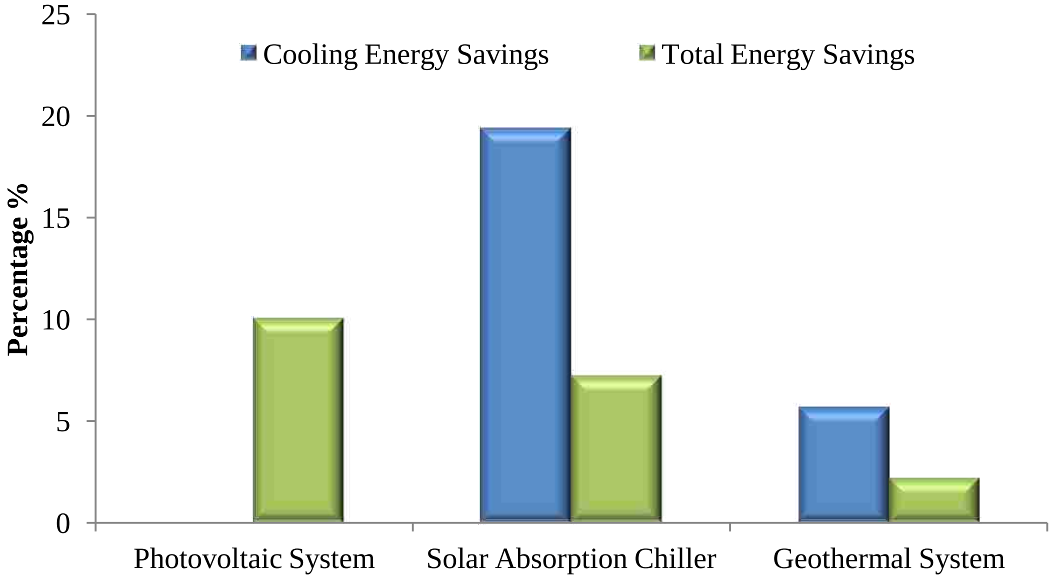



Figure 5.34: Three Renewable Energy Systems Savings in Percentage

# Chapter 6: Summary and Conclusions

This research intends to be a contribution to the growing interest and increased focus on energy savings and improving sustainability standard in the built environment in the United Arab Emirates. The aim of the study is to improve the "*Estidama*" performance of Abu Dhabi Educational Council public schools through a representative case study that achieved two Pearls. A representative school (out of the new 100 sustainable schools intended to be build from 2010 to 2020) the "Sheikha Bint Suroor Public School", was selected as a case study due to the availability of the documents provided by ADEC. The approach was based on a qualitative critical analysis and quantitative simulation testing. The qualitative analysis was made on *Estidama* performance of the school based on PBRS to identify the gaps and opportunities within the un-attained credits. The critical assessment showed that there is a potential in pursuing credits from the 'Resourceful Energy' section since 70% of it was not implemented in the school, although *Estidama* has urged the importance of energy mitigation strategies by allocating one fourth of the PBRS for 'Resourceful Energy'. Thus, the technical and economical feasibility of renewable energy systems namely photovoltaic, solar-powered absorption chiller and geothermal systems were studied. The process consisted of a thorough literature review of three systems which revealed that the systems improved the energy performance and led to increased energy savings. The systems were evaluated using TRNSYS Simulation Software under UAE climatic conditions to test their performance. Finally, a simple payback period was done to assess the applicability of the systems in the school.

The photovoltaic system relied on the optimization of selection of the PV type, slope of panels and azimuth angle and targeted 10% of the annual energy consumption. The selection of the slope and azimuth were based on transient temperatures, transient power, gross power, losses in power and net power. The absorption chiller system was sized to reduce 10% from the annual cooling load and optimized the concentration ratio and the water flow rate. Concentrated solar collectors were used in the absorption chiller to increase the solar radiation temperature. Selection of variables was based on the collector outlet temperature, useful energy gain and chilled water energy. The last tested system was the geothermal system which optimized the pipe length, pipe flow rate, pipe diameter, pipe material, pipe depth and pipe spacing using different variables. The optimum parameters of geothermal system were selected based on the higher delivered energy and highest difference in temperature between the inlet and outlet flow rate.

The considered systems contributed in different ratios to the energy savings. The most efficient PV system was the Mono-Crystalline PV panel with 24 degrees panel slope and south orientation with a total of 342 PV panels and 1110.6 $m^2$ for the whole array. The 10% targeted from the PV reduced 208849.32 kWh of the total energy consumption of the school. Simulation done on the several parameters of solar absorption chiller revealed that the optimized system required 30 collectors connected in parallel where each collector had a 3 $m^2$ area. The concentration ratio used was 25 solar concentrations with a total water flow rate of 240 kg/hr and a 36 kW chiller capacity. Results revealed 19.35% savings in annual cooling and 7.2% savings from the overall energy consumption of the school. The geothermal optimum design characteristics indicated the use of a 2800 $m^2$ area for horizontal buried pipes made of polyethylene with 5 m depth and using 2800 Kg/hr pipe flow rate. The findings implied that the geothermal system saved 2.2% from the total energy consumption and 5.8% from the annual cooling consumption.

The three renewable energy systems have shown 19% savings from the annual energy consumption. The proposed school design consumes 1,684,467.2 kWh, whereas the baseline case of the school consumes 2,088,493.2 kWh. Based on *Estidama* PBRS, the highest energy reduction from renewable energy is 20%, while in the thesis 19% was reached. The simple payback period calculations showed that the payback period for PV and solar absorption chiller is 3.5 years and for the geothermal system is 8 years. Results imply that there is a huge potential in the application of renewable energy systems in ADEC schools in the UAE context. The performance of the school was enhanced and it increased the credits of the school by 18 additional credit points to reach a total of 99 credits and the targeted three Pearls based on PBRS. If considerations of selection have to be limited, based on the systems' performances results, the priority of implementation would be for the photovoltaic system first, then absorption chiller system, and then geothermal system. However, availability in market, needed expertise and technology must be given into consideration when selecting the systems.

Although the research reached its aims, some unavoidable limitations were identified. First, this study was limited to one prototype as per availability of the data. However, there was no access to data of three Pearls schools. If the data was available, it would have been possible to know the steps and strategies that ADEC applied to reach 3 Pearls. Additionally, if information of the 3 Pearls schools were provided, the research could have been approached in a different way. The second limitation was that ADEC did not provide accessibility to visit the school. During the qualitative critical analysis, the daylighting credit was not achieved by ADEC where it could have been studied if accessibility was given. However, due to lack of accessibility this credit was disregarded from the study.

Further research possibilities include the connection between the PV and the grid can be studied in the future to use the electricity generated in holidays and weekends. Additionally, performance of the buried horizontal pipes of the geothermal system can be studied under different soil types, since the UAE has several soil types including sand, silt and clay. Future work can be done on the integration of the three renewable energy systems in one model in TRNSYS to test their performance and look at the effect of integration of the systems. Moreover, the integration of the three systems into the building and looking at the architectural feasibility can be further investigated in order to consider the aesthetical appearance of the systems and their compliance with the architectural building codes. *Estidama* offers calculators for water and ventilation calculations. However, it does not provide calculators that would predict the performance of renewable energy in buildings. Thus, further research would be to enhance *Estidama* guidelines in order to develop calculators that would promote the use of renewable energy systems and give an estimation of the energy savings and performance of the systems to be used by designers and consultants.

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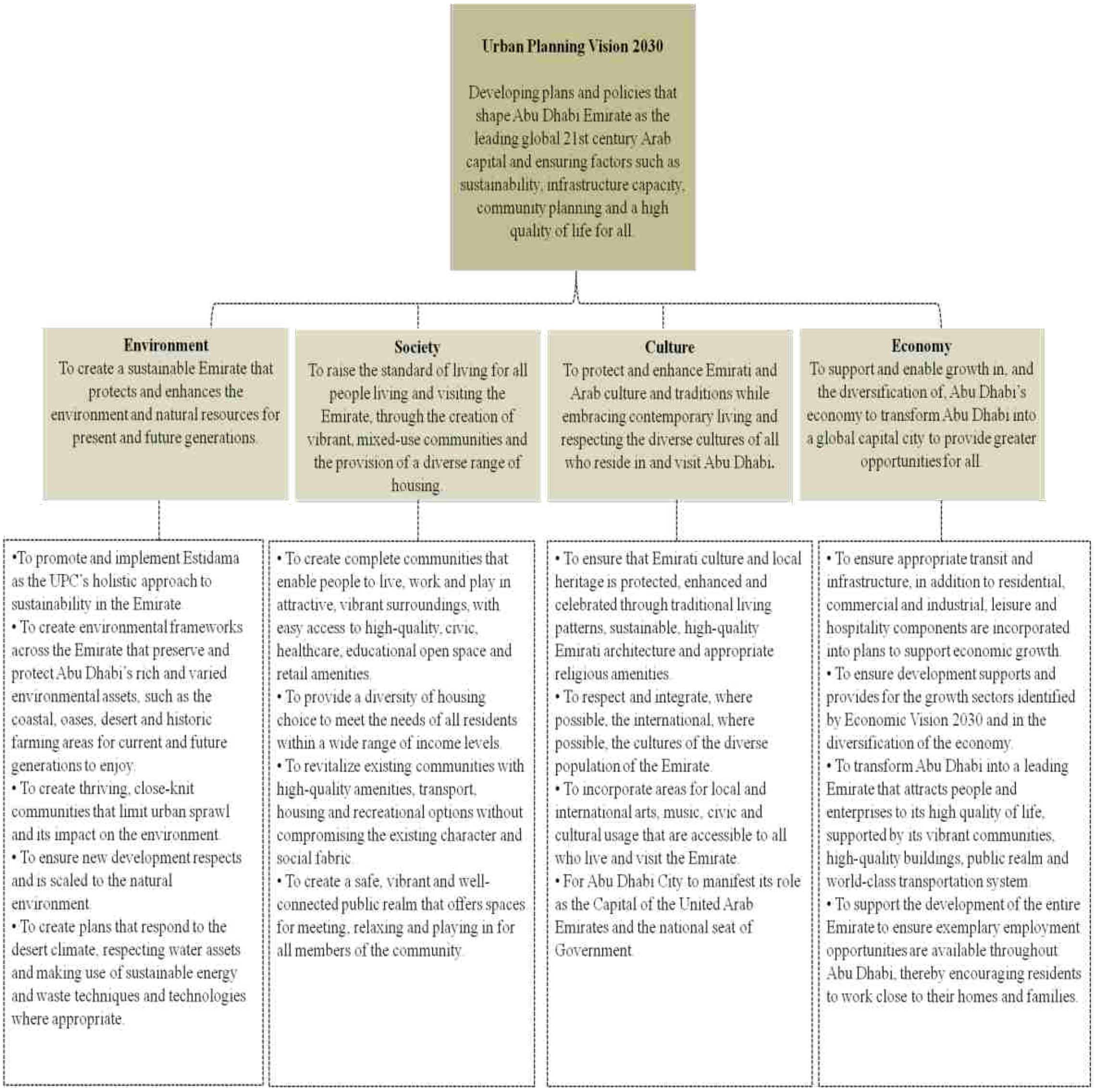
# Appendix A

Urban Planning Vision 2030 (UPC, 2016) (Refer to Chapter 2)



# Appendix B

Estidama Performance Analysis of the School (Refer to Chapter 4)

| **Achieved Credits** | **Credits Listed As Maybe** | **Un-Achieved Credits** |
|---|---|---|
| **Integrated Development Process (IDP)** | | |
| IDP-R1 Integrated Development Strategy (Required) | IDP -4 Building Envelope Verification ( 1 Credit Listed As Maybe) | IDP -1 Life Cycle Costing (4 Credits Not Achieved) |
| IDP -R2 Tenant Fit-Out Design & Construction Guide (Required) | | IDP -2 Guest Worker Accommodation (2 Credits Not Achieved) |
| IDP -R3 Basic Commissioning (Required) | | |
| IDP -3 Construction Environmental Management (2 Credits, 1 Achieved And 1 Unachieved) | | IDP -3 Construction Environmental Management (2 Credits, 1 Achieved And 1 Unachieved) |
| IDP -5 Re-Commissioning (2 Credits Achieved) | | |
| IDP -6 Sustainability Communication (2 Credits Achieved) | | |
| **13 Possible Points Available In Integrated Development Process (IDP) Section 5 Credits Achieved, 1 Listed As Maybe And 7 Unachieved Credits** | | |
| **Natural Systems (NS)** | | |
| NS -R1 Natural Systems Assessment (Required) | | NS-1 Reuse Of Land (2 Credits Unachieved) |
| NS -R2 Natural Systems Protection (Required) | | NS -2 Remediation Of Contaminated Land (2 Credits Unachieved) |
| NS -R3 Natural Systems Design & Management Strategy (Required) | | NS -4 Habitat Creation & Restoration (6 Credits Unachieved) |
| NS -3 Ecological Enhancement (2 Credits Achieved) | | |
| **12 Possible Points Available In Natural Systems (NS) Section, 2 Credits Achieved 10 Unachieved Credits** | | |
| **Livable Buildings : Outdoors (LBo)** | | |

| | | |
|---|---|---|
| LBo-R1 Plan 2030 (Required) | LBo -1 Improved Outdoor Thermal Comfort (2 Credits Listed As Maybe) | |
| LBo -R2 Urban Systems Assessment (Required) | | LBo -2 Pearl Rated Communities (1credit Unachieved) |
| LBo -R3 Outdoor Thermal Comfort Strategy (Required) | | LBo -6 Public Transport (3 Credits Unachieved) |
| LBo -3accessible Community Facilities (1 Credit Achieved) | | LBo -7 Bicycle Facilities (2 Credits Unachieved) |
| LBo -4 Active Urban Environments (1credit Achieved) | | LBo -8 Preferred Car Parking Spaces (1 Credit Unachieved) |
| | | LBo -9 Travel Plan (1 Credit Unachieved) |
| | | LBo -10 Light Pollution Reduction (1 Credit Unachieved) |
| **13 Possible Points Available In Livable Buildings : Outdoors (LBo) Section, 2 Credits Achieved, 2 Listed As Maybe And 9 Unachieved Credits** | | |
| **Livable Buildings Indoors (LBi)** | | |
| LBi-R1 Healthy Ventilation Delivery (Required) | LBi-10 Safe & Secure Environment (2 Credits Listed As Maybe) | LBi -1 Ventilation Quality (3 Possible Credits, 2 Credits Achieved, 1 Credit Unachieved) |
| LBi -R2 Smoking Control (Required) | | LBi -5.3 Thermal Comfort & Controls: Thermal Comfort Modeling (2 Credits Unachieved) |
| LBi -R3 Legionella Prevention (Required) | | LBi -7 Daylight & Glare (2 Credits Unachieved) |
| LBi -1 Ventilation Quality (3 Possible Credits, 2 Credits Achieved, 1 Credit Unachieved) | | LBi -9 Indoor Noise Pollution (1 Credit Unachieved) |
| LBi -2.1 Materials Emissions : Adhesives & Sealants (1 Credit Achieved) | | |
| LBi -2.2 Materials Emissions : Paints & Coatings (1 Credit Achieved) | | |
| LBi -2.3 Materials Emissions: Carpet & Hard Flooring (1 Credit Achieved) | | |

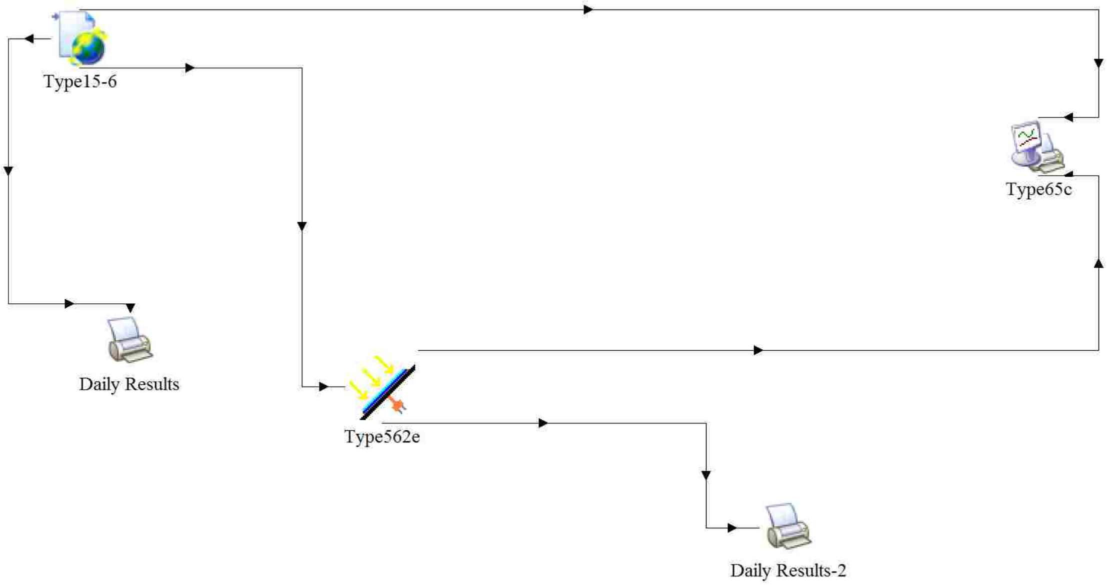
| | | |
|---|---|---|
| LBi -2.4 Materials Emissions : Ceiling Systems (1 Credit Achieved) | | |
| LBi -2.5 Materials Emissions : Formaldehyde Reduction (2 Credits Achieved) | | |
| LBi -3 Construction Indoor Air Quality Management (2 Credits Achieved) | | |
| LBi -4 Car Park Air Quality Management (1 Credit Achieved) | | |
| LBi -5.1 Thermal Comfort & Controls: Thermal Zoning (1 Credit Achieved) | | |
| LBi -5.2 Thermal Comfort & Controls: Occupant Control (2 Credits Achieved) | | |
| LBi -6 High Frequency Lighting (1 Credit Achieved) | | |
| LBi -8 Views (1 Credit Achieved) | | |
| **24 Possible Points Available In Livable Buildings Indoors (LBi) Section, 16 Credits Achieved, 3 Listed As Maybe And 5 Unachieved Credits** | | |
| **Precious Water (PW)** | | |
| PW-R1 Minimum Interior Water Use Reduction (Required) | | |
| PW -R2 Exterior Water Monitoring (Required) | | |
| PW -1 Improved Interior Water Use Reduction (15 Credits Possible, 7 Credits Achieved, 2 Listed As Maybe And 6 Credits Not Achieved) | PW -1 Improved Interior Water Use Reduction (15 Credits Possible, 7 Credits Achieved, 2 Listed As Maybe And 6 Credits Not Achieved) | PW -1 Improved Interior Water Use Reduction (15 Credits Possible, 7 Credits Achieved, 2 Listed As Maybe And 6 Credits Not Achieved) |
| PW -2.1 Exterior Water Use Reduction: Landscaping (10 Credits Possible, 8 Credits Achieved And 2 Listed As Maybe) | PW -2.1 Exterior Water Use Reduction: Landscaping (10 Credits Possible, 8 Credits Achieved And 2 Maybe) | |
| PW -2.2 Exterior Water Use Reduction: Heat Rejection (8 Credits Achieved) | | PW -4 Storm-Water Management Detection (4 Credits Unachieved) |

| | | |
|---|---|---|
| PW -2.3 Exterior Water Use Reduction: Water Features (4 Credits Achieved) | | PW -3 Water Monitoring & Leak Detection (4 Credits Possible, 2 Credits Achieved And 2 Credits Unachieved) |
| PW -3 Water Monitoring & Leak Detection (4 Credits Possible, 2 Credits Achieved And 2 Credits Unachieved) | | PW -3 Water Monitoring & Leak Detection (4 Credits Possible, 2 Credits Achieved And 2 Credits Unachieved) |
| **45 Possible Points Available In Precious Water (PW) Section, 29 Credits Achieved, 4 Listed As Maybe And 12 Unachieved Credits** | | |
| **Resourceful Energy (RE)** | | |
| RE-R1 Minimum Energy Performance (Required) | | |
| RE -R2 Energy Monitoring & Reporting (Required) | | |
| RE -R3 Ozone Impacts Of Refrigerants & Fire Suppression Systems (Required) | | |
| RE -1 Improved Energy Performance(15 Credits Possible, 1 Credit Achieved, 3 Listed As Maybe And 11 Credits Unachieved) | RE -1 Improved Energy Performance(15 Credits Possible, 1 Credit Achieved, 3 Listed As Maybe And 11 Credits Unachieved) | RE -1 Improved Energy Performance(15 Credits Possible, 1 Credit Achieved, 3 Listed As Maybe And 11 Credits Unachieved) |
| RE -2 Cool Building Strategies (6 Credits Possible, 3 Credits Achieved And 3 Listed As Maybe) | RE -2 Cool Building Strategies (6 Credits Possible, 3 Credits Achieved And 3 Listed As Maybe) | |
| RE -3 Energy Efficient Appliances (3 Achieved Credits) | | |
| RE -4 Vertical Transportation (3 Possible Credits, 2 Credits Achieved And 1 Unachieved Credit. | | RE -4 Vertical Transportation (3 Possible Credits, 2 Credits Achieved And 1 Unachieved Credit. |
| | | RE -5 Peak Load Reduction (4 Unachieved Credits) |
| RE -6 Renewable Energy (9 Credits Possible, 3 Credits Achieved, 6 Credits Unachieved) | | RE -6 Renewable Energy (9 Credits Possible, 3 Credits Achieved, 6 Credits Unachieved) |
| RE -7 Global Warming Impacts Of Refrigerants & Fire Suppression Systems (4 | | RE -7 Global Warming Impacts Of Refrigerants & Fire Suppression Systems |

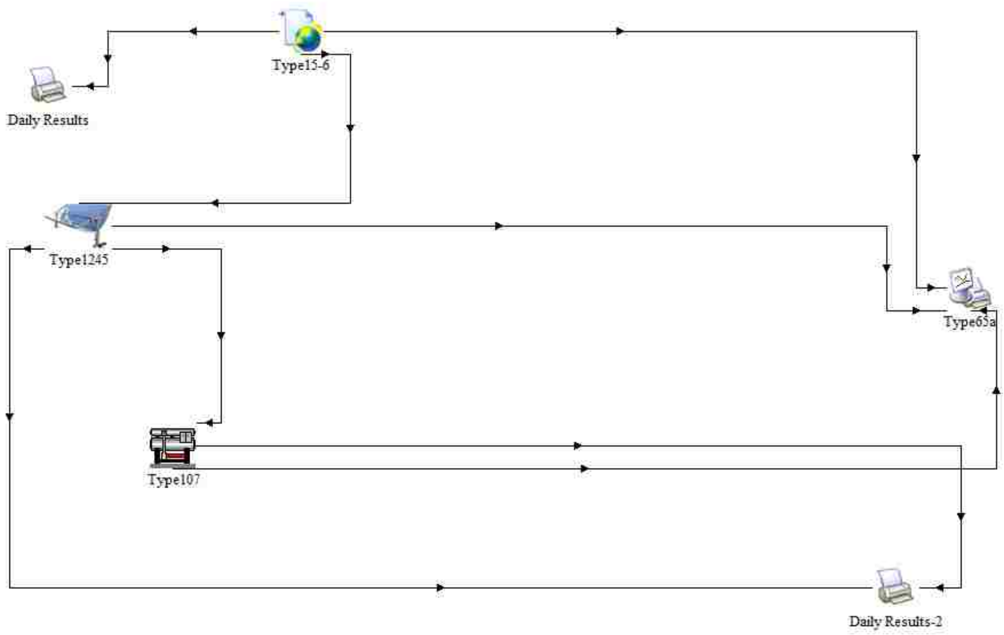
| | | |
|---|---|---|
| Credits Possible, 1 Achieved And 3 Unachieved) | | (4 Credits Possible, 1 Achieved And 3 Unachieved) |
| **44 Possible Points Available In Resourceful Energy (RE) Section, 13 Credits Achieved, 6 Listed As Maybe And 25 Unachieved Credits** | | |
| **Stewarding Materials (SM)** | | |
| SM-R1 Hazardous Materials Elimination (Required) | | |
| SM -R2 Basic Construction Waste Management (Required) | | |
| SM -R3 Basic Operational Waste Management (Required) | | |
| SM -1 Non-Polluting Materials (3 Credits Possible, 1 Achieved Credit And 2 Unachieved Credits) | | SM -1 Non-Polluting Materials (3 Credits Possible, 1 Achieved Credit And 2 Unachieved Credits) |
| SM -6 Design For Durability (1 Credit Achieved) | | SM -2 Design For Materials Reduction (1 Credit Unachieved) |
| SM -9 Regional Materials (2 Credit Achieved) | | SM -3 Design For Flexibility & Adaptability (1 Credit Unachieved) |
| SM -12 Reused Or Certified Timber (2 Credit Achieved) | | SM -4 Design For Disassembly (1 Credit Unachieved) |
| SM -13 Improved Construction Waste Management (2 Credit Achieved) | | SM -5 Modular Flooring Systems (1 Credit Unachieved) |
| | | SM -7 Building Reuse (2 Credits Unachieved) |
| SM -14 Improved Operational Waste Management (2 Credit Achieved) | | SM -8 Material Reuse (1 Credit Unachieved) |
| SM -10 Recycled Materials (6 Possible Credits, 2 Credits Achieved And 4 Credits Unachieved) | | SM -10 Recycled Materials (6 Possible Credits, 2 Credits Achieved And 4 Credits Unachieved) |
| SM -15 Organic Waste Management (2 Credit Achieved) | | SM -11 Rapidly Renewable Materials (1 Credit Unachieved) |
| **28 Possible Points Available In Stewarding Materials (SM) Section, 14 Credits Achieved And 14 Unachieved Credits** | | |

# Appendix C

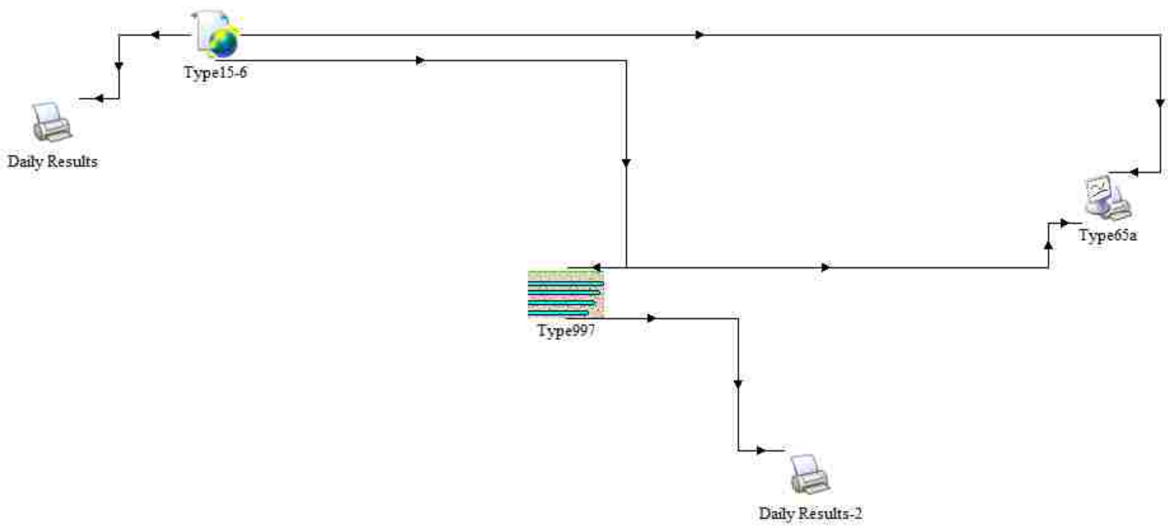
(Refer to Chapter 5)




Photovoltaic System Model in TRNSYS




Absorption Cooling System Model in TRNSYS




Geothermal Model in TRNSYS