Investigating Energy Savings Due to Implementing Green Roof on Existing Residential Buildings in UAE

دراسة حول تأثير استخدام الاسقف الخضراء على استهلاك كهرباء المباني السكنية القائمة

By: Athari Khamis Alnaqbi

Student ID number 90073

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Faculty of Engineering & IT

Dissertation Supervisor
Professor Bassam Abu-Hijleh

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Athari Khamis Alnaqbi	**90073**	**SDBE**	**May/2013**

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ABSTRACT

In recent years, building energy consumption keeps rising due to growth in population, increasing demand for comfort in indoor environment and global climate changing. The contribution from buildings toward global energy consumption is approximately 40% mostly from heating, ventilation and air conditioning (HVAC) systems. Fossil fuels are the main source for electricity production however they are finite reserves. Reducing fossil fuel dependency in the built environment is required and necessitates drastic reactions amongst this issue. Building refurbishment is one of the critical aspects that lowers the dependency on fossil fuels and mitigates the future energy crisis.

Green roof has been used on building roofs since ancient times. A widespread use of roof vegetation as a refurbishing technique has significantly increased in recent years. The specific purposes of green roof installations vary, between storm water reduction and/or improved building energy efficiency and often both. As energy efficiency concerns; green roofs have been introduced as a viable and effective method for reducing building electrical consumption.

The main purpose of this study is to investigate the potential saving due to green roof as a refurbishment technique on residential houses in UAE. Dual based research method (calculations and Simulation) was conducted on a multi-story family house. Heat flux through the green roof was examined to calculate the conduction gains. House model was constructed in IES-VE energy software to calculate the cooling load due to green roof and compared it to bare roof cooling load. The green roof model was altered to study the impact of the metrological conditions, soil substrate thickness, leaf area index, and soil water content on the thermal performance of the assembly.

The results of this dissertation showed that, promising energy savings potential are offered by implementing green roof as retrofitting method in UAE. The evaporative cooling effect and the insulation offered by soil substrate were always being able to reduce the conduction gain thus cooling load. The assembly lowered the cooling load by 6% and 12% in winter and summer, respectively. The researcher found that, the optimum energy reduction was obtained because of the evaporative cooling effect of canopy evapotranspiration phenomenon and the insulation provided by the soil substrate. The evaporative cooling phenomenon was able to reduce the cooling load by 7.3% comparing to bare roof building. The insulation effect of the soil substrate however, was able to reduce the cooling load by 7.7%.

الخلاصة

الفترة الحالية تشهد ارتفاعا ملحوظا في معدل استهلاك الكهرباء يعود الى عدة اسباب اهمها: زيادة عدد السكان، الرغبة بحياة مريحة داحل المباني بالاضافة الى تغير الطقس الملحوظ بسبب الاحترار الحراري. المباني تساهم بدور كبير في الاستهلاك العام للكهرباء يقدر ب 40% من الاستهلاك الكلي للكهرباء ومعظم هذا الاستهلاك يعود لاجهزة التكييف بالشكل الاول. انتاج الكهرباء المتزايد يؤدي لزيادة معدلات حرق مشتقات البترول وبالتالي زيادة الاحترار الحراري. و لتقليل الاستهلاك بدون اللجوء لاجراءات كبيرة ومكلفة بنفس الوقت كهدم المباني أو تغيير نظامهم الميكانيكي، يمكن اللجوء الى اضافة بعض التجديدات كاضافة الاسقف الخضراء على المباني.

على الرغم من أن الاسقف الخضراء قد عرفت منذ سنين عديدة في بعض الحضارات، الا أن استخدامها قد ازداد في الآونة الأخيرة لعد أسباب مثل: تقليل استهلاك الكهرباء و تلطيف جو المباني الداخلية بالاضافة الى تقليل المياه المترتبة من تساقط الامطار.

هذه الدراسة تهدف الى توضيح و استبيان تأثير استخدام الاسقف الخضراء على معدلات استهلاك كهرباء المباني السكنية القائمة في دولة الامارات العربية المتحدة. لتحقيق ذلك تم استخدام نهج المعادلات الحسابية بالاضافة الى برنامج محاكاة على الكومبيوتر لتقدير و حساب معدل استهلاك المبنى السكني للكهرباء. قياس و حساب معدلات كمية أشعة الشمس الي تصل لسقف المبنى تم حسابها بناءا على معلومات الطقس الخاص بالمنطقة. تم استخدام برنامج لمحاكاة المبنى السكني و حساب الحمل الحراري له بحالتي: عدم استخدام السقف الاخضر و بعد تطبيق السقف الاخضر عليه. الاحمال الحرارية الناتجة من استخدام السقف الاخضر تمت دراستها بناءا على :الظروف الجوية المتغيرة خلال فصلي الصيف و الشتاء، تغيير سمك طبقة التربة، كثافة النباتات في طبقة الزراعة واخيرا، تغيير كمية رطوبة التربة.

نتائج الدراسة جاءت مبشرة بجدوى استخدام الاسقف الخضراء و قدرتها على تقليل استهلاك كهرباء المباني السكنية القائمة. فقد وضحت الدراسة أن الاسقف الخضراء قد اسهمت بتخفيض 6% من معدلات استهلاك الكهرباء في الشتاء و 12% من استهلاك الكهرباء في الصيف. بينت الدراسة أن ظاهرة التبريد الناتج من تبخر مياه التربة و تنفس النباتات لها دور كبير ساهم في التخفيض بنسبة تصل الى 7.3% من معدلات استهلاك الكهرباء. بالاضافة الى ذلك، وضحت الدراسة أن 7.7% من الكهرباء تم تقليله بسبب قدرة طبقة التربة على حجز ومنع أشعة الشمس من الوصول لسقف المبنى الداخلي.

Acknowledgment

I would like to gratefully and sincerely thank Prof. Bassam Abu Hijeleah for his guidance, understanding and, patience during my graduate studies at BUID. His mentorship was paramount in providing a well-rounded experience consistent my long-term career goals.

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I am very grateful for my family and friends for their support, encouragement, and quiet patience.

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CHAPTER ONE:

INTRODUCTION

1.1 Global Context

Climate change is the main challenge that encounters the planet since last century; it casts its shadows on different levels of the human health, animal existence and, economy. Ban Ki-Moon the Secretary General of the United Nation had worn from serious consequences of the climate at the UN Framework Convention on Climate Change (2011):

> "The future of our planet is at stake. The science is clear. The World Meteorological Organization has reported that carbon emissions are at their highest in history and rising. We are nearing the point of no return"

Global warming is the reason behind climate change due to growing industrialization and deforestation. Harmful gasses especially CO2 accumulate in the atmosphere, act like blanket over the surface and, create greenhouse effect. Greenhouse effect furthermore, causes several relevant environmental issues such as higher atmospheric temperatures, intensive precipitation and flooding.

Several researchers agree that, proportional relation relates greenhouse gasses to electricity production, transportation, industry, and land use. Electricity production sector however, is the major source for emissions due to coal and oil combustion. International Energy Agency (IEA) (2009) estimates that, total of 18456 TWh of world electricity consumption is responsible for 28999 Mt of related CO_2 emissions.

A continuous cycle is exited between the climate outside and indoor buildings temperature. When the outdoor air temperature increases, occupants of buildings experience discomfort. The demand for air conditioning and mechanical ventilation will increase and eventually lead to higher energy consumption which will emit more CO_2 thus higher outdoor temperature. Properly this is the main reason behind consuming more electricity by building sector.

Huan et al., (2012) estimated that, buildings sector in the developed countries are responsible for almost 40% of the global energy consumption and emit more than one third of world CO_2 emissions (Kelly, 2006). Energy Information Administration EIA (2010) furthermore, estimated that, 50% of US energy demand was consumed by building sector, and buildings were responsible for almost half of CO_2 emissions (Yudelson, 2010). On the other hand, Hinnells (2008) claims that, building stock accounts for approximately half of UK carbon dioxide emissions. Buildings in China however, consume 33 per cent of total end user energy (Liang et al., 2007), and emit around one quarter of the total China's CO_2 emissions (Li, 2008).

Among building sector, residential buildings are responsible for most of the consumed electricity. They consume around 39 and, 30% in USA and UK respectively (EIA, 2010). Since that, RAENG (2010) estimates that, 80 per cent of 2020's buildings have been already built by this time, therefore, it is essential to reduce exiting buildings energy efficiently in order to cut down energy use thus CO_2 emissions by retrofitting exiting building stock.

Energy refurbishment involves improving existing buildings thermally to reduce the energy consumption. Usually, retrofitting is implemented either by upgrading mechanical and electrical systems, adding renovation technologies or, repairing envelopes of old buildings.

1.2 Building envelope

Throughout centuries, providing shelters is the humanity most important extinct. Shelters protect from weather fluctuations and ensure humans survival. Moreover, they secure privacy and, add social value to the occupants.

For centuries vernacular buildings have been developed according to the available materials and to local weather conditions. According to Roaf et al (2005), first man-made houses were built out of mud brick at 7200 BC in Zagros Mountains. Mud bricks are adaptable substances that offer thermal insulation to houses to offer warmer conditions at winter and cooler environments at summer.

Similarly, buildings in mild climate were made mainly from mud in addition to rubble masonry or thick clay mortar (Heschong, 1979). These materials have the ability to retain solar radiation at day time and release it at night.

Figure 1.1: Mud houses in North Africa (dbajurin, 2007)

To cope with the extreme hot arid weather conditions; people at the deserts had to choose wool of goats as fabric for their movable houses. Wool is a high heat tolerant material where, it absorbs solar radiation through the day and releases it back at night (Heschong, 1979).

The Turcoman yurt is a tundra cold climate tent, it has wood framework to support the structure and usually it was made of felt fabric (Roaf et al., 2003). The form of the used yurt was compacted to reduce the surface area and thus decreasing heat loss (roaf et al., 2005).

Figure 1.2: Turcoman yurt (Sachara, 2003)

On the other hand, indigenous people of Eskimo used dry snow cubes to form external walls of their igloos and furs to internal walls, to maximize indoor warming (Rapoport, 1969).

Native people of hot humid regions used bamboo and reeds for walls and roofs to minimize thermal mass therefore, offering their huts cooler internal conditions. Japan however, utilized removable papers for walls to offer cooling opportunity for houses during humid summer days. (Heschong, 1979)

Figure 1.3: Japanese traditional house (The Nihon Sun, 2009)

Now a day, building envelope materials have changed according to the development modifications. Regardless climate type, combination of concrete and steel are used to construct most of the current buildings.

Thermal mass of building envelope moreover, has a significant effect on building energy consumption. Usually, it offers thermal storing elements to absorb solar radiation during the day and release it through night. However, temperature differences between day and night times are insignificant in the hot arid climate thus, cement based walls and roofs retain thermal energy for longer time and they are not capable to release it all at night (Alvarado et al., 2009). The accumulated heat necessitates utilizing bigger air conditioning system to provide adequate indoor environment.

Usually, roofs are the most exposed building element to the sun. Haziq and Zulhabri (2011) demonstrated that, around 75% of solar radiation is projected directly to the roof. Solar radiation absorbed by the roof surfaces raises the surface temperatures, driving transfers toward the interior of buildings, as well as towards the ambient air causing more cooling load. Therefore, to reduce thermal load on the structure, considering roof is logical to begin with.

1.3 UAE scenario

Over the last 40 years United Arab Emirates depended mainly on electricity for energy demand. UAE annual electricity statistics (2011) demonstrates that, a total of 89,587 GWH electrical power was consumed at 2010 with growth rate of 43 per cent since 2006. As a direct consequence to population growth therefore electricity consumption, UAE 2010 CO_2 emission per capita scored one of the world highest rates by 20.50 tons (IEA, 2012).

Figure 1.4 shows that, Abu Dhabi and Dubai are showing similarity in electricity consumption patterns with continuity in rising. Sharjah however, and the other emirates comparing to Abu Dhabi and Dubai have acceptable consumption range which tend to decent rise every year. The consumption difference between Dubai and Sharjah is due to the presence of bigger commercial malls in Dubai.

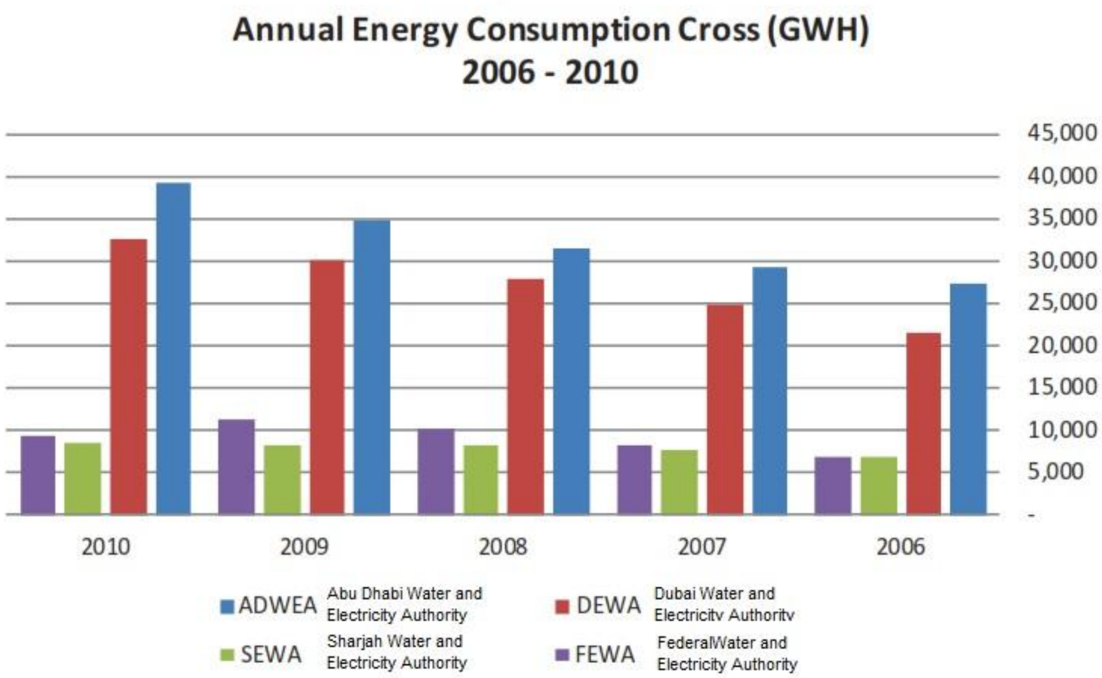


Figure 1.4: UAE federal electricity scenarios from 2006 to 2010 (FEWA, 2011)

According to UAE annual energy report (2011), residential buildings sector is the predominant energy consumer in Sharjah, they account for almost 50 per cent of the total. Dubai's domestic buildings however is the second dominant after the commercial sector, they are responsible for 28 per cent of the total production. Radhi (2010) argues that, buildings construction, heavy reliance on cooling systems and, domestic electrical appliances are the main reasons behind high electricity consumption in residential buildings.

Prior to year 2003 the construction projects in UAE, were selected mostly according to their cost and not necessarily on their energy performance ability. At year 2003 more energy efficient based regulations were added to the local building codes of Dubai and Sharjah. However, most of the existed domestic buildings were built before 2003. Actually they account for 16,650,939 and 2,594,890 in Dubai and Sharjah respectively (Alnaqbi et al., 2012).

Integrating low energy refurbishment methods to the exiting residential stock could decrease their negative effects on the atmosphere (Hulme et al., 2002 cited in Barlow and Fiala, 2007) thus prevent excessive energy use related to installing further cooling systems.

1.4 Motivation

Recently, United Arab Emirates country shows further interest in reducing the reliance on oil consumption for energy demand especially in building sector. As over half of the existing UAE building stock was built before any roof insulation was required, it is older buildings that will benefit most from any retrofitting process. However, small number of studies covered the impact of building refurbishment methods on the energy consumption in the country. The present study considers investigating the energy savings potential of implementing green roof technique in the existed residential buildings UAE.

1.5 Dissertation organization

The dissertation is classified as follows:

Chapter one: offers global discussion background around the global warming and the climate change and discusses global energy shifting toward energy regulation to mitigate the problem. Moreover, it discusses buildings envelope development through centuries in general with specific reference to recent envelope material and the effect of solar radiation on building energy.

Chapter two: provides several literature reviews that have similar interest.

Chapter three: discusses the preferred methodology for the research.

Chapter four: demonstrates the results and discussion of the simulated models

Chapter five: presents the obtained conclusions and recommendations

CHAPTER TWO:

LITERATURE REVIEW

2.1 Refurbishment

Poel et al., (2007) defines refurbishment as upgrading or enhancing existing building to more efficient one. Several researchers stated that, building envelope offers great potential for improvements Bell and Lowe (2000) for instance, found that, retrofitting the envelope alone had positive contribution on buildings thermal performance where almost 30% of energy bill were cut.

In addition to enhancing thermal performance of the buildings, envelope refurbishment has the following direct and indirect impacts:

- Reducing carbon dioxide emissions
- Enhancing indoor comfort
- Reducing the negative construction impact on the environment
- Preserving the environmental resources
- Increasing buildings cost
- Protecting the architectural heritage
- Providing lower financial alternative to demolition and reconstruction

Usually, most of the retrofit related studies focus on two objectives: reducing energy consumption and cutting down bills payments. Bojic et al. (2012) for instance, focused on reducing the consumed energy of non-insulated buildings in Serbia. In order to reach their goal, they used simulation methodology to evaluate the energy consumption then they calculated financial savings.

Most of the researchers tend to utilize mathematical approaches to achieve significant results out of the retrofitting. However, achieving that is not always possible. Asadi et al., (2012) for instance, constructed different mathematical models to study several innovative technologies impact on thermal performance of buildings. These models were based on Portuguese thermal regulations such as glazing thermal transmission coefficient; windows surface area and, thermal conductivity of external wall insulation material. The model however, faced difficultly differentiating mean radiant temperature from internal temperature. Therefore, inaccurate results were obtained.

Deurinck et al., (2012) on the other hand, used different simulation software that was able to differentiate between internal and radiant temperatures and indoor comfort was considered more. Comparing to realistic consumption rate their model achieved more appropriate results.

2.2 Green Roofs

Most of the researchers agreed on the definition of the green roofs, as an artificial fully or partially man made gardens on flat or inclined rooftops used to enhance both energy performance and indoor comfort.

McDonough moreover, adds expressive definition relates rooftops plantation to their effects on humankind physical and mental comfort.

"The interactive design of green roof enables the building and it inhabitants to participates in natural processes, allowing for an appreciation of the relationship between creativity and the abundance of nature." (McDonough 2005, p. 11)

According to Hsieh et al. (2010), green roof concept were first introduced two thousand years ago on the Babylon period (figure 2.1) to cut down storm water flooding and for visual leisure. Conversely, green roofs were planted in Scandinavian countries to provide warm buildings during cold season (Sondgrass and Sondgrass, 2006). Moreover, during the Benedictine Abbey period green roof witnessed flourishing growth as a sample of art and exquisiteness (Hsieh et al., 2010).

Figure 2.1: Babylon green roofs (Coplin, 2012)

Recently, use of green roof has significantly increased globally to overcome the global warming and related issues. European countries for instance especially German has been utilizing green roofs for more than 30 years now (Köhler, 2010) to manage storm water (Solomon, 2003). Norway on the other hand, focuses more on cutting down electricity expanses (Solomon, 2003).

Furthermore, other countries like India, Japan, Singapore, Taiwan and Greece are concerned on reducing heat island effect and thermal loads (Kumar and Kaushik, 2005, Osmundson, 1999, Onmura et al., 2001, Wong et al., 2003, Fang, 2008).

Contemporary green roofs are different than the ancient ones constructional wise. Previously, heavy ordinary soil was dispersed all over the roof as planting base or plantations were localized in individual containers. Recent green roofs however, are integrated into the building construction in substrates and utilize ultra-weighted materials (Dunnett and Kingsburry, 2008).

2.3 Green Roof Technologies

Green roofs are divided into three categories: intensive and extensive. Fioretti et al. (2010, P: 1891) listed some reasons behind this classification as follow: thickness of the layers, predictable use of the rooftop, plantation type and, finally maintenance cost.

Peck and Callaghan (1999, cited in Tabares-Velasco and Srebric, 2012) had anatomized intensive green roofs structures showing that, intensive green roofs (Figure 2.2) have larger depth and more complicated structures to support the irrigation systems. They have higher investment costs, more plants selection, and their weight range from 290 Kg/m2 to 968 Kg/m2 and substrate depth between 20-60 cm. Tsang and Jim (2011) moreover, added that, intensive green roofs can support larger plants such as trees and shrubs, therefore they provide biodiversity habitat for wider range of birds and insects. For all the previous reasons Oberndorfer et al. (2007, cited in Williams et al., 2010) and Jim and Tsang (2011) agreed that, intensive green roof are unusually installed because they are more expensive and require frequent plants irrigation.

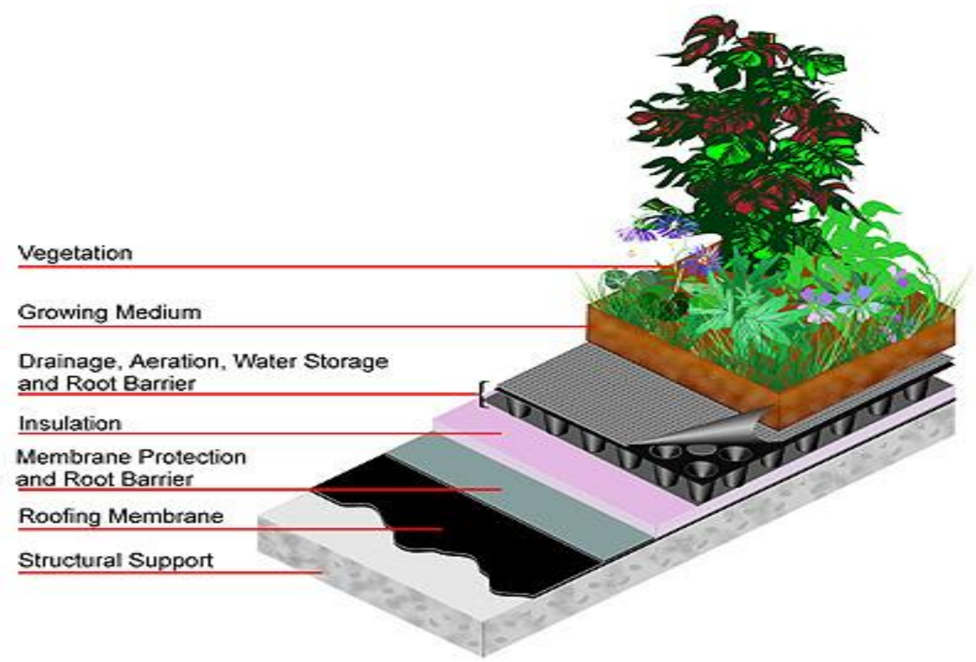


Figure 2.2: Intensive green roof (green spec, 2013)

Extensive green roofs (figure 2.3) however, are more common due to their lower capital cost, lesser weight, lower layer depth and usually they require minimum maintenance (Williams et al., 2010) and does not require any additional roof structural adjustments to install (Sadineni et al, 2011). They have weight range between 72 to 169 Kg/m2 (Tabares-Velsco and Srebric, 2012). Due to shallow soil substrate, extensive green roof can support lightweight lawn plants such as grass, herb or sedum. (Williams et al., 2010 and, Dunnett and Kingsbury, 2004).

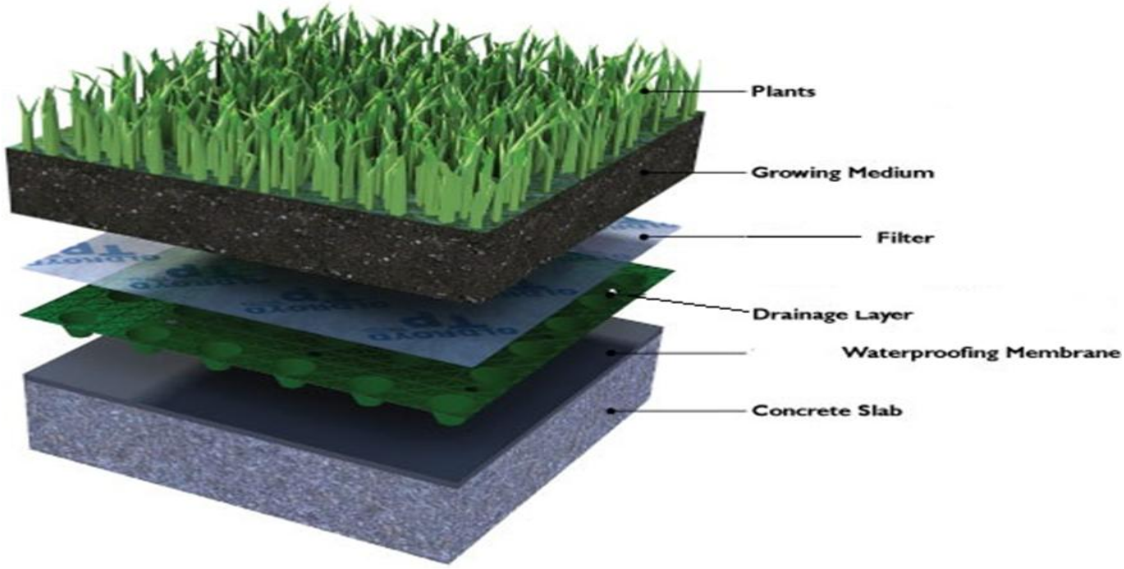


Figure 2.3: Extensive green roof (Guard, 2013)

For refurbishment purposes extensive green roofs are more popular. According to Williams et al., (2010) the soil substrates are made of recycled light weighted materials such as steel mill slag, tuff and burned coal ash. In addition to crushed rick and roofing tiles.

Green roofs typically consisted of different substrates:

1. The soil Substrate

The soil medium main objective is to support the plants and to provide nutrition for vegetation. Usually it has a depth ranges between 5 cm to 20 cm. Peck and Callaghan (1999, cited in Tabares-Velasco and Srebric, 2012) explained that, soil substrate is made of combination of organic matters such as sand, gravel, and peat, and nonorganic matters such as crushed brick, and vermiculite. Hsieh et al. (2010) explained the reasons behind utilizing synthetic materials instead of regular soil; soil is heavy in weight and usually, synthetic materials cost less, more practical and preserve the environment.

2. Filter membrane substrate

It is a fabric made membrane separates between the soil and the drainage layers to avoid drainage blockage by plants roots. Filter layer also protects fine particles by retaining them from draining.

3. The drainage substrate

The drainage layer comprises of gravel, clay, lava and pumice and sometimes plastic or polystyrene woven fabric. Drainage layer plays dual roles: ensuring vegetation roots are moisturized properly in arid season and purging excessive storm water in rainy season (Eumorfopoulou and Aravantinos, l998).

4. Root-proofing membrane/ root barrier

Root barrier is a substrate used to protect roof structure from destruction by the deep grown roots of vegetation.

5. Insulation layer

It is a significant part of the green roof structure. It isolates the roof from solar radiation and provides thermal resistance.

6. Waterproof membrane

Waterproof membrane is essential layer in the green roof. It is made of double bitumen layers and PVC (polyvinyl chloride)

Several researchers found that, green roofs contribute to energy savings by two general methods: reducing heat flux of the roofs by vegetation biological processes and/or insulating heat by soil layers. However, the impact of the vegetated roofs differs from climate to other depending on the temperature, humidity and, net radiation (Alexandria and Jones, 2008). As direct consequence for that, green roofs have been subjected to various investigations for different climate conditions.

Lin and Lin (2011) for instance, focused on the tropical climate. They examined the temperature of a building beneath vegetated roofs due to different soil layer types: sand, sand with white charcoal debris; man mixed and burned reservoir sludge. They found that, burned sludge had the best results reducing temperature by 89%.

He and Jim (2010) on the other hand, focused on subtropical climate conditions. Similar to other researchers they developed a mathematical model to study the impact of the vegetated roofs on buildings' roof temperature and they found significant results. Temperatures were reduced by 17 °C comparing to ground temperature. Correspondingly, Lin and Lin (2011) and Meng and Hu (2005) studies demonstrated that green roofs usually obtained considerable and positive results toward temperature reduction underneath roof and save energy in subtropical climate.

On the other hand, Santamouris et al. (2007) conducted a study on the Mediterranean climate and they found that; reductions between 6 to 49% underneath buildings' temperatures were recorded. Similarly, Sfakianaki et al. (2009) study for same climate proved that, vegetated roofs lowered indoor temperature by 0.61 °C and contributed reduction in the cooling load by nearly 11%. On the contrary, Niachou et al. (2001) and Zhou et al. (2004) results were moderate.

Although several researchers believed that climatic conditions are significant, others rely more on plant biological process. Okeil (2010) for instance assumed that, evaporative cooling effect of plant transpiration is the main cause of the cooling presence of vegetated roofs. Okeil theory is corresponded by several scientists such as Barrio (1998) and Theodosiou (2003).

Pearlmutter and Rosenfeld (2008) theory however, slightly differed from previous researchers. They believed in the effectiveness of the evaporative cooling of the green roof however, they assumed soil water content is more effective than plantation. Accordingly, Pearlmutter and Rosenfeld (2008) conducted experiment to examine the temperature beneath rooftop due to several soil moisture level and they found that temperature reduction achieved was noticeable.

On the contrary, Niachou et al. (2001) and Theodosiou (2003) assumed that, the evaporative cooling effect of the plantation and soil moisture level are overestimated and temperature reduction is due to the shading offered by leaf area index (LAI). Ouldboukhitine et al. (2011) agreed with Pearlmutter and Rosenfeld on the role of LAI however, he assumed that leaf area index provides shield effectiveness to the roof by vegetation thus reflects solar radiation and reduce conduction heat on roof surfaces.

On the other hand, Eumorfopoulou and Aravantinos (1998) were concerned more on net solar radiation reduction. Both researchers assumed that, heat flux is reduced while solar radiation passes through the green roof. They claimed that plantations consume solar radiation partially through their biological functions such photosynthesis and respiration. Their study demonstrated that almost 60% of the solar radiation was used for plants biological functions.

Benefits of green roofs are not restricted to enhancing energy performance and reducing roof temperature, other advantages were observed such as indoor comfort. Researchers such as He and Jim (2010) and, Yang et al. (2008), studied the impact of green roof on buildings indoor climate and they found that, enhancing air quality was clearly achieved.

Lin and Lin (2011) and, Hilten (2005, cited in Ayata et al., 2011), studied the effect of green roof on the storm water management and they found that, roof top plantation offered admirable results. Actually, green roofs were able to enhance the quality of storm water run-off (Berndtsson et al., 2009).

Furthermore, Castleton et al., (2010) and, MacIvor and Lundholm (2011) agreed that green roofs encourage biodiversity by establishing local fauna habitat. They believe that, green roofs could function as islands of biodiversity within urban environments.

Green roofs have some direct and indirect influences. Frequently, green roofs capture carbon dioxide from the atmosphere through photosynthesis. On the other hand, plantations cool the surrounding environment by evapotranspiration, decrease the energy consumption, and thus cut down carbon emissions.

Although all the previous literature reviews show that, green roofs have significant potential to decrease the impact of the global warming by reducing energy consumption in buildings. However, Lin and Lin (2011) found that, using decaying biodegradable materials in soil substrates increased maintenance thus management cost.

Theodosiou (2003) mentioned that, green roof has a significant impact on buildings energy through the combined effects of heat isolating, evaporative cooling effect, and shading of the plant canopy. In order to understand the thermal behavior of the vegetated roofs, correlated factors such as plant biology and heat transfer, should be taken under consideration.

2.4 Green Roof Physics

2.4.1 Heat flux

Ayata et al. (2011) listed in their study four fundamental mechanisms that influence the cooling effect of the green roof assembly: (1) interception of solar radiation due to the shadow produced by the plantation, (2) thermal insulation provided by the plantation and soil layer and, (3) combined evaporative cooling that occurs due to plant evapotranspiration and water content of soil layer.

Through the green roof; heat flux breaks down into evapotranspiration, convection and, conduction gains (Figure 3.1). Tabares-Velasco and Srebric (2009), Ekaterini and Dimitris (1998) claimed that nearly 27% of the net radiation reaches roofs is reflected, 60% is absorbed by canopy and soil through evapotranspiration, and 13% is transferred into the soil. Wang et al. (2004) stated that, the amount of conduction gain absorbed by a green roof and the amount of energy converted to convection, and evaporative gains are regulated by the biophysical properties of the vegetation such as leaf density index (LAI), soil properties such as water content ,thermal conductivity and, specific heat capacity.

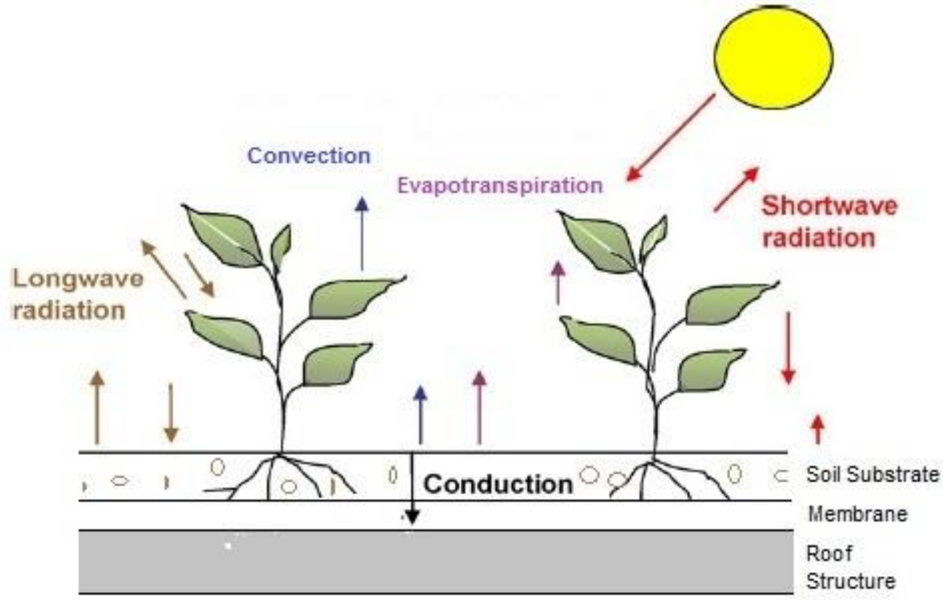


Figure 2.4: Representation of the energy balance through green roof structure

2.4.2 Shading Effect

Different researchers were concerned in studying the effectiveness of green roof in respect to shading provided by vegetation layer. Feng et al (2010) and Barrio (1998) described that, green roof canopy offers shading protection to the roof and therefore, the roof surface temperature rarely rises above the ambient air temperature. Laboratorial experimental based approach was favorable, however, field measurement method were used as well. Green roof assemblies' performances were analyzed based on the shading ability of their plants. Several plants were chosen to be investigated to study their ability to reflect solar radiation.

In order to understand the reflectivity of vegetation layer and to select the most suitable plant, Lin and Lin (2011) studied the leaf coverage ratio of different plants through laboratorial experiment. The researchers divided the planting containers into grids to indicate the leaf coverage. The leaf coverage ratio (%) was calculated by dividing the total number of grids covered by vegetation by the total number of grids. The results showed that, Sansevieria trifasciata cv. Laurentii Compacta and Rhoeo spathaceo cv. Compacta scored the best coverage ratio and were able to reflect solar radiation by 13%.

Similarly, Kumar and Kaushik (2005) conducted laboratorial experiment to study the parametric variations of leaf coverage area (LAI) and foliage height thickness to estimate heat flux penetration through green roofs canopy. Results determined that larger LAI reduces air temperature underneath the canopy and, reflects solar flux nearly 4W/m2.

Jim and Tsang (2011) utilized field experiment method and they found that, canopy shading reduces temperature of beneath rooms due to the effect of plantation shading. However, their multi plant heights experiment showed that, better results occurred at 1.6m above the soil surface which indicates that the shield effectiveness of plantation works better for intensive green roofs.

2.4.3 Insulation Effect

Different researchers investigated the effectiveness of green roof in respect to insulation provided by soil layer. Field experimental based approach was favorable. Green roof assemblies' performances were analyzed based on the insulation ability of the soil layer. Several soil types were chosen to be investigated to study their ability to insulate solar radiation.

In order to investigate the energy efficiency of green roof structure, Lin and Lin (2011) conducted long-term monitoring experiment on four-floor building in Taiwan. The study examined four different soil substrates to indicate their ability to reduce solar radiation. Among the substrates, burned sludge has the best thermal reduction percentage of heat amplitude under the roof slab surface (up to 84.4%).

Similarly, Wong et al. (2003) conducted field measurement experiment in Singapore to Investigate the thermal impacts of vegetated rooftop in terms of insulation. They measured the heat conduction due three different soil types and they found that, green roof add s thermal benefits on the buildings and their surrounding environments by reducing the heat gain nearly 76%.

Fioretti et al. (2010) conducted field experiments in Italy on top of two public buildings. The thermal performance of the green roof structure due to insulation was examined by comparison between the external surface temperature on the traditional roof and the temperature below the green roof layers, using a sensor positioned under the drainage layer. According to the results it was evident that the green roof has a lower temperature level due to insulation provided by the soil layer in addition to plantation.

2.4.4 Evaporative Cooling Effect

Niachou et al. (2001) explained that, plants for their biological processes such as photosynthesis, transpiration and, evaporation absorb portions of solar radiation and release an evaporative cooling effect in return. The evaporative cooling depends mainly on the type of plant and sun exposure in addition to climatic conditions such as wind which usually increases evapotranspiration rate of canopy (Pérez et al., 2011 and Cheng et al., 2010).

Sailor et al. (2008) however, stated that, the moisture content of the soil layer contributes as well in the evaporative cooling effect and thus it is important to measure the performance of the green roof under different soil moisture conditions.

Studying the effect of green roof on the energy consumption of building covered with plantation is challenging to a certain extent. Cooling load in general depends mainly on the conduction heat gain directed on the roof surface. In order to calculate the thermal performance of the green roof, several researchers such as Santamouris et al. (2007) depended on the energy balance equation within the green roof to obtain the conduction gain in addition to numerical calculation method to calculate the thermal load.

Consequently, green roofs are questionable method as passive cooling system and need further study to obtain their influence on buildings energy in hot arid climate. Therefore, the main purpose of this research is to investigate the ability of adapting extensive green roofs as part of retrofitting exiting buildings in UAE climate and study their effect on energy consumption.

2.5 Green Roofs in UAE

Since establishing the United Arab Emirates, UAE economy has witnessed an exponential growth. Tremendous construction projects were established to maintain the present development. Most of the projects were designed and selected according to their cost and to their aesthetics (Radhi, 2010). Accordingly, environmental concern was not concerned and the municipalities building codes were not suitable enough to sustain these projects.

Prior to 2003 UAE governmental building regulations have not provide any guide regarding energy performance. The situation however, has been changed since 2003 and serious steps toward thermal efficient buildings were established. Dubai Municipality for instance, regulated green codes to reduce the energy consumption within building passively (Dubai Buildings Codes, 2003). Sharjah on the other hand, altered their building codes by adding proper insulation and glazing (Sharjah Building Codes, 2003).

Although these building codes encourage insulating buildings' envelopes to reduce cooling load in new constructed buildings. However, retrofitting old exiting buildings measures are not taken under consideration. Green roofs as retrofit approach academic studies to investigate their impact on energy consumption are not available in UAE. UAE studies are very rare especially energy efficient measures.

2.6 Problem Statement

Recent concern of the world countries in general and UAE in particular to energy reduction measures; has directed technologies manufacturers and academia studies toward investigating less carbon foot printed techniques such as green roofs. Green roofs techniques investigations however, were mostly studied due to cold or subtropical climates. Implementing such technique to UAE hot and arid climate offer more adequate back ground to decision makers, interested companies, engineers, architects and finally background to other academic researchers.

The study investigates the effect of implementing green roofs techniques on the total energy consumption of existing residential buildings, as well as trying to explore the economic benefits behind it.

2.7 Aims and Objectives

This research aims to assess the potential energy savings from existing buildings in Dubai and Sharjah by implementing different green roof technologies/techniques.

The research will precede the assessment attempt through investigation of:

1. The existing buildings and their energy consumption

2. Implementing green roof techniques on existing buildings and their potential effects on energy consumption

3. The following objectives will be explored to achieve the aims of the study:

4. Examine the current energy consumption of the representative building due to bare roof configuration

5. Examine the effect of green roofs on cooling loads according to the following:

- Outside temperature
- Several soil thickness
- Several leaf area index
- Several soil moisture content

• Compare the energy consumption results of both roof configurations (bare and green roof) to determine the potential savings in energy.

CHAPTER THREE:

METHODOLOGY

In order to select the most suitable methodology for the purpose of examining the green roof thermal performance on exited building; several related literature review were read and analyzed. Different studies in different climates were reviewed to indicate their general trends and to obtain the most significant parameters. The researcher builds on some of the following literature review and decides the favorable approach to conduct her dissertation paper.

3.1 Energy Balance Methods

The researcher found that, there were two of common approaches that used to measure the energy flux through green roof structure combined to potential energy savings: simulation and experiments. Experiment-based methods typically, use measured heat flux data to estimate the overall resistance to heat transfer through the green roof assembly.

Ayata et al. (2011) conducted a laboratorial experiment to measure sensible heat fluxes to/from a green roof assembly. The setup was physically modeled to create different environmental conditions. Different wind velocities to create free and forced convection conditions around green roof were tested. Furthermore, the study proposed a “basic model” for calculations of the convective heat transfer at green roof assemblies.

Tabares-Velasco and Srebric (2012) conducted a laboratory based experiment to examine the evapotranspiration, conduction and convection gains of a green roof assembly. They selected different parameters to test the assembly against such as metrological conditions, soil thicknesses, moisture content and leaf area index. However, the researchers found that this approach tended to underestimate the evapotranspiration gain due to incapability of the utilized apparatus.

Sailor et al. (2008) emphasized that, experiments are useful; however they disincline evaporation due to the transpiration, thermal conductivity, density, and specific heat capacity of the soil substrate and miscounted heat storage in the soil layer which underestimates the heat reduction thus savings reduction.

Therefore, several researchers developed numerical approaches to model the energy balance transfer within the green roof which took under consideration soil properties. Barrio (1998) for instance developed single model where, the air renews by the urban air within the foliage however, all the other variables such as temperature and water content of the soil are constants.

Alexandri and Jones (2007) furthermore, developed a modified form of the partial differential equations of heat transfer to model the energy balance within the green roof structure. However, they assume non constant form of temperature and humidity throughout the vegetation layer.

Sailor et al. (2008) on the other hand, separated the energy balance model into two equations; one for the foliage and other for soil surface. These researchers however, neglect the thermal inertia of the substrate and assume constant proportions of air mixture within the vegetation layer.

Feng et al. (2010) developed a model for heat balance throughout the green roof. These researchers depended on the plant photosynthesis phenomena as the major source for energy distribution within the canopy layer and neglect the other energy parameters.

The researcher of this study simulated building model and adapted the heat transfer data offered by the predecessor research to calculate and measure conduction heat gain and thus cooling load. Furthermore, another simulated was simulated according to building codes prior to 2003 and measured the conduction heat gain and thus the cooling load. Finally green roof model predictions were compared to bare roof model’s.

He and Jim (2010) on the other hand developed an efficiency shading model (SEM) based on the theory of transmission of electromagnetic waves. The researchers took into account the radiative properties of the solar radiation reaches the vegetation and assumed multilayered foliage canopy.

Ouldboukhitine (2011) modified Sailor's model that accounts for the effects of water transfer on the thermal properties of the assembly; employing the Penman–Monteith equation. Similar to Sailor et al., Ouldboukhitine neglect the thermal inertia of the substrate and assumed constant mixture of the air within the foliage layer.

Tabares-Velasco (2011) furthermore, developed a model based on laboratorial experimental data to calculate the energy balance within the green roof properly. However, he assumed steady state case all over the green roof assembly and neglect the thermal inertia of the soil substrate.

Lazzarin et al. (2005) accounted for changes in the water content of the substrate due to evapotranspiration and precipitation of plants where, evapotranspiration was mainly calculated by the vapor pressure deficit (VPD) method.

Overall, all these researches can be summarized and classified into three categories: hydrologic water evaporation, micrometeorology and, heat balance methods. According to Jim and He (2010), the hydrologic water evaporation method is more concerned in the monitoring the physical change of vegetation due to energy transfer through it.

Geros et al. (1999) explained that, the micrometeorological method often depends on several numerical equations such as Penman–Monteith, Priestley–Taylor equation and, Bowen ratio equations and it more useful for field experiments where measurements such as air temperature and humidity gradients, net radiation, and soil heat flux are considerably available. Lacroix (1993) stated that, the Steady-state energy balance method uses the principle of basic energy conservation equation to calculate heat transfers.

Most of the energy balance calculation-based approaches however, are confined to evaluating effects of green roofs to a short time periods and especially summer and fail to provide an in-depth presentation of the function of a vegetated roof as a passive under various climatic conditions in addition to that, these experiments consume longer time to get the results. Sailor (2008), encouraged utilizing software programs instead to assess the potential benefits of green roofs and save time and effort.

Theodosiou (2003) combined his energy balance calculations with energy software program to complete the energy analysis for the tested building and he stated that, the software was able to provide acceptable accuracy.

Wong et al. (2003) utilized a simulation energy program to determine the effect of the roof top vegetation on energy performance of a building. Similar to Theodosiou (2003) approach, they combined the green roof energy balance calculations with an energy software program to calculate the potential savings in the cooling load in addition to the annual energy consumption.

Lazzarin et al. (2005) utilized a data logging system with temperature, humidity, rainfall, radiation sensors on green roof assembly and rooms underneath. Their study aimed to measure and evaluates the evapotranspiration role in summer time as well as winter time. A model was developed in building simulation software to calculate thermal and energy performances of a building with a green roof.

Kotsiris et al. (2012) evaluated green roof thermal performance in terms of the thermal in real scale and under dynamic conditions. To prove their work they combined their field measurement data with simulation software. They constructed several green roof systems on the roof of a building. The relation between the estimated thermal transmittance and the substrate moisture content was investigated. They model the green roof for a single-storey residential building in order to quantify their possible energy savings. The results from the simulation showed significant results.

Takakura et al. (2000) studied the cooling effect of four kinds of vegetated roofs by both experimental model and computer simulation. Concrete roof models were constructed as well as different coverings were arranged for each: bare concrete, soil layer, soil layer with turf, and soil layer with ivy. Air temperature under the roof was measured along with other environmental parameters to calculate the cooling effect. Model was developed in the simulation software to simulate the systems and to evaluate cooling load.

Jaffal et al.(2012) studied the impact of a green roof on building energy performance. A model of green roof thermal behavior was coupled with a building code to evaluate the green roof foliage and soil surface temperatures.

Simulations were conducted for a residential house in a temperate French climate. The heat flux through the roof was evaluated as well. The impact of the green roof on indoor air temperature and cooling and heating demand was analyzed.

All the previous researchers agreed that, coupling simulation approach with numerical calculations is more beneficial in terms of evaluating energy performance of a building. Takakura et al. (2000) for instance mentioned that, the simulated results they achieved from their simulation program agreed fairly well with measured values. Sailor et al. (2008) emphasized on the speed of obtaining results comparing to calculations method.

On the other hand and in terms of the simplicity of these programs, Feng et al. (2010) stated that, simulation programs are complicated in some cases; and these programs should be improved for better accuracy and greater practicality. Furthermore, they proceeded that these models fail to account for photosynthesis and plant respiration which will underestimate the effect of the evapotranspiration within the green roof assembly.

Kotsiris et al. (2012) mentioned that, in order to improve the usefulness of these programs, several inputs should be utilized and they need to have more range of options which will enhance their inaccuracy.

Based on the previous investigations thus it is found that:

1. Most of the studies that have been presented so far depended on simulation, experimental or mixed methodologies.

2. The researchers depended on short time periods validation to evaluate their mixed methodologies (experiment and simulation) model.

3. Most of the validation were set to study the experimental models and did not take under consideration existing planted roof construction.

4. In most cases, validation and results were restricted to certain seasonal conditions, and failed to study the influence of green roofs on all climatic conditions.

Table 3.1: Advantages and disadvantages of the investigated methodologies:

Characteristics	Experiments Method	Mixed Method (Experimental Simulation)
Time management	+ve	-
accuracy	-	+ve
geometrically complex	+ve	-
Human resources	+ve	-
Predicting future behavior	-	+ve
Parameters control	+ve	-
Rate of errors	-	+ve
Reliability	-	+ve
Validation	-	+ve

+ve = represents best result

Based on these investigation results, the researcher found that, mixed approach gave very promising view to conduct the research through it.

3.2 Dissertation Methodology

3.2.1 Calculations Method

Incorporating green roof in UAE climate is relatively new concept, few actual assemblies were constructed and for our best knowledge the heat flux transfer within the assemblies were not tested nor measured. Therefore, adapting data from measurement based experiment that had similar climatic conditions to calculate conduction gains due to UAE local climate and coupled it with a simulation program may reflect proximate results to real time ones.

Energy Balance Calculations

Several researchers such as Ayata et al., (2011), Jim and He (2010) adapted an energy balance approach for modeling green roof heat fluxes as shown in equation (1):

$$R_n = H + L + G \qquad (1)$$

Where;

R_n is the net radiation (W/m^2), H is the sensible heat flux (W/m^2)
G is the soil heat flux (W/m^2), and L is the latent heat flux (w/m^2)

All terms in the equation (1) can represent positive or negative values. Negative sensible heat fluxes account for delivering energy to the roof surface and positive value account for removing energy from the roof structure. The latent heat flux represents the evapotranspiration rate of vegetation layer and soil substrate. Evapotranspiration rate can be directly measured by measuring the rate of water losses from a roof structure. Net radiation Rn and soil heat fluxes G however, can also be measured from experimental setup or calculated using related equations once the surface temperature of the plants and soil substrate are known.

However, measurements of the sensible heat flux are more complicated and not easily obtained. Most of the researchers measure convection heat flux through laboratory measurement of temperature gradients above the surface and all layers of experimental setup calculate H from the energy balance equation, if all other equation terms are known.

Evapotranspiration Heat Gain

In Plant Physiology, the evapotranspiration of plants–soil system is made up by the transpiration of plants and the evaporation from the soil. Evapotranspiration usually, needs solar radiation to complete their biochemical process. Based on the relevant theories in the field of Plant Physiology and Physical Chemistry, Tabares-Velasco and Srebric (2012) attempted to calculate the thermal effects of evaporation and respiration combined due to equations 2, 3 and 4:

$$Q\ evapotranspiration_{plant} = LAI\ (\rho.C_p / r_s + r_a)\ (e_{plant} - e_{air}) \quad (2)$$

$$Q\ evaporation_{soil} = (\rho.Cp / \gamma\ (r_{soil} + r_a)\ (e_{soil} - e_{air}) \quad (3)$$

$$QET = Q\ evapotranspiration_{plant} + Q\ evaporation_{soil} \quad (4)$$

Predecessor researchers applied the last equation on green roof to due to several changeable parameters such as climatic conditions, soil thickness, leaf area index and, soil moisture content.

In plantation evapotranspiration calculations, leaf area index LAI represents vegetation density. LAI is defined as leaf area per unit ground area. LAI is defines as LAI = S/2G, where S is the leaf area of the canopy standing on the ground area G. Since both of terms, S and G, are measured as areas (m2), LAI is dimensionless. Most commonly, S is measured as the projected area after placing a sample leaf on a horizontal surface. Another way of measuring LAI is by measuring the total surface area of leaves in a canopy.

On the other hand, ρ is the air density (kg/m^3), C_p is the heat capacity of the air (J/kg K), and aerodynamic resistance to heat transfer r_a (s/m) was calculated from wind speed and temperature difference between the leaf surfaces and surrounding air, whereas, r_s is the stomatal resistance of both sides of the leaves.

In soil evaporation calculation, ɣ is the psychometric constant (Pa/K) and e_{air} is the water vapor pressure in air. The e_{soil} (Pa) is the saturated water vapor pressure at surface temperature. The equivalent resistance r_{soil} (s/m) to vapor transfer combine the aerodynamic resistance to water transport--assumed to be equal to r_a the stomatal resistance of both sides of the leaves.

Convection Heat Flux

Tabares-Velasco and Srebric (2012) attempted to calculate the sensible heat flux as shown in equation (5):

$$Q\ \text{convective}_{\ plant} = 1.5\ \text{LAI}.\ h_{\ convective}\ (T_{plant} - T_{air}) \qquad (5)$$

Where, LAI is leaf area index, $h_{\ convective}$ is convective heat transfer of plant leaves. T_{plant} is the temperature at leaf and T_{air} is the air temperature (K).

On the other hand, and according to Tabares-Velasco and Srebric (2012), soil substrate convection can be calculated due to equation (6):

$$Q\ \text{convection}_{\ substrate} = h_{substrate}\ (T_{substrate} - T_{air}) \qquad (6)$$

Where, $h_{\ substrate}$ is convective heat transfer through soil substrate. $T_{substrate}$ is the soil temperature and T_{air} is the air temperature (K).

Conduction Heat Flux

The predecessor study (Tabares-Velasco and Srebric, 2012) attempted to calculate the conductive heat transfer through the green roof substrate through utilizing equations (7) and (8):

$$Qconduction = k_{substrate} (T_{top ;substrate} - T_{bottom; substrate})/L \qquad (7)$$

Where;

$K_{substrate}$ is the heat capacity of the soil layer and it can be calculated according to equation (8):

$$K_{substrate} = a_1 + a_2 * vwc \qquad (8)$$

Heat capacity of the soil layer is estimated from its gravimetric water content vwc and soil type density a_1 and a_2

$T_{top ;substrate}$ and $T_{bottom; substrate}$ are the temperature differences at the top and bottom of the substrate, L is the depth of the green roof assembly.

3.2.2 Software Simulation Method

A synced simulation method is utilized to calculate the conduction gain within the green roof assembly. Ventura (2010) stated that, simulation software is the best method to represent the results of the tested model for long period of time and they have the ability to reduce effort in terms of time and cost. Therefore, the researcher aims to find the most suitable software that offers a comprehensive thermal analysis data within the available resources.

Simulation is a modeling approach that was conducted to model the behavior of the examined elements. By utilizing simulation, the researcher created a model of a building that described some involved process such as climate conditions, thermal behavior or cooling loads. The mechanisms of the simulation model operated with varying degrees of accuracy. Although the components of the simulation are interconnected and have complex input-output relationships, the flow of entities through the system is controlled by logic rules that derive from the operating policies. The simulation process consists of problem definition, conceptual modeling, model verification, experimentation and analysis of results, and solution implementation. (Kumar, 2011)

The researcher decided to use the simulation methodology to conduct her study. The researcher took in mind the advantages of the simulation method listed in the table 3.1 as well as the following purposes:

1. Cost limitation

Conducting laboratory apparatus may consume undesirable expenses for the researcher.

2. Labor unavailability

   Dissertation research is an individual work, others participation is undesirable effort.

3. Time limitation

   Dissertation time line is limited to 8 months

4. Laboratory apparatus unavailability in BUID campus

5. Local field case studies rarity

Green roofed buildings are rare in UAE and to measure in site results time will be consume to try to get security passes.

Selecting Simulation Software

Building Information Modeling software (BIM) is directing the engineering and construction industry to futuristic technology. BIM offers a powerful tool in the form of a digital model. It provides a record for the whole life cycle of the buildings. It relates the architecture plans of buildings to their geographic data, manufacturer details, construction schedules, and fabrication processes.

Several BIM programs are available for energy performance purposes such as Ecotect, IES-VE, Energy Plus, and Design Builder. These programs are range from simple to more extensive and sophisticated ones. Most of them support 3D modeling and have the ability to import drawing from other drawing formats. They provide range of different application such as modeling, simulation, solar and lighting analysis, ventilation computations, heating and cooling loads and computational fluid dynamics (CFD) analysis.

In order to choose between the two simulations programs offered by the university Ecotect and IES-VE, the researcher had to research and compare between their capabilities and their ability to match dissertation topic demands.

Figure 3.1 summarizes Attia et al., (2009) survey results; it demonstrated a comparison between Ecotect, IES-VE and eight different energy analysis programs.

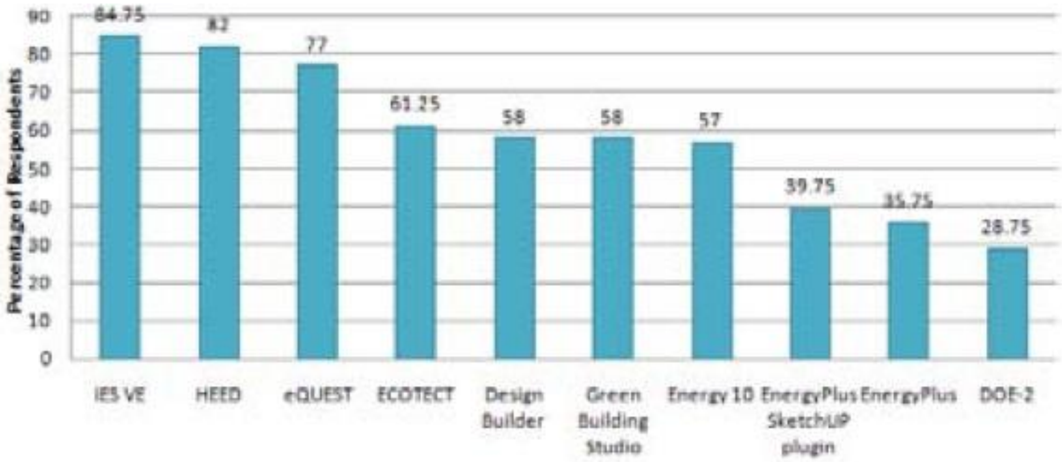


Figure 3.1: Comparison between ten energy simulation programs (Attia et al., 2009)

Figure 3.1 showed that about 85 per cent of the survey respondents preferred IES-VE for the following justifications:

1. Easy to learn
2. User friendly interface application
3. Significant thermal performance analysis results
4. Involvement in different design phases
5. Graphical representation of output results
6. Flexible use and navigation
7. Easy follow up structure
8. Creation of comparative reports for multiple alternatives

9. Quality control of simulation input

10. Allowing assumptions and default values

11. Provide guidelines for building codes

12. Provide case studies data base for decision making

13. Allow examining sensitivity and uncertainty of key design parameters

14. Embrace overall design during most design stage

Ecotect on the other hand, scored 61 per cent due to these respondents' reasons:

1. Inconvenience due to the complexity of integration the tools with the architectural design process

2. Rigidity in facilitating the design process moving from conceptual to detailed design

3. Lack in the comprehensiveness, Ecotect should always be used with at least one or more other tool.

Based on the previous results the researcher decided to use the IES-VE software to analyze the case study building thermally.

IES-VE Simulation Software

The related software is a BIM application presented by the Integrated Environmental solutions. It is a 3D modeling software that offers thermal analysis, airflow analysis, HVAC computation, lighting and occupant comfort calculation tools.

3D drawings can be easily imported from other CAD format by utilizing gbXML. Site location and weather data can be assigned from the Apache Locate. Different materials of construction elements can be selected from Apache construction database. Apache Systems however, simulates HVAC systems.

IES-VE has the ability to deal with several complex variables instantaneously; it offers detailed reports for the cooling and heating loads, lighting loads, internal temperature and CO_2 emissions for every thermal zone. IES-VE relates climatic conditions as well to the studied model results and provides comparative reports for both of them.

IES-VE software overview

IES-VE is a simulation program that dynamically measure buildings thermal loads, energy and CO_2 emissions. Moreover, IES-VE is used to analyze building envelope temperature, humidity, outer surface solar radiation, heat gain, convection and conduction gain. IES-VE usually uses two input files to run the simulation: weather data file and building parameters file.

IES-VE input file

The Input Data File (IDF) includes geometry of buildings, their construction materials, glazing properties and, HVAC systems. Apache construction database is a library that contains different kind of construction materials for:

walls, roofs, doors and glazing. HVAC systems however, can be modeled using HVAC Apache.

IES-VE weather data file

IES uses a weather data file, which is based on Typical Meteorological weather data. The weather data provides values of direct radiation, diffuse radiation, dry bulb temperature, dew point, relative humidity, and wind speed.

Software Validation

Most of the researchers that coupled their measurement based research with simulation programs validated their software before relying on it by checking their simulated results with exited real time results. Theodosiou (2003) for instance used real data taken from an existing construction in the Mediterranean area for validation purposes. Moreover, Kotsiris et al. (2012) developed model for a building in their simulation program and calculated its cooling load and compared them to the actual building cooling load in Greece.

Nevertheless, Sailor (2008) validated his program by integrating model of the energy balance of green roof structure in energy simulation program and calculated several variables. These variables then were compared to data that been collected from field measurement of real time building in Florida.

In this paper, the researcher will adapt similar validation approach to Kotsiris et al. (2012), where she's going to construct a model actually exited in Sharjah into the simulation program and calculate its annual cooling load. This resulted cooling load will be compared to the real time electricity bill which will be collected from Sharjah Authority of Electricity and Water in order to gain confidence in the simulation program capability.

3.3 United Arab Emirates

The United Arab Emirates is located at Southwest Asia. It is one of sixth Arabian states on the Arabian Gulf. It oversees Gulf of Oman at the east and the Arabain Gulf at the west. UAE shares borders with Oman, Qatar and Saudi Arabia. UAE lies between 22°50′ and 26° north latitude and between 51° and 56°25′ east longitude. It has area of approximately 83,600 square kilometers.

UAE is consists of 7 emirates: Abu Dhabi, Dubai, Sharjah, Ras AlKhaima, Umm Al Quwain, Ajman, and Al Fujairah. 87 percent of the UAE's total area belongs to emirate of Abu Dhabi 67,340 Km2. The smallest emirate, Ajman, covers 259 Km2 approximately.

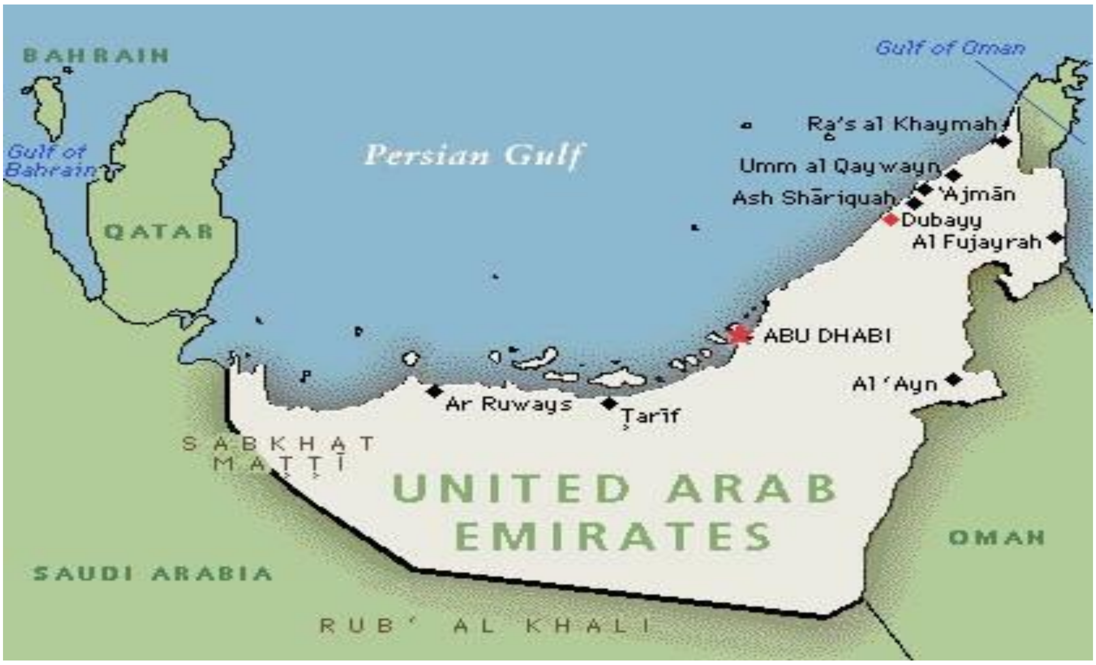


Figure 3.2: United Arab Emirates geographical location (world Atlas, 2013)

Dubai is the second largest Emirate in UAE; it is located on the western coast of UAE over an area of 3,900 km2. Due to the commercial growth of Dubai in since the last decade, Dubai population is continuously growing and it reaches more than two million people at 2012 (Dubai Statistics web site, 2012).

Sharjah however, is the third largest emirates of UAE. It is the only emirates that have land on both the Arabian Gulf Coast and the Gulf of Oman. Sharjah covers an area of 2,600 Km2 and it has more than 950,000 residents (Sharjah commerce and tourism development authority, 2012).

Generally, UAE climate is hot and arid however and, due to tropic of cancer passing through south, UAE climate exposes to high temperature and high humidity rates during months of June, July and August.

3.3.1 Climatic Analysis

Temperature

Winter seasons are relatively cool in UAE. They extended between December and March and they considered as most comfortable climatic conditions throughout the year. The coldest month is January with an average minimum of 13.7 °C (Dubai weather tool). Summers on the other hand, in UAE are hot and arid with maximum 42 °C on August.

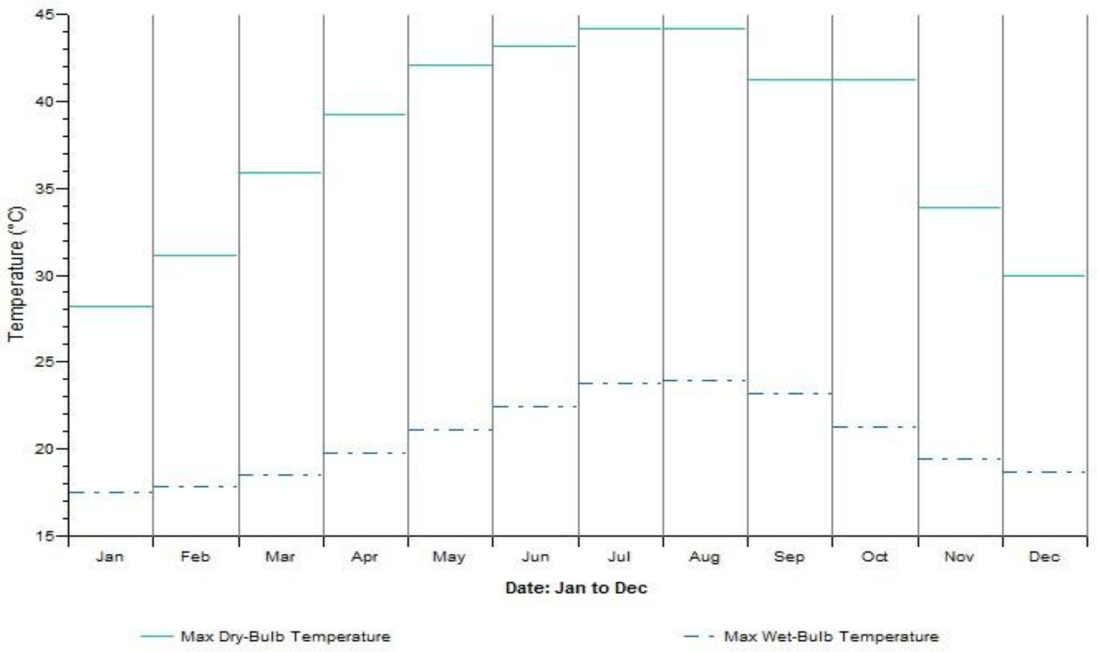


Figure 3.3: Dubai annual dry temperature (Weather tool, 2010)

Relative humidity

Humidity in UAE is acceptable most of the year days; however at the middle of June to the beginning of September, the weather reaches uncomfortable level due to high level of humidity. Figure 2.7 illustrates all year relative humidity in Dubai.

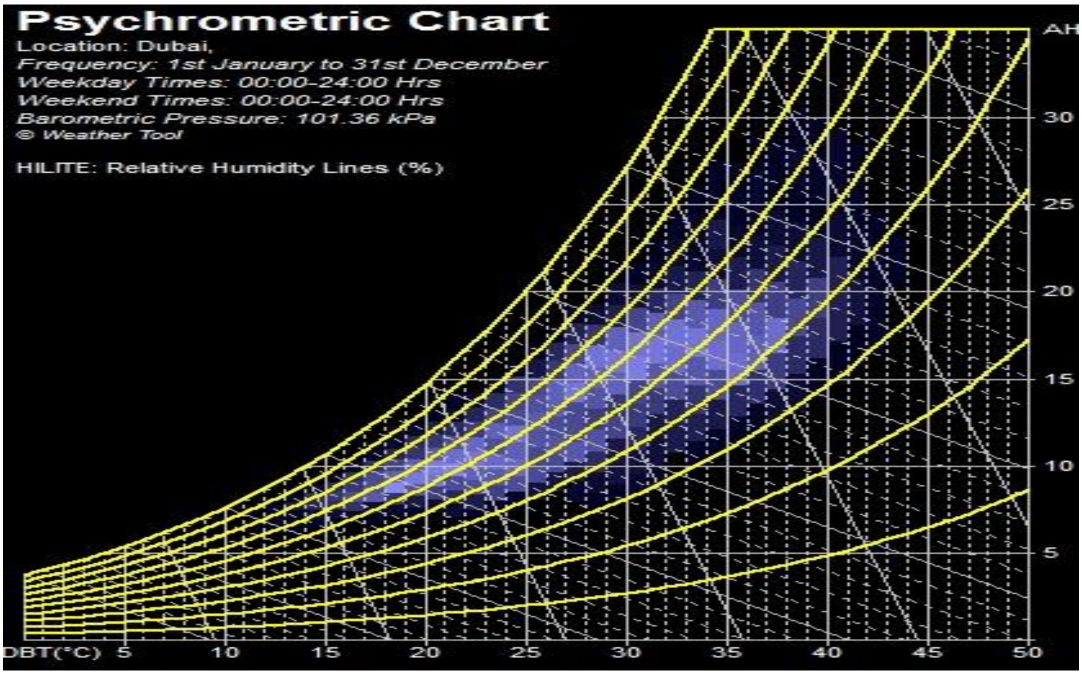


Figure 3.4: Annual relative humidity (Ecotect weather tool, 2009)

Precipitation

The weather in Dubai and Sharjah bring short and irregular rainfall as is typical for the Arabian Gulf countries. Most of the rainfall in occurs between December and March. According to Abu Dhabi meteorological station (2009); rain fall is very rare however, in some individual days precipitation can reaches 54.6 mm.

Solar radiation

According to Abu Dhabi meteorological station (2009), typical annual direct solar radiation varies from 700 to 950 (W/m^2).

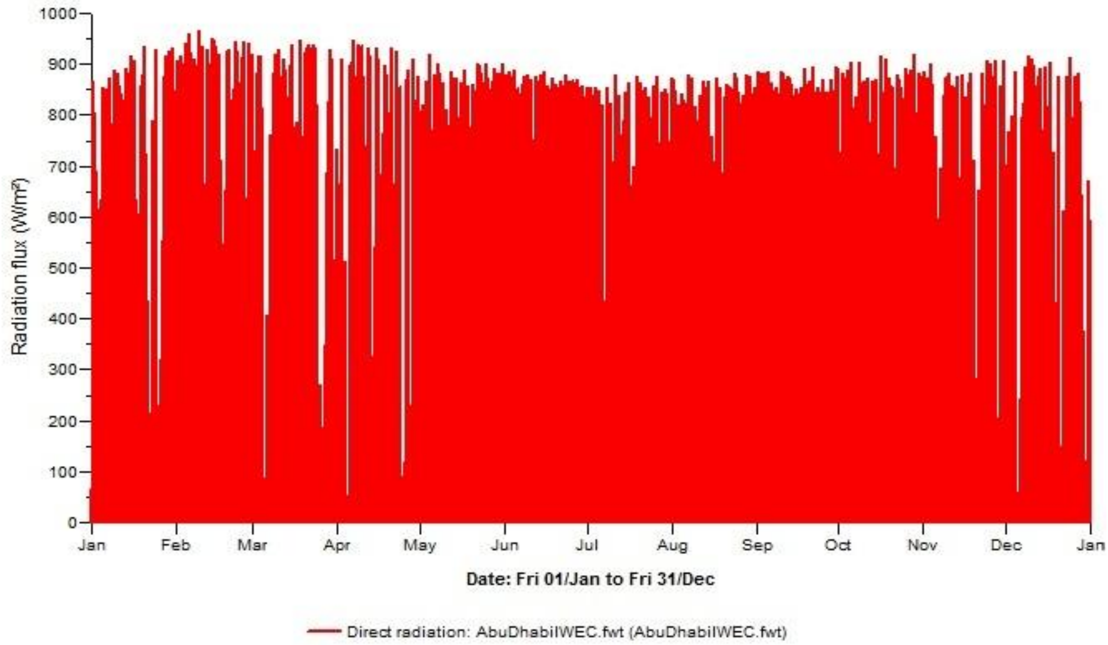


Figure 3.5: Annual solar radiation (IES weather data, 2010)

3.4 Validation Model

Architectural plans were used to construct the model in the simulation program. The tested model is a multi-storey building with total area of 350 m2 and total height of 6.3 meters.

3.4.1 Validation Model Design Parameters

Materiality

The buildup of the building case model is based on Sharjah building code issued by Sharjah Municipality due to the 1980-2002 periods. Using this materiality allows the building to matches the real time specification of the tested building. Table 3.2 listed the materials used for the model according to Sharjah specifications.Specification below are the materials that been selected according to Sharjah building code and available from the IES-VE construction database library.

Table 3.2: Validation building's simulation materials

Construction	IES ID	Description	ASHRAE U-Value
Roof	FROOF2	Flat roof	1.0212
Ground/Exposed Floor	STD_FL01	Floor construction	0.0713
1St Floor	STD_FL02	Floor construction	0.4338
External Wall	W25	Concrete wall	1.1322
Glazing	LWDB000	Clear glazing	6.5160

All the materials are matching real time building model to have fair results to compare to. Thermal conditions that been selected matched the real building ones as well. The main cooling systems were set to split systems with cooling plant radiant fraction equal to 0.20, 0.8 L/s.m^2 minimum outside flow and 0.5 ach additional cooling flow. Internal gains are assigned to people, miscellaneous and fluorescent lambs. Air exchange however, was set to infiltration and auxiliary ventilation.

<u>Simulation</u>

The simulation program is undergone to simulate the energy performance of the building. The model will be tested for a whole year to measure the cooling load for each month due to the following climatic conditions. The following figures demonstrate the climatic conditions due to UAE climate.

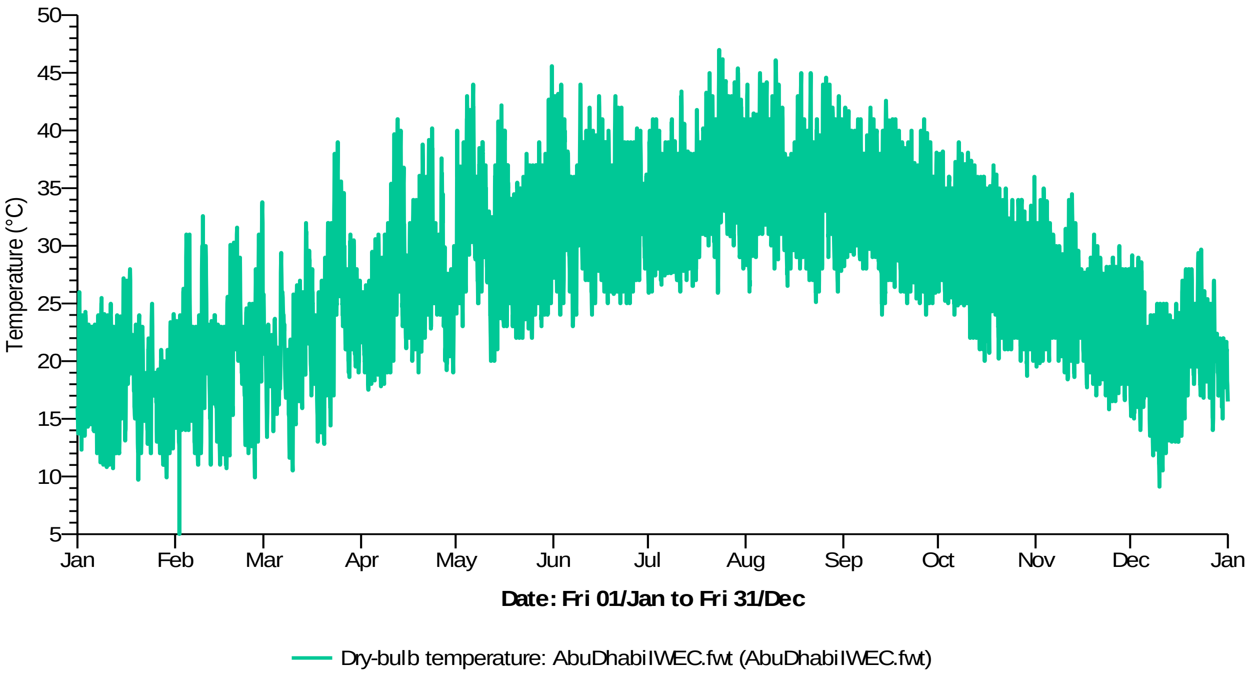


Figure 3.6: Annual ambient air temperature

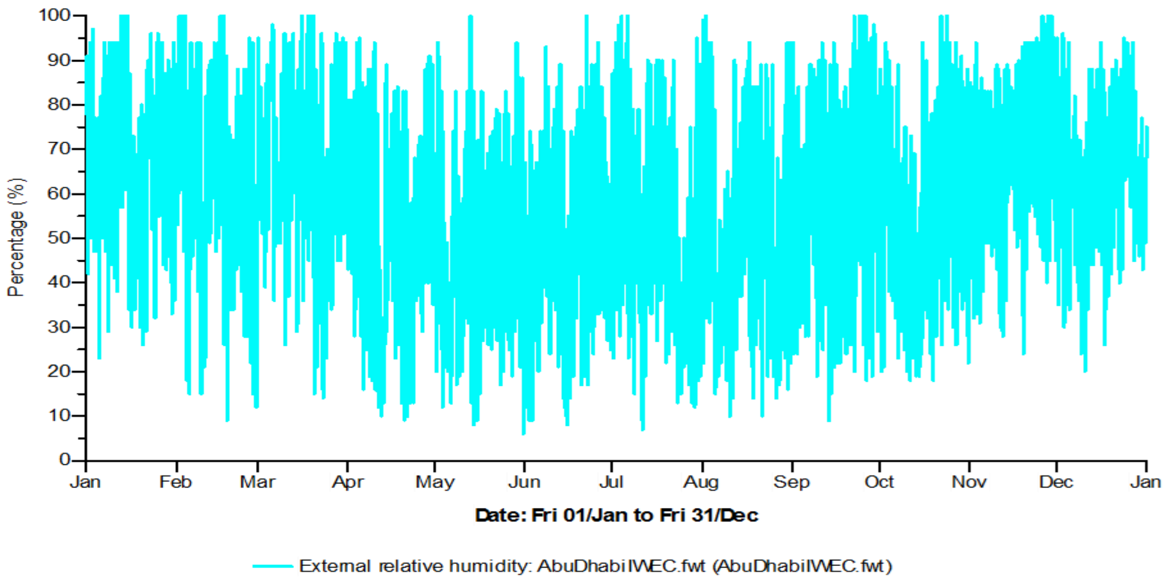


Figure 3.7: Annual relative humidity

Where; dry bulb temperature refers to the ambient air temperature measured with thermometer and, relative humidity refers to the amount of vapor content in the air. Reading the graphs, temperature profile indicates that, temperature reaches high magnitudes in summer time around 46 °C and drops to 11° C in winter. Relative humidity profile on the other hand, shows high values of humidity through most of the year months.

Figure 3.5 below presents the a basic matrix of the simulation and describes the input and output of the energy simulation program

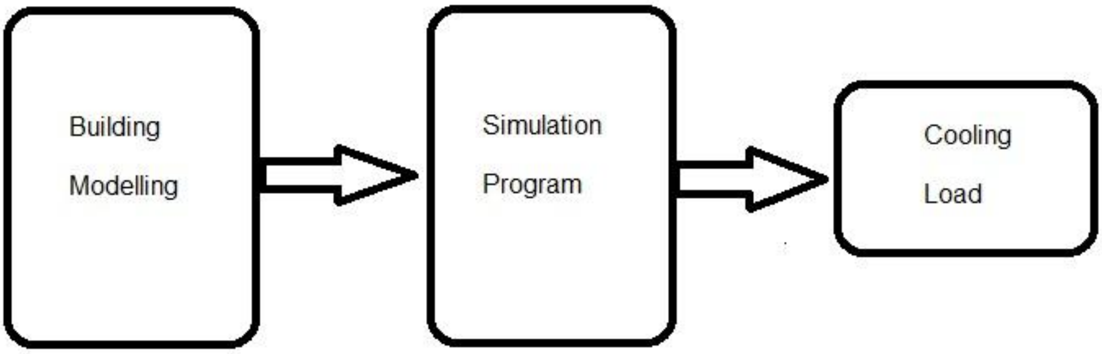


Figure 3.8: Simulation matrix

Subsequently to simulation running, results are compared to the real time electricity bill to identify the capability of the program.

3.4.2 Software Validation

Overview

In order to test the IES-VE simulation software; a basic validation is conducted to verify energy consumption measured by IES-VE against the tested villa model real electricity consumption bill. The validation aims to test the capability of ies to generate resemble results to the tested actual energy consumption model. In addition to; enhance the confidence of the researcher to utilize the software to conduct the research.

To validate the ies software; the researcher selected familiar domestic house where she has an access to its annually electricity bill and she's familiar with the occupants thermal behaviors. The tested model has two stories with a total area of 350 m2 and total height of 6.3 meters. The building is located in Sharjah and it was constructed at the beginning of 1995 and occupied after 3 years. The villa glazing and external cladding were refurbished at year 2005 and all mechanical cooling systems were updated to spilt air conditioning system.

Figure 3.9: The validation building image

Building Model

The model was constructed using the model builder in IES-VE to avoid the complexity of shifting the initial drawings from AutoCAD to IES-VE as well as to differentiate rooms from other objects such as shading devices.

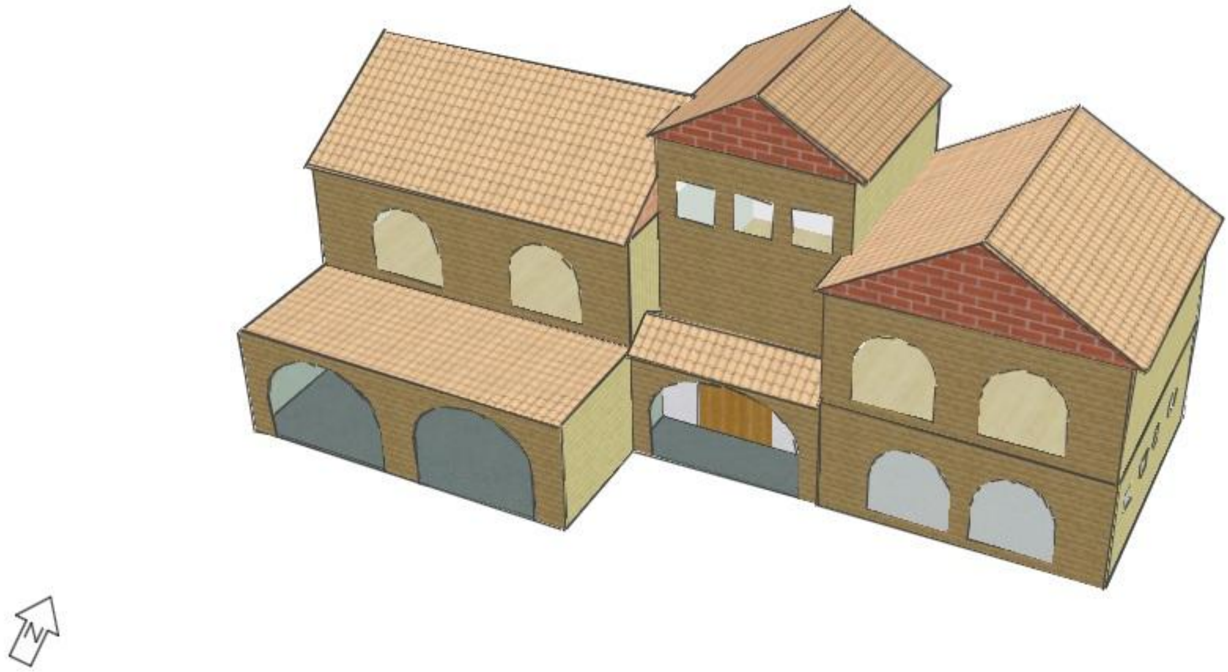


Figure 3.10: The validation building IES-VE model

To set the weather data to UAE climate; APLocate tab were used. APLocate uses Ashrae as design weather source according to the available Dubai airport weather data.

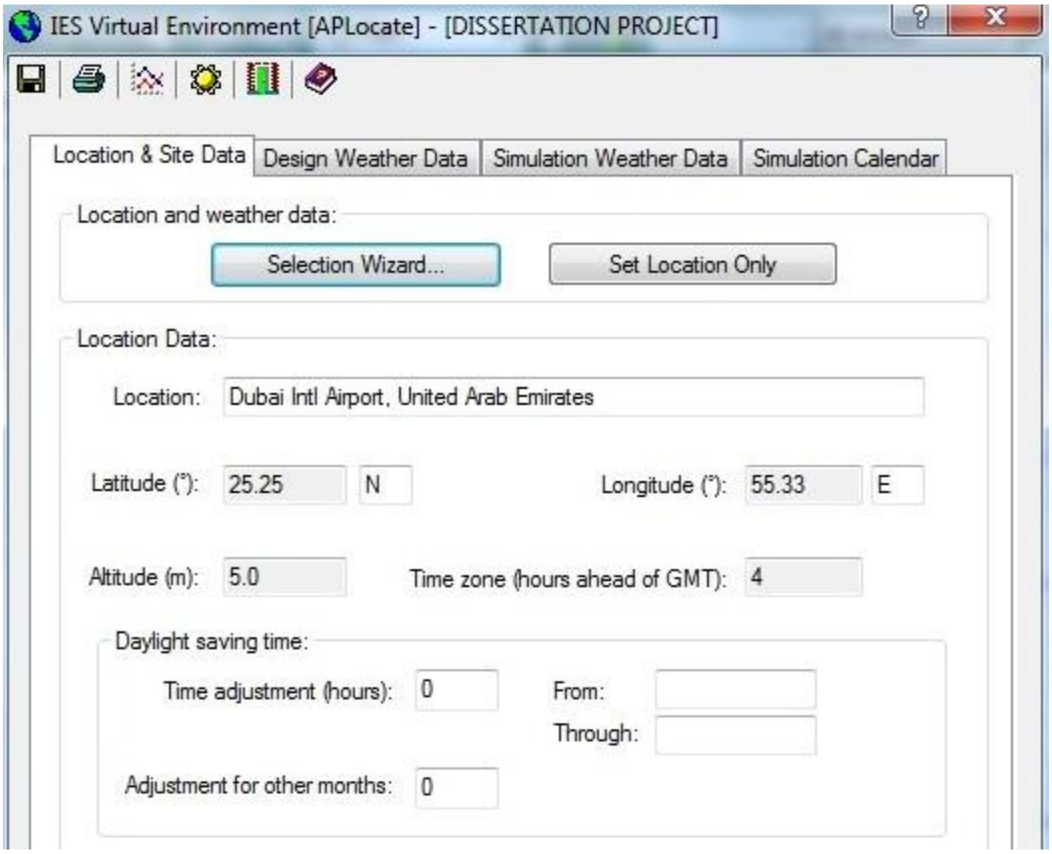
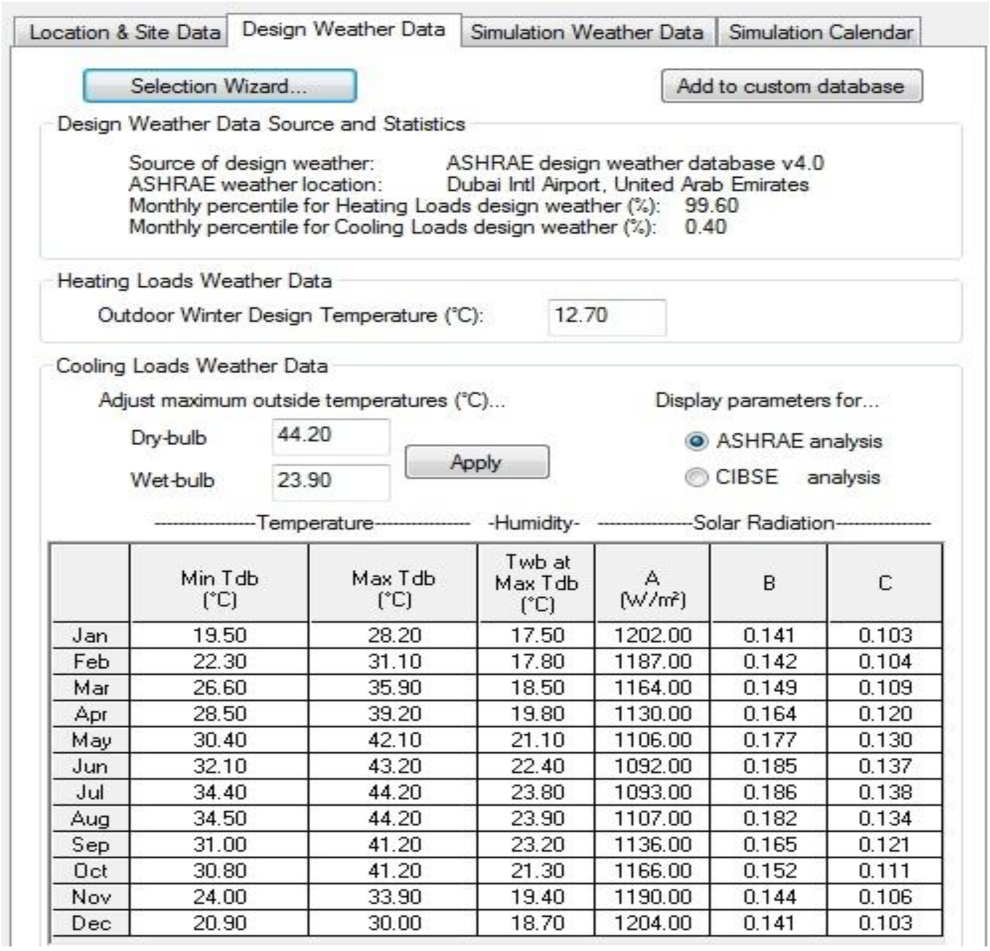


Figure 3.11: IES-VE APLocate tab

Weather Data

IES uses a weather data file, which is based on Typical Meteorological weather data. It is part of the APlocate module and its provide values of direct radiation, diffuse radiation, dry bulb temperature, dew point, relative humidity, and wind speed.



	Min Tdb (°C)	Max Tdb (°C)	Twb at Max Tdb (°C)	A (W/m²)	B	C
Jan	19.50	28.20	17.50	1202.00	0.141	0.103
Feb	22.30	31.10	17.80	1187.00	0.142	0.104
Mar	26.60	35.90	18.50	1164.00	0.149	0.109
Apr	28.50	39.20	19.80	1130.00	0.164	0.120
May	30.40	42.10	21.10	1106.00	0.177	0.130
Jun	32.10	43.20	22.40	1092.00	0.185	0.137
Jul	34.40	44.20	23.80	1093.00	0.186	0.138
Aug	34.50	44.20	23.90	1107.00	0.182	0.134
Sep	31.00	41.20	23.20	1136.00	0.165	0.121
Oct	30.80	41.20	21.30	1166.00	0.152	0.111
Nov	24.00	33.90	19.40	1190.00	0.144	0.106
Dec	20.90	30.00	18.70	1204.00	0.141	0.103

Figure 3.12: Weather data tab

To determine the occupational profiles for each thermal zone (rooms-rest rooms-halls-kitchen); thermal conditions were assigned from the building template manager tab as well according to the configuration shown in figure 3.10. The main cooling systems were set to split systems with cooling plant radiant fraction equal to 0.20, 0.8 L/s.m^2 minimum outside flow and 0.5 ach additional cooling flow. Internal gains are assigned to people, miscellaneous and fluorescent lambs. Air exchange however, was set to infiltration and auxiliary ventilation.

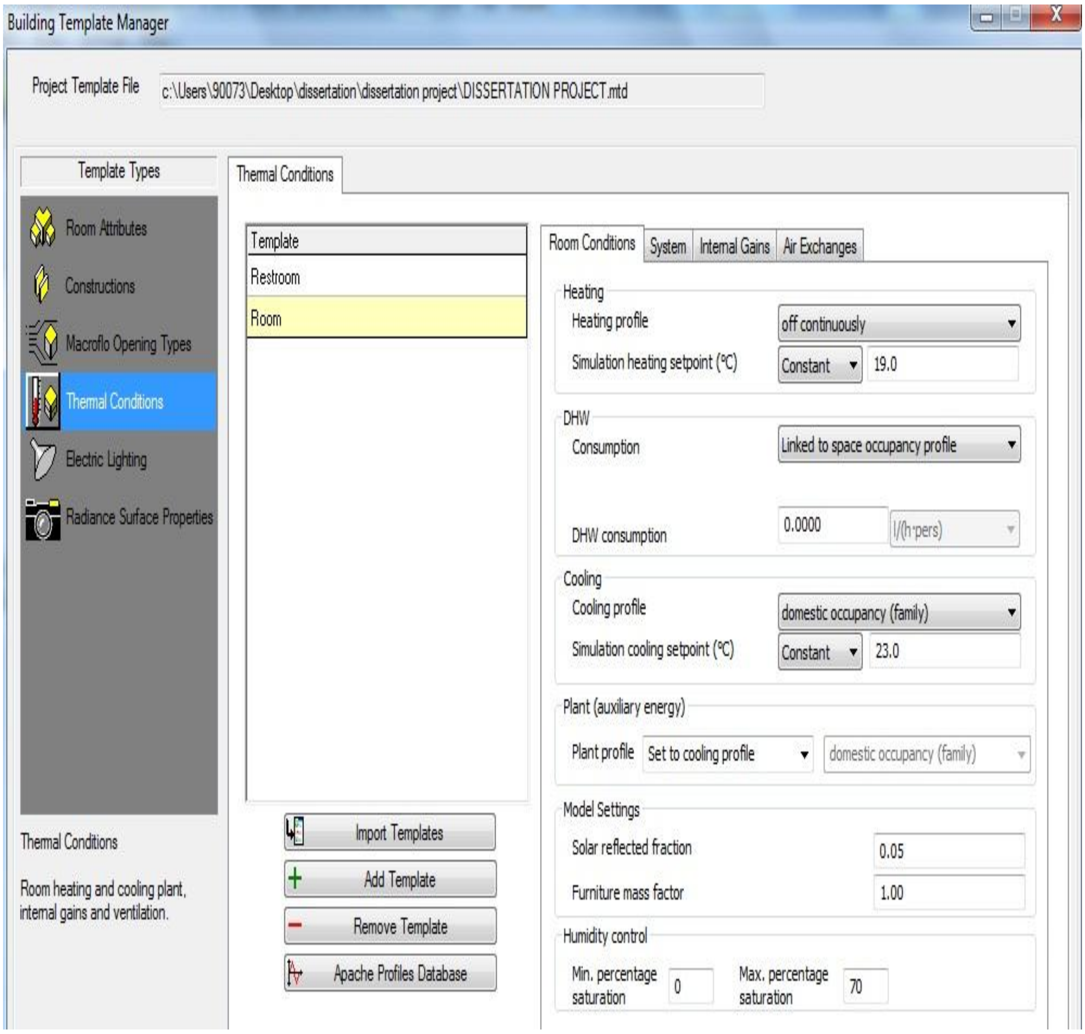


Figure 3.13: Thermal conditions of the thermal zones

SunCast is then utilized to simulate the solar shading analysis. Accordingly, Apache thermal module is activated to calculate the annual energy consumption. Annual energy consumption option is selected from Apache simulation where the sun cast analysis is taken under consideration.

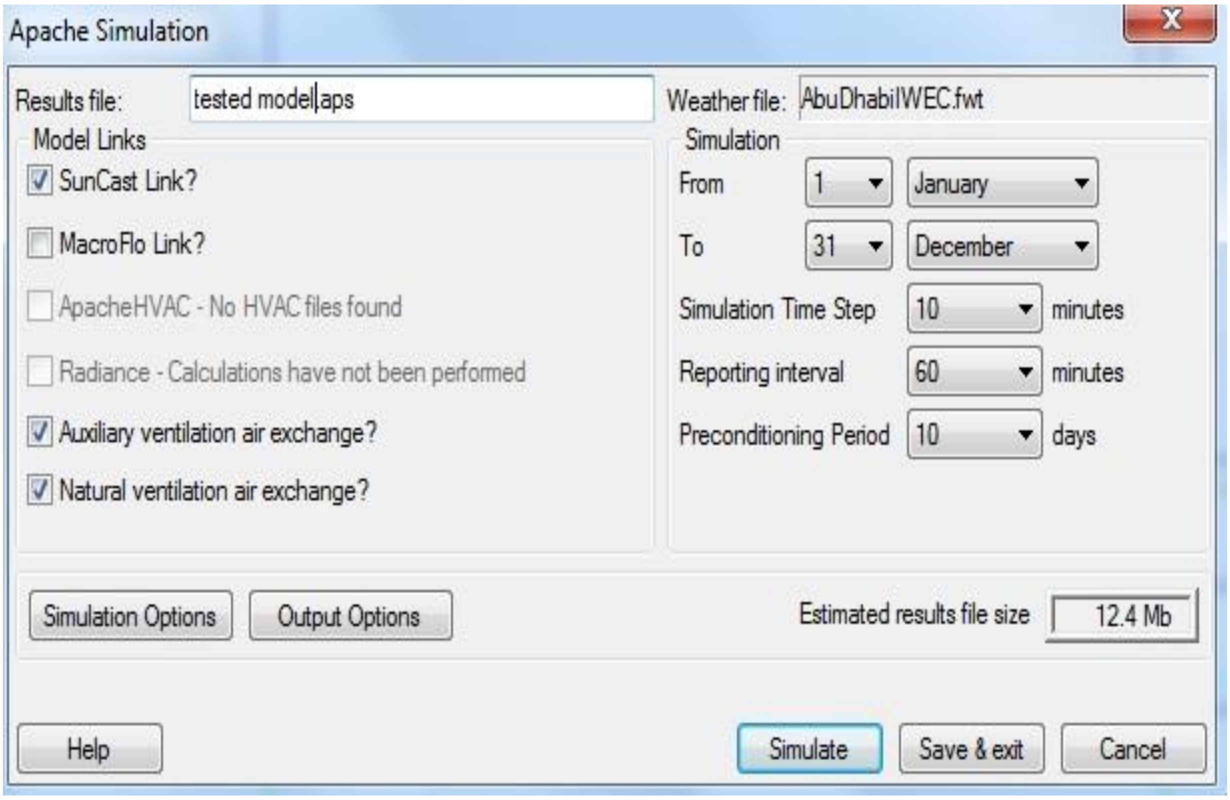


Figure 3.14: ApacheSim module tab

Data Comparison

Real time electricity consumption bill for validation model for a whole year was collected form Sharjah Electricity and Water Authority (found in appendix A) and was compared to IES-VE simulated energy consumption in Table 3.3. Observations from table 3.3 and Figure 3.12 show that, actual and ies simulate energy consumption are almost identical in most cases and follow the same trend. However, there is a substantial differences in January, April and August where simulated electricity where more than the actual usage. This could be accounted for the different occupational patterns due to schools vacation days where some of the occupants tend to travel abroad.

Table 3.3: Validation model results

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

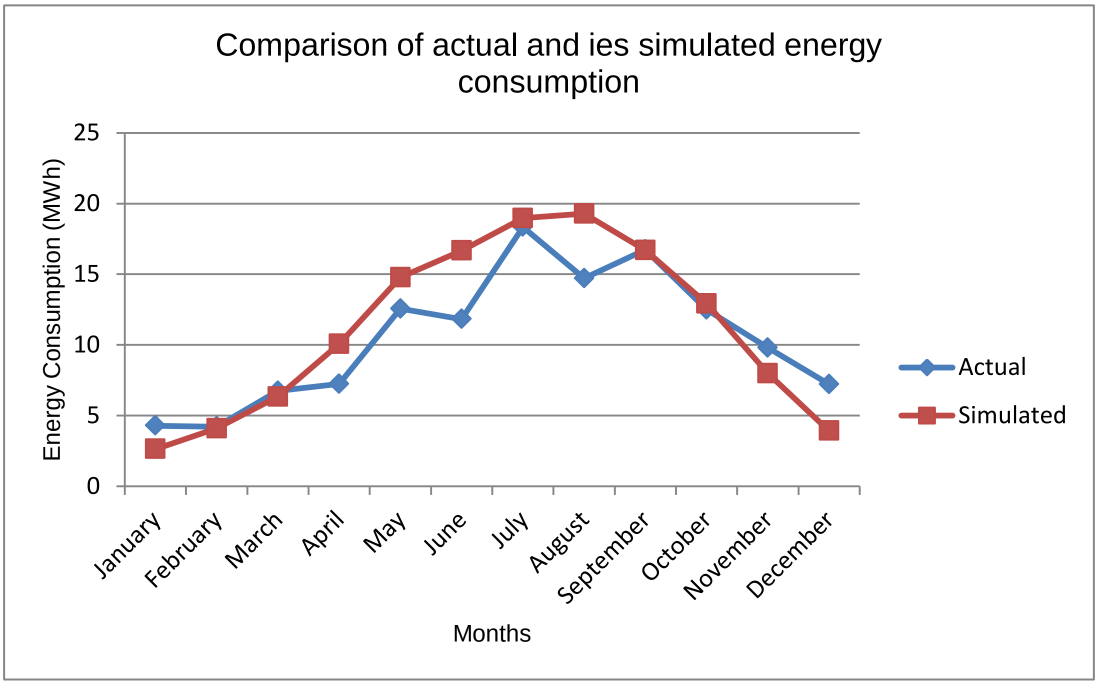


Figure 3.15: Comparison of tested villa actual and simulated energy consumption

CHAPTER FOUR:

SIMULATION AND DISCUSSION

4.1 Simulation

The dissertation researcher decided to investigate different residential building than the one used in the validation simulation one due to the fact that; on the contrary to the validation house, this two story house have flat roof which ensures the homogeneity of heat flux transfer through roof surface.

Investigated Villa Review

The investigated model is a domestic house in Sharjah (architectural plans are found in Appendix B). It has two non-uniform stories with a total area of 360.45 m2 and total height of 7.0 meters. Two small roof terraces are presented at the first floor with areas of 26.25 m2 and 38 m2 respectively. Walls are constructed from 20 cm^2 concrete blocks, 1.5 cm sand-aggregate plaster and 2 cm emulsion finishes. Glazed windows are made of clear float glass. Roof however, is covered with typical white screed. This model was selected as a representative of the residential houses because it represents a typical domestic house in Sharjah and the location of the house is nearby the researcher residence thus visual site visits are facilitated.

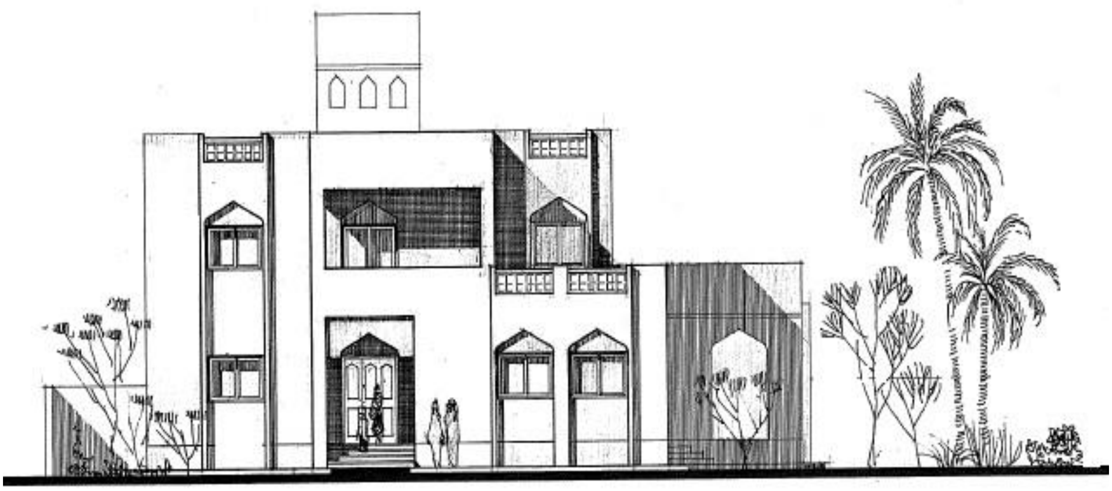


Figure 4.1: Front elevation of the villa

Figure 4.2: First and second floors plan

Building Model

The model is constructed using the model builder in IES-VE in order to avoid the complexity of shifting the drawings from other format and to ensure that all the involved rooms are differentiate properly to thermal zones.

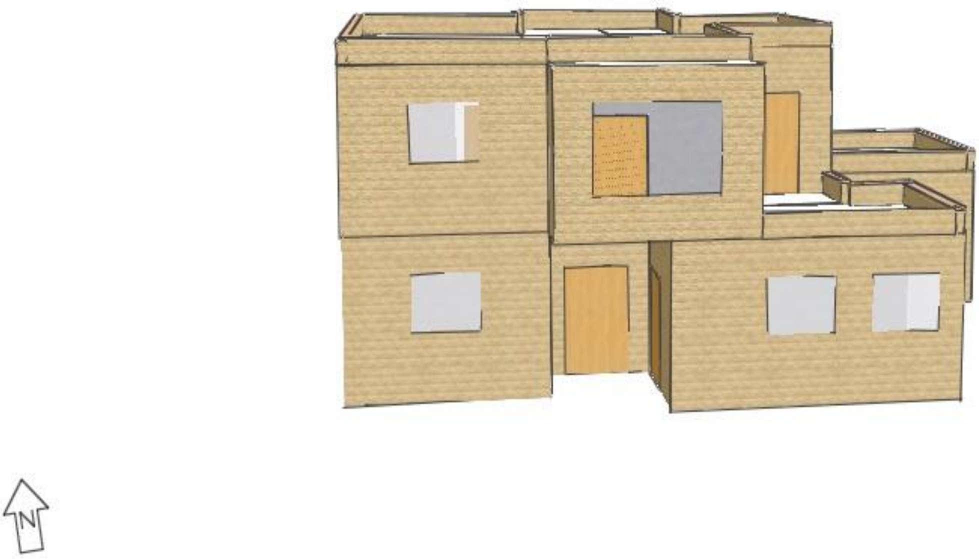


Figure 4.3: Simulated IES-VE model

The weather location settings were selected from the APLocate tab which includes weather data according to ASHRAE weather library. Basically, Dubai weather data was the best choice for Sharjah's climate since Dubai and Sharjah are two adjacent emirates.

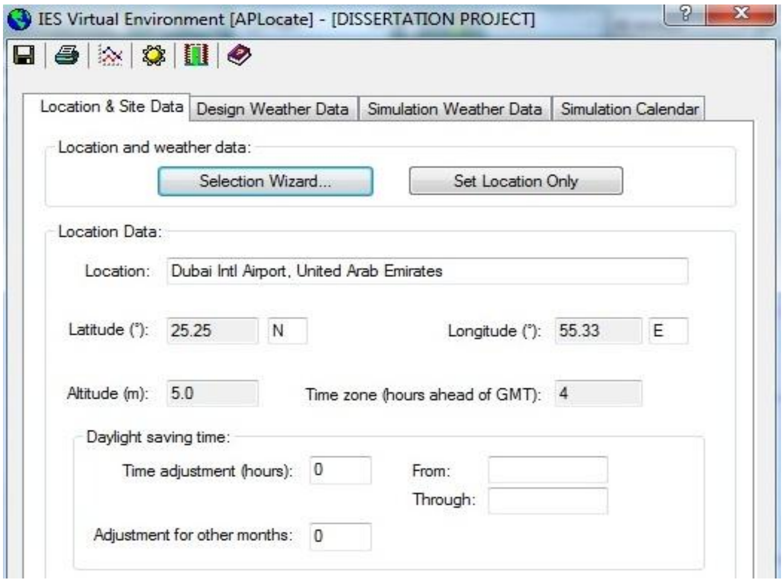


Figure 4.4: APLocate tab

Construction materials then were assigned from the building template manager library to materialize building's roof, walls and, glazing.

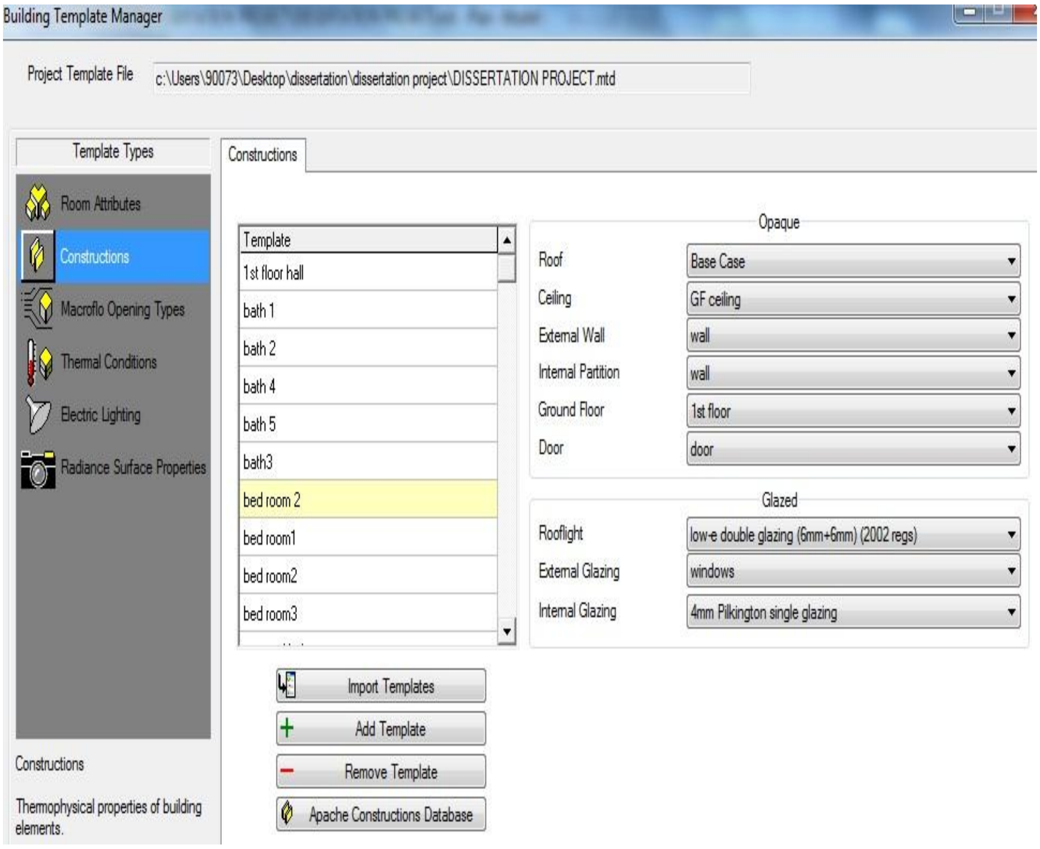


Figure 4.5: Building template manager tab

Where, Roof, walls and glazing construction materials were assigned in Apache construction database according to the configurations shown in Tables 4.1 and 4.2 respectively.

Table 4.1: Bare roof configuration (Sharjah building code, 1980-2002)

Element	**Materials description**	**Conductivity W/m.K**	**Density Kg/m3**	**Specific heat capacity J/Kg.K**	**U-Value (ASHRAE)**
	Screed	0.4100	1200	840	
	Bitumen layer	0.5000	1700	1000	
Roof	Cast concrete (Dense)	1.4000	2100	840	
	Plaster (Dense)	0.5000	1300	1000	1.0212
	Stucco	1.3521	2659	837	

Table 4.2: Buildings materials configuration (Sharjah's building code)

Element		Materials description	Conductivity W/m.K	Density Kg/m3	Specific heat capacity J/Kg.K	Element U-Value (ASHRAE)
External walls		Stucco	0.7210	2659	837	1.1322
		Cement Plaster-sand aggregate	0.7200	1860	800	
		Concrete Block (heavy weight)	1.6300	2300	1000	
		Cement Plaster-sand aggregate	0.7200	1860	800	
		Stucco	0.7210	2659	837	
		Cast Concrete	1.400	2100	840	
		Plaster (Dense)	0.500	1300	1000	
Flooring	Ground Floor	Synthetic Carpet	0.0600	160	2500	0.0713
		Slate Tiles	2.000	2700	753	
		Cement Plaster-sand aggregate	0.7200	1860	800	
		Cast Concrete (Dense)	1.400	2100	840	
		Gravel Based Soil	0.5200	2050	184	
	First Floor	Synthetic Carpet	0.0600	160	2500	0.4338
		Slate Tiles	2.000	2700	753	
		Cement Sand aggregate	0.7200	1860	800	
		Cast Concrete (Dense)	1.400	2100	840	
		Plaster (Dense)	0.500	1300	1000	
		Stucco	1.3521	2659	837	
Doors		ALUMINIUM	160	2800.0	896.0	6.6692
Glazing		Single glass	SHGC 0.8428		shading coefficient 0.9687	6.5160

To determine the occupational profiles for each thermal zone (rooms-rest rooms-halls-kitchen); thermal conditions were assigned from the building template manager tab as well according to the configuration shown in figure 4.12. The main cooling systems were set to split systems with cooling plant radiant fraction equal to 0.20, 0.8 L/s.m^2 minimum outside flow and 0.5 ach additional cooling flow. Internal gains are assigned to people, miscellaneous and fluorescent lambs. Air exchange however, was set to infiltration and auxiliary ventilation.

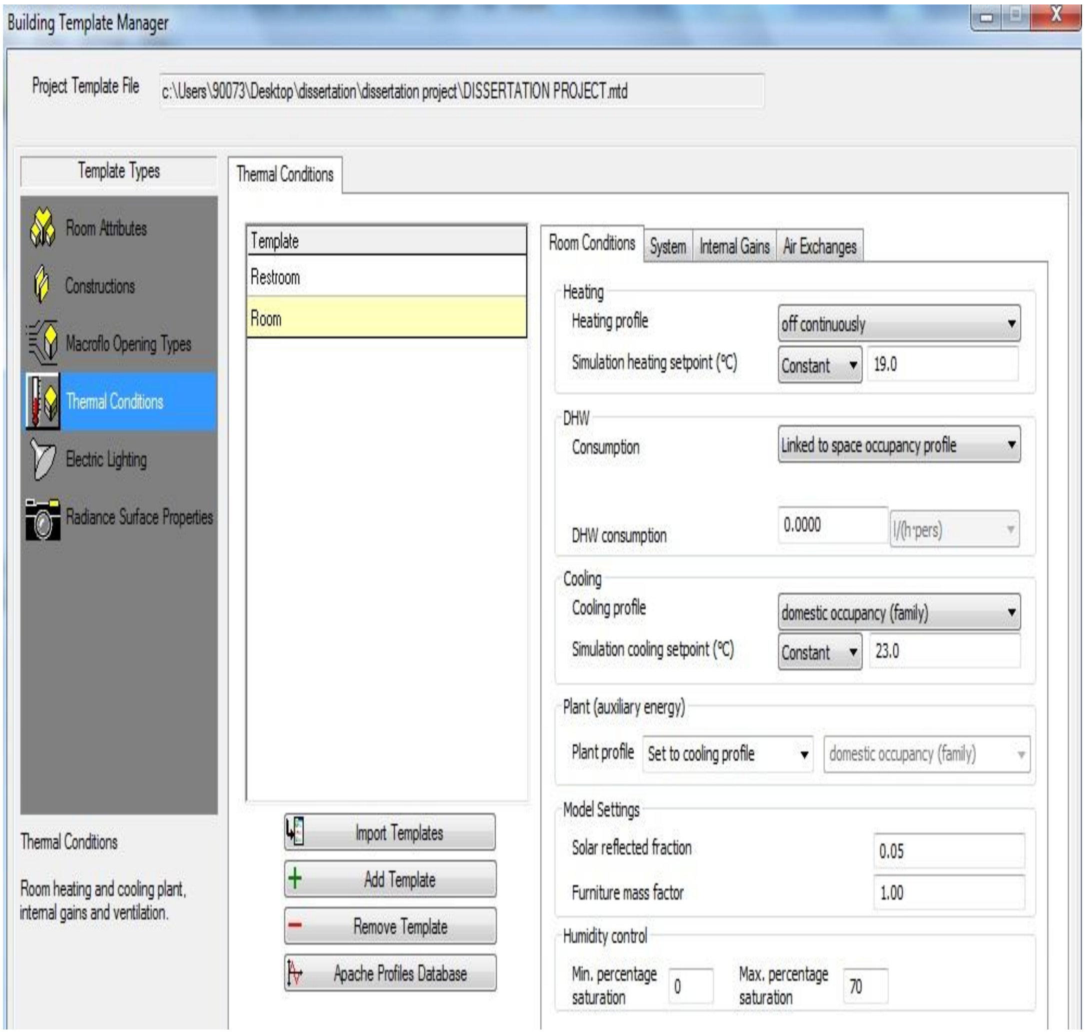


Figure 4.6: Thermal conditions of the thermal zones

Moreover, solar SunCast module were selected to analyze the shading effect resulted from the balcony on the adjacent and beneath rooms and from the second floor on the beneath floor rooms. SunCast module also analyzes the net radiation that reaches surface of the roof which will be used later in the calculations part. In order to activate the ApacheSim module; SunCast analysis is required as well.

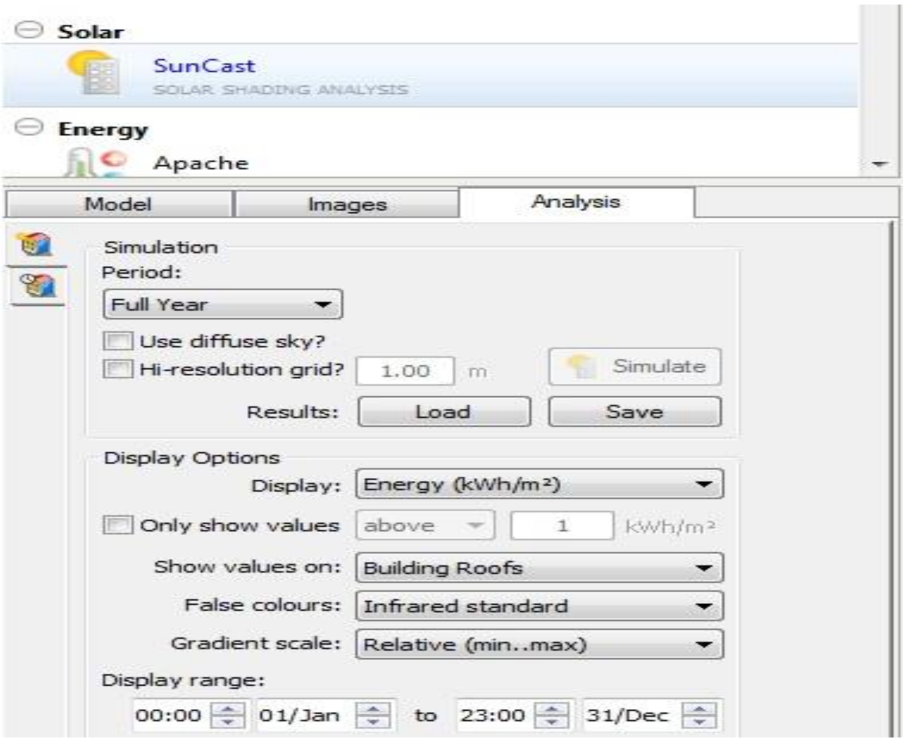


Figure 4.7: Solar SunCast tab

ApacheSim calculation then incorporated to calculate the annual cooling load of the simulated house according to the following simulation assumption:

1. External convection model was calculate due to ASHARE simple
2. Internal convection model was calculate due to CIBSE fixed values
3. Sky and ground long wave radiation model due to CIBSE
4. Internal Air emissivity model was on
5. Solar radiation model due to anisotropic
6. Initial temperature due to 18.0 °C
7. Simulations period took place from 1st of January to 31 of December
8. Simulation reporting took place at every hour

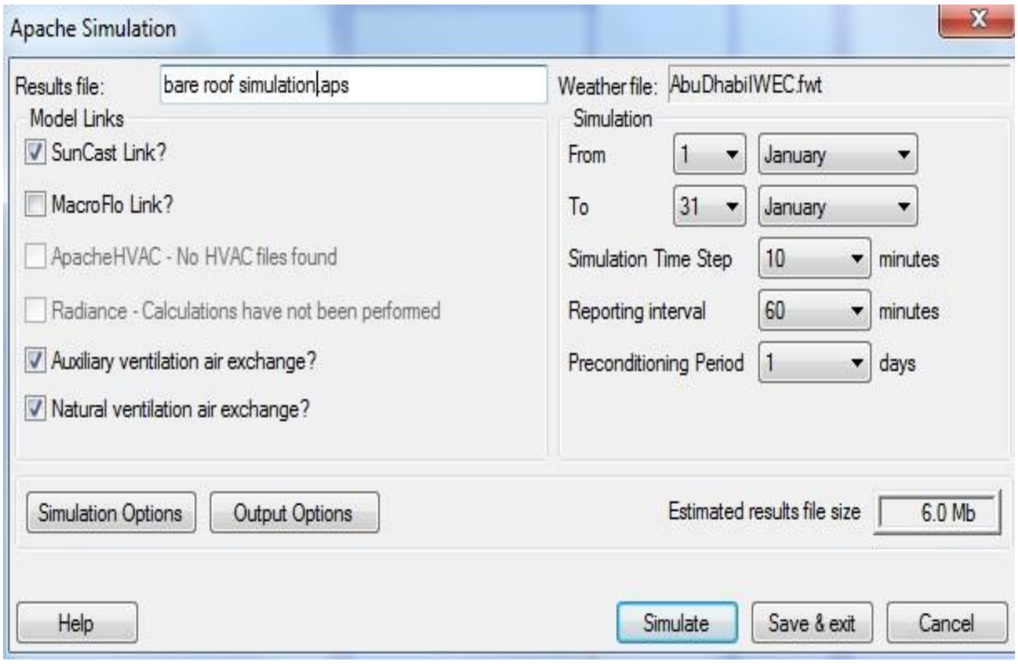


Figure 4.8: ApacheSim tab

Similar to bare roof model, green roof structure was assigned in Apache construction database due to the configuration shown in Table 4.3. Density, Conductivity and Specific heat values are based on Sailor et al., (2008).

4.3: Green roof configuration (Sailor et al., 2008):

Green roof layers	Thickness (cm)	Density (kg/m^3)	Specific heat (J/(kg.K))	Thermal conductivity (W/(m.K))
	9 Sand and pumice (5% moisture content)	1020	1093	170
	9 Sand and pumice (15% moisture content)	1020	1181	280
Soil	9 Sand and pumice (25% moisture content)	1020	1356	450
	9 Sand and pumice (30% moisture content)	1420	1259	570
Drainage	0.108	25	1200	0.15
Waterproofing sheet	0.01	1200	1470	0.17

In order to investigate the potential energy savings corresponding to green roof; the conduction gain and cooling load of the green roof assembly were calculated according to four parameters.

Four different scenarios were developed to examine the theoretical concept of the dissertation. The modules were investigated through altering four parameters:

1. Effect of seasons (winter and, summer)
2. Soil substrate thickness
3. Leaf area index LAI
4. Soil moisture content

During the simulation part of the study, the researcher found that, the IES-VE capability to break down the net radiation through the green roof structure is limited to conduction gain by the insulation ability of the green roof whereas, IES-VE is unable to calculate the evapotranspiration and convection gains. Therefore, the researcher used Tabares-Velasco and Srebric (2012) experiment data and built on it.

4.1.1 Parameter 1 (Effect of Seasons):

This parameter was tested to investigate the effect of the season meteorological conditions on the performance of the green roof assembly.

The conduction gain and cooling load of the investigated villa is simulated due to three representative days; 24 January and 13 August that represent two seasons winter and, summer respectively. These days were selected according to the temperature data that were available from Tabares-Velasco and Srebric (2012) experiment. The researcher used the temperature values at the predecessor experiment as a reference to select the design days dates from the metrological data provided by Dubai airport (included in Appendix C).

Conduction Gain Calculation

To achieve realistic and informative analysis and to calculate the conduction gain reaches rooms beneath green roofs properly, the researcher used the evapotranspiration and convection gains from Tabares-Velasco and Srebric (2012) experiment and extract the conduction heat simulated by IES-VE to get modified conduction gain that represents the heat gain reaches to underneath rooms. MS Excel calculations were performed in order to obtain these values. These calculations were carried out on two seasonal representative days (24 January and 13 August) and their data have been recorded and tabulated in appendix D.

The soil type was a combination between sand and pumice and layer thickness was 9 cm in depth on average, with areal density of 1020 kg/m2. The specific heat of soil in real conditions was 1106 J/(kg.k) and, soil water content was 20%. The canopy was 7 cm in depth on average, with a coverage ratio of about 100%. Leaf area index (LAI) was measured to be 2. The evapotranspiration and convection heat gains were obtained by cold plate experiment conducted by the predecessor researchers and tabulated in Table 4.4.

Table 4.4: Evapotranspiration and convection heat gains due to season's variation, (Tabares-Velasco and Srebric, 2012)

Temperature °C	**Q_{ET} W/m^2**	**Q_{conv} w/m^2**
14	173.3	301.8
34	73.1	286.3

Q_{ET} = Evapotranspiration heat gain, Q_{con} = Convection heat gain

To calculate the conduction heat gain the researcher utilized the IES-VE to measure the conduction gain at the roof surface with the above conditions and subtract the evapotranspiration and convection gains values from this IES-VE conduction gain to get modified conduction gain.

Figure 4.9 shows that, significant reductions in the heat conduction appear corresponding to green roof implementation. Conduction heat reduction obviously, differs throughout the seasons. The reduction peaks at 34.9 C° (summer) with 36% while at 14.9 C° (winter) on the other hand, reduction exceeds 25%.

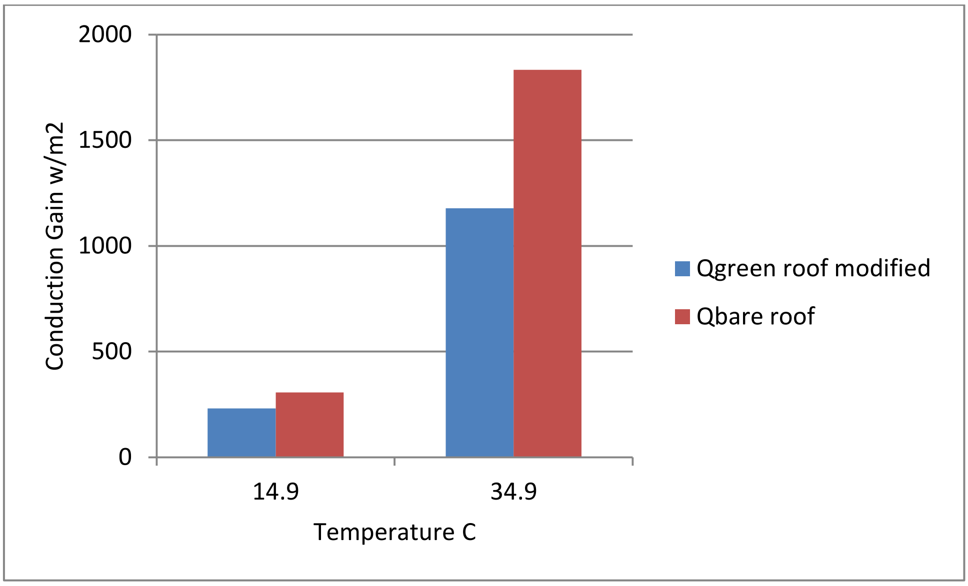


Figure 4.9: Seasons variation effect on the conduction gain of the green roof

In order to understand the effect of other meteorological conditions on the conduction gain at roof surface; ambient relative humidity has been studied as well. Higher rates of relative humidity cause lower evapotranspiration gains thus more conduction gains (Hodo-Abalo et al., 2012).

Figures 4.10 and 4.11 indicate that, summer day (August 13^{th}) has lower relative humidity rate than the winter day (January 24^{th}) therefore relative humidity is one of the reasons behind lowering the conduction gain at summer days.

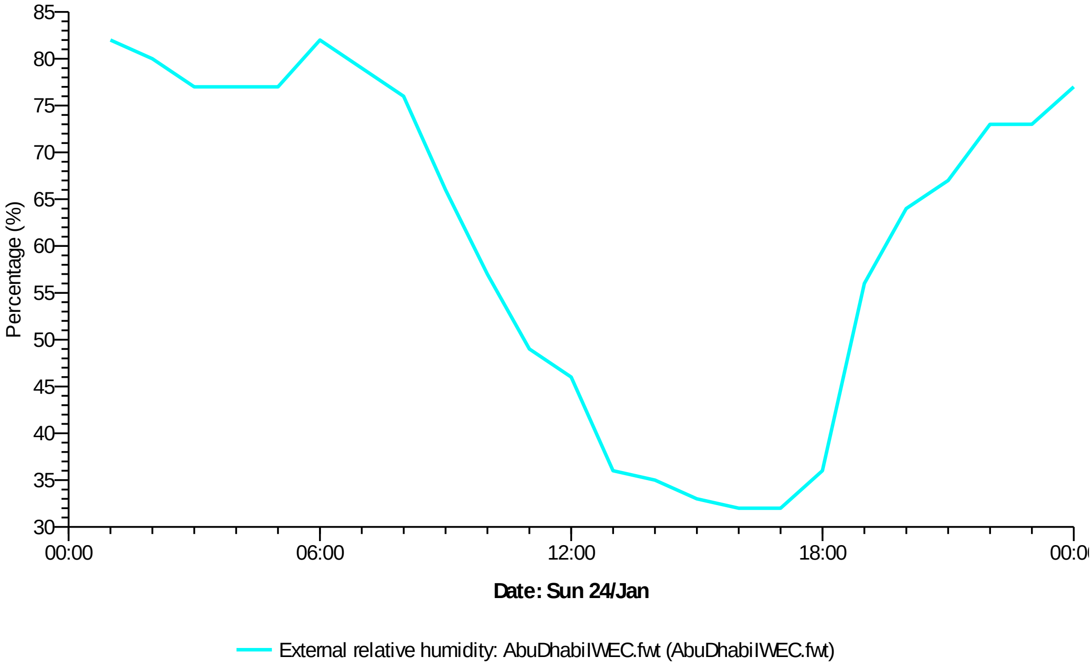


Figure 4.10: Relative humidity at 24th of January (winter)

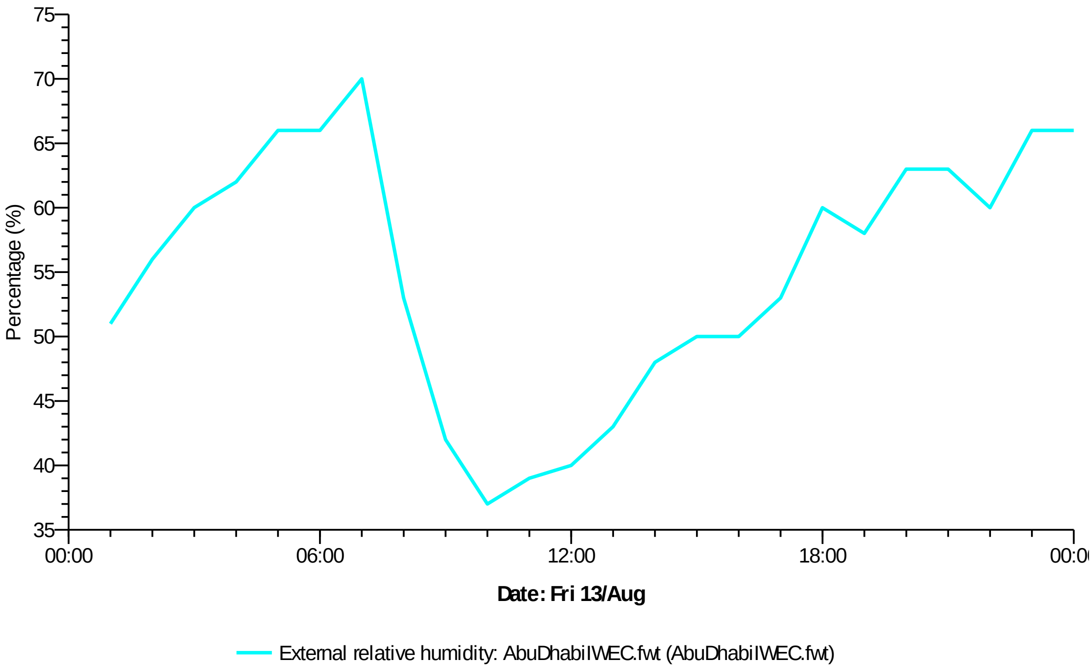


Figure 4.11: Relative humidity at 13th of August (summer)

Figures 4.9 to 4.11 indicate that, reduction in conduction gain caused by green roof assembly is influenced positively by high temperature and low humidity on summer days.

Cooling Load Calculation

To provide insightful analysis and investigate the effect of green roof on thermal performance of the tested model, cooling loads of bare roof was calculated using IES-VE whereas cooling load calculations due to green roof were manipulated. The manipulation was due to the fact that, the IES-VE is unable to calculate the cooling load of the building after implementing green assembly on the surface top.

In order to calculate the thermal load due to green roof implementing, the researcher had to measure the heat gain reaches the building envelope accordingly through IES-VE and charted these results. The percentage of the heat conduction through the roof was then calculated and then multiplied by the total cooling load to obtain the cooling load due to it. To obtain the cooling load due to green roof; the researcher multiplied the cooling load due to roof by the heat conduction reduction percentage from the previous section. All these results are tabulated in appendix D

Frequently, building envelope (external walls, roof and glazing) is directly exposed to the sun; it can absorb a lot of heat. Reinforced concrete structure without adequate insulation can significantly elevate temperature. Such heat will be transmitted inwards to raise the ceiling surface temperature. This will act as a heated surface and increases cooling load. Conduction gain penetrates buildings envelope differs throughout the seasons and depends mainly on solar altitudes. Figure 4.12 illustrates the percentage of the heat entering the building throughout the representative days (24 January and 13 August). All the simulated data are tabulated in appendix D.

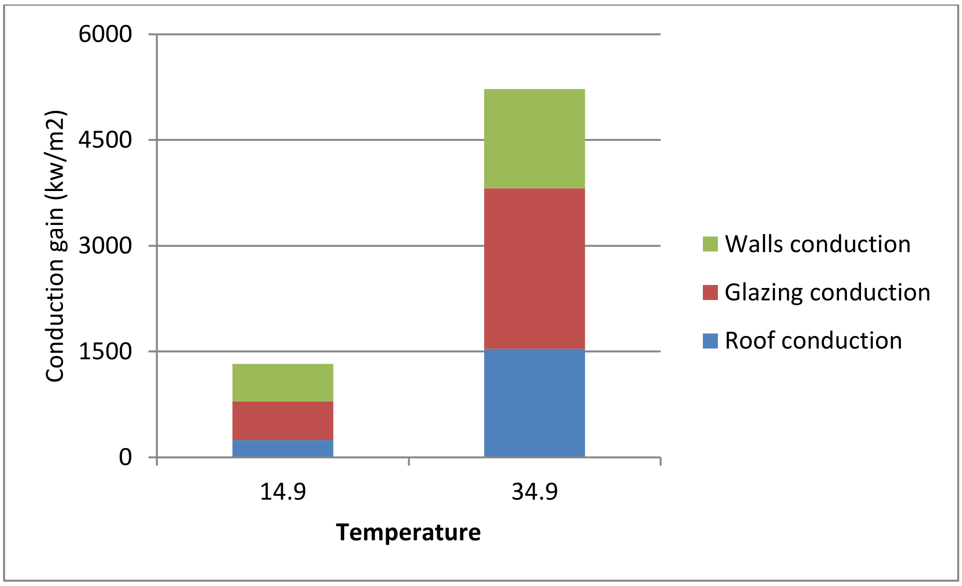


Figure 4.12: Building envelope's conduction gain breakdown (W/m^2)

Although the previous figure shows that, most of the heat gain on the envelope of the building enters through the glazing however, reasonable amount enters through the roof as well. Figure 4.12 demonstrates that, 29% and 19% of heat are gained through roof during summer and winter respectively. According to that, the reduction in the cooling load due to lowering the conduction gain through the roof might be reasonable as well.

Figure 4.13 shows that, the cooling load was lowered by 6% from 4250 to 3985 W in winter. On the other hand, green roof assembly reduces the total cooling load from 17965 W to 15831 W in summer and achieves 12% reduction in the cooling load.

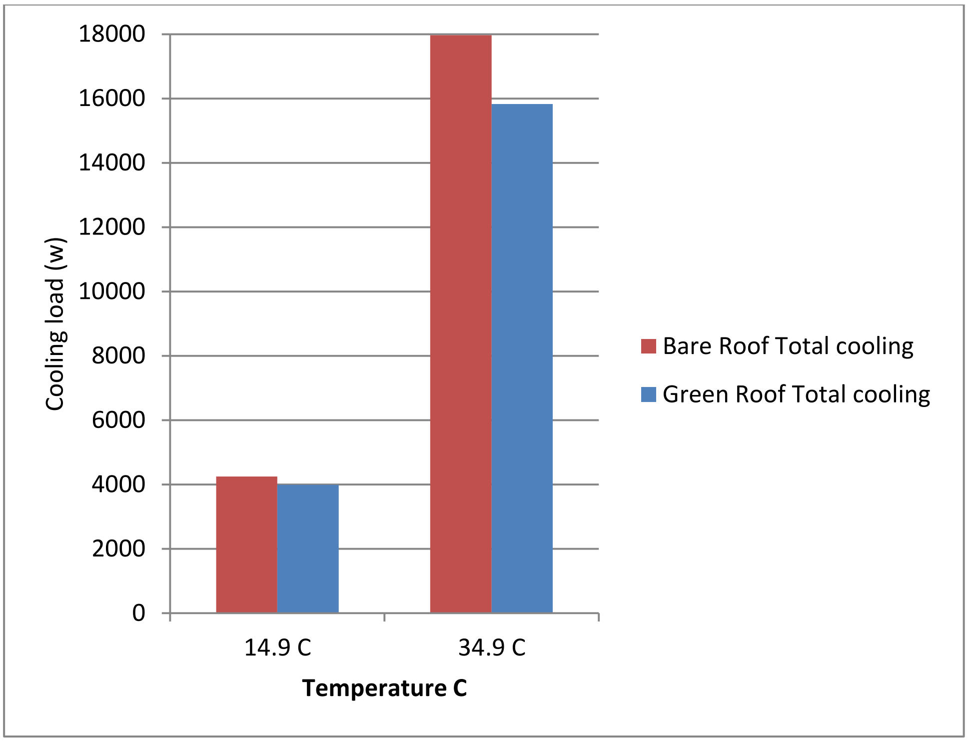


Figure 4.13: Season variation effect on cooling load

These findings suggest that, implementation of the green roof reduces the total cooling load by 6% and 12% in winter and summer days respectively.

Parameter2: Soil Substrate Thickness

Applying the green roof as a refurbishment technique to reduce the thermal load requires taking the weight of the assembly under consideration to avoid excessive weight. In order to achieve that, this parameter was chosen and investigated to determine the ideal soil depth that can reduce the conduction gain at very reasonable weight.

Furthermore, this parameter was selected to investigate the insulation part of the green roof assembly provided by the soil substrate. In order to examine that, four different soil thickness (3, 7, 11 and 15 cm) were simulated to measure the conduction gain and cooling load according to UAE climate conditions at certain date (26 of April). These substrate depths were selected based on the information that was available from Tabares-Velasco and Srebric (2012) experiment. The researcher tended to investigate this certain date further because the metrological conditions parameter showed that, green roof is less efficient in the spring time.

To achieve realistic and informative analysis and to calculate the conduction gain reaches rooms beneath green roofs properly, the researcher used the evapotranspiration and convection gains from Tabares-Velasco and Srebric (2012) experiment and extract heat the conduction heat simulated by IES-VE to get modified conduction gain that represents the heat gain reaches to underneath rooms. On the other hand, the researcher utilized IES-VE to calculate the cooling load of each soil thickness value.

Conduction Gain Calculation

The simulation was performed to validate the energy balance model (described in the methodology chapter) to analyze the energy flows of typical extensive green roofs with Sedum plants. This simulation was carried out on 26 of April and their conduction gain and cooling load data have been tabulated in appendix D.

The soil type was a combination between sand and pumice and with density of 1020 kg/m2. The specific heat of soil in real conditions was 1106 J/(kg.k) and, soil water content was 20%. The canopy was 7 cm in depth on average, with a coverage ratio of about 100%. Leaf area index (LAI) was measured to be 2. The evapotranspiration and convection heat gains were obtained by cold plate experiment conducted by the predecessor researchers and tabulated in Table 4.5.

Table 4.5: Evapotranspiration and convection heat gains due to soil layer depth variation, (Tabares-Velasco and Srebric , 2012)

Soil thickness (cm)	**Q_{ET} (W/m2)**	**Q_{con} w/m2**
3	153.9	265.3
7	159.7	273.5
11	162.1	276.8
15	163.3	278.5

QET = Evapotranspiration heat gain, Qcon = Convection heat gain

To calculate the conduction heat gain the researcher utilized the IES-VE to measure the conduction gain at the roof surface and subtract the evapotranspiration and convection gains values from this IES-VE conduction gain to get the actual conduction gain of the green roof.

Figure 4.14 determines that, soil substrate as insulation item has a decent impact on reducing conduction gain. Actually the reduction was obvious and varied between 28.6 to 30.2% compared to bare roof conduction gain. However, these reduction values are proximate and altering the depth from 3 cm to 15 cm did not show drastic differential reduction. Jim and Tsang (2011) explain that, heat transfer in soil as conduction heat is interrelated with moisture content and ambient temperature only and do not rely on the thickness of the substrate itself. In our case; the outside temperature and water content are fixed therefore, non-differential reduction results are very explainable.

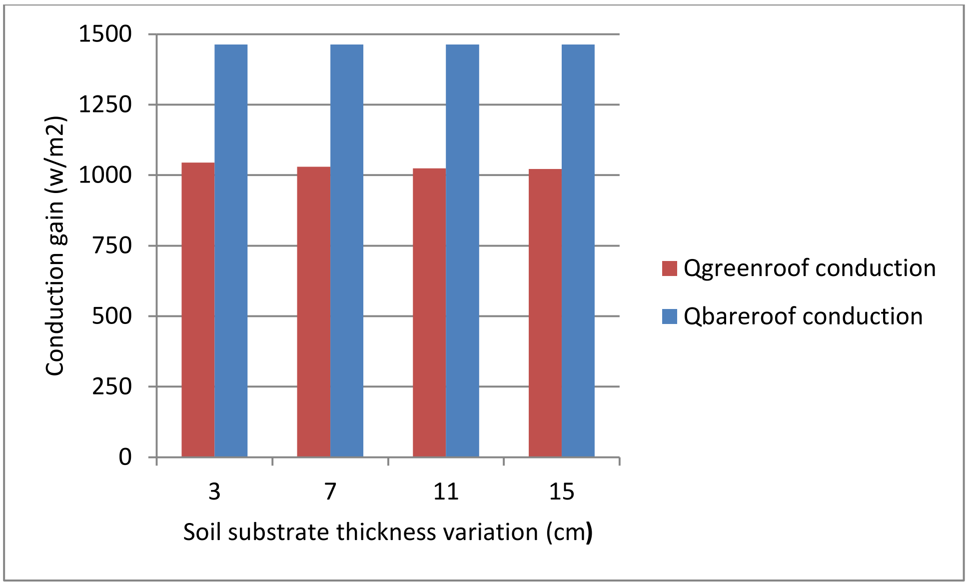


Figure 4.14: Soil substrate thickness variation effect on conduction gain

Cooling Load Calculation

In order to calculate the thermal load due to green roof implementing, the researcher had to measure the heat gain reaches the roof at four different soil substrates depth accordingly through IES-VE and charted these results. The percentage of the heat conduction through the roof was then calculated and multiplied by the total cooling load to obtain the cooling load due to it. To obtain the cooling load due to green roof; the researcher multiplied the cooling load due to roof by the heat conduction reduction percentage from the previous section for the four investigated depth. All these results are tabulated in appendix D.

Green roof usually acts as an insulation layer on the top of the roof surface. This effect contributes in addition to the reduction incorporated by the evapotranspiration and convection phenomenon in reducing the heat gain exerted on the rooftop.

Figure 4.15 shows that, as predicted the reduction maximizes as the depth increases, the reduction in the cooling load due to parameter two varies between 7.3 to 7.7%. Soil depth of 3 cm was able to reduce the cooling load from 7420 W to 6867 W and accomplished 7.3% reduction in the total cooling load. Next evaluated soil depth is 7 cm which had the ability to reduce the cooling load from 7420 W to 6858 W and achieved almost 7.6% reduction. On the other hand, 11 cm soil depth reduced the cooling load to 6850 W and accomplished 7.7% reduction. Similar to 11 cm effect, 15 cm soil thickness was able to reduce the cooling load by 7.7%.

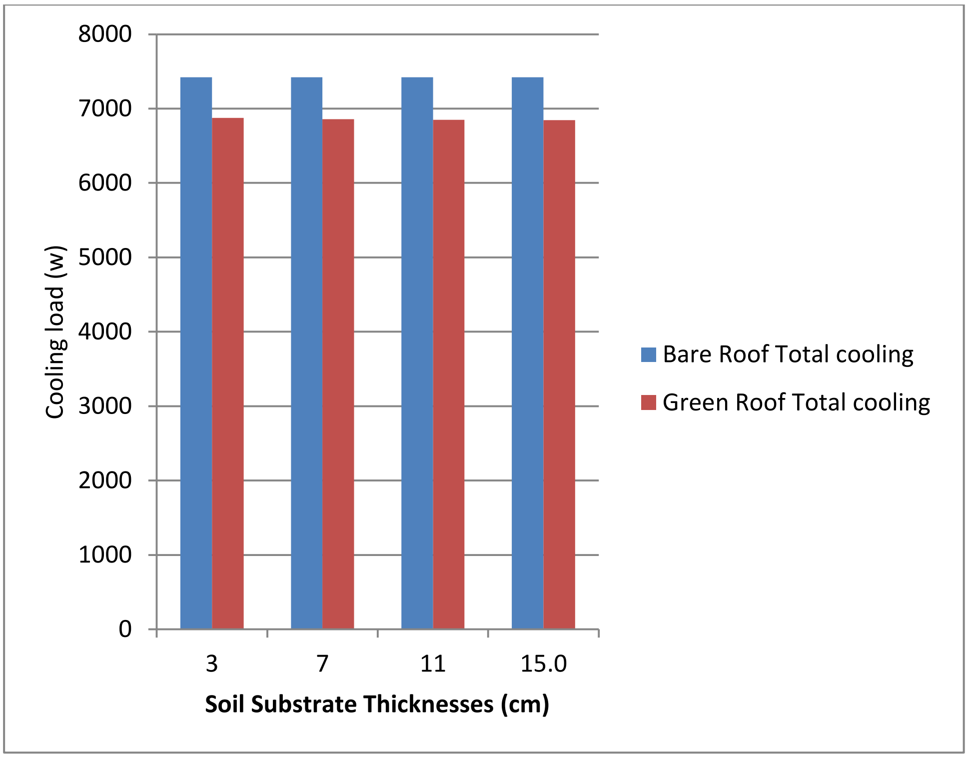


Figure 4.15: Soil substrate thickness variation effect on cooling load

These findings suggest that, variation of soil substrate depth of the green roof do not produce drastic impact on the reduction of conduction gain thus cooling load. This determines that, utilizing 3 cm soil substrate depth have proximate insulation effect as the 15 cm substrate.

Parameter3: Leaf area index LAI

This parameter was selected to investigate the conduction heat gain based on altering the evapotranspiration gain provided by the vegetation. In order to examine that, four different leaf area index LAI (2, 2.5, 3 and 3.5) were tested to measure their evapotranspiration heat gain and cooling load according to UAE climate conditions at certain date (26 of April). These vegetation leaf densities were selected based on the information that was available from Tabares-Velasco and Srebric (2012) experiment. The researcher tended to investigate this certain date further because the metrological conditions parameter showed that, green roof is less efficient in the spring time.

To achieve realistic and informative analysis and to calculate the conduction gain reaches rooms beneath green roofs properly, the researcher used the evapotranspiration and convection gains from Tabares-Velasco and Srebric (2012) experiment and extract heat the conduction heat simulated by IES-VE to get modified conduction gain that represents the heat gain reaches to underneath rooms. On the other hand, the researcher utilized IES-VE to calculate the cooling load for the tested model.

Conduction Gain Calculation

The simulation was performed to validate the energy balance model described in the methodology chapter) and analyze the energy flows of typical extensive green roofs with Sedum plants. This simulation was carried out on 26 of April and their simulated data has been recorded and analyzed in appendix D.

The soil type was a combination between sand and pumice and with density of 1020 kg/m2. The specific heat of soil in real conditions was 1106 J/(kg.k) and, soil water content was 20%. The canopy was 7 cm in depth on average, with a coverage ratio of about 100%. Leaf area index (LAI) was varied (2, 2.5, 3, and 3.5). The evapotranspiration and convection heat gains were obtained by cold plate experiment conducted by the predecessor researchers and tabulated in Table 4.6.

Table 4.6: Evapotranspiration and convection heat gains due to LAI variation (Tabares-Velasco and Srebric, 2012)

Leaf area index	**Q_{ET} W/m^2**	**Q_{conv} w/m^2**
2	145.9	273.7
2.5	227.8	255
3	287.7	228.2
3.5	340.6	199.4

QET = Evapotranspiration heat gain, Qcon v= Convection heat gain

Figure 4.16 shows that, significant reductions in the heat conduction appear corresponding to green roof implementation. Actually the conduction varies between 29 to 37% compared to bare roof conduction gain. The reason behind that might be due to the high evapotranspiration rates of the tested plants as well as the shading effect provided by the vegetation leafs.

On the other hand, variation of LAI shows, minor reduction differences comparing to each other. Apparently, the reduction peaks gradually as the LAI increases. However, this growing is very minor and can be neglected. For instance the reduction percentage in conduction heat achieved by LAI equal to 2 differs only 8.2% from the reduction accomplished by LAI equal to 3.5.

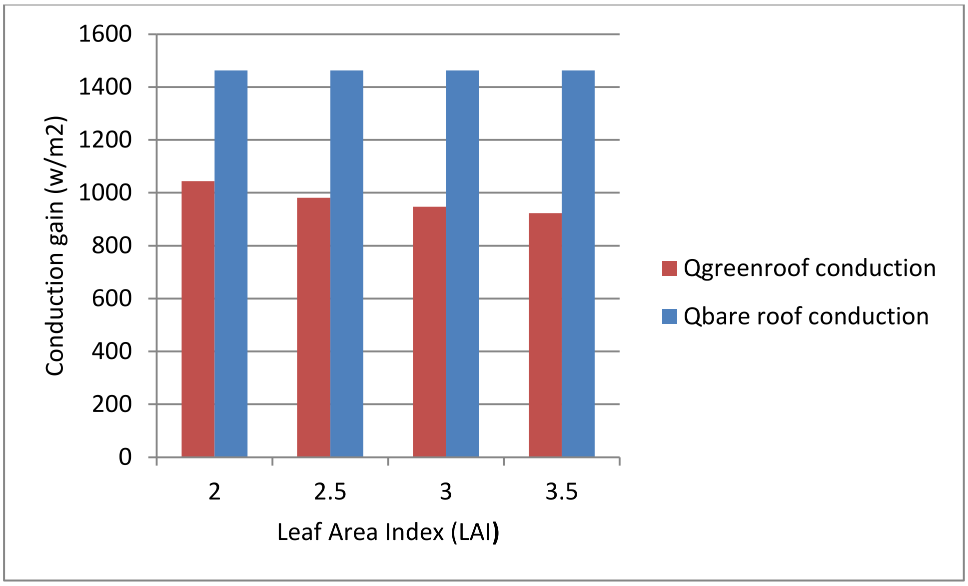


Figure 4.16: Leaf density index variation effect on the conduction gain

This suggests that, the evapotranspiration rates of the plants have a significant impact on the conduction gain reduction.

Cooling Load Calculation

Figure 4.17 shows a significant reduction appears towards the tested parameter. The reduction of the cooling load achieved by this parameter varies between 5.7 to almost 7.3% compared to bare roof thermal load. However, altering LAI did not show much of reduction difference between one LAI value and another where this difference can be neglectable.

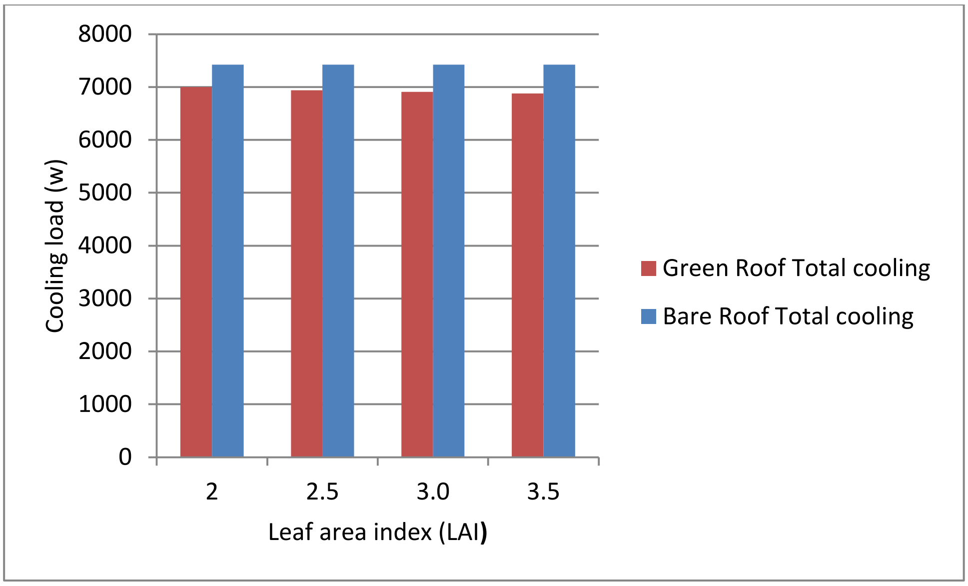


Figure 4.17: Leaf density index variation effect on the cooling load

This suggests that, the evapotranspiration rate of the vegetation in addition to the shading effect of leafs have an obvious impact on the cooling load.

Parameter4: Soil Moisture Content

This parameter concerned in investigating the conduction gain and cooling load due to four soil water contents (5, 15, 25 and 30%). These values were selected according to the data that were available from Tabares-Velasco and Srebric (2012) experiment.

To calculate the conduction gain reaches rooms beneath green roofs properly, the researcher used the evapotranspiration and convection gains from Tabares-Velasco and Srebric (2012) experiment and extract heat the conduction heat simulated by IES-VE to get modified conduction gain that represents the heat gain reaches to underneath rooms.

<u>Conduction Gain Calculation</u>

This simulation was carried out on 26 April and the simulated data has been in appendix D.

The soil type was a combination between sand and pumice and layer thickness was 9 cm in depth on average, with an areal density of 1020 kg/m2. The specific heat of soil in real conditions was 1106 J/(kg.k) and, soil water content was 20%. The canopy was 7 cm in depth on average, with a coverage ratio of about 100%. Leaf area index (LAI) was measured to be 2. The evapotranspiration and convection heat gains were obtained by cold plate experiment conducted by the predecessor researchers and tabulated in Table 4.7. To calculate the conduction heat gain the researcher utilized the IES-VE to measure the conduction gain at the roof surface and subtract the evapotranspiration and convection gains values from this IES-VE conduction gain to get the actual conduction gain of the green roof.

Table 4.7: Evapotranspiration and convection heat gains due to soil water content variation, (Tabares-Velasco and Srebric, 2012)

Moisture %	**Q_{ET} W/m^2**	**Q_{con} w/m^2**
5	8.8	350.6
15	84.5	306.9
25	217.1	245.7
30	235.5	239.5

QET = Evapotranspiration heat gain, Qcon v= Convection heat gain

Figure 4.18 shows that, reasonable reductions in heat conduction appear corresponding to green roof implementation. The resulted reduction varies between 25 to 32% compared to bare roof conduction gain. This result might be corresponded to the high evaporation rates of soil with water content.

On the other hand, variation of soil substrate water content shows, slightly reduction differences comparing to each other. Actually, the reduction peaks gradually as the water content increases. However, this growing is very minor and can be neglected. For instance the reduction percentage in conduction heat achieved by water content equals to 5% differs only 7% from the reduction accomplished by water content equals to 30%.

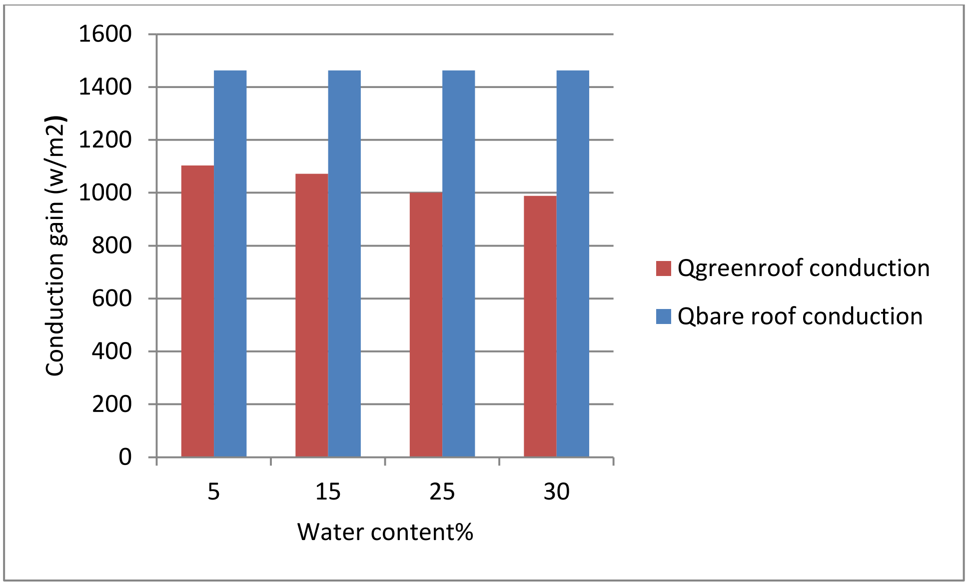


Figure 4.18: Soil moisture content variation effect on the conduction gain

<u>Cooling Load Calculation</u>

The evaporative cooling effect of the green roof assembly was proven by many researchers such as Ekaterini and Dimitris (1998) and Hodo-Abalo et al. (2012). This effect contributes in addition to the reduction incorporated by the transpiration, convection and insulation in reducing the heat gain exerted on the rooftop. Applying the green roof as a refurbishment technique to reduce the thermal load requires taking the weight of the assembly under consideration to avoid excessive weight. In order to achieve that, this parameter was chosen and investigated to determine the ideal soil moisture content that can reduce the conduction gain at very reasonable weight.

Figure 4.19 shows that reduction values in the cooling load due to parameter four vary between 4.9 to 6.3%. Soil moisture of 5% was able to reduce the cooling load from 7429 W to 7058 W and accomplished 4.9% reduction in the cooling load. Next evaluated moisture content is 15 cm which had the ability to reduce the cooling load to 7025 W and achieved 5.3% reduction. On the other hand, 25% soil moisture reduced the cooling load from 7420 W to 6952 W and accomplished 6.3% reduction. Proximate to 25% water content effect, 30% soil moisture was able to reduce the cooling load by 6.3% as well.

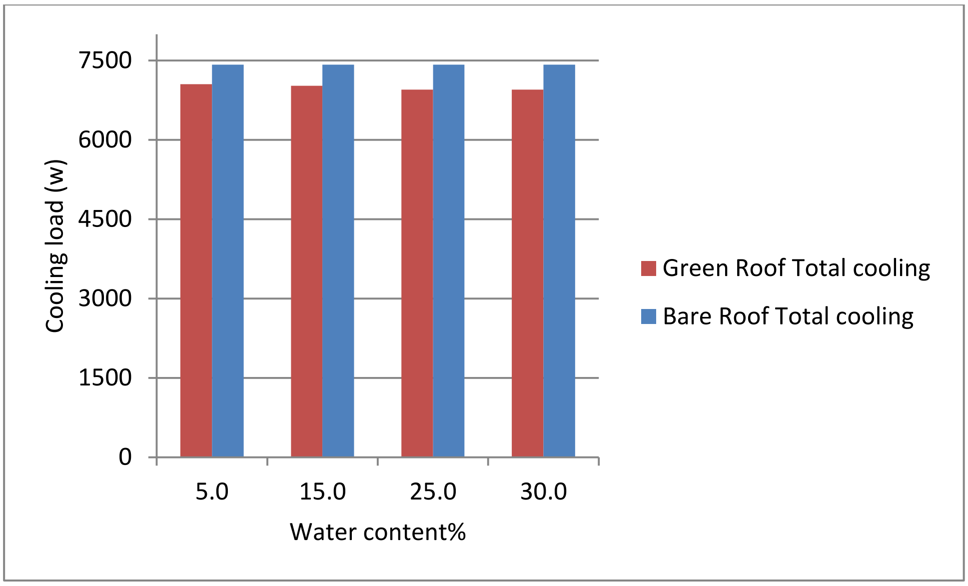


Figure 4.19: Soil moisture content variation effect on cooling load

This finding suggests that, the evaporative cooling effect of the soil water content has an obvious effect on the reduction of the cooling load. Cooling load were reduced 4.9 to 6.3% respectively due to 5 to 30% water content.

CHAPTER FIVE:

CONCLUSION AND RECOMMENDATIONS

In this paper, the impact of green roofs on exited building's energy performance in UAE climate is investigated. A green roof model is presented and integrated into energy software in a way that allowed an objective comparison with conventional roofs. The impact of a green roof on the cooling load of multi-story family house was simulated and the results were analyzed based on UAE climate. Numerical approach (simulation and calculations) was utilized in this study and all the results were charted and tabulated in the appendixes. The findings of this study led to propose integrating green roof as a refurbishment technique to reduce the energy consumption in UAE.

5.1 Conclusions

The results show that the presence of a green roof protects the roof from extreme conduction heat gains. This protection is afforded by a number of thermal phenomena that provided by the green roof assembly, such as shading, evaporative cooling, and insulation.

Results show that, the effectiveness of green roofs subjected greatly on solar attitude which control the conduction heat penetrates through the roof. Due to climatic conditions only, the green roof achieves considerable reductions in both the conduction gain and the cooling load. The conduction gain was reduced by 25% and 36% in winter and summer days. Furthermore, the assembly lowers the cooling load by 6% and 12% of the 19% and 29% of the heat conduction enter through the roof in winter and summer, respectively due to the solar attitude.

To study the general effect of the soil substrate as insulation layer, the depth of the soil was varied and analyzed. The findings show that, the presence of green roof contributes as an insulation layer prevents the conduction heat penetration considerably by 28.6 to 30.2% comparing to bare roof conduction gain. This insulation role of the soil substrate led to obvious cooling load reduction 7.3 to 7.7%. However, the variation in the soil depth do not add an obvious result in isolating the conduction heat therefore, utilizing 3 cm soil substrate insulates almost the same as the 15 cm soil layer. Thus for refurbishment purpose it might be better to use 3 cm soil layer to avoid excessive weight on rooftop.

In order to understand the role of the evaporative cooling effect of the vegetation on lowering conduction gain thus cooling load; their leaf density index LAI were investigated and analyzed. the findings show that, vegetation' evapotranspiration phenomena contributes significantly in reducing the conduction heat by more than 37% compared to bare roof conduction gain. Vegetation' evapotranspiration phenomenon lowers the cooling load by 7.3% compared to bare roof cooling load. However these values are contributed only by fully roof coverage.

Soil water contents were tested as well to comprehend the evaporative cooling effect. The findings show that, the evaporative cooling effect of the soil incorporates greatly in lowering the conduction heat in addition to cooling load. This phenomenon reduces the conduction gain by more than 32% compared to bare roof conduction gain. Frequently, any reduction in the conduction gain leads to reduction in cooling load thus, the evaporative cooling lowers the cooling load significantly by 4.9 to 6.3%.

Overall, and in terms of energy reduction, green roof assembly provides better reduction results in summer days than winter days. Moreover, the insulation provided by the soil substrate is the main reason behind the ability of the green roof to lower the cooling load therefore; the green roof is an advantageous passive technique for retrofitting exiting building in UAE hot arid climate.

5.2 Recommendations

- A number of main recommendations may be drawn from the findings of this study. This study investigated the potential savings of the green roof on residential building that was built according to 1980-2002 building code. Further studies are needed to study the potential savings according to 2003-2013 building code.

- The study findings are encouraging to conduct further laboratorial experiments to measure the actual evapotranspiration, convection and conduction gains for local UAE climate.

- The findings noticeably showed that the evaporative cooling effect resulted from the evapotranspiration is more likely to be the reason behind the performance of the green roof. However, UAE sedum plants' evapotranspiration rates offer large opportunities for future studies

- Irrigation of the soil layer on a roof can be used as an effective means of evaporative cooling and has the particular benefit of reducing the cooling load in local climate. Quantifying the water requirement for this type of treatment can be further explored and studied.

- Literature reviews showed that, the water used for this system need not be as clean as water for human usage. Saline or stored rain water could be used to water the roof, saving potable water for other important needs. Specifying water quality requirements provides another opportunity to explore.

- Findings showed that, the performance of the green roof depends mainly on solar attitudes and in addition to roof, the conduction gains penetrate building envelope through external walls and glazing. Further studies are needed to investigate the potential savings produced by green walls and low-e double glazing as refurbishment techniques.

- This study results showed that, the presence of the green roof contributed in reducing the conduction gain through the roof as well as the cooling load. At the same time, several literature reviews pointed to the fact that painting the roof with white painting coat incorporates the same effect. Therefore, studying the impact of white roof on cooling load of UAE building is encouraging for further studies.

- One of the findings pointed to the fact that, substantial contributions for cooling were achieved when the soil was shaded by the plantation leafs. However, studying the effect of the shading of another method on the roof which may reduce the cooling load and decreasing water consumption should be taken under consideration.

- The study found that, the soil layer as part of the green roof assembly was able to works as insulation layer and lowered the cooling load. Thus studying the effect of different soil type on the insulation ability of the green roof needs further studies and explorations.

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APPENDIX A

(Validation Building Plans

and

Energy Bill)

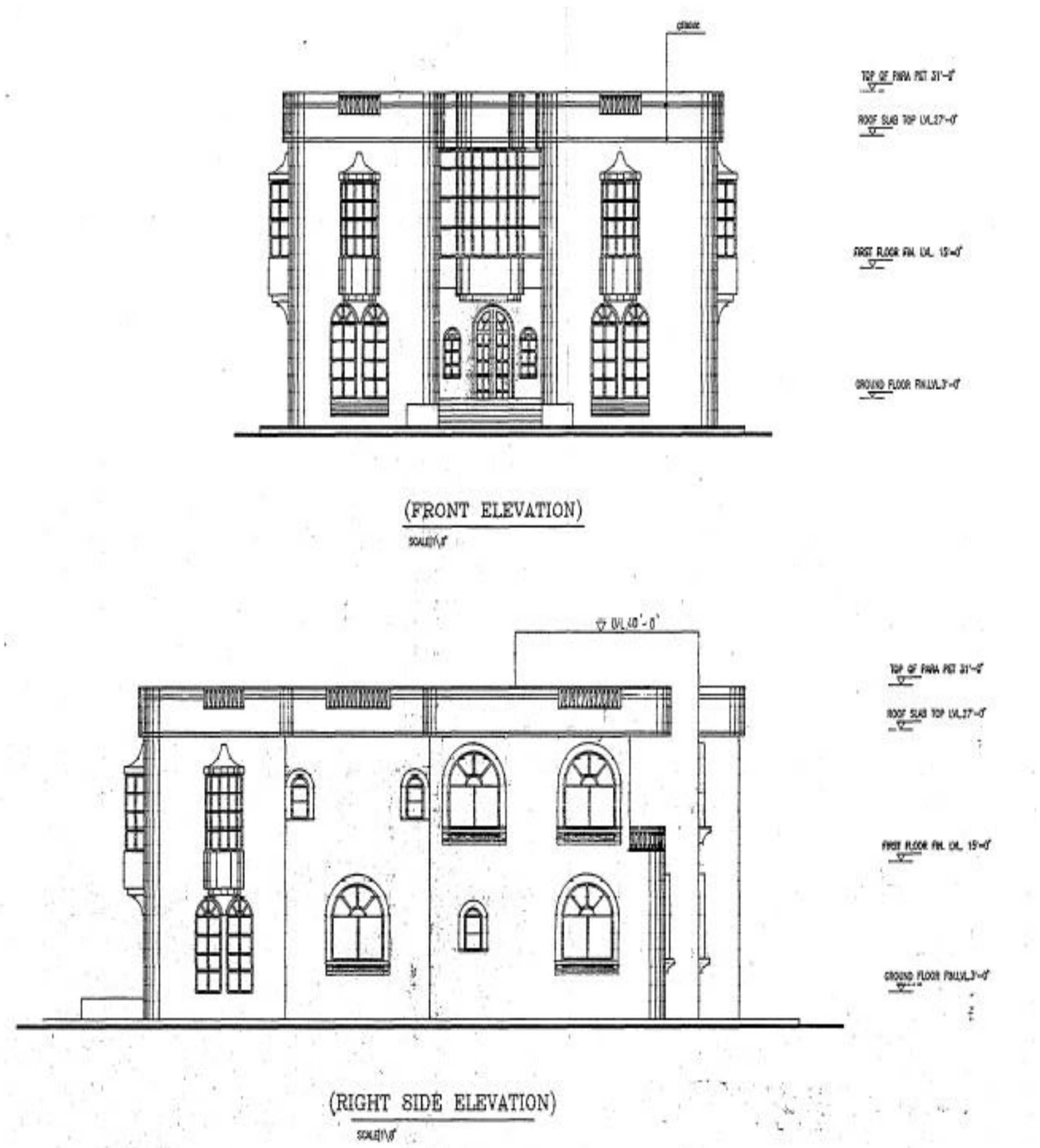

Figure A.1: Front and right side elevations

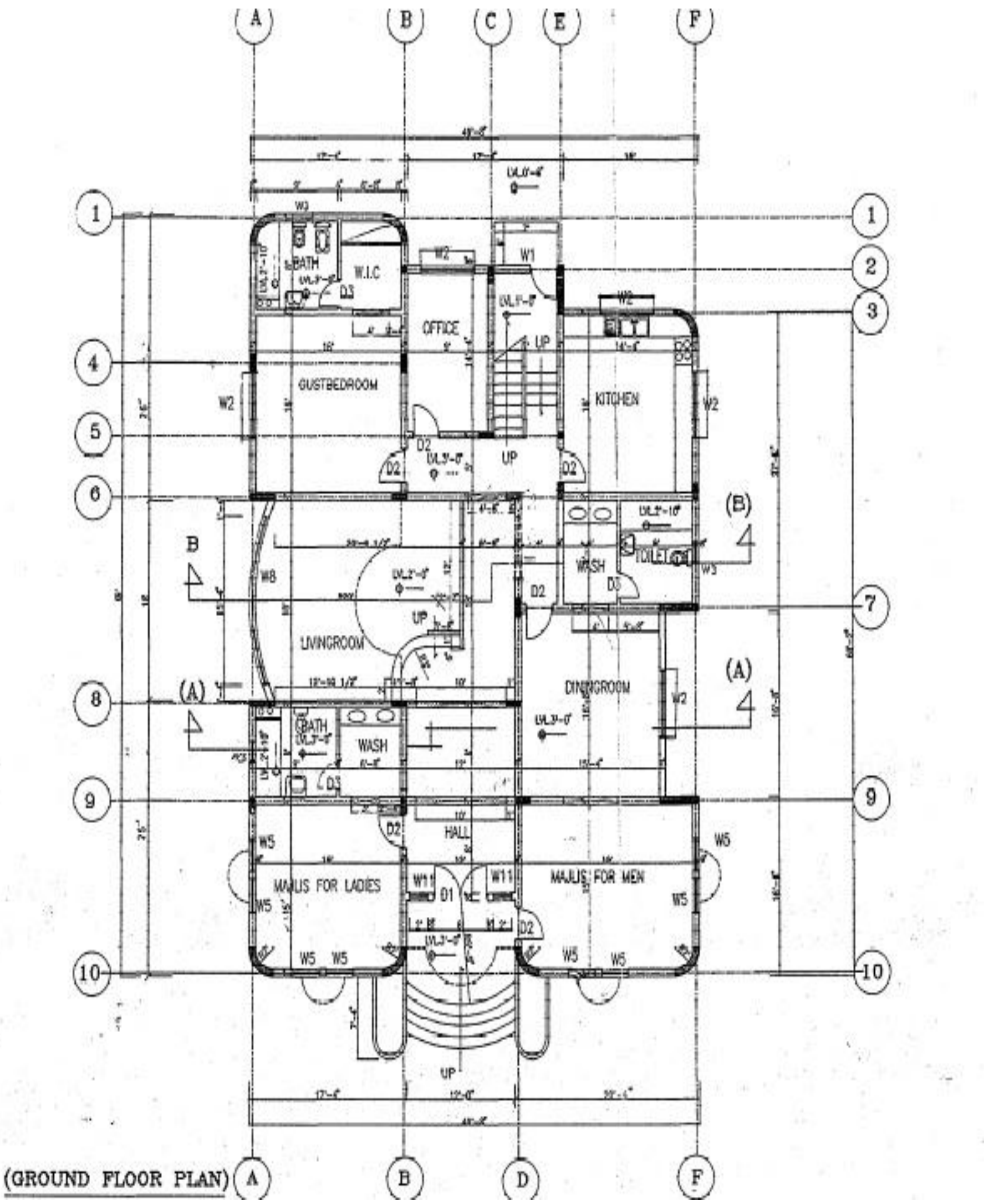

Figure A.2: Ground floor plan

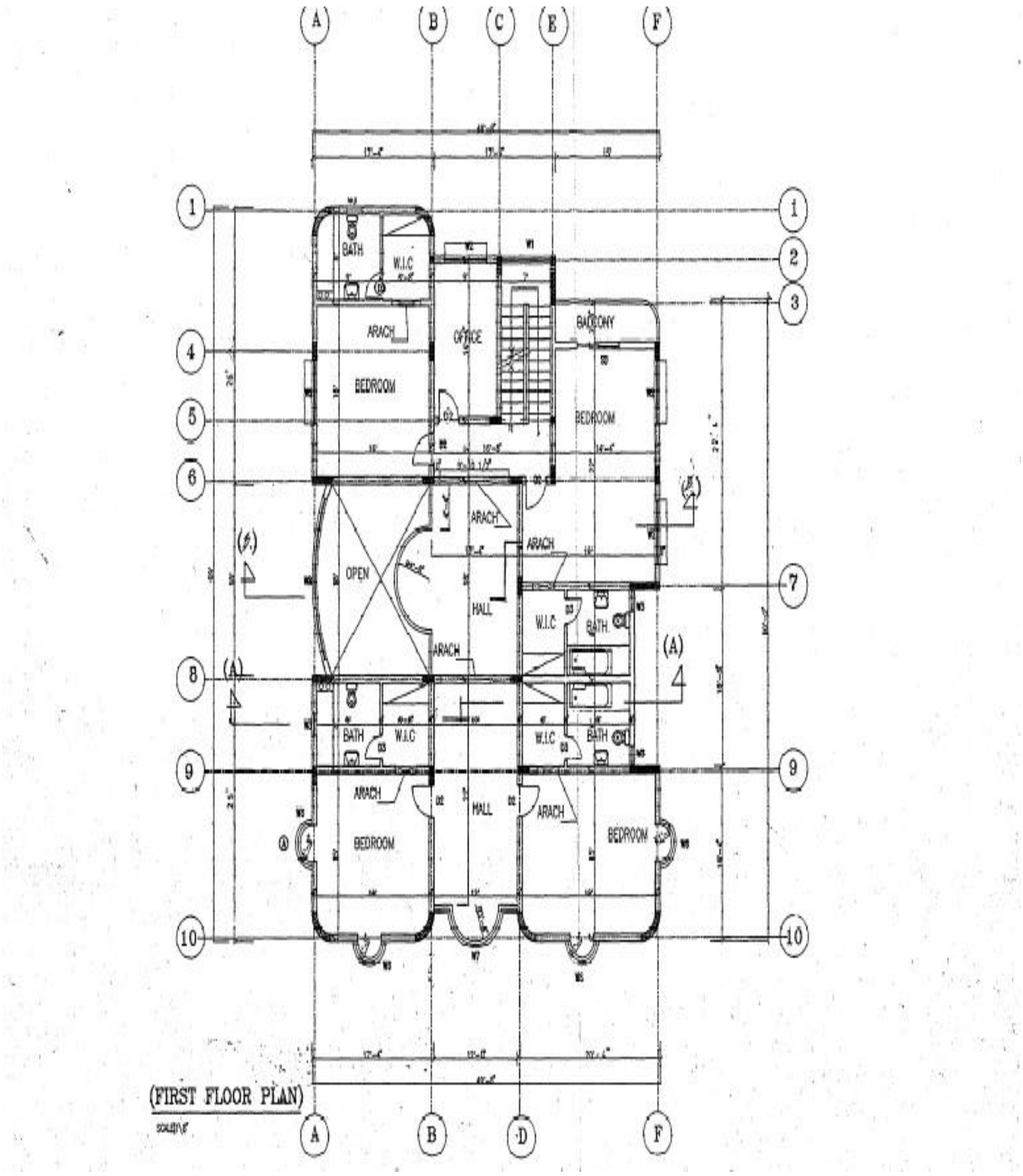

Figure A.3: First floor plan

HISTORY ELECTRICITY & WATER AUTHORITY, SHARJAH DATE: 01/04/2013

Account No. : 12-6563-002-8 APR/13 Tenant:RASHID ALI MOHAMMED AL SAYABI
Area : 12 Addres:
Tariff:S48
Delevry mode : H Catego:X1
E.M-F : 1.00 W.M-F : 1.00

				<------ELECTRICITY------> MTR NO 21032720	W	<---------WATER/SEWERAGE MTR-NO 95100/09		X	
DC	DOC-NO	-DATE	RC	Consump Reading	Chrg-Amt Elec-Adj	Consump Reading	Chrg-Amt Wat-Adj	Chrg-Amt Sew-adj	Tf
OP		01/04/12		1169750	5229.25	3886	-140.00	0.00	
BL	348615	30/04/12		7240	548.00	4000	65.00	0.00	S4
OP		01/05/12		1176990	5777.25	3886	-75.00	0.00	
BL	371963	31/05/12		12560	947.00	4000	65.00	0.00	S4
OP		01/06/12		1189550	6724.25	3886	-10.00	0.00	
BL	395429	30/06/12		11820	891.50	4000	65.00	0.00	S4
OP		01/07/12		1201370	7615.75	3886	55.00	0.00	
AD	201107	31/07/12	AA		-2700.00		-720.00	0.00	
BL	418996	31/07/12		18340	1380.50	4000	65.00	0.00	S4
OP		01/08/12		1219710	6296.25	3886	-600.00	0.00	
RC	7159746	14/08/12			-3000.00		0.00	0.00	
BL	442299	31/08/12		14710	1108.25	4000	65.00	0.00	S4
OP		01/09/12		1234420	4404.50	3886	-535.00	0.00	
BL	465673	30/09/12		16740	1260.50	4000	65.00	0.00	S4
OP		01/10/12		1251160	5665.00	3886	-470.00	0.00	
RC	7179110	15/10/12			-2000.00		0.00	0.00	
BL	489203	31/10/12		12490	941.75	4000	65.00	0.00	S4
OP		01/11/12		1263650	4606.75	3886	-405.00	0.00	
BL	512856	30/11/12		9800	740.00	4000	65.00	0.00	S4
OP		01/12/12		1273450	5346.75	3886	-340.00	0.00	
BL	536528	31/12/12		7220	546.50	4000	65.00	0.00	S4
OP		01/01/13		1280670	5893.25	3886	-275.00	0.00	
BL	9437	31/01/13		4290	326.75	4000	65.00	0.00	S4
OP		01/02/13		1284960	6220.00	3886	-210.00	0.00	
BL	33249	28/02/13		4220	321.50	4000	65.00	0.00	S4
CL		01/04/13		1293830	6895.25		-80.00	0.00	
GS:				0	0.00				
					NET AMOUNT			6815.25	

Figure A.3: The energy bill (Sharjah Water and Electricity Authority, 2012)

APPENDIX B

THE INVESTIGATED MODEL PLANS

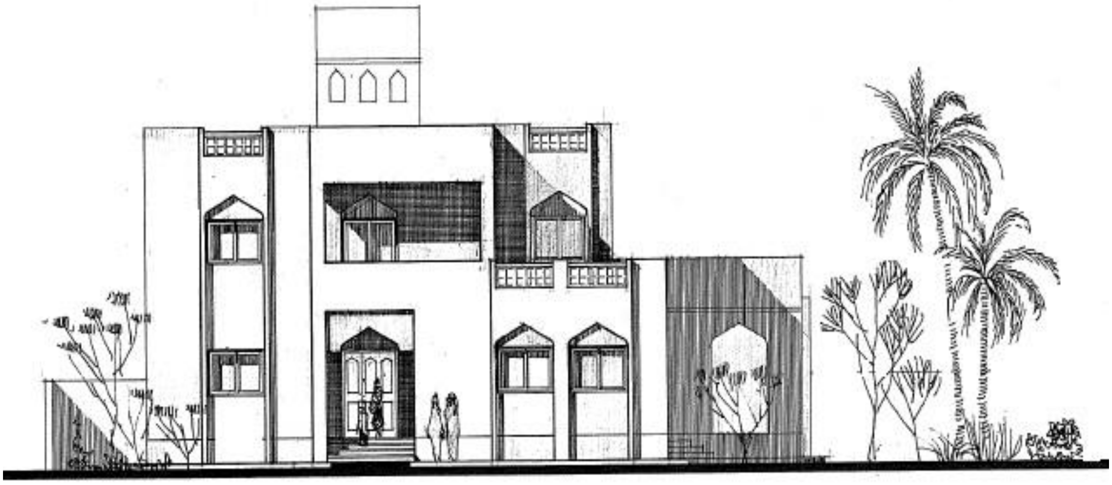

Figure B.1: Front elevation plan

Figure B.2: First and second floors plans

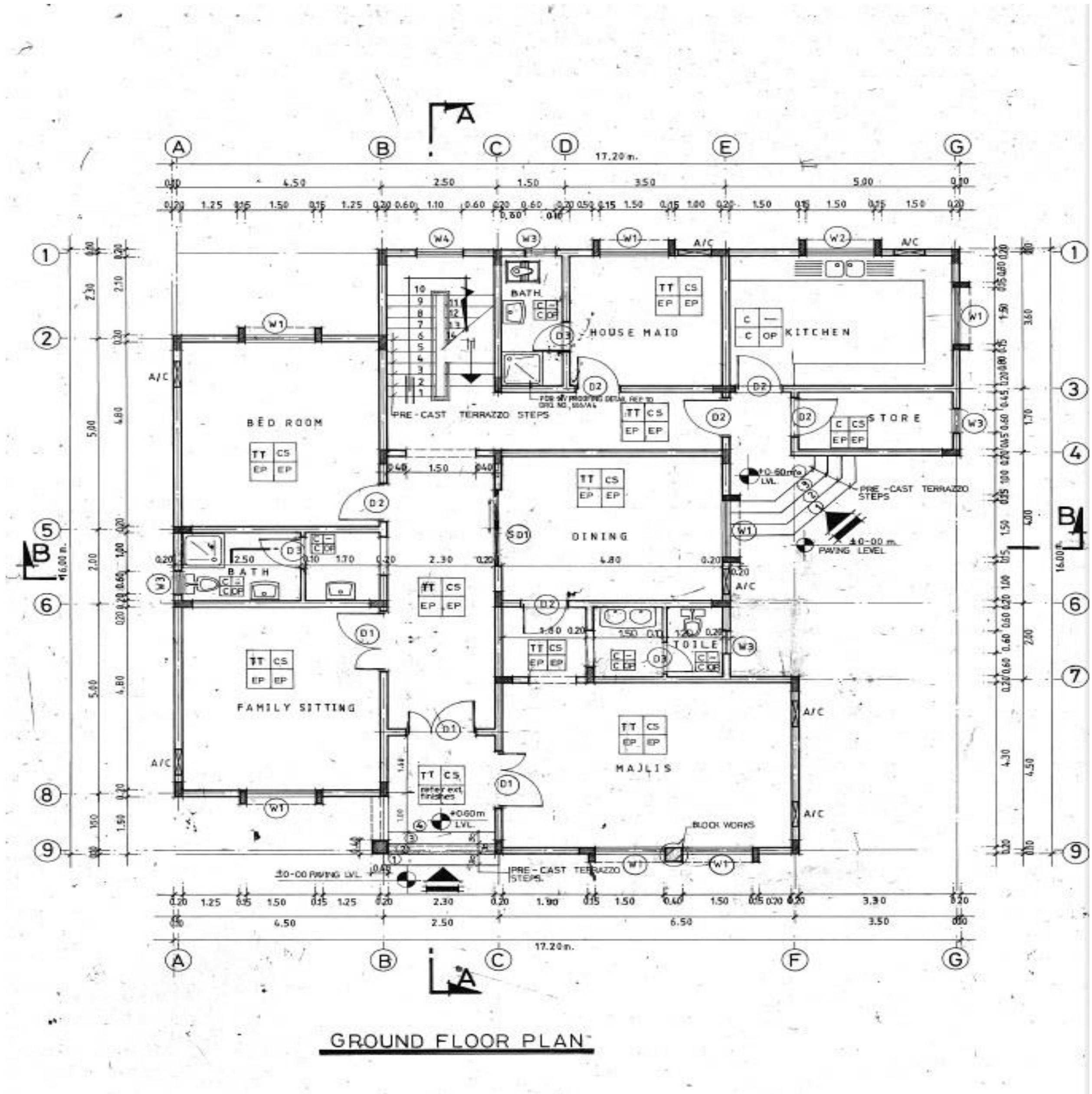

Figure B.3: Ground floor civil plan

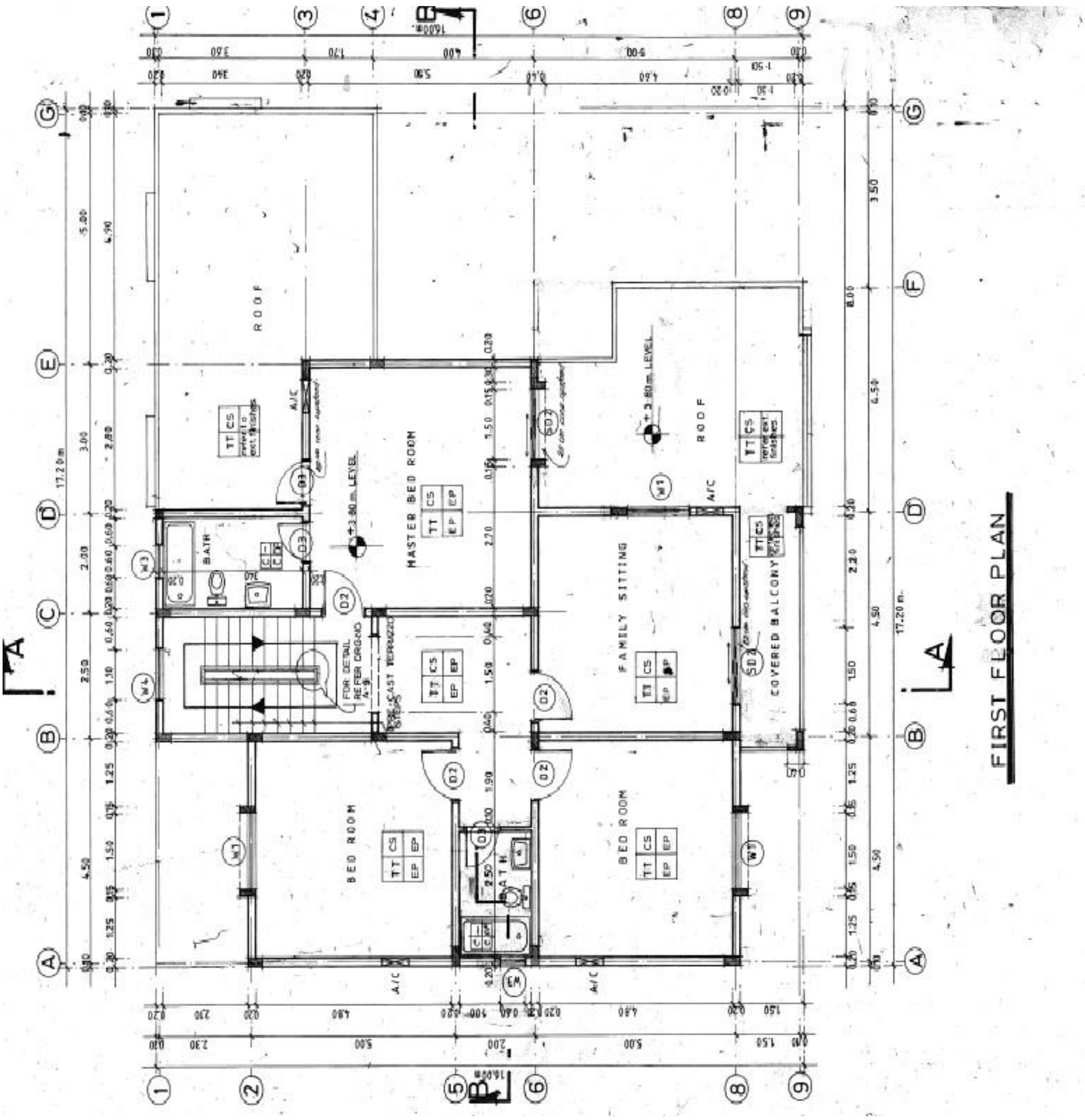

Figure B.4: First floor civil plan

APPENDIX C

Dubai Airport Metrological Data

Table C.1: Dubai Metrological data (January)

Year	Month	Day	Air Temperature (˚c)			Relative Humidity (%)			Rainfall (mm)
			Max	Avg.	Min.	Max.	Avg.	Min.	Total
2009	1	1	27.7	19.5	13.9	100	74	34	0.0
2009	1	2	28.5	21.0	14.6	83	62	25	0.0
2009	1	3	21.2	18.7	16.3	76	65	54	0.0
2009	1	4	21.0	18.2	14.5	74	64	54	0.0
2009	1	5	21.9	18.3	13.0	81	66	55	0.0
2009	1	6	21.2	18.5	16.6	68	61	54	0.0
2009	1	7	21.6	17.8	13.8	91	70	55	0.0
2009	1	8	22.6	17.8	12.2	91	78	57	0.0
2009	1	9	22.3	17.5	11.7	92	75	52	0.0
2009	1	10	23.3	17.3	11.9	90	72	37	0.0
2009	1	11	25.2	17.7	11.9	87	70	34	0.0
2009	1	12	27.1	18.9	12.7	81	63	25	Trace
2009	1	13	22.9	18.5	15.7	82	71	59	Trace
2009	1	14	20.8	17.5	15.6	89	70	55	0.1
2009	1	15	19.3	15.4	11.6	85	66	50	1.2
2009	1	16	21.1	16.2	10.3	86	62	40	0.0
2009	1	17	21.7	16.1	10.5	83	63	32	0.0
2009	1	18	22.8	16.8	11.6	73	58	37	0.0
2009	1	19	18.7	14.6	09.5	92	74	55	0.7
2009	1	20	21.4	15.4	08.8	97	76	45	0.0
2009	1	21	20.9	16.3	10.6	92	75	52	0.0
2009	1	22	21.0	16.0	10.3	99	71	42	0.0
2009	1	23	20.7	14.7	10.6	95	75	40	3.8
2009	1	24	18.9	14.9	10.0	95	71	46	0.0
2009	1	25	20.3	15.9	10.6	89	73	53	0.0
2009	1	26	21.9	17.2	11.2	92	75	47	0.0
2009	1	27	22.0	16.9	11.5	97	81	51	0.0
2009	1	28	23.3	17.6	12.0	96	83	52	0.0
2009	1	29	23.0	18.1	13.7	99	84	58	0.0
2009	1	30	26.5	18.1	14.2	100	78	23	0.0

Table C.2: Dubai Metrological data (August)

Year	Month	Day	Air Temperature (˚c)			Relative Humidity (%)			Rainfall (mm)
			Max	Avg.	Min.	Max.	Avg.	Min.	Total
2009	8	1	38.3	33.8	30.8	65	42	22	0.0
2009	8	2	39.3	33.8	30.3	68	51	24	0.0
2009	8	3	45.0	36.0	30.7	73	46	10	0.0
2009	8	4	45.4	36.5	29.6	75	38	10	0.0
2009	8	5	45.8	37.3	31.4	59	31	10	0.0
2009	8	6	45.7	37.4	30.4	42	25	12	0.0
2009	8	7	46.4	37.5	30.3	52	30	10	0.0
2009	8	8	44.2	35.6	30.1	68	46	15	0.0
2009	8	9	44.4	36.1	29.9	69	45	12	0.0
2009	8	10	41.1	35.0	28.9	63	46	26	0.0
2009	8	11	40.8	34.1	28.9	75	56	33	0.0
2009	8	12	39.9	34.5	29.5	77	64	43	0.0
2009	8	13	41.4	34.9	31.7	74	59	31	0.0
2009	8	14	42.0	35.1	31.7	76	55	27	0.0
2009	8	15	41.7	34.5	30.0	79	63	27	0.0
2009	8	16	39.5	34.1	29.5	83	63	26	0.0
2009	8	17	44.8	36.4	31.5	70	51	18	0.0
2009	8	18	42.9	36.1	32.4	67	49	26	0.0
2009	8	19	41.1	34.5	30.5	76	53	28	0.0
2009	8	20	40.8	35.0	31.0	75	48	29	0.0
2009	8	21	41.0	35.3	31.1	64	46	26	0.0
2009	8	22	42.8	36.0	31.9	60	42	22	0.0
2009	8	23	44.1	36.9	30.4	54	36	17	0.0
2009	8	24	45.5	37.0	30.8	48	34	15	0.0
2009	8	25	45.1	36.5	29.9	40	29	10	0.0
2009	8	26	43.6	35.5	29.6	70	44	18	0.0
2009	8	27	44.5	36.0	29.3	83	50	16	0.0
2009	8	28	45.3	35.2	29.4	84	57	14	0.0
2009	8	29	42.0	33.7	29.3	87	65	23	0.0
2009	8	30	39.3	33.7	28.7	94	69	41	0.0
2009	8	31	41.0	34.7	30.0	82	63	31	0.0

APPENDIX D:

Conduction Gain Calculations

and

Cooling Simulation Results

Parameter 1 (Effect of Season):

Soil type: sand and pumice
*Lsoil = 9 cm
water content =20% Specific heat=1106 conductivity= 218

Parameter 1 (Effect Of Season) Evapotranspiration, Convection And Conduction Gains:

Tair (°C)	QE (W/m2)	Qconv (W/m2)	Sim. Qgr cond (W/m2)	Modif. Qgr cond (W/m2)	Qbare (W/m2)	Reduction %
14.9	173.3	301.8	244.6	230.500	306	25
34.9	73.1	286.3	1536.6	1177.200	1833	36

Lsoil= Depth of soil substrate QE=evapotranspiration gain Qconv= convection gain

Sim. Qgr cond= Green roof conduction gain Qbare cond= Bare roof conduction gain

Modif. Qgr cond =Green roof modified conduction gain

Roof Conduction Gain @Temperature=14.9 °C

Room Name	Bare Roof Maximum Gain	Green Roof Maximum Gain
bed room3	0.0191	0
family sitting	0.0526	0.042
bed room2	0.0227	0.0205
bath4	0.0027	0.0017
master bed room	0.0673	0.0585
family sitting	0.0073	0.0073
bath room1	0	0
bed room1	0	0
house maid	0.0035	0.0037
dinning	0	0
bath5	0.0004	0
majlis	0.0525	0.0446
kitchen	0.0688	0.0578
bath room2	0	0
bath room3	0.0044	0.0037
entrance	0	0
1st floor hall	0.0051	0.0048
Total (kw/m2)	**0.3064**	**0.2446**

External Glazing Conduction Gain @Temperature =14.9 °C

Room Name	Green Roof Maximum Gain
bed room3	0.0437
family sitting	0.0369
bed room2	0.0482
bath4	0.014
master bed room	0
family sitting	0.0503
bath room1	0.0161
bed room1	0.0529
house maid	0.0441
dinning	0.0488
bath5	0.0164
majlis	0.074
kitchen	0.0726
bath room2	0.014
bath room3	0.0155
entrance	0
1st floor hall	0
Total (kw/m2)	**0.5475**

External Walls Conduction Gain @Temperature =14.9 °C

Room Name	Maximum Gain
bed room3	0.0398
family sitting	0.0595
bed room2	0.0178
bath4	-0.0011
master bed room	0.0748
family sitting	0.0523
bath room1	0.0117
bed room1	0.0253
house maid	0.0038
dinning	0.0078
bath5	-0.0018
majlis	0.1221
kitchen	0.1176
bath room2	-0.0036
bath room3	0.0091
entrance	0.002
1st floor hall	-0.007
Total (kw/m2)	**0.5301**

Roof Conduction Gain @Temperature=34.9 °C

Room Name	Bare Roof Maximum Gain	Green Roof Maximum Gain
bed room3	0.1755	0
family sitting	0.2152	0.1964
bed room2	0.1788	0.1649
bath4	0.0484	0.0408
master bed room	0.262	0.2424
family sitting	0.1279	0.1279
bath room1	0	0
bed room1	0	0
house maid	0.0813	0.0769
dinning	0	0
bath5	0.0482	0.0441
majlis	0.2032	0.1854
kitchen	0.2498	0.2232
bath room2	0	0
bath room3	0.036	0.0328
entrance	0	0
1st floor hall	0.207	0.2018
Total (kw/m2)	**1.8333**	**1.5366**

External Glazing Conduction Gain @Temperature=34.9 °C

Room Name	Maximum Gain
bed room3	0.1847
family sitting	0.1624
bed room2	0.1829
bath4	0.0566
master bed room	0
family sitting	0.1924
bath room1	0.0603
bed room1	0.2006
house maid	0.1813
dinning	0.1865
bath5	0.0599
majlis	0.3454
kitchen	0.3473
bath room2	0.0589
bath room3	0.0575
entrance	0
1st floor hall	0
Total (kw/m2)	**2.2767**

External Walls Conduction Gain @Temperature=34.9° C

Room Name	Maximum Gain
bed room3	0.1332
family sitting	0.1207
bed room2	0.0912
bath4	0.0325
master bed room	0.1341
family sitting	0.1099
bath room1	0.0678
bed room1	0.1329
house maid	0.0189
dinning	0.0508
bath5	0.0199
majlis	0.1761
kitchen	0.1734
bath room2	0.0124
bath room3	0.0338
entrance	0.0702
1st floor hall	0.0322
Total (kw/m2)	**1.41**

IES-VE Simulated Bare and Green Roofs Cooling Load Due To Temperature Variation:

Tair (°C)	14.9	34.9
Bare Roof Conduction Gain	306	1833
External Walls Conduction Gain	530	1410
External Glazing Conduction Gain	548	2277
% Cooling Load Due to Bare Roof	22	33
Total Cooling Load (w)	**4250**	**17965**
Cooling Load Due to Bare Roof (w)	935	5928
Cooling Load Due to Green Roof (w)	234	2134
Total Cooling Load Due to Green Roof (w)	**4017**	**15831**
Reduction %	6	12

Parameter 2 (Soil substrate thickness)

Soil type: sand and pumice
Tair (°C) = 24.9 @ 26 Apr
Water content% = 20%

Soil thickness (cm)	QE (W/m2)	Qconv (W/m2)	Sim. Qgr cond (W/m2)	Modif. Qgr cond (W/m2)	Qbare (W/m2)	Reduction %
3	153.9	265.3	1463.2	1044.0	1463.0	28.6
7	159.7	273.5	1463.2	1030.0	1463.0	29.6
11	162.1	276.8	1463.2	1024.3	1463.0	30.0
15	163.3	278.5	1463.2	1021.4	1463.0	30.2

Lsoil= Depth of soil substrate QE=evapotranspiration gain Qconv= convection gain

Sim. Qgr cond= Green roof conduction gain Qbare cond= Bare roof conduction gain

Modif. Qgr cond =Green roof modified conduction gain

Conduction Gain of Bare Roof @Temperature =24.9 °C

Room Name	Maximum value
bed room3	0
family sitting	0.03
bed room2	0.016
bath4	0.0033
master bed room	0.0232
family sitting	0.0143
bath room1	0
bed room1	0
house maid	0.0012
dinning	0
bath5	0.0012
majlis	0.0213
kitchen	0.0242
bath room2	0
bath room3	0.0009
entrance	0
1st floor hall	0.0107
Total (Kw)	**0.1463**

Roof Conduction Gain @ Soil = 3 , 7, 11 and 15 cm

Room Name	Maximum value
bed room3	0
family sitting	0.03
bed room2	0.016
bath4	0.0033
master bed room	0.0232
family sitting	0.0143
bath room1	0
bed room1	0
house maid	0.0012
dinning	0
bath5	0.0012
majlis	0.0213
kitchen	0.0242
bath room2	0
bath room3	0.0009
entrance	0
1st floor hall	0.0107
Total (Kw)	**0.1463**

IES-VE simulated bare and green roofs cooling load due to soil substrate thickness variation:

Soil Thickness (cm)	3	7	11	15
Bare Roof Conduction Gain	1463	1463	1463	1463
External Walls Conduction Gain	3196	3196	3196	3196
External Glazing Conduction Gain	1056	1056	1056	1056
% Cooling Load Due to Bare Roof	26	26	26	26
Total Cooling Load (w)	7420	7420	7420	7420
Cooling Load Due to Bare Roof (w)	1899	1899	1899	1899
Cooling Load Due to Green Roof (w)	544	562	570	574
Total Cooling Load Due to Green Roof (w)	6876	6858	6850	6846
Reduction %	7.3	7.6	7.7	7.7

Parameter 3 (Leaf Density Index LAI):

Lsoil (cm) = 9

Plant type: S.spurium and D. nubigenum

Soil type: sand and pumice

Tair (°C) = 24.9

Water content % = 20

LAI	QE (W/m2)	Qconv (W/m2)	Sim. Qgr cond (W/m2)	Modif. Qgr (W/m2)	Qbare (W/m2)	Reduction %
2	145.9	273.7	1463.2	1044	1463	29
2.5	227.8	255.0	1463.2	980	1463	33
3	287.7	228.2	1463.2	947	1463	35
3.5	340.6	199.4	1463.2	923	1463	37

Lsoil= Depth of soil substrate QE=evapotranspiration gain Qconv= convection gain

Sim. Qgr cond= Green roof conduction gain Qbare cond= Bare roof conduction gain

Modif. Qgr cond =Green roof modified conduction gain

IES-VE Simulated bare and green roofs cooling load due to LAI variation LAI:

LAI	**2**	**3**	**3.0**	**3.5**
Bare Roof Conduction Gain	1463	1463	1463	1463
External Walls Conduction Gain	3196	3196	3196	3196
External Glazing Conduction Gain	1056	1056	1056	1056
% Cooling Load Due to Bare Roof	26	26	26	26
Total Cooling Load	**7420**	**7420**	**7420**	**7420**
Cooling Load Due to Bare Roof (w)	1929	1929	1929	1929
Cooling Load Due to Green Roof (w)	424	483	512	541
Total Cooling Load Due to Green Roof	**6996**	**6937**	**6908**	**6879**
Reduction %	5.7	6.5	6.9	7.3

<u>Parameter 4 (Water Content %):</u>

Tair = 24.9 C @ 26 April

Lsoil = 9 cm

Water conten t %	QE (W/m2)	Qconv (W/m2)	Density (kg/m3)	Conduct (w/m.k)	specific heat (J/kg.k)	Sim. Qgr cond (W/m2)	Modif. Qgr cond (W/m2)	Qbare (W/m2)	Reduction %
5	8.8	350.6	1020	0.145	1091	1463	1104	1463	25
15	84.5	306.9	1024	0.217	1258	1463	1072	1463	27
25	217.1	245.7	1036	0.300	1310	1463	1000	1463	32
30	235.5	239.5	1040	0.323	1362	1463	988	1463	32

Lsoil= Depth of soil substrate QE=evapotranspiration gain Qconv= convection gain

Sim. Qgr cond= Green roof conduction gain Qbare cond= Bare roof conduction gain

Modif. Qgr cond =Green roof modified conduction gain, Conduct= Conductivity

IES-VE Simulated Bare and Green Roofs Cooling Load Due To Soil Substrate Water Content Variation:

Water Content %	5	15	25.0	30.0
Bare Roof Conduction Gain	1463	1463	1463	1463
External Walls Conduction Gain	3196	3196	3196	3196
External Glazing Conduction Gain	1056	1056	1056	1056
% Cooling Load Due to Bare Roof	26	26	26	26
Total Cooling Load	**7420**	**7420**	**7420**	**7420**
Cooling Load Due to Bare Roof (w)	1899	1899	1899	1899
Cooling Load Due to Green Roof (w)	366	395	468	468
Total Cooling Load Due to Green Roof	**7054**	**7025**	**6952**	**6952**
Reduction %	4.9	5.3	6.3	6.3