A Study on Reducing Heat Gains through the use of Green Envelope

دراسة حول الحد من زيادة الحرارة من خلال استخدام غلاف أخضر

By: Mania Alabadla

Student ID number 100105

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Faculty of Engineering & IT

Dissertation Supervisor
Professor Bassam Abu-Hijleh

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Abstract

The increment of ambient temperature in urban areas caused by heat island phenomenon increases the stress on cooling loads and increases the electricity peak demand. 75% of electricity consumption in Abu Dhabi is used for cooling the buildings which increase the carbon footprint of UAE significantly. The rising anxiety of climate change and the importance of energy resources, led to the creation of Estidama rating system by the government of Abu Dhabi in order to promote green buildings that incorporate green roofs and green facades. This dissertation focuses on evaluating the thermal behaviors of green envelope (green roofs and green facades) on the buildings cooling loads and the overall energy consumption.

The software that been used to investigate the performance of green roofs and living walls is the IES Virtual Environment (VE). IES is a thermal load and energy analysis simulation program, to find out the end user`s annual energy of five cases were modeled. The first model is the base case which is the building with conventional facades and conventional roof while the other cases are for green roofs with different thickness and living wall case and finally a case for the combination of green roof and living wall.

Green roofs can contribute in reducing building`s cooling load however this reduction is varying from the whole building load and the last floor load at a high rise building that is consisting from sixteenth floors which make installing green roofs in low rise buildings more efficient than high rise buildings unless combined with living walls. The usage of green roof and living walls in high rise building reduced the cooling loads by 24.35% comparing to the base case. The energy use of the whole building dropped by 23% compared to the base case while the CO_2 emissions dropped by 17%. Irrigation approach was to treat grey water resulted from the building and use it to irrigate green areas within the building itself. It was important to find out that the irrigation water demand compromising 55.7 % of the overall treated grey water that been generated within the building .This low percentage enables the use of the extra treated water in other activities which can compensate the capital cost of grey water treatment systems .

ملـخـــص

الزيادة في درجة الحرارة المحيطة في المناطق الحضرية الناجمة عن ظاهرة الاحتباس الحراري تزيد من الضغط على أحمال التبريد وتزيد من ذروة الطلب على الكهرباء . 75٪ من استهلاك الكهرباء في أبو ظبي يستخدم لتبريد المباني مما يزيد انبعاثات الكربون من دولة الإمارات العربية المتحدة بشكل كبير. القلق المتزايد لتغير المناخ وأهمية مصادر الطاقة، أدى إلى خلق نظام استدامة من قبل حكومة أبوظبي من أجل تعزيز المباني الخضراء التي تضم الأسطح الخضراء والواجهات الخضراء. هذه الأطروحة تركز على تقييم السلوك الحراري للغلاف أخضر (الأسطح الخضراء والواجهات الخضراء) و تأثيرها على أحمال التبريد في المباني واستهلاك الطاقة بشكل عام.

البرنامج التي تم استخدامه للتحقق في أداء الأسقف الأخضر والجدران الخضراء هو (IES VE) .برنامج (IES VE) هو برنامج يعمل على حساب الحمل الحراري والطاقة المستهلكة في المباني. خمس حالات تم انشاؤها لدراسة العوامل المؤثرة على آداء الأسطح الخضراء. النموذج الأول هو الحالة الأساسية المكونة من سقف و واجهات تقليدية بينما الحالات الأخرى لأسطح خضراء ذات سماكات مختلفة و حالة لدراسة تأثير الجدران الخضراء و الحالة الأخيرة هي لمبنى ذو سطح أخضر و جدران خارجية خضراء.

أسطح المباني الخضراء تسهم في الحد من الطلب على أحمال التبريد لكن هذا الانخفاض يختلف بين أحمال التبريد للمبنى كله و أحمال التبريد للطابق الأخير فقط في مبنى مكون من 16 طابق اذ يظهر تأثير الأسطح الخضراء أكثر وضوحا على أحمال تبريد و استهلاك طاقة الطابق الأخيرمما يجعل انشاء الأسطح الخضراء في المباني منخفضة الارتفاع أكثر كفاءة من المباني العالية الارتفاع ما لم تقترن بالجدران الخضراء. استخدام الأسقف والجدران الخضراء في مبنى عالي الارتفاع مكون من 16 طابق أدى لخفض أحمال التبريد بنسبة 24.35% مقارنة بالحالة الأساسية بينما انخفض استخدام الطاقة في المبنى بأكمله بنسبة 23٪ في حين أن انبعاثات ثاني أكسيد الكربون انخفضت بنسبة 17٪.

كان الاتجاه المتبع في مياه الري اللازمه للأسطح و الجدران الخضراء هو استخدام المياه الناتجه من أحواض الاستحمام و أحواض غسيل الأيدي الناتجه من المبنى نفسه بعد معالجتها .كان من المثير للانتباه ان المياه اللازمه لري الاسطح و الجدران الخضراء لكامل المبنى المكون من ستة عشر طابقا تشكل 55.7٪ من مجمل المياه المعالجة الناتجه من استخدام سكان المبنى نفسه. تمكن هذه النسبة المئوية المنخفضة من استخدام المياه المعالجة في الأنشطة الإضافية الأخرى التي يمكن أن تعوض تكلفة أنظمة معتاجة المياه العادمة.

Dedication

I lovingly dedicate my work to my beloved parents, my husband Sameh, my kids Abdalla and Mansour, my brother Ameed and sisters Mai, Lama, Deema and Dania.

Acknowledgment

This dissertation wouldn't be achieved without the support of many people in my life. I will always have an everlasting grateful to the following:

First of all, I have to thank Allah the most Gracious the most merciful for his blessing and granting me the ability to success throughout my entire life.

My everlasting gratitude is to my husband Sameh for his endless support and his patience with the burden of my studying. without Sameh`s support and compensating my absence at home, I wouldn`t be able to achieve this accomplishment in my life.

My deep gratitude is to my parents for their endless unconditional encouragement, love and sacrifices.

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Chapter 1: Introduction

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1.1 Overview

Heat island and climate change phenomenon led to a massive increment in the ambient temperature intensify reliance on energy resources, created discomfort conditions and created pollution problems.
This chapter focuses on highlighting climate change phenomenon and the need to greenery to mitigate it.

1.2 Climate change

Urbanization`s rapid pace and the rising anxiety of climate change that occurred in the current century increase the trend to bring back the nature into the cities. Replacing green areas with streets and buildings increases the ambient temperature and surface radiation which lead to hot urban environments. The temperature variation between urban areas and adjacent rural areas called "heat island phenomenon".

Heat island is considered as the most recognized phenomenon resulted from climate change. It was documented since a century and resulted due to the thermal un-balance between urban areas and the adjacent rural and suburban areas (Santamouris, 2001).
Urban heat is caused by anthropogenic heat release, lack of cool sinks and lack of green areas, solar radiation storage by urban structures and air non-circulation in urban areas (oke et al., 1991).

The increment of ambient temperature in urban areas increases the stress on cooling energy consumption. Santamouris et al. (2001), found that heat island phenomenon in Athens triples the peak electricity demand, doubles building`s cooling load and reduces the mechanical cooling system`s coefficient of performance by 25%.

1.3 Mitigation methods

Mitigation methods is used to create a balance in city`s thermal budget by decreasing thermal gains and increasing the corresponding losses. The most important methods to mitigate the heat island phenomenon are those that related to increasing green areas within urban , using natural heat sinks and increasing the urban environment`s albedo.

Limitation of areas at ground level in urban environments and its associated great economic value make it difficult to implement mitigations methods on large scales. All cities and urban areas have two impervious elements: pavement and rooftops that contribute to 45% of city`s surface area (Liptan & Strecker, 2003). Green buildings are the immediate solution to create green cities as a solution for its fundamental structure that lack to green areas. Creating a living landscape can be achieved by planting city skin like streets, walls, roofs and other spaces. This living city will be pleasant aesthetically and at the same time create environmentally friendly buildings (Johnston& Newton, 2004).

According to Santamouris (2012), there are two mitigation methods that can be implemented on buildings` roofs; first, by increasing roof albedo to create reflective or cool roofs and second by covering roofs with plants and vegetation to create living roofs or green roofs. The two methods contribute in reducing sensible heat flow to the surrounding atmosphere and reducing building`s cooling demand.

Djedjig et al. (2012),found that the paved surfaces in the urban environment that are exposed to the solar radiation can increase the ambient temperature by 30°C while the ambient temperature at the vegetated areas is the same of leaf temperature because of evapotranspiration process. They also found that the water content in soil and evapotranspiration can offer a passive cooling method that is cooling the building itself and the surrounding atmosphere.

1.4 Urban greenery role

Urban greenery is considered as an attractive mitigation method against hot urban environments however to make it feasible, it is important to realize the potential spaces in the urban areas that suit greenery. Thus, buildings` envelope offers opportunities to insert greenery into the urban areas by using green roofs and green walls. Green envelope is considered as innovative feature of architecture, ecological landscaping and city planning. Jaafar et al. (2012) stated that greenery contributes in mitigating Heat Island phenomenon in two ways; indirectly by evapotranspiration cooling and directly by shading surfaces.

Many theoretical and experimental researches have been conducted to investigate the thermal behaviors of green roofs. The energy conservation benefits associated with green roofs depend on the local climate, green roof design and building characteristics. Liu &Minor (2005) found that green roofs promote the building`s thermal insulation and achieve a solar heat gain reduction in summer by 70-90%.

Green roof system have several properties that contribute to its thermal characteristics like : plants evaporative cooling, substrate evaporative cooling , plants direct shading , additional insulation layers by growing media and plants and growing medium thermal mass (Liu & Baskaran 2003).The variation in these factors have a direct influence on the green roof performance for example if the vegetation used is not evergreen this would reduce the evaporative and insulation function of the green roof.

Water content has a great influence on the performance of green roof as it contributes to the regulation of thermal balance and determines the release of latent heat. Green roof irrigation will be discussed in details within the dissertation.

Facades greenery which is known as vertical greenery systems (VGSs), offer a great opportunity to mitigate heat island phenomenon by shading and evapotranspiration. (Wong et al. 2010), however, they are yet fully investigated.

There are many categories of vertical greenery systems based on the construction method, growing medium and plants type.

Green walls offers more greenery opportunities than green roofs based on the area of facades compared to roof area especially at high rise buildings that became predominantly & Hien (2009)found that implementing a plant ratio at a skyscraper equal to one to seven would contribute significantly to urban greenery as the area of the façade would be three times to the area of the site.

75% of electricity consumption in Abu Dhabi is used for cooling the buildings. A simulation carried out by Al- Sallal & Al-Rais (2011) to find out that Eco-house design can reduce the cooling energy consumption by 24%and improve the building performance by 19%.

1.5 Grey Water use in irrigation

New water sources have been developed to face the problem of water scarcity. However; many of these new technologies have a negative influence on the environment if compared to the conventional system. For example: desalination plants increase the CO_2 emissions to the atmosphere and cause marine environment disturbance. Treated grey water is considered as the optimum water source in arid and semi-arid regions that is suffering from fluctuation in rain falls, water scarcity and water pollution rise.

Grey water is the water generated from all house activities except waste water generated from toilets, dishwasher, or kitchen sink. In the industrial countries, the domestic in-house water demand ranges from 100-150l/c/d (liter/capita/day) and 60-70% of this water demand transfer to grey water while the rest is used in water flushing, (Friedler et al. 2005). Quality of gray water varies basically depends on water supply quality, household activities and distribution type (biological and chemical processes, piping leaching...etc.).

The common application for treated grey water is irrigation however it has been practiced in recreational, industrial, urban and environmental reuse. The reuse of treated gray water in landscape irrigation can reduce the use of potable water significantly.

1.6 Aim and objectives

The aim of this research is to investigate two parameters of a residential building in Abu Dhabi. The first parameter is the thermal performance of different systems of green roofs and green walls. The second parameter is to investigate the feasibility of integrating treated grey water to be used in irrigation of green roof and green walls.

The objectives of the research are:

1. To determine the parameters of green roof that have a direct impact on the cooling loads of the buildings.
2. To measure the influence of soil thickness and plant types on the cooling loads and then on the electricity consumption
3. To determine the parameters of green walls that has a direct impact on the cooling loads of the buildings.
4. To investigate different methods to treat grey water of the building
5. To measure the volumes of grey water generated in a building and evaluate if it can be used in different application.

1.7 Dissertation structure

Chapter 1: Introduction

This chapter focuses on the Heat island and climate change phenomenon, thermal role of green envelope, grey water system role in sustainable development and aims and objectives.

Chapter 2: Literature review

This chapter illustrates the researchers conducted to investigate the thermal behavior of green roofs and green walls.

Chapter 3: Green Envelope

This chapter illustrates the green envelope`s benefits, history, types and construction. Plant types and irrigation also will be discussed in this chapter.

Chapter 4: Grey water

This chapter illustrates grey water history, benefits, limitations, Health and Environmental concerns, water treatment processes, regulation and global experience.

Chapter 5: Methodology

This chapter illustrates the methodology, Comparison between different methodologies, Selection of method, data collection and simulation program.

Chapter 6: Results and discussion

This section contains the results and discussion of green envelope simulation, grey water calculation and irrigation calculation.

Chapter 7: Conclusion and recommendation

This chapter includes the Conclusion of the dissertation and recommendation for further researches in the future.

Chapter 2: Literature review

Chapter 2: Literature review

2.1 Introductions

Thermal matters in the built environment are the conflicts between urban climate and buildings. A conceptual model considered the plants positive impact on that conflict proposed by Chen & Wong (2005) to clarify the three critical components interactions.

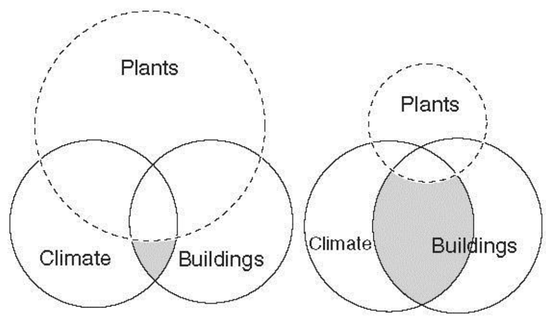

Figure 2.1: Environment model. Chen & Wong (2005)

With reference to figure 2.1; When buildings and climate are influenced greatly by plants, the shaded overlapping area` is decreased which indicate that the conflict is less, while when the plants influences is less on the building and climate the shaded overlapping area` is increased which means that more negative conflicts generated.

Worldwide researches classified greenery into three groups: vertical gardens, green roofs and public green areas. Public green areas are the open spaces` rural greenery areas. Their size is not important however they are crucial to promote the built environment quality and the city image. Public green areas turned into environmental luxuries because of the rapid urbanization and population's increment.

Roof is the best element of the building that can be used to enhance city life quality by planting it. There are many opportunities to create green roofs in the cities by planting the roofs of office buildings, underground car parks, residential buildings, terraces …etc. Green roofs are artificial spaces on the building`s rooftops. They have many benefits like creating a recreation space and beautifying buildings and ugly surfaces.

Vertical gardens also are artificial spaces where the vegetation introduced vertically to the building`s facades. they are still non common if compared to green roofs and urban parks because of the lack to researches, however Yu & Hien (2009) found that there is massive  potential to be implemented because of the recent researches and the façade`s vast area.

Vertical gardens can cover more hard surfaces in the urban environment especially if the dominant buildings are high-rise buildings. It was believed by Yeang (1998) that if a plant ratio of a skyscraper is 1:7 then the planted area will be three times the area of the site which contribute significantly to the environment greening. Yu & Hien (2009) believe that if two-thirds of the façade covered by plants this also will contribute to double green the site area.

2.2 Green Roof and Green Walls Role in Sustainable Development

Parizotto & Lamberts (2011) investigated green roof`s thermal performance and its water content effect of a single family house in Brazil. Three kinds of roofs had been evaluated: metallic roof, white ceramic roof and green roof. They also measure indoor air temperature of the three kinds of roofs .Researchers found that: the lowest surface temperature was in green roof while the highest was of the metallic roof. Substrate, drainage and the layer of air between them have diffusing properties that reduce heat transfer. Minimum temperature can be reduced by increasing the substrates' water content. The indoor temperature of green roof is less by 0.5-0.1 °C in summer while in winter all the types have the same indoor temperature. In general, they found that Green roof have the lowest heat gain in a comparison to the other kinds. Figure2.2 shows the heat flow through metallic roof, white ceramic roof and green roof in Brazil between 25th, May 2008- 30th, May 2008. The figure shows that the green roof is effective at that period of summer which reduces the cooling energy demand significantly.

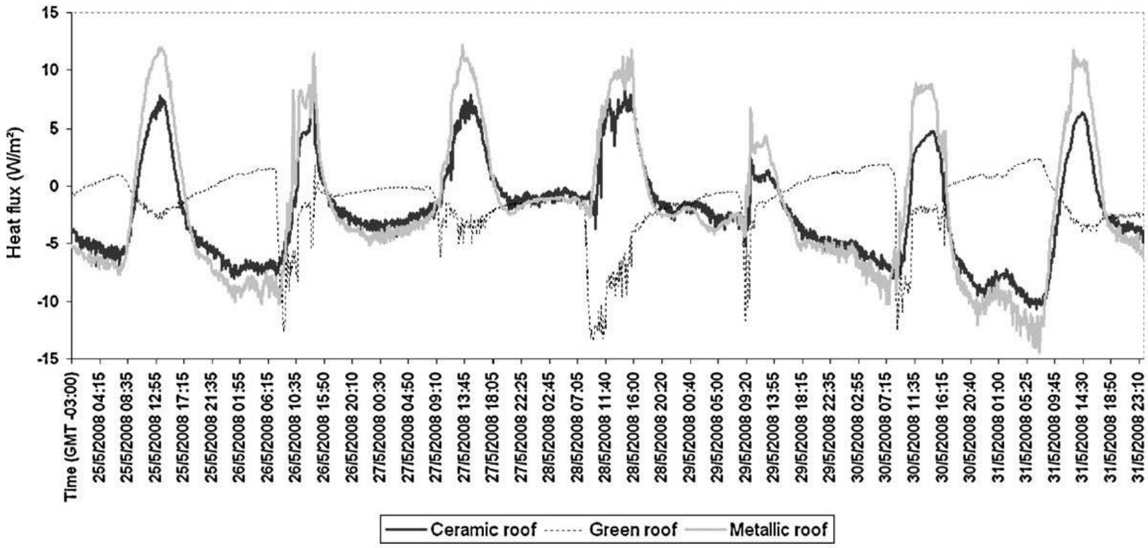

Figure 2.2: Heat flux in different types of roof. (Parizotto& Lamberts, 2011)

Fiorettiet al. (2010) investigated the thermal performance and thermal flow of green roofs of two public buildings in Italy. They found that the shade offered by plants can achieve an irradiance reduction on the soil which reduces its temperature and heat gain. In addition it was found that green roofs layers with different plants reduce heat flux into the indoor areas within the building which reduce the cooling loads needed.

A simulation was carried out by Sailor (2008) using Energy Plus building energy program to evaluate heat and moisture transfer through green roof and its influence on the electricity consumption. Different soil thicknesses, irrigation and planting density have been investigated. He found that the increment in soil thickness, vegetation density, and irrigation quantity can lead to cooling demand reduction and electricity consumption reduction.

Barrio (1998) explored the green roof`s thermal behaviors incorporating many parameters like: soil thickness, moisture, soil density, foliage geometry and leaf area index (LAI).He found that green roof is one of the best insulation methods to be used.

In order to get the maximum reduction in heat flux, designers should use light soil layer to reduce heat transfer by conductivity and should use vegetation with horizontal leaf distribution. Also he found that if density increased, the thermal diffusivity increases.

An experiment carried out to investigate evaporative cooling effect by green roofs by Onmura et al. (2001).They found that green roofs achieve a 50% reduction in heat flux from outdoor environment to indoors which reduce cooling energy demand. Also they found that heat flux and Moisture content have an influence on the temperature distribution. Roof temperature under green roof is very less than bare surface of concrete.

Theodosiou (2009) investigated the thermal behaviors of different layers of green roof. Figure 2.3 shows the green roof energy balance. Plants canopy produce shading to the surface of soil at summer. Shading efficiency depends on foliage density that expressed by index of leaf area. Foliage has the ability to absorb solar radiation and use it in photosynthesis and evapotranspiration which reduce the leaf temperature and then reduce the surrounding air.

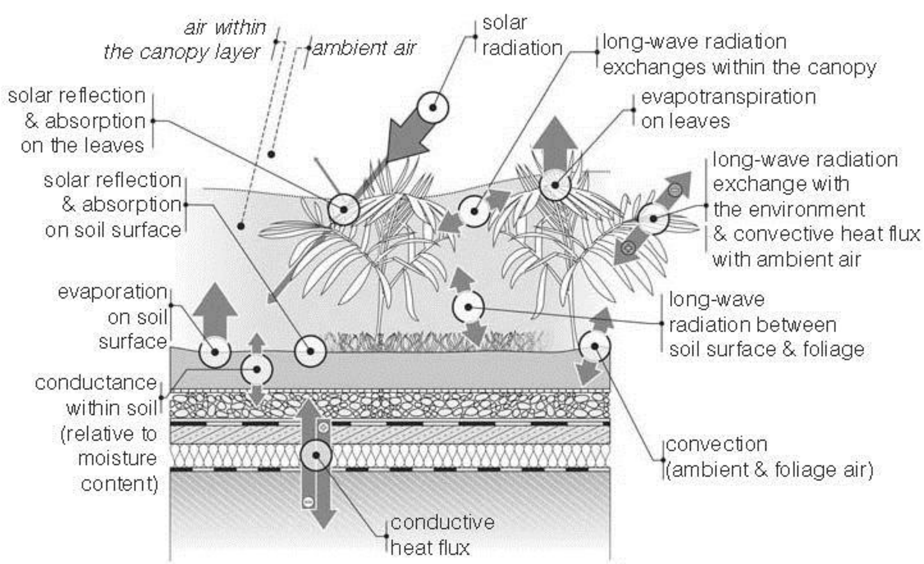

Figure 2.3: Green roof energy balance. (Theodosiou, 2009).

Maintenance is an important issue too, in un-greened roofs maintenance cause degradation to the roof materials by the engineers and personnel work to maintain ventilation and HVAC systems with soil and plants of green roofs produce protective layer between roof and human traffic. Theodosiou, (2009) found that Installing green roofs in tall building limit its benefits by the building`s upper storey so the energy conservation is limited while in the buildings that are consisting from single storey ,the energy conservation is higher which justify the initial cost increment.

Living walls contribute to surface temperature reduction. Bass & Baskaran (2003) Stated that living walls performing better than green roofs by reducing the temperature of surface by more than16ºC, and energy consumption by 8% annually.

Climbers can produce shading to the building which reduces the maximum temperature of the buildings. Furthermore, they can reduce the temperature fluctuation by 50% in warm summer zones. This reduction is depending on the total shaded area of the surface not the thickness of the climbers.

Climbers are effectively insulating the building against solar radiation as they are stopping the heat flux in the building first. It is more effective if it is used on the facades that have long exposure to the sun. Reduction of air temperature by 5.5°c immediately outside the building can achieve an air conditioning reduction of 50-70 %(Peck et al. 1999). In addition, greening facades contributes dust generation and heat island phenomenon reduction. Climbers have many advantages in winter also, for example the usage of evergreen climbers on the walls that are not exposed to the solar radiation can reduce heat loss.

Green walls can increase summer cooling by evapotranspiration which contribute in reducing air condition energy .the usage of evergreen climbers have a considerable advantage which is insulating the building in winter by reducing the wind chill on the surfaces and by maintain an air pillow between wall and the plant.

Cheng et al. (2010) found that Vertical gardens have the ability to reduce façade`s temperature and over time buffer its fluctuation which reduce the cooling loads of air conditioning. Vertical gardens cause temperature`s Time lag keep the indoor temperature low after sunset. The associations growth media moisture, cooling effect and planting coverage encourage to maintain healthy plant cover to maintain its transpiration and irrigation.

Alexandri & Jones (2004) found that Vegetation has the ability to mitigate the harsh climate of the built environment however this is depending on the location of planting (wall or roof) and the climate. Arid climate regions gets more benefits from existence of vegetation as humidity levels are low at these regions so plants evapotranspiration changes the concentrations of humidity which lead to significant thermal effect.

2.3 Grey water treatment role in sustainable development

Water is considered as one of the rare resources during current century which encourages many countries to implement sustainable solutions like onsite grey water recycling to reduce the overall demand of urban water. Grey water is the water generated from all house activities except waste water generated from toilets, dishwasher, or kitchen sink. It is estimated that 60% of domestic wastewater is grey water.

Pinto and Maheshwari (2007) investigated the health concerns about the use of treated grey water for irrigation purposes in Sydney, Australia. They found that the main concern of public was the water quality, health risk and cost. They believe that using treated grey water in in irrigation would overcome water scarcity occurred in Australia. They also recommended to the government to promote educational program to increase the awareness about water saving and grey water importance and applications.

The performance UF membrane filtration system was evaluated by Li et al. (2008). The system consisting from submerged spiral wound module. They found that the quality of treated water can enable its usage in soil fertilization and irrigation. The treated water characterized by less TOC, soluble nutrients; less turbidity and clear from suspended solids.

Li et al. (2009) evaluated different grey water treatment systems based on the characteristics of grey water, feasibility and standards. According to the researchers, all types of non-potable treated grey water have good biodegradability however in case of using biological treatment system so it is recommended to mix grey water generated from kitchen with the flow generated from laundry and toilet in order to produce good COD: N: P ratio. They found that physical treatment is not enough in grey water treatment to produce a proper quality of reduced organics content. In addition, they recommended chemical system to be used for single household as it is effective in the removal of surfactants, organic materials and suspended solids.

Anaerobic processes were not recommended by researcher due to their poor efficiency in surfactants and organic substances removal. The most feasible and economical grey water system consists from the combination of physical filtration, disinfection and aerobic process. For residential buildings it is attractive solution to use MBR system to treat medium and high strength flow of grey water.

Kulabako et al. (2011) investigated the characteristics of grey water and its involvement in the irrigation of tower garden in Kampala, Uganda. They conducted field surveys and collected and analyzed samples from soil and grey water. They found that irrigating tower gardens with treated grey water would have a limited influence on soil nitrogen, potassium and organic matter however it would increase the phosphorus content. The plants that been irrigated with treated grey water were thrived however pests attacked them which required a pest control. They stated that the tower garden`s hydraulic load should be determined in order to find out the quantity of grey water generated within the building for better performance.

2.4 UAE energy and water current consumption

Al-Omar, 2012, stated that United Arab Emirates is considered as the second largest consumer of water per capita after the United States in the world. (WWF, 2008). Rapid growth of population, hotel industry growth, orchards expansion and in efficient water consumption leads to increment in the water demand year on- year. Water demand increment increases the use of desalination plants that have various advantages and disadvantages (EAD 2009), *(*Roberts et al. 2010).

The total estimated population of UAE is 8 million. It was estimated in 2011 that 12% of the populations are nationals while the rest are expatriates. Abu Dhabi population is estimated to be 1,305,060 with the same percentage of nationals and expatriates.

According to (EAD 2006) the annual population growth rate in Abu Dhabi is 3.7%.
Water policy in Abu Dhabi Emirate focused on water resource`s increment rather than improving water demand management which increase the risk on both seawater quality and groundwater availability.The daily domestic consumption is considered high and been estimated to be 350-550 liters per capita. Gornall &Todorova (2009) found that daily consumption of villa dwellers' residents is 270 - 1,760 liters / person /day while daily consumption of Flat residents is 170 - 200 liters / person /day.

Environmental Agency is planning to reduce the water consumption within few years to make it 200 liters / person /day. Agriculture water demand fulfilled by the ground water , while household and drinking water demand fulfilled by seawater desalination plants that have a capacity of 683 (MGD) (Statistical center ,2010).

38% of water demand in Abu Dhabi is sourced from groundwater and used in agriculture while 23% is sourced from desalination plant and used for household or drinking. Treated water represent 6% of the total water consumption and used in forestry and landscaping.

Water resources in UAE are classified into conventional and Unconventional Water Resources. Conventional Water Resources are consisting from groundwater, springs and rainfall resources. The annual Rainfall is low and in Abu Dhabi City it reaches 20.4 mm only (EAD 2006). Rainy days have a cycle of 4-5 years and mostly occurred during February while annual rate of evaporation is high and reach 2,000 mm (EAD 2009).Generally the estimated annual rain water stock is 24 million cubic meter (Mcm) (EAD 2009).

According to Gornall &Todorova (2009) the groundwater reservoir reduced by 18 % since 2003 and the water consumption increased than the capacity of natural recharging by 24 times. Springs are usually located in Al-Ain city and its water is brackish. Groundwater is not used for drinking purposes as it has high content of nitrate and boron.

The only potable water source in Abu Dhabi Emirate is Seawater desalination plants. The total water production was 66,772.58 million gallon (MG) in 1998 and increased into 183,560.79 MG in 2010(Statistical center, 2010).It was reported that desalination plants plan to extend their capacity in order to cope the demand increment. The expansion of desalination plants will influence the marine environment drastically because of the hot brine water discharge. Figure 5.2 shows the water resources in Abu Dhabi emirate.

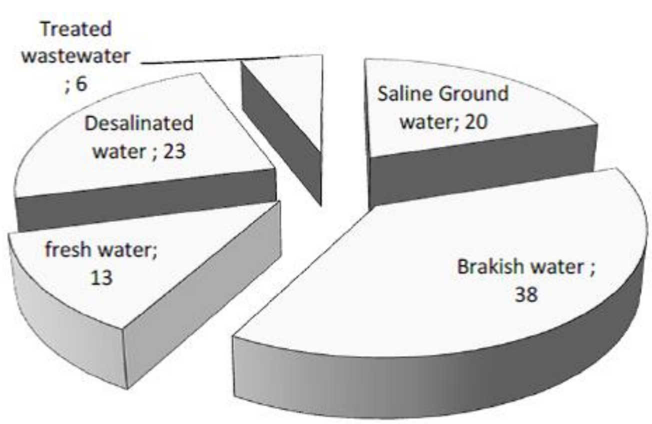

Figure 2.4 Water sources in Abu Dhabi Emirate. (Al-Omar, 2012).

There is another unconventional resource of water in Abu Dhabi which is reclaimed wastewater. Two sewage treatment plants are located in Abu Dhabi and Al Ain city to treat 95% of sewage (EAD 2009).An estimation occurred in Abu Dhabi in 2003 to find out that 4% of consumed water was from treated waste water (EAD 2006) .

Al-Sallal & Al-Rais (2011) found that the major electricity consumer in Abu Dhabi is buildings air conditioning and cooling that reaches up to 75% which generates high levels of greenhouse emissions .No researches and studies carried out in UAE to investigate the influence of Landscape on heat gain mitigation. New policies have been carried out in UAE to adopt green building like Estidama guidelines. In arid climate regions like Abu Dhabi where there is water scarcity, Landscaping is challenging because of its high water consumption .Estidama encourages the application of green roofs and landscaping in order to mitigate the effects of heat island phenomenon. Dubai Municipality (DM) introduced circular no. 171 on July 2009 to encourage green roofs and green walls usage in new buildings with considerations to the proper selection of irrigation system, membrane system, insulation materials and vegetation type.

2.5 Green Envelope Challenges

Green roofs important benefits notwithstanding, they have many constrains and challenges that should be considered. Cost is one of the important challenges in the construction of green roof as the capital cost is high and it takes long time to return on investment (Edmund& Lucie, 2006). Installing green roof on the top of 20 stories building will require efforts in conveying material to the top, either by labors or by using crane. Load bearing is another important challenge that affecting the vegetation planting and growing and materials hauling to the roof. The failure in selecting proper plants on green roof and installing the required growing medium and irrigation system will affect the green roof durability and make un-sustain. Lack of economic and environmental policies to support green roofs is another important issue that makes it undesirable for stakeholders. Lack of experienced professionals also an obstacle in designing, installation and maintaining green roofs which can add cost and mistakes. The availability of green roof materials like modules, premixed medium, roofing systems and vegetated mats is another concern specially that most of these products originating in Germany which can add significant cost and time to the projects.

According to Peck et al. (1999) green roofs obstacles are categorized in to four categories:

- Lack of Awareness and Knowledge
- Incentives Lack
- Cost
- Uncertainty Risks and Technical Issues

2.5.1 Lack of Awareness and Knowledge

However vertical gardens and green roofs are widespread in Europe, they still unknown in other regions. The qualitative and quantifiable benefits are still unknown for industry professionals, general public and politicians. Four groups of stakeholders should be aware of vertical gardens and green roofs:

1. Policy Makers.

Policy Makers should be conscious of the benefits and cost associated of vertical gardens and green roofs like job creation, storm water improvement and stakeholder`s reaction to program measures and government policy that support their incorporation.

2. Professionals

Professionals should be aware of vertical gardens and green roofs designs, implementations, products, concepts, plants, cost, and maintenance. Each layer of green system is reliant on the layer below it so each sub trade should know the requirements of other sub trades.

3. Researchers.

Researchers should be aware of energy savings information associated with different systems, storm water benefits information, economic benefits, large scale benefits like greenhouse gases reduction and ecological and Climatologically studies of green systems.

4. General Public

General Public should be aware of green roofs `public benefits to encourage governmental incentives and industrial, commercial and residential applications demand.

Lack of information about green systems characteristics and different types increases the belief that it is costly. For example green roofs can be established within one year while vertical gardens can be established within2-3 years however this can be solved by incorporating older plants or hydroponic system or inter-planting annual climbers or fastening containers to the wall.

Building owners should be aware of periodic maintenance that is required for each system incorporated to their building. There are some misconception related to vertical gardens and green roofs like the misconception of those climbers can damage the walls that attached to. This Misconception is correct if the used joints are installed poor .This problem can be avoided by using trellis or structure so vines can wrap around without the need to be directly cling to the building. Another important issue should be addressed is the height of vertical gardens above eight stories. Some plants are more suitable to be planted at high levels than lower levels according to local wind and temperature. Also supporting structure should be designed properly to tolerate to plants growth and wind.

There are no standards for living walls or green facades infrastructure however there are few professionals and firms that have a track record of the design and installation of living walls. However living walls contribution to the building is more than roof contribution based on the area, still living walls not popular according to the following reasons reported by Stav, (2008):

1. The concept of vertical vegetation still less familiar to the perception of human.
2. Living wall systems are complex because of Moisture retention issues.
3. The variation in the amount of light between higher and low levels which make it difficult to be considered in the design phase
4. Plant which placed on the high levels should be wind tolerance species.

2.5.2 Incentive`s Lack

Green roof industry`s development in Europe specially in Germany lead to legislation that requires green roof installation in new developments. Financial incentives carried out by municipal governments to create green roofs industry. Government can support the industry by: Subsidies and grants implementation, Policies to incorporate vertical garden/ green roofs to public buildings, Research and building codes and Legislation.

Government lack of support reasons are:

1. Lack of information about the benefits
2. High capital costs white the benefits are long-term which is disincentive for stakeholders want to invest in green systems.
3. Economic benefits like operations not accrued by investors or developers.
4. Lack of information about local success stories
5. social benefits are resulted from widespread applying of green systems

2.5.3 Cost

There is lack of information about cost associated with green roofs and vertical gardens installations which creates interrelated barriers to their implementation. It is difficult to sell vertical gardens and green roofs to clients unless they are part of the new projects. Most of building owners didn’t track the financial benefits of green systems incorporated to their buildings.

Cost including: capital cost, lifecycle costs and maintenance costs. Direct, long-term and tangible benefits still not understood which make it appear costly than actual. In addition, there is a market disincentive of long-term benefits. Maintenance costs should be within the original budget while commonly it is cut when operations budgets become restricted. Also the overall maintenance budget should be small as the building envelope will be protected however this cost still unknown.

Additional capital cost can be required as structural engineers and Consultants will be needed which make the un-favored by developers who tend to get operational cost saving. Infrastructure costs can be required. High initial cost is the core disadvantage of green roofs according as stated by Minton, (2012).The initial cost is based on the costs of root barriers, Waterproofing and maintenance systems. This initial cost can be compensated over the whole life cycle of green roof and can double or triple the life expectancy of membranes however it depends on eliminating the exposure of membranes to the solar radiation.

No financial or environmental analysis of living walls available as they still a budding practice (Stav, 2008). Maintenance of living walls could be environmentally demanding more than of green roofs maintenance due to the barriers of access and maintaining the vertical substrate with high moisture content which increase the demand for a test for their performance to show their benefits and barriers.

2.5.4 Uncertainty Risks and Technical Issues

Funding green roofs and vertical gardens researches are difficult to access. Funding sources are hard to be granted according to the multi-disciplinary nature of green systems. Unfortunately, lowest research budget is for construction industry comparing to other sectors. Due to the lack of information ,designers always sourcing new products and make assumptions regarding the capacity of load bearing and the different plants, layers and water compatibility. Most of the materials and products are available in the market not specifically to be used in vertical gardens or green roofs so it hard to get the warranty that usually clients request.

Lack of examples as well as the lack of special products in the market did lead to client lack of confidence in system, products and designers. Specialized products cost and transfer cost is an important barrier for example some minerals use in growing medium are 10-15 times expensive if transferred. However became a popular interest, gardeners have lack of experience in designing and maintaining techniques in addition to the lack of seed mixes and plants to be purchased. Plants nurseries specialized in green roofs and vertical gardens plants are not available everywhere which add a transportation cost and designers should order them a year before. Direct seeding is cheaper however it requires more initial irrigation and maintenance.

An important barrier related to the lack of information that some plants are seasonally which makes them looking bad from aesthetic point of view in winter. Improper maintenance which resulted from management difficulties can damage the roof. Also, designers and consultants who design the green roof may not be available after their installations which increase the warranty concerns. Trained maintenance staff is required especially in the first year of installation. Maintenance failure leads to green roof failure. Most of green roof system`s failure caused by the damage during maintenance or installation, faulty installations and improper drainage.

2.6 Policy and Politics of Green Envelope

Polices should be laid down by decision makers in order to promote green roofs. There is a variation in the political cultures in using ‘carrots “and “sticks” in democratic countries to encourage the economic and social sectors to commence the installation of green roofs. In economic countries that plan to extend largely like china, policy makers can lead to achieve the targets and results.

In order to support green roofs, three tools should be followed at the local level:

1. Subsidization the construction industry
2. Reductions on storm water fees
3. Include green roofs requirements at local development plans.

Environmental problems are considered as the main supporter of green roof policies. For example, the phenomenon of heat island that been occurred in Tokyo in 2001 led to Tokyo metropolitan government's decision that requested all the new public buildings over 250m² and all new private buildings over 1000m²to cover 20% of its roof by vegetation.

Some countries choose to tax property owner in order to encourage them to undertake means to reduce the environmental problems. For example Germany, property owners are charged for storm water management that is separated from the conventional sewage system using a discounts system to encourage the usage of techniques to reduce runoff. As an example of carrot rather sticks policy, some countries subsidize buildings that incorporate green roofs .Basel city in Switzerland supported green roofs by starting a campaign to promote the public awareness, house owner in Basel who incorporated green roofs to their buildings could get a 20% of their investment costs from the government which led to 3% of the existing flat roofs covered by vegetation within 18 months only.

A specific problem associated with all new technologies like green roofs is the capital cost and the benefits cash flow expectations. Subsidization and discounts can helps to solve this problem in countries that have high taxes however in other countries that don't have high taxes it is important to clear the economic benefits of green roofs. For example, in warm climate countries, reducing the cost of air conditioning and protecting roofing materials from degradation are two important incentives. In cities that are suffering from small open spaces to install storm water drainage system like swales and detention pools, green roofs will be economically attractive solution.

Peck et al.(1999) stated there are two programs can be adopted by governments to stimulate the use of green roof and vertical garden systems:

1. Creating incentive program of indirect subsidies or grants to encourage their usage. Government incentive can make up the market failure to recognize the different benefits of green systems.

2. Making green systems installation is mandatory by planning instruments or legislation to the building code.

Policies can provide a direct fund to the green roofs via subsidization or grants over tax relief for the installation of green roof in order to mandate green roofs goals like reducing heat flux or managing stormwater.

Jurisdictions can encourage the use of green roofs either by performance standards or by economic incentives. Maybe it is difficult to change the contemporary roofing practices however governments can start by incorporating green roofs into public buildings to show their commitment to sustainability and at the same time to provide a reference site for other developers. Private benefits can be spotted that can encourage the private sector to incorporate green roofs like marketing the company`s green initiatives, energy saving targets and providing a ‘functional space’’ for gathering.

Green roofs polices should be directed and customized according to each country conditions as green roofs still considered novel. According to Carter & Fowler (2008), it is important to integrate the collected data about local green roofs into policy recommendations. In order to increase the benefits of green roofs, greening scenarios should be demonstrated according to spatial analysis that been implemented to industrial and commercial corridors with policy recommendation. Private enterprise and public initiatives are the main drivers of green roof`s future industry. Counting ability of public benefits of green roofs and limitations factors that affect them are the key to evaluate the effectiveness of policy instruments of green roofs. Day by day the tool of urban greening is becoming more popular so it is important to recognize its limitation factors to maintain the policy and public support of green roofs functions. Using green roofs as an innovative practice not only reduce building`s ecological footprint in ecosystems but also can be the base to create broader plan of green infrastructure. Theodosiou (2009) stated that private buildings with areas that are greater than 1000 m^2 and public buildings that their areas are greater than 250 m^2 are obligated to install a green roof occupying 20% of the total area of the roof in Tokyo, Japan, while in Germany 13.5 million m² of green roofs are added annually based on the buildings regulations enforcement. Toronto city implemented a policy that requires 50–75% of the building’s footprint to be covered by green roof.

Chapter 3: Green Envelope

Chapter 3: Green Envelope

3.1 Introduction

A green roof is a roof that is containing a layer of soil and a layer of vegetation on its outermost surface. Since centuries green roofs were incorporated into many buildings in many counties, however nowadays there is a huge interest in their installation in new and retrofit buildings for their many advantages.

According to Green Roofs for Healthy Cities (2008), a 'Green Wall', is a terminology used to describe all the forms of vegetated walls. Green walls popularity is growing because of their aesthetic value, small footprint and their influence on mitigating heat island phenomenon. They are considered as an alternative to green roofs in contemporary cities as the wall to roof ratio is high.

This chapter focuses on highlighting the history, benefits, types and construction of green roofs and living walls, plant and irrigation.

3.2 Green Envelope benefits

There is a wide range of green envelope benefits if compared to conventional building`s envelopes. The achieved benefits of green envelope depend on the scale. Some benefits will work if the many large green roofs and living walls are installed in any specific area and can be apparent on city or neighborhood scale. Other green roofs and living walls operated directly on the individual buildings. The green envelope benefits can be classified into three categories: aesthetic and amenity, economic and environmental. It is recommended to distinguish between private and public benefits of green envelope when promoting its idea depending on the audience. Private benefits are related to promote the personal and financial benefits to individual building, developer or owner. Examples of private benefits are such as: energy cost saving, improving the aesthetic appeal and roof life span extension. On the other hand, public benefits will enhance planning regulations and polices adoption to promote environment and life quality and to promote cost efficiency at long term. Public benefits are such as: habitat and biodiversity promotion, storm water management and mitigation of urban climate.

3.2.1 Environmental benefits

I. Promoting wild life and biodiversity

One of the most important benefits of green envelope is its ability to promote wildlife and biodiversity in urban areas that been largely barren by urbanism. Green roof have produce the habitat for semi-natural plants communities on roof top similar to dry environments with rocky and shallow soil. It also support the habitat of endangered species that are rare and valuable .One of the plants ecology fundamental facts is that wide range of plants can be supported by infertile habitat because aggressive vigorous plants cannot grow and dominate delicate plants unlike fertile soil. As a result of the plants diversity, animal’s diversity will be achieved. Extensive green roofs are usually isolated and separated from people thus it is provides undisturbed habitat for birds, insects and plants.

Researchers studied the birds activity on green roofs and found that they mainly visiting the green roof looking for the food. Birds species that been recorder were house sparrows, rock doves, wagtails and black redstarts. It was also noted that green roofs in areas near agricultural lands are less visited than the ones in densely urban area and the reason was because the lack of food in urban areas that makes birds looking for food and new habitats on green roofs.

Planting native trees promote insect’s life which provides the food for many birds and even bats. Hybrid green spaces which include native and non-native trees can promote wild life and at the same time offer an aesthetic beauty. Some non-native shrubs and trees like buddleia and sycamore can attract many kinds of insects. For example buddleia provides an abundant nectar source by its flowers for butter flies (Johnston& Newton, 2004).

Invertebrates species can be found in the green facades have the ability to form the rich web basis of life as they are the food of birds specially the migrant species. Climbers also provide nesting and roosting sites for birds and small insectivorous species. Climbers produce the insect's food like nectar and some leaves can be the food of larva. Climbers can offer a hibernation place for some insects like lacewing, moths and butterflies.

II. Water management

The rain water fall on vegetated area is different than if it is fall onto urban hard surfaces. In vegetated areas rain is absorbed by soil, plants and some is go back to atmosphere through transpiration while on hard surfaces, water cannot be absorbed then it run off through sewage system which remove it quickly and cause its loss.

It was found by researchers that impervious surfaces run off can cause streams quality degradation. The loss of rain water affects the ground water table drastically which can affects humanity and nature and cause drought. Green roofs have the ability to reduce the runoff with increased open spaces, less densely buildings and increasing the holding capacity of water.

The advantages of these two solutions are: Replenishing ground water, reducing the pressure on the drainage system and providing areas of wet lands, flood risk reduction, reducing drainage schemes cost by reducing the bore pipes size. According to the Dennett& Kingsbury (2008), roof surfaces represent 40-50% of impermeable surfaces that are within the urban design so implementing green roofs promote the sustainable urban drainage system as shown in figure 3.1. There are many components in the sustainable urban drainage system that are cheaper than piping and more sustainable like Biowales that can enable the water to penetrate through the soil and evaporate to atmosphere, Storm water planters and rain gardens intercept runoff ,drainage basins , storm water management ponds, pavement surfaces and porous roads.

The role of green roofs with runoff is that the falling water can be absorbed by substrate materials, can be directed in to pore spaces within the substrate, absorbed by plants or evaporated into atmosphere. Water also can be stored by the drainage system on the green roof and retained back, storing water for a period of time before it runoff make it acting like a buffer between the drainage system and the weather. Rainwater storage for a period of time at summer heavy rainfall storms reduce the peak which reduce the pressure on drainage system that deal with moderate flow at longer periods than massive flow at shorter periods. Water storage depends on many parameters like: substrate depth, season, substrate moisture content, slope, type of layers plants type, growing media physical properties and rainwater intensity. Water storage on green roof can be achieved by using wells, cisterns pools and ponds.

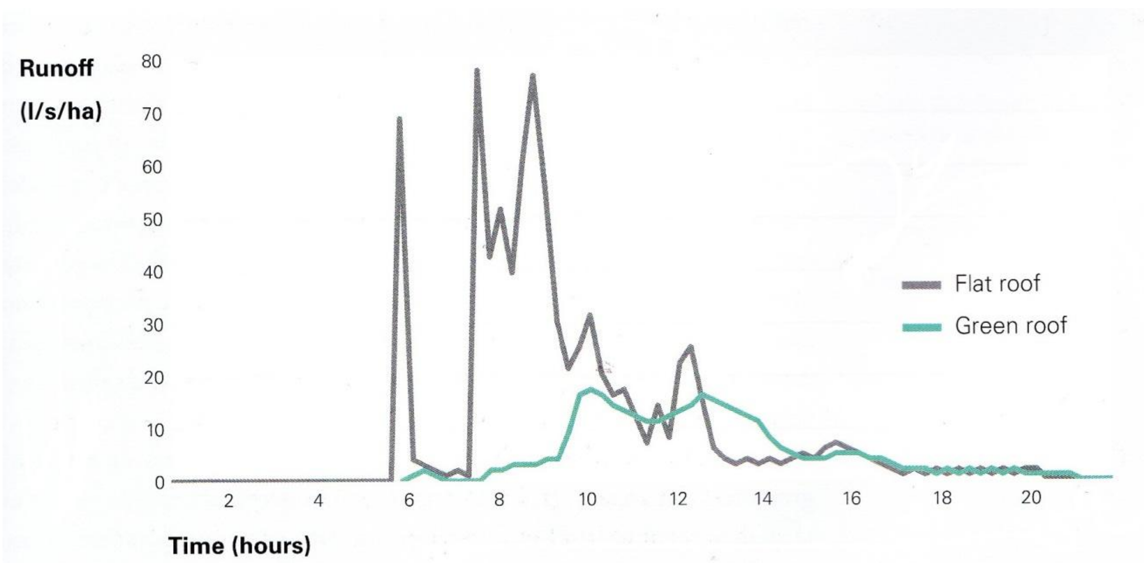

Figure3.1: runoff comparison between extensive green roof and conventional roof. (Dennett. & Kingsbury ,2008).

III. Quality of run off

Green roofs offer a valuable benefit in reducing pollutants in runoff which improve its quality. For example it was found by Berghage et al. (2007) that green roofs reduce the nitrate quantity significantly and at the same time have higher pH level which reduces the acid rain. It was found also that the nutrient quantity in green roof influenced by two factors which are the composition of medium and growing substrate as the materials can leach elements like phosphorus after the installation of green roof. This leach is not significant unless used for sensitive areas so in that case it is recommended that the growing media in the green roof should not be compost rich .The second factor is the fertilizer application. It was demonstrated by Emilsson et al. (2007) that the runoff resulting from using conventional fertilizer in the green roofs consisting of lightweight sedum have high levels of phosphate and nitrogen.

IV. Carbon sequestration and air pollution

Vehicle engines are the main cause of particulate matters and air pollution because of its emissions .Green roofs filter the air from fine airborne particles because it settled on the stem and leaves of the plants and then washed off into the soil by rain or irrigation.

Plants foliage has the ability to absorb the gaseous pollutants and sequester them in their tissue. In order to achieve that valuable benefit of green roofs, it is recommended to use evergreen vegetation and incase of using intensive green roof it should be supported by shrubs and trees. Another important benefit of green roofs is that they are acting as carbon sinks.

Dust and gaseous can be absorbed by leaves. It was found that planted streets contain only 10-15% of dust if compared to streets that are not planted .However this percentage can be increased to 60% in winter in the absence of foliage. Johnston& Newton(2004) reported that green walls with climbing plants are covering a large area so they can filter more pollutants and dust .Thonnessen (2002) found that 4% of dust can be trapped by plants of green facades at Dusseldorf. Darlingtonet al., (2001) found that vegetation also improves indoor air quality by removing VOCs (Volatile Organic Compounds). According to Gonchar, (2007) Bio-filtration is considered as a significant benefit of indoor living walls.

V. Noise pollution

Hard surfaces that compromise the urban areas tend to reflect sound depending on the substrate layer thickness. For example it was found that green roofs with 12 cm substrate reduce the noise by 40 decibel while green roofs with 20 cm substrate reduce the noise by 46-50 decibel. Trees offer a pleasant soothing sound and reduce the noise .However the noise reduction depends on vegetation type thus it can vary between 1.5 dB to 30 dB per 100 meters (Johnston& Newton, 2004).

3.2.2 Economic benefits

I. Roof life span increment

The main concern of professional and industry makers in regards to green roofs is its content of water which can lead to damp penetration and leakage to the buildings. However, the usage of appropriate construction method will make green roofs last longer than conventional roof with cost benefits.

Heat can reduce the durability of conventional roof because it accelerates the bituminous materials aging. Ultraviolet radiation degrades the mechanical properties and changes the chemical composition of bituminous materials. The membrane that been used on conventional roofs absorb the heat during the day time depending on its reflectance and color. At night time the conventional roof re radiate the heat and its temperature drops. this daily fluctuation in temperature produce a thermal stress on the membrane which performance, durability and its ability in reducing water infiltration to the building.

Green roofs have a role in increasing the life span of structural roof by moderating the fluctuation in temperature during different seasons of the year. The fluctuation reduction is depending on vegetation type.

Porsche & Köhler (2003) stated that Waterproofing layers replacement occurred every 20 years in conventional roofs while in green roofs it can be retained up to 90 years.

II. Insulation , Cooling and Energy Efficiency

The direct economic benefit of green roofs is its ability to reduce air-conditioning or heating costs for individual buildings. Green roofs have several properties that contribute to its thermal characteristics like : plants evaporative cooling, substrate evaporative cooling , plants direct shading , additional insulation layers by growing media and plants and growing medium thermal mass (Liu & Baskaran ,2003).The variation in these factors have a direct influence on the green roof performance for example if the vegetation used is not evergreen this would reduce the evaporative and insulation function of the green roof.

Wong et al. (2003), used DOE-2 (simulation program) to evaluate green roof`s thermal transfer value, cooling loads and energy consumption in a building consisting from five stories in Singapore. They made two simulation comparisons: the first between three types of roofs (conventional roof, green roof and exposed roof).the second between three different soil thicknesses and moisture content within a green roof. Researchers found that a significant reduction achieved by Green roofs in regards to peak space load, annual energy consumption and cooling loads. The varying soil thicknesses lead to variable reduction in peak space load, annual energy consumption and cooling loads and the best vegetation to be used on a green roof is the Shrub.

An experiment carried out by Santamourisa et al. (2007) to investigate green roof efficiency of a nursery in Athens. They found that green roofs achieve a significant reduction in cooling loads in summer and promotes the distribution frequencies as shown in figure 3.2.

In regions that using air conditioning is essential for indoor thermal comfort the usage of green roofs can be a major reason because every 0.5°c reduction in indoor air temperature can reduce 8% of air conditioning electricity. It was found that in a typical building in Canada, the installation of 10 cm substrate with a grass green roof reduces 25% of cooling required in summer. Green roof installation reduces the peak and annual energy consumption. Additionally, Liu and Minor (2005) found that green roofs reduce the heat flux by 75-90% in summer and 10-30% in winter.

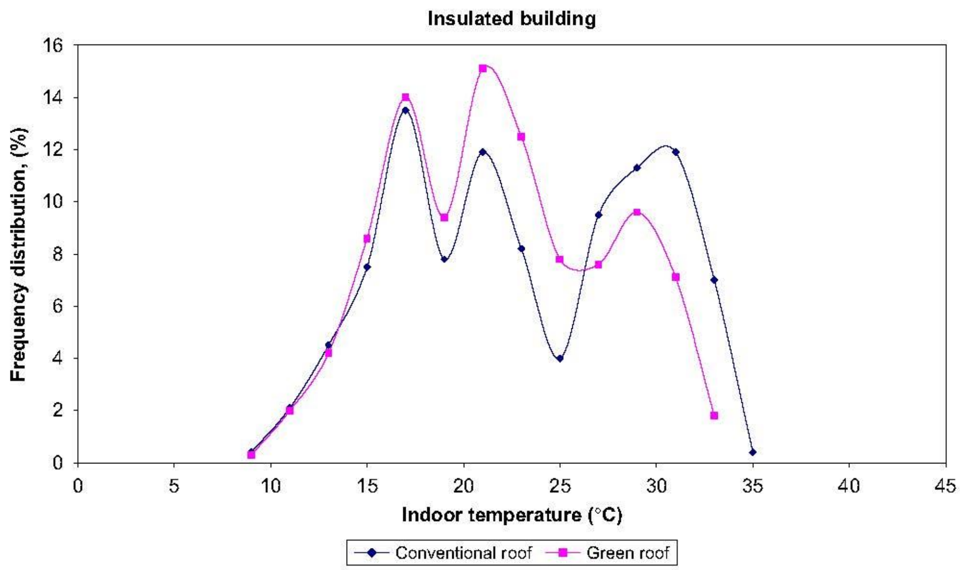

Figure3.2: Distribution frequencies of green roof and conventional roof. (Santamourisa et al., 2007).

Green roofs and green facades not just reduce the heating and cooling cost but also reduce the air conditioning equipment required and the insulation needed. According to Johnston& Newton (2004)Shade offered by trees depend on tree types, for example, thick dense canopies provide a 98% of solar radiation interception while light thin canopies provide a 60-80% of solar radiation interception . The interception achieved by reflecting 10-25 % of solar radiation and absorption the rest radiation by photosynthesis and transpiration.

Planting deciduous trees allows 40-70% of solar radiation to reach during winter to the building. Humidity increased in planted areas by moisture release which increases the cooling effect of atmosphere. It was estimated that cooling effect by grown tree transpiring 450litres/day by its leaves is equal to 5 air conditioners of average size room running for 20 hours/day (Johnston& Newton, 2004). Planting shrubs and trees contribute to energy saving of buildings however this saving depends on prevailing climate, planting location, building type and trees type. For example planting trees on the west side of the building can provide shading in summer, heat gain in winter and reducing wind penetration(Johnston& Newton, 2004).

Alexandri & Jones (2004) demonstrated that vegetation has the ability to mitigate the harsh climate of the built environment however this is depending on the location of planting (wall or roof) and the climate. Arid climate regions gets more benefits from existence of vegetation as humidity levels are low at these regions so plants evapotranspiration changes the concentrations of humidity which lead to significant thermal effect.

Green walls can reduce the temperature fluctuation by 50% in warm summer zones. This reduction is depending on the total shaded area of the surface not the thickness of the climbers. Furthermore, they can effectively insulate the building against solar radiation as they are stopping the heat flux in the building first. They are more effective if they are used on the facades that have long exposure to the sun. Reduction of air temperature by 5.5°c immediately outside the building can achieve an air conditioning reduction of 50-70 %(Peck et al. 1999).

Cheng et al. (2010) found that vertical gardens have the ability to reduce façade`s temperature and over time buffer its fluctuation which reduce the cooling loads of air conditioning. Vertical gardens cause temperature`s Time lag keep the indoor temperature low after sunset. The associations growth media moisture, cooling effect and planting coverage encourage to maintain healthy plant cover to maintain its transpiration and irrigation. Alexandri & Jones (2004). Stated that vegetation has the ability to mitigate the harsh climate of the built environment however this is depending on the location of planting (wall or roof) and the climate.

Living walls contribute to surface temperature reduction. (Bass & Baskaran, 2003), Stated that living walls performing better than green roofs by reducing the temperature of surface by more than16ºC, and energy consumption by 8% annually.

Schmidt (2006) investigated green façades evapotranspiration effect in cooling; he reported that evapotranspiration rates of green facades produce average cooling of 157kWh per day.

III. Public relations and green building assessment

Green roofs can gain points in different green buildings rating schemes .For example under the US LEED program, one point can be gained by covering 50% of roof by green roof to reduce heat island effect and one extra point for storm water management (U.S. Green Building council, 2009).Gaining more points under green buildings rating schemes can increase the economic value of the buildings and attract environmentally –conscious people. Green roofs can gain points (up to 15) in many LEED categories like:

1. water efficiency
2. energy and climate
3. materials and resources
4. indoor air quality
5. innovation in design
6. Reduced site disturbance, protecting or restoring open space.

Abu Dhabi Emirate recognized the importance of water, nutrients and energy sources so it creates Plan Abu Dhabi 2030 environmental policy in order to develop sustainable infrastructure technologies that are managing waste, water and energy.

Estidama is a green rating system that is developed by Abu Dhabi Emirate to comply with Abu Dhabi 2030 requirements. Green roofs and /or living walls can gain points in many ESTIDAMA categories like: Natural Systems, Precious Water, Livable Buildings, energy and materials. Table 3.1 shows the credits that can be earned by incorporating a green roof and/or living walls within buildings which shows that implementing green roofs can gain points and the use of native plants that their water demand is minimal also can gain points.

Table 3.1: Estidama credits can be achieved by installing green roof. (Abu Dhabi Urban Planning Council, 2010).

Credit	Intent
NS-3: Ecological Enhancement	Credit is awarded if 50% of specified plants are native and drought and saline tolerant.
	Credits are awarded if 70% of specified plants are native and drought and saline tolerant.
NS-4: Habitat Creation & Restoration	Credits are awarded if restoration Strategy or Habitat Creation implemented
LBo-3: Accessible Community Facilities	Credit is awarded if the building is located within 350m of five amenities like Public open space
LBo-4: Active Urban Environments	Credit is awarded if outdoor activity area implemented like recreation area and Playground areas.
PW-2.1: Exterior Water Use Reduction: Landscaping	**Plant Selection** Credits are awarded if Average irrigation demand < 4 liters/m2/day
	Credits are awarded if Average irrigation demand < 2 liters/m2/day
	Credit is awarded if Water Efficient Irrigation System has been implemented.
	Recycled Water Credits are awarded if two credits of plant selection achieved in addition to providing the building by 100% Exterior Water Allowance or installing recycled water mainline loop
PW-4: Stormwater Management	**Quantity Control:** Credit is awarded if peak runoff rate of post-development doesn’t exceed the one of pre-development within 2-year by using combination of Non-structural and structural methods.
	Credits are awarded if peak runoff rate of post-

	development doesn't exceed the one of pre-development within 2-year by using combination of Non-structural methods.
	Quality Control Credit is awarded if the management system of stormwater has the ability to collect and treat at least 90% of stormwater.
RE-R1: Minimum Energy Performance	Prerequisite is achieved if 12% improvement in the performance proofed be simulation modeling.
RE-1: Improved Energy Performance	Credits are awarded if further reduction of the building energy consumption achieved.
RE-2: Cool Building Strategies	To determine the most effective solution to reducing a building's cooling demand by incorporating passive design strategies as a priority.
	Credits are awarded depending on the energy reduction resulted from incorporating passive
	Credit is awarded in case of using high Solar Reflectance Index for roofing materials (SRI) >78
RE-5: Peak Load Reduction	Demonstrate the following: Credits are awarded If the electrical peak loads lower than 80% greater than the design annual electrical load.
	Demonstrate the following: Credits are awarded If the electrical peak loads lower than 60% greater than the design annual electrical load.
SM-2: Design for Materials Reduction	Credit is awarded if 50% or more of the roof or 10% of the walls covered by vegetation.
SM-6: Design for Durability	Credit is awarded if building components protected from water ingress, condensation and improper drainage

3.2.3. Aesthetic and amenity benefits

I. Green Roof amenity value

Green roofs produce recreational areas in neighborhoods that have little green space on the ground level. One of the important considerable advantages of recreational green roofs that its access is controlled so it is safer than ground level green spaces that are suffering from different social problems .

Residential neighborhoods and commercial developments with green spaces and planted street are more desirable than other. (Johnston& Newton, 2004). Another advantage of green roofs is that it is easier to install than ground level gardens that have the obstacles of ground permeability, underground pipes and cost of land.

II. Food production

In North America and Europe there is a concern regarding food transfer over long distances which consume energy and produce pollution. Shipping fruits and vegetables from far side of the world and it reach its destination after a period of time deteriorates its nutritional quality.

Green roofs can be used to plant healthy crops especially in high density areas .for example herb species performing better in sunny situations in free-drainage soil. Alpine strawberry can be planted in shady areas. In some countries like Colombia, Thailand, Russia and Haiti balconies and roof tops were used to produce marketable products like vegetable, fruits and even orchids (Dennett & Kingsbury, 2008).

Vertical gardens can produce fruits, climbing vegetables (like: beans and tomatoes) and grapes. Vegetables, grains and fruits also can be produced by green roofs.

If the green roof is intended to plant crops, special considerations should be given to the green roof depth and the structural roof design. Green roof can be leased to be used for food production which increase its economic benefits also producing food on the roof top will not require cost to extra land purchase. According to Peck et al. (1999) developing countries employed vertical gardening and green roofs in food generating for local consumption. This employment has many advantages like:

- Increasing the food access by everyone.
- Producing Fresher.
- Decreasing environmental and travel costs.
- Increasing the economic opportunity.
- Improving fertilizers and soil control.

III. Aesthetic Value

It was found by US Forest services that tress contribute to 7-15% of property value. According to a study done by Roger Ulrich, it was found that patients in a room with view to deciduous trees can recover in 24 hours less than usual which reduce hospital care cost. Recovery period reduction reduces the cost of medicine and nursing attention.

Urban greening is considered as an effective strategy to beautify the built environment. Earliest records in the Studies showed that Western cultures promote nature appreciation in their citizens and encourage them to negatively affect the beauty of their cities (Peck et al., 1999). Vegetation can be used to disguise bad building`s design or to promote building`s design by adding visual interest to roofs and walls. Also it has the ability to blend new buildings with the suburban or rural surroundings.

According to Johnston& Newton (2004) green roofs offer the following:

1. Offering visual beauty.
2. Providing psychological link with surroundings.
3. Reflecting seasons changing.
4. Offering natural element to built-environment.

IV. Job Creation

Green roofs have the potential of creating jobs. Green roof industry growth in Europe is remarkable, for example, the green roof industry`s annual growth is 15-20% in Germany. Green roof industry can promote the following (Pecket al., 1999):

- Root barriers and roof membranes manufacturers and suppliers.
- Irrigation systems, drainage layers and other special products manufacturers and suppliers.
- Light-weight soils and substrate manufacturers and suppliers.
- Landscapers and Contractors.
- Maintenance companies.
- Roof consultants, professionals and Designers.
- Plants nurseries that specialized in the plants of vertical garden and green roofs applications like: sod with wildflowers, varieties of alpine/succulent, vine…etc.

V. Human well-being

Nature and Greenery have a therapeutic effects that been documented by many researches stated that people prefer a natural setting than being sitting in a congested built environments. Also these studies recommended implementing garden view in order to reduce stress and restore calm. Banting et al., (2005) indicates that working areas that exposed to nature spaces influence the people and increase their cope with stress, ideas creation, focus, and productivity and at the same time reduce volatility.

Laverne & Winson-Geideman (2003) reported that implementing good aesthetic landscape would increase the rental value of residential and offices properties. In addition, living walls have the ability to produce two important benefits which are: green view and accessible natural landscape to the street so they should be designed properly not to block the visual view from windows and at the same time produce the aesthetic value all the year by using evergreen plants for example.

3.3 Green roof`s history

Tigris and Euphrates river valleys and Romans civilizations were the first to create green roofs in seventh and eighth centuries. Babylon hanging gardens are the most famous example of ancient green roofs. In the middle of 1800 s concrete were developed to be used as a roofing material and later in 1868, the first nature roof was produced in Paris within the world exhibition. In 1903, roof gardens and planted terrace were implemented in Paris.

Later in 1914, the first restaurant constructed with roof garden in Chicago designed by frank Lloyd wright. From 1920s, Le Corbusier is considered as the first architect to use systematically roof gardens however this approach only shown in the elite buildings that were related to wealthy clients. It was known that the use of flat roofs constructions that have the ability to carry large loadings led to the usage of green roofs for aesthetic reasons only. Urban plazas were constructed in the second half of the twentieth century as a large roof landscape however they were un- recognized by people because it was in roads, subways and over underground car parking.

Grass roofs are considered as elements of vernacular architecture of some countries and regions like Scandinavia, Millennia and Kurdistan (areas include Iran, Iraq and Turkey).In these countries, mud was the conventional building material that was used to construct flat roofs covered by mud and colonized by grasses to create turf roofs. These roofs used to reduce heat loss in winter and to reduce the heat gain in summer.

Rooftop greenery was found in traditional houses in Japan and china .Green roofs were used in Japan to strengthen the roof structure in rains season. Examples of plants used in Japan green roofs are: *polygonatum, hosta, hemerocallis, allium, lilium auratum and selaginella tamariscina*. Turf grass cheapness was the main reason to use it as a building material in Scandinavia.It was mainly used to protect cottage and small buildings from rain by installing birch bark layers, straw or twigs and turf. Birch bark layer is considered as the sealing membrane while twig layer is considered as the drainage layer. Building materials development reduces the green roofs construction in Scandinavia. These developed materials affordable, available in areas that don't have turf and required less maintenance.

The origin of the contemporary green roofs is the German speaking European countries as a result of ecological pressure groups, environmental aware, scientific research and the political pressure to implement it widely. Integrating buildings with plants was first experienced in Germany and Switzerland in 1960s and 1970s.*terrassenhäuser* is an example of house that been built on steep gradient and its lower roof is the garden of its upper part. In addition, underground parking was covered with vegetation and earth.

Many technical difficulties related to roots penetration and water leakage were found at this period of time. In 1970s, Germany was promoting the publishing of green roofs article and books in order to encourage the designers to incorporate green roofs into their buildings as a demand to promote the urban environment not as luxury approach.

The most prominent green roof in Vienna was designed by the Australian architect Friedenseich Hundertwasser using 250 shrubs and trees and 992 tons of soil. The green roof designed by Hundertwasser was eccentric style and colorful that was part of the 1960s-1970s counter-culture. Later of 1960s,"greening the city" approach started in order to promote the counter-culture movement. In European cities like Berlin, whole blocks took over plants in containers that been made from recycled materials found in flat surfaces, vegetables planters shown on the roofs, climbers planted to the walls, and waste ground areas were added to community gardens.

In the middle of 1970s, most researches focused on extensive green roofs. Green roof study group creation in 1977 within the German landscape research, development and construction society is considered as one of the important developments of green roofs as it was concerned with landscape researches, specifications and standards. Green roof researches started in 1950s in Germany as a result of the recognition of its value to the environment and ecology especially in the areas that are considered as brown field sites. In later 1960s, investigations carried out about the techniques of plants growth in thin layer of substrate. In later 1970s it was found the influence of green roof on water runoff minimization and energy conservation by Professor Hans-Joachim and Dr. Walter Kolb. At the same period of time, companies like Optigrün and ZinCo started to offer specialist services of roof greening including research programs and product development which produce the commercial extensive green roofs that are based on sedum .Environmental costs is the main reason of transferring green roof ideas into mainstream thinking in order to reduce environmental damage and pollution which is at the same time affecting the economy. As a main idea, planting plants into the urban areas can reduce the costs that imposed by urbanism into the environment.

3.4 Green roof types

There are two categories of green roofs; Intensive and extensive. Each type has its own methods, aims and applications. The differences between extensive green roofs and intensive green roofs were discussed in table 3.2.The division between the two types of green roofs is basically because their overall weight.

Extensive green roofs generally are within the usual capacity of roof structure`s load bearing because of their lightweight while intensive green roofs have structural implications and have serious load that should be considered. Thus the selection of green roof type depends on the load bearing capacity of roof structure.

Installing green roof within new building construction is achievable as the load bearing capacity can be considered at the design stage of the roof structure ,however retrofitting green roof in existing buildings needs either to upgrade the roof structure or to design the green roof to suite the existing loading capacity of the roof structure .

Extensive green roofs with a 5-15 cm substrate lead to increment of 70-170 kg/m^{2}of the roof loading while intensive green roofs with soil substrate lead to increment of

290-970 kg/m²of the roof loading (Dennett& Kingsbury, 2008). The implications of green roof`s load requires that the structural engineer to be involved in the design stage to consider it in the structural design. Green roof materials load vary depending on their moisture content and compactness degree.

3.4.1 Intensive green roof

Usually called roof garden and require intensive management. It is consisting of thick growing medium around 200m or more mulch or soil, irrigation system, different types of plants. The main objective of this type of green roofs is to create open space so it is usually incorporate seating areas and paving.

Roof garden can incorporate all the features that found in a wildlife garden like shrubs, trees, ponds, lawn and flower beds. Shrubs and trees are important for birds nesting, feeding and covering. It is important to use flowering species to feed insects in spring and to feed birds later period of the year. Hedges also can be used to protect plants from wind.

3.4.2 Extensive green roof

This type is usually used for ecological reasons and to produce aesthetic appeal but not for creation. It requires less water, maintenance and fertilizers and considered as self-sustaining. The growing medium is less than the one used for intensive green roofs 50 mm and the plants are selected to survive against different climate conditions.

3.5 Construction of green roof

Green roof can be constructed on any properly designed roof structure as long as loading capacity considered and implemented. Contemporary green roofs can be complex with many different layers and materials as illustrated in figure 3.3. Dennett& Kingsbury (2008) clarified the main components of typical green roof:

1. Structural roof: supports the green roof different layers and materials.

2. Vapor control layer: facilitate the roof vapor to get out of the roof and avoid condensation.
3. Thermal insulation: there are three positions of roofing insulation. The first on the top of roof structure and called warm room, the second is beneath the roof structure and called cold roof and finally, the on the top of water proofing and roof structure and called inverted roof (refer to figure 3.4).
4. Membrane or Water proofing layer:
5. Shingle, pavers or gravel to eliminate the direct exposure to solar radiation and protect the membrane.

Table: 3.2: Extensive and extensive green roofs structure comparison. (Oberndorfer et al., 2007).

Characteristics	Intensive green roof	Extensive green roof
Purpose	Aesthetic and function	Functional: for thermal insulation and storm water management
Structural requirements	Should be considered at building designing phase at it requires structural considerations	Within structural roof load.
Substrate type	Low organic matter, high porosity, lightweight to heave	Low organic matter, high porosity, lightweight.
Substrate width	20 cm or more	2-20 cm
Plants	No specific restrictions, selection depends on the substrate width , climate, irrigation and exposure	Low growing plants, climate tolerance
Irrigation	Required	Little or low irrigation
Maintenance	Required	Little or no maintenance
Cost	200$/m²	10-30$/m²
accessibility	accessible	Generally accessible for maintenance only

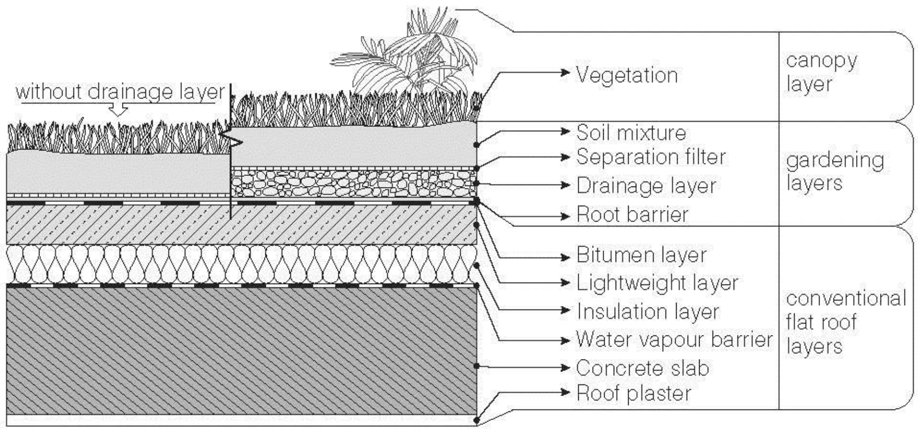

Figure 3.3: Typical structure for green roof. (Theodosiou,2009).

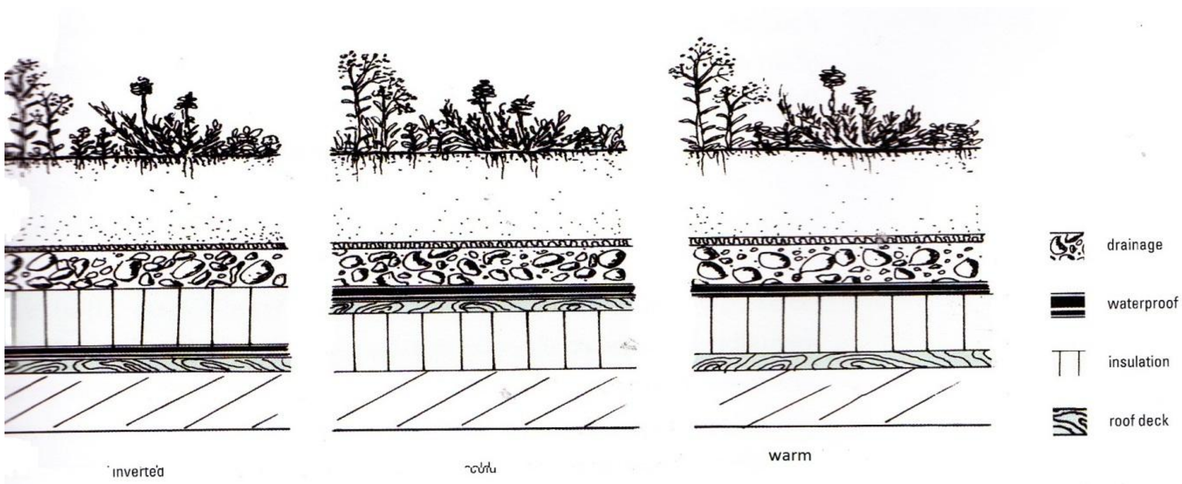

Figure3.4: Roof construction types according to the insulation layer location. (Dennett, &Kingsbury, 2008).

3.5.1 Roof insulation

Water proofing terminology refers to liquid applied sealants that are used to weatherproof concrete substrate while roofing terminology is used to describe the roll goods that are usually used to weather proof different types of roof substrate (Luckett, 2009).

Insulation materials are always on the form of boards or sheets and placed flat over the surface of the roof. Insulation material can be laid above or below waterproofing or roofing materials however in case that been laid above water proofing or roofing it should have the ability to be exposed to moisture. Some insulation materials cannot be exposed to high temperature which requires installation of another protecting layer called cover boards.

Cover boards are consisting from materials that have the ability to be exposed to high temperature when it installed within a roofing system that apply heated liquids like hot liquid rubber ,coal tar pitch and hot bitumen. The commonly used insulation materials are: polyisocyanurate, extruded polyester, expanded polyester and Fesco board.

There are three types of water proofing membranes: fluid applied membrane, single ply membrane and built – up roof (Osmundson 1999).Built – up roofs are commonly used and consist of bituminized fabrics or asphalt/bitumen felt. Generally they have a limited life span of 15-20 years, cannot tolerate to ultraviolet radiation and extreme temperature and sensitive to the growth of plant`s roots which require the installation of root barriers (Edmund & Lucie ,2006).

Single ply membranes are consisting from synthetic rubber or inorganic plastic and on the form of rolled sheets. This system is used commonly and effective however should be applied properly. This system is also sensitive to ultraviolet radiation and extreme temperature so it should be protected. Fluid applied membrane usually applied by painting or spray. They are easy to apply and self-sealed. A protection layer can be installed to protect the membrane like expanded polystyrene or PVC.

3.5.2 Protection material

I. Extruded polystyrene

It is usually used as primary roof insulation. Impervious to water which make it suitable to be used as protection board and insulation by placing them above water proofing material. In order to protect the water proofing material, insulation should be covered by green roof materials immediately. The weight per inch is 0.25lb/ ft^2.

II. Fesco board (wood fiber)

This material should be installed below the roofing membrane and should be kept dry. It is used to protect the insulation layer from chemical and heat during the installation of hot applied membrane. It is less durable than gypsum products because it`s less density. If it is used as mechanical fasteners under the green roof, it should loose-laid or adhered. Its common thickness is ½ inch.

III. Gypsum based cover boards

This material should be installed below the roofing membrane and should be kept dry. it is used to protect the insulation layer from chemical and heat during the installation of hot applied membrane. It reduces the installation damage during the construction of green roof by distributing the traffic load over a greater area. it should loose-laid or adhered. There are three common thicknesses; 1/4, 1/2 &3/4 inch.

3.5.3 Moisture retention materials

I. Dimpled and Eggshell mats

These products are used to create pathways to facilitate water laterally movement which promote water drainage from roof top. The tissue dimples and cups acting as a plant reservoir when it filled by water.

II. Gel packs and particles

These products are based on starch and available in many applications like: packed in packets, enclosed in permeable pouches near the plants roots and blended uniformly into the growth media.

The main concern of these materials is its water absorption. They are absorbing water hundred times its volume and discharge it slowly which make it unsuitable for long term irrigation systems. This high absorption expands the product which makes it displace the growing media and when it discharges the water, voids appear in the growing media and reduce its capacity.

III. Fabrics

Geo-textile fabrics are usually used horticulture and agriculture industry. They absorb water and store it for hydrating plants. There is a concern regarding these materials that it is located under root barrier, plants roots up taking water via direct contact with the roots. These materials can remain wet long which can damage drought tolerant succulents and sedums .in arid regions, these materials can be placed above the root barrier which can reduce the needed irrigation significantly.

3.5.4 Filter fabrics

Filter fabrics eliminate particulate within runoff from penetration into the drainage system. They are usually containing chemicals that hold off root growth and be used as root barrier. They don’t retain much water and are light weight.

3.5.5 Root barriers:

Root barrier installation is essential to protect the membrane from roots growing especially if the membrane consists of asphalt, bitumen or organic materials. PVC is the common Root barriers and usually comes on the form of rolls with different thickness and lay on the water proofing membrane. There are many environmental concerns regarding PVC manufacturing however it has any advantages like: long-lasting, can perform multiple functions, can be recycled, can be heat seamed and can reduce the leaks significantly. Its long life span can reduce the cost of replacing new materials.

3.5.6Drainage layer materials

According to Edmund& Lucie (2006), Proper drainage layer is extremely important on green roofs systems for many reasons: first to protect the water proofing membrane from continuous contact with water that can damage it. Second, is to protect the drought resistant plants from excessive water that can cause plants failure. Third is to promote the thermal insulation characteristics of green roof. Fourth is to promote runoff drainage. There are many materials can be used within the drainage layer like: Granular materials, porous mats, polystyrene, light weight plastic modules and geotextile.

Johnston& Newton (2004) stated that there are two methods to provide proper drainage:

1. Using dual water retention and drainage layers that is allowing to drain excessive water while acting as a reservoir
2. Installing the roof with gentle slope (10-15°) and using granular materials to run the water through it like pea gravel or light expanded clay aggregate

3.5.7 Growing media

The ideal substrate should be greatly efficient in absorbing water and retaining it and at the same time have efficient drainage system. In addition, it should have the ability to absorb, supply and retain nutrients over time. These properties can be achieved by using the mixture of granules materials and fine particles. Weight is another important parameter that should be considered especially if the growing medium will be used at extensive green roofs.

Types of vegetation should be considered also to avoid plants failure. for example if it is intended to use naturally growing plants like alpines and sedum, water logging substrate will lead to plants failure as the roots cannot respire(Edmund& Lucie ,2006). Edmund & Lucie (2006) illustrates examples of green roof substrate in table 3.3.

The ideal soil should incorporate 15-25%air, 35-45% water and consisting of 30-40%firm substances and 60-70% pore volume, pH should be about 6 and slightly acidic (Johnston& Newton, 2004) .Mulch can be used to reduce water loss by evaporation in summer. Johnston &Newton (2004) recommended the following soil thickness for different vegetation:

- Trees :800-1300 mm
- Shrubs and herbaceous plants:500-600mm
- Grass: 200-250 mm

Table 3.3: Examples of green roof substrate. (Edmund& Lucie, 2006).

Material	comment
Sub soil	Low fertility , available, heavy
Crushed concrete	Available, cheap, limited nutrient and moisture retention.
Waste or recycled materials ,crushed tiles or clay brick , brick rubble	Have some nutrient and moisture retention, uniform, stable, can raise pH in the substrate if it contained cement or mortar.
Rockwool	Don't have nutrient and moisture retention .very lightweight.
Light expanded clay granules(LECA)	Produce much pore spaces and absorb more water, lightweight.
Vermiculite	Don't have nutrient and water retention capacity, very lightweight, over time it can disintegrate.
Perlite	It can collapse over tie because of its consisting of particles
Gravel	Heavy
Pumice and lava	Lightweight
Sand	Reduce the pore spaces, if drainage is poor, it can cause saturation problems. Coarse sands need constantly irrigation as it can be so free draining.

3.6 Green walls history

It was documented that green facades are not a new technology and Vine were used since two thousand years to cover facades in Mediterranean countries as shown in table 3.4. In 1980s, there was an interest in the environmental issues in Europe so they create incentive programs to promote green facades adaptation (Stav, 2008). Green Wall systems classified into two categories: façade system and living wall system (Sable &Sharp, n.p.).

The variation in types and systems of green facades and living walls lead to different approaches in design, maintenance and installation. The following factors should be considered by manufactures, installers and designers (Green Roofs for Healthy Cities, 2008):

1. Attachment system to the building façade if it will be free standing or secured to the façade.
2. Structural loads calculations especially for large systems.
3. Plant selection to tolerate to local climate conditions
4. Plant growth and aesthetics expectations.
5. Plant maintenance plan including irrigation and soil considerations
6. Proper plants selection to correct plant spacing and geographic region.
7. Availability of Professionals like specially trained installers to carry out the system successfully.

Table 3.4: Green Walls history brief. (Green Roofs for Healthy Cities ,2008).

period	
3rd C. BCE to 17th C. AD	Grape vines trained by Romans on villa facades and on garden trellises. Climbing roses were used in castles and Manors
1920s	Garden city movement in North American and Britain promote house and garden integration through self-clinging Climbers, trellis structures and pergolas.
1988:	stainless steel cable system first used for green facades
Early 1990s	Wire-rope and cable system and modular trellis panel systems produced in the American market.
1993	Trellis panel system first applied in California.
1994	bio-filtration system with Indoor living wall first applied in Toronto
2002	MFO Park opened in Zurich , the park featured 1,300 climbers
2005	30 different modular green wall systems presented by Japanese federal government
2007	Green Factor that includes green walls first applied in Seattle
2008	Green Wall Award of Excellence launched by GRHC

3.7 Green wall types

Green Wall systems classified into two categories: façade system and living wall system (Sable &Sharp, n. p.). Each category will be discussed in details within the coming sections.

3.8 Green facades

Green Facades is a system where climbers trained to cover supporting structures. They can be installed as freestanding structures or they can be attached to existing facades. Climber`s extensive use started at the twentieth century in the German speaking countries as a part of the integration of house and garden movement. At the same time, a similar movement occurred in Britain.

In the Western Europe, climbers were commonly used in the parks and gardens to cover pergolas and other structures. Since 1930s façade greening declined. Green walls are more efficient than green roofs as the surface area of the walls is greater than the green roof surface area especially in the high rise buildings.

Climbers are rooted in the ground at the bottom of these structures and it takes 3-5 years to achieve the full façade coverage (Green Roofs for Healthy Cities, 2008). Traditionally, buildings were covered by self –cling climbers that don’t need any extra supporting network of trellis or wires.

Vines have been used for summer cooling by covering the building surfaces and pergola structure to produce shade. Stav (2008) stated that there are two supporting systems that are used commonly to support climbers and keep them away from facades; Cable and Wire-Rope Net and Modular Trellis Panel systems.

3.8.1 Climber`s supporting structure

The selection of supporting system have an influence on the success of façade greening. The maximum height that can be greened is 24m .green facades rely on trellis, spacers, steel cables and ancillary equipment.

I. Trellis

Wooden trellis: wood have a life span reached up to 25 years if treated properly. Their long lasting depends on the timber used, and how they were prepared. They decay rapidly if very dense climbers attached to them. The decay can be reduced if they are positioned away from the wall which allow for air flow. The longest timber that can last like: oak, elm or larch.

Metal trellis: are long lasting if they been corrosion treated. Examples of metals that can be used: stainless steel and galvanized steel. The minimum thickness of metal trellis is 55 mm and should be coated by zinc at 380 g/m² .stainless steel and aluminum are the ideal materials to be used in corrosive environment. In areas that are not polluted or salt induced corrosion , rebar can be used . Because of the system rigidity, it can be used for green walls that are freestanding as shown in figure 3.5.

II. Wires and cables

The cable and wire-rope net systems composed either from wire-net or cables or both. Cables can be used to support fast growing climbers with denser foliage while Wire-nets system is used to support slower growing climbers. Wire-nets system is flexible and can be applied in wider range of applications than cable system. Both systems are composed from high tensile steel in different patterns and sizes.

Traditional wire called vine eyes can support climbers up to two stories height and cannot support heavier climbers. It have the an amateurish appearance as it is hard to supply tension to the wires. The advantages of using wires comparing to rigid frameworks are that they are flexible and easy to transport while rigid frameworks should be constructed on site or should be pre-assembled which increase the cost of transportation , lifting and scaffolding equipment. The new design of steel rope is depending of stretching the ropes vertically and horizontally across a wall and the intersection points connected by cross clamps which produce a non-rigid trellis. There is a hybrid cables available in some regions .they are consisting of steel that is coated with natural fibers. The advantage of this type is that it is looking attractive and when the outer material decay by time, the steel will be hidden by plants.

III. Glass fiber

Glass fiber products have good tensile strength, lightweight and don’t corrode. The minimum cables diameter is 7.75mm .the material is expensive however it is the only option when a combination of weight, flexibility and strength is required.

IV. Rope

Rope is usually made of natural materials like manila and hemp. rope is not durable however have a good climber`s adhesion. It can be used for annuals in short term projects as they are easy to use, cheap and attractive.

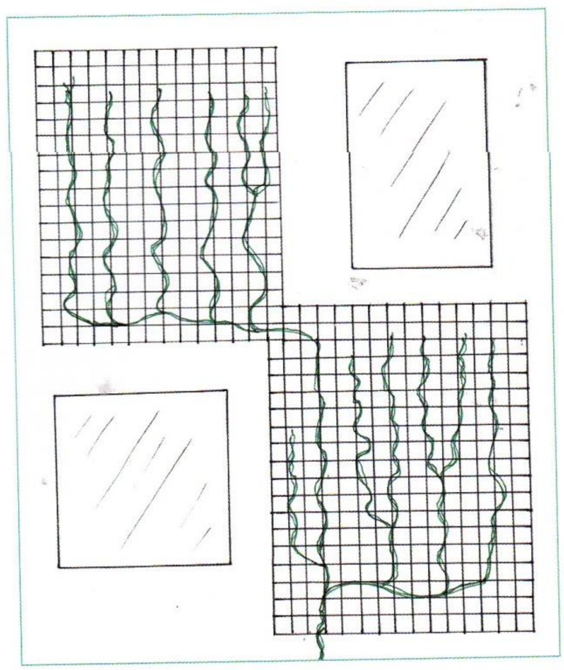

Figure 3.5: Trellis. Dennett, N. & Kingsbury, N., (2008).

3.8.2 Factors affect the selection of Construction supports

Choosing the appropriate climbers support is very important specially if it is used to cover facades that are more than two stories height. Supporting method selection depends on many factors like: plant vigour, plants climbing mechanism, plants eventual size, design factors and climate conditions.

I. Plant vigour & eventual size

A denser support network is needed in case of using climbers that are below average or of average vigour.40-80cm support for vertical cables and lattices of 30x40cm are required to vigorous climbers. The distance between the wall and the support is varying depending on the stem thickness.

- 10 cm for thin stem plants like Lonicera, Clematis and Akebia.
- 15 cm for thicker stem plants like Vitis and actinidia
- 20 cm for large woody plants like Wisteria and Celastrus

II. Plants climbing mechanism

As there different climbing mechanism for plants, there are different supporting methods. Some plants require vertical support and others require vertical and horizontal support on the trellis form. The easiest supporting method is the vertical support.

III. Climate conditions

When calculating the required materials for a proper supporting system, the following should be considered: supporting system weight, plant weight, snow and water weight and wind load.

IV. Design factors

Supporting system aesthetic appeal can be an important factor that affecting the selection of supporting system.

V. Load bearing and fixing

Improper fixing attaché can lead either to climbers collapse or to fixing failure which can also affect the structure. Traditional brick or wall walls are load bearing and can attach climbers supporting fixture directly on them while attaching the fixture to cladded wall is very difficult as they were designed not to take any load so should be drilled to attach the fixture to the load bearing wall. In case that it is not possible to support the climbers into the wall, they can be supported from the building top or from the ground rigid support as shown in Figure 3.6.

1. Direct wall fixing: (1) this system depends on supporting vertical rigid bars to the wall. This system is ideal to be attached to brick or stone walls as they are load bearing.
2. Hanging system (2),this type of fixation depends on hanging the supporting system from strong point on the roof .this system can be used if the wall can take little load. Climbers on the hanging system are away from the building surface.
3. Rigid rod upright standing system: in this system, the load is taken by the ground. This system can be used if the wall can take little load.
4. Various tensioning methods. This system is the most sophisticated system that is reducing the need for building supports and produces a look that is less cluttered. It is ideal to be used with the building that doesn't have opportunity to insert fixation to the facades.

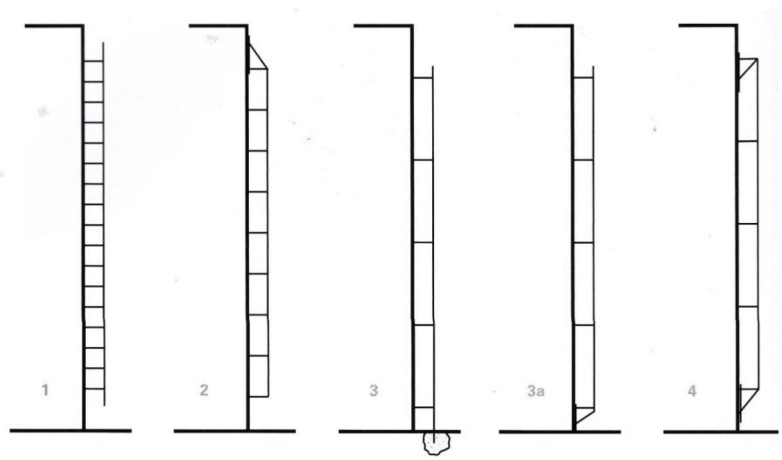

Figure 3.6: vertical support systems. (Dennett&Kingsbury,2008)

3.8.3 Climbers' selection

It is desirable to use green facades on the buildings' part exposed to the sun. Plants selection depends on using plants that can tolerate to solar heat. Plants should be used to be self-clinging. If the self-clinging plant's stems left for a year or two to run along the ground, it can create an extensive root system and then climb quickly into the facade.

I. Climate and aspect

Selection should be based on the climate conditions at the height that the climbers will reach. Usually the velocity and temperature of the wind at the ground level are less than that on the higher levels.

II. Size

It is important to choose the climber that its maximum growth matching the building size. It is recommended to use supporter with a size greater than the maximum size of the plants to avoid the problems related to self-strangulations and tangled growth.

III. Support mechanism

Basically the selection of green facades plants depends on the selection between two types; either self-clinging or supported climbers. The use of supported climbers is preferable because of many reasons: desired appearance on the façade, the ability to limit plant`s growth, visual appearance. Sometimes, the selection of supporting system depends on design considerations.

IV. Visual aspect

Climbers are generally used for their flowers production while their foliage is more important than the flowers. Most of the climber's species have good foliage quality .some hardy climbers have dramatic and large leaves like: aristolochia, actinidia and vitis. Species that can produce fruits add value to the aesthetic appeal.

V. Ecological aspects

It is easier to incorporate green facades in warm climate regions. the species that can be chosen are varying greatly in color , shape and texture and are able to grow faster than if planted in cold regions. It is beneficial to use green facades to shade buildings and promote building cooling to reduce air conditioning. there are many types of plants that can be used in sub-tropical and Mediterranean climates like: senecio , lantana , pandorea, cestrum , solanum , jasminum , passiflora , plumbago and bougainvillea. The suitable climber to be used in humid tropics is philodendron .irrigation is one of the problems related to planting climbers in warm regions. These regions are suffering from drought seasonally which affects the growth of the climbers. The roots of the climber should be in shaded and cool soil, the reduced moisture and high temperature can cause a plant failure. Climber`s ecological value depends on the following:

1. Food source for insects: flowers produce a valuable nectar source.
2. Fruit source for insects and birds: during winter, fruit-bearing vines are recommended.
3. Nesting places for birds: if the climber is the thicker, it will be twiggy which increase the opportunities for birds to build their nests.

3.9 Living walls

In this section, Living walls will be discussed as means of covering the walls with vegetation that is rooted to the building surface or can survive independently on the surface without the need to be rooted in the ground. Living walls have an advantage that it can compromise from non-climbing plants. (Sable &Sharp, n.p.).

One of the most important advantages of living walls that it can cover blank walls with growing plants on a growing medium that been attached to the wall itself. however , there is problem occurring when the leave and stem growing toward the light so any attempt to make them growing vertically can cause damage to the stem and cause plant failure. In order to solve this problem, many technical approaches have been implemented depending basically on the plant selection and on the following:

1. plants and growing medium holding technique
2. irrigation and nutrient delivery means
3. growing medium type(it is recommended to use non-biodegradable and inert medium to reduce the need for replacement)

in case of no water can be held for long time, the solution is by using hydroponics which depends on growing vegetation without the need to soil depending on nutrients that provide the water and food requirements. This type of wall should be kept moisture constantly by appropriate irrigation system.
One of the advantages of living walls its ability to filter the air from pollutants which reduce the need to filtration and ventilation means specially if it is developed for indoor areas.

A U.S. based company marketed a living wall system using HDPE panels with slanted pockets to hold plants and compost, the irrigation applied from pipes at the back and then collected at the bottom by a gutter . In the Japan, spectacular schemes called vertical carpet bedding produced using monocultures. The problems with using monocultures are that it has poor diversity, poverty of visual richness and facing the risk of full foliage failure.

Selection of plants is crucial as some light-loving plants can have growing problems if there is lack of light as well as the plants that cannot tolerate to high levels of light can also face growth problem in excessive lighted areas. For example sedum, woodland and ferns should be placed at the upper level to be exposed to the sun while areas with moderate sunlight amount can be planted with grass, forbs and ferns.

Vertical gardening have an exciting visual effect as the leaves can be seen from below because it grows upward which can be attractive if theses area planted with colorful foliage like heucheras. Some plants species should be avoided specially the ones that are invasive and producing tears in supporting fabric and overwhelming the adjacent plants.

The most successful plant to be used in vertical gardening is gaultheria procumbens as it is evergreen, produce fruits and flowers and considered as creeping habitat. In addition, small forbs like astilbe and aster also successful .saxifrage types are successful, evergreen and producing variety of foliage colors. Patrick Blanc is a

French designer and researcher who create a vertical gardening with floristic diversity in humid regions. He creates a diversity of vertical hydroponics .the system thickness is 13 mm and consisting of young plant`s pockets fixed to a capillary mat over a wall that been isolated by a waterproofing sheet of PVC .evergreen plants are desirable to create a tropical effect. The systems can be established on free-standing structure or in front of existing structure. Ideal irrigation system is drip irrigation as damaged tips can be replaced.

Living wall systems are consisting from vertical modules, planted blankets and pre vegetated panels that have been fixed into a frame or a structural wall. Many materials can be used to create theses panels and promote plants density and diversity like: expanded polystyrene, concrete, metal, clay, synthetic fabric and plastic. Based on the plants density and diversity, living walls require more intensive maintenance than green facades requirements. According to Green Roofs for Healthy Cities (2008), living walls can be used externally or internally. There are different types of living walls like: Modular Living Wall, Vegetated Mat Wall and Bio-filtration.

I. Modular Living Wall

Modular living walls have the ability to support high density plants, flowers and ferns. Modular living wall is consisting from rectangular or square panels that hold the growing medium to support the growth of plants. Growing medium composition can be customized based on the plants and design requirements. Irrigation in modular system is based on gravity and provided in different levels. One of the system advantages is that it provide an instant green influence as the panels are usually pre planted and pre-grown however a period of 12 –18 months is needed to secure pre-grown panels .

II. Vegetated Mat Wall

‘Mur Vegetal’ is an exceptional type of green walls created by Patrick Blanc. The system is consisting from two synthetic fabric layers with pockets that support the growing medium and the plants. Fabric walls are backed by a waterproof membrane against the façade to protect the building from high moisture content. Irrigation in this system is cycling water from the top to the down.

III. Bio-filtration

Bio-filtration is an innovative living wall that been integrated to buildings and has been designed to bio-filter the indoor air and to regulate the thermal conditions. The system is hydroponic supplied by water that is rich in nutrient that is re-circulated from wall top through a manifold to the collection gutter at the wall bottom .roots of the plants inserted between the two layers of synthetic fabric that is used to support mass of dense root and microbes. Foliage absorbs carbon dioxide and monoxide.

While microbes of the roots eliminate the volatile organic compounds (VOCs) natural processes of plants produce cooling effect and fresh air that distributed into the building after it is drawn by a fan through the system.

3.10 Plants

Selecting plants to be used within green roofs or green walls depends on the climate, soil depth and irrigation requirements .Some plants can tolerate to heat and survive with little water quantities like succulents and sedums, on the other hand, some plants needs extensive irrigation to tolerate to the heat like wetland plants and prairie plants.

The selection to use native plants reduces the requirements of maintenance and irrigation that usually needed with typical landscaping schemes. Native plants are usually irrigated at establishment period only .sometimes soil depth should be increased to accommodate native plant growth and vigorous root barriers may be needed to protect roofing membrane from native aggressive roots.

The usage of one species of plants can produce pleasant appearance with uniform color, texture and height however it is risky as Pests and climate can attack that monocrop green roof and wipe it out without warning so it is recommended to use plants diversity consisting from at least five species of plants (Luckett, 2009).

It is recommended to blend some evergreen plants in to the planting system and to use varying leaf plants. It is more sustainable to use plants with different leaf textures that have different water metabolism during different conditions. Leafy plants can tolerate to heat and drought by storing large quantities of water in summer, dormancy in winter and grow in spring. Plants that have needle like leaves like reflexum sedum and album sedum remain colorful during winter season.

3.10.1 Plant and vegetation selection

Johnston& Newton (2004) recommended some parameters to choose the proper plants to be used on extensive green roof. They recommended that plants should have the ability to establish a layer of dense root and resilient cover,after stress periods can be regenerating, gowning rate should be less than 60 cm, can be tolerate to drought , thin soil , water logging, nutrient poverty and favor free-draining soils. Because of the location of growing medium in the roof, it should be more porous, lighter, and less rich than the ones used in ground level garden. Geography and environment have a great influence on the selection of plants. The selection of plants should also be based on the conditions of climate like temperature fluctuation, shade, wind, and solar radiation exposure.

Generally, the most successful and suitable green roof plants are shallow rooted, low growing perennial plants that have the ability to tolerate to the different climate conditions (Edmund& Lucie, 2006). Also they should require less maintenance and nutrients. As it is difficult to install water reservoir at the bottom of growing medium, so the plant species should withstand to periods of heat and dryness. Some plants like delosperma and sedum cannot tolerate to excessive moisture which can lead to mortality.

According to Edmund& Lucie (2006), Based on continuing and yearly growth cycle, plants as classified to three categories; perennials, biennials and annuals. Annual plants grow, set seed, flower and die in one growing season. Biennials plants grow in the first season, then flower, set seeds and die in the second season. They usually create gaps in the roofscape after finishing its blooming and die which make it un-suitable to be used in green roofs. Perennials grow, flower and set seed in more than one growing season but don't die after that. Annuals and perennials are suitable to be used on green roof as accent plants however its locations should be selected carefully to be planted on medium deep growing media with proper irrigation. According to Johnston& Newton (2004)many factors should be considered at species selection:

1. Aesthetic contribution desired
2. Relationship between specious in regards to shape and size with adjacent buildings.
3. Objectives of trees for specific environment benefits
4. Soil conditions, space restrictions and sun light availability.

There is a tendency in many developments to use older plants in order to ultimate its objective however it need expensive techniques in order to insure successful transplantation procedure. On the other hand the selection of young plants is better as the planting procedure is cheaper and the plants itself cheaper and have the chance to grow into its surroundings.

Because of the usage of thin soil layer, the selection of planting is limited .it is appropriate to use shrubs and trees. The appropriate vegetation is like mosses, grass, succulents and herbaceous plants. Mosses are the best to be used in extensive green roof because of its little weight , moisture storage , drought survival , minimum nutrient requirements and its ease to cover large areas, its tolerate to pH levels and light levels. Turf is recommended on flat roofs as it is helping to stabilize soil. (Johnston& Newton, 2004)

3.10.2 Plants Types

I. Annuals

To make green roof cost effective, annuals should not be the dominant plant because of its longevity. Annuals need at least 3 in. regular rainfall and may it need supplement irrigation. Some drought tolerant annuals like townsendia and phacelia capanularia can be used to produce quick color at their first growing season.

II. Herbaceous perennials

Herbaceous perennials are desirable plants because of its aesthetic appeal. They require moisture and deep substrate more than offered in the extensive green roofs and their tolerant to heat and dryness is limited however they produce variety of textures and colors .shallow rooted ,low growing perennials can work well like petrohagia, organum ,viola ,achillea ,potentilla ,allium, teucreum ,campanula ,phlox and dianthus. However, perennials produce a wide palette; they increase the load of the roof by 2-5 pounds per square foot. Most Herbaceous perennials are weeds` hospitable in rich growing medium which will increase maintenance costs. Few types of herbaceous perennials are ever green so if winter interest is desired so alternative should be used to compensate its dormant in winter.

III. Hardy succulents

Hardy succulents are considered as the extensive roof`s workhorses with a growing medium of 4 in or less. They have a supreme ability to tolerate to wind and drought conditions, can store water for long periods in their leaves and their metabolism process can conserve water. These plants can open stomates at night time to store carbon dioxide and close it at day time which reduce transpiration losses. They have shallow roots and can tolerate to long periods of drought and extreme temperature. Their types like delosperma, jovibarba , talinum ,sempervivum and sedum are the best choice for extensive green roof .sedum for example, offers yearly colorful and visual interest with its wide varieties plus it is low growing spreading over the ground. One of the interesting characteristics of sedum that other perennials don't have is that it changes its color over the seasons and produces a winter interest. in addition, sedum can tolerate to different climate conditions .it also have a variety of leaf texture and colors, well desired by insects and birds , non-invasive and have variable heights. For all these characteristics sedum considered ideal to be used in green roofs.

IV. Grasses

Usage of grasses on green roofs stills new. It adds texture and motion, offer habitat for insects and birds and more vertical than succulents however if left unpruned it is have limited winter interest. It require deeper growing medium than succulents which influence the load. Some types are dormant in winter and some are dormant in summer which creates un desirable brown spots .the most appropriate types of grass to be used on extensive green roof are the short ones like deschampsia,carex and festuca.

V. Herbs

Examples of herbs are: allium, salvia, origanum and thymus. origanum and thymus require a growing medium more than 4 in. and irrigation system. It has good drought tolerance. It can be planted on the roof of hospitals, restaurants, private residence or institutional buildings and can be harvested for educational purposes, therapeutic, aromatic and culinary

VI. Evergreen plants and seasonal flowering

In plants selection, it should be considered if the plants should be year –round visual interest or not. Hardy succulents like sedum, sempervivum and jovibarba usually are evergreen colored and have textured foliage which make them aesthetically desired while herbaceous perennials lose their leaves in winter and have limited flowering period. Annuals after their first year can be self-sawing but they spread on the roof haphazardly. To achieve a yearly round interest it is recommended to use a mixture of annuals, herbaceous perennials and Hardy succulents (Dennett& Kingsbury, 2008).

VII. Accent plants versus Ground cover

Ground cover with limited accent plants should be used predominantly in green roofs. Benefits of ground cover are: reliable, rapid, cost effective, with 6-10in. covering plugs. There are many groundcovers examples like: phlox subulata, petrorhagia saxifrage, S. sexangulare, S.spurium and sedum album.

Accent plants have a desired visually appeal however may not exist more than five years on the green roof, offer seasonal interest, don’t spread rapidly and to cover an area, more plants are needed and require periodic re-sowing. Examples of successful accent plants are: S.cauticola, sedum matron, talinum calycinum, allium and dianthus .

VIII. Native plants

Native plants have many characteristics that make it the most suitable plants to be used in green roofs .They adapt to the climatic and ecological conditions, resistant to indigenous diseases, resistant to animals and insects damage, produce a stable biodiversity. Successful native green roof depends on the proper selection of plants communities that are working together.

3.11 Irrigation

It is was found that early drought and media depth and type affects the establishment of green roof thus Berghage et al. (2009) recommended to apply 80 - 100 mm of irrigation during green roof installation which lead to a better rate in plants survival. Also they recommended amending the planting medium with lime after 10 years to keep the capacity of pH buffering.

There are four main methods usually used in green roof irrigation:

1. Standing- water system: this system retains a water layer at the green roof bottom. This system has an advantage which is by using float control device it can be maintained, self-regulated and can be filled with rainfall.
2. Capillary system: this system is ideal to be used in shallow green roofs with substrate thickness 20 cm or less. In this system water delivered to the substrate base by porous mats. The water is usually introduced to the roof through few locations and then distributed by capillary mat.
3. Drip and tube system: this system can be either buried in the substrate or attached to substrate surface. Sub irrigation system is not visible and delivers water to the roots directly which reduce water loss through evaporation.
4. Surface spray with sprinkler: this system is un-desirable as much water can be wasted and it encourages the rooting on the surface which makes the roots exposed to climate conditions.

Chapter 4: Grey Water

Chapter 4: Grey Water

4.1 Introduction

New water sources have been developed to face the problem of water scarcity. However; many of these new technologies have a negative influence on the environment if compared to the conventional system. For example: desalination plants increase the co2 emissions to the atmosphere and cause marine environment disturbance.

Grey water is the water generated from all house activities except waste water generated from toilets, dishwasher, or kitchen sink. The common application for treated grey water is irrigation however it has been practiced in recreational, industrial, urban and environmental reuse.70% of consumed water is grey water but it contains only 30% of organic fraction and 9-20% of nutrients (Pidou et al., 2007).

This chapter focuses on highlighting the generation, history, types and benefits of grey water treatment systems.

4.2 Grey water generation

In the industrial countries, the domestic in-house water demand ranges from 100-150l/c/d (liter/capita/day) and 60-70% of this water demand transfer to grey water while the rest is used in water flushing (Friedler et al. 2005).

Quality of gray water varies basically depending on water supply quality, household activities and distribution type (biological and chemical processes, piping leaching...etc.).There is a variation in the compounds levels in the water from source to another where it is been influenced by the lifestyles and the usage of different products of chemical household .this composition variation influenced by time and place which is affected by water consumption and discharge. Also it is affected by the chemical compounds degradation during storage and through the transportation network (Eriksson et al., 2002). The usage of treated gray water in toilet flushing can reduce the urban water demand significantly and up to 10-20% by reducing the water consumption by 40-60 l/c/d. (Friedler et al., 2005).

Treated grey water is the optimum water source in arid and semi-arid regions that is suffering from fluctuation in rain falls, water scarcity and water pollution rise. The reuse of treated gray water in landscape irrigation can reduce the use of potable water significantly.

In order to use treated gray water in landscape irrigation it should be processed and reused immediately before reaching anaerobic level. The major difficulty of gray water treatment is the large variation in the composition, for example; COD varying from 40 to 371 mg/l. this variation resulted from the varying quantities and the type of detergents used.

4.3 Water treatment Historical development

Water treatment defined as the manipulation of waste water generated from different sources in order to produce a water quality that meets the standards and the goals. Boiling water in containers was the earliest technique to treat water in households.

Water borne disease (like cholera and typhoid fever) elimination was the major challenge at the second half of nineteenth century and the first half of twenty century. In the last thirty years of the twentieth century ,the public health concerns with chronic health influence of anthropogenic contaminants traces ,at twenty first century , the focus was on reducing the exposure to man-made chemicals , reducing microbial contamination and developing the methodologies of risk assessment that can help in reducing the effect of chemical compounds traces. Table 4.1 shows the history of water treatment since 4000 B.C.

Table 4.2 shows the water treatment methods that been used at the beginning of twentieth century. That entire methods still used up to now, the term poisoning process converted into disinfection process. The modern technology of using membrane technology is not included in the table.

Table 4.1: Water treatment`s history. (Crittenden et al., 2005).

period	Event
4000 B.C.	Recommendation of water treatment methods were found at Greek and ancient Sankrit writings. The methods that were noted to purify impure Water at this period were by using the fire to boil water, using solar radiation to heat the water, dipping heated iron into the water, using coarse gravel or sand to filter the water.
3000 to 1500 B.C.	Advance technologies developed by Minoan civilization in Crete that been developed and used in north America and Europe in last half of nineteenth century.
1500 B.C.	Egyptians used chemical alum to settle out the water by suspending the particles.
Fifth century B.C.	Hippocrates sleeve invented by Hippocrates when he noted that rainwater should be boiled and strained.
Third century B.C.	Supply systems for public water were developed in Greece, Rome, Egypt and cartage.
340 B.C. to 225 A.D.	Water supply system was invented by roman engineers to provide Rome with water through aqueducts. The system was able to deliver 130 million gallon of water per day.
1676	First observation of microorganism by Anton van Leeuwenhoek
1703	Proposal of having rainwater cistern and sand filter at each household was proposed by a French scientist.
1746	The first filter designed by the French scientist Joseph Amy. The filter consists of charcoal, sponge and wool.
1804	The installation of the first municipal water treatment plant in Scotland. The distribution of the treated water was by a cart and a horse.
1807	Glasgow in Scotland considered as the first city to pipe to

	consumers treated water.
1829	Slow sand filter installation in London
1835	The recommendation of adding small quantity of chlorine to the contaminated water to make it potable by Dr. Robley Dunlingsen.
1856	It was found that pressurizing water systems can prevent external contamination.
1864	Disease germ theory was been articulated by Louis Pasteur.
1892	The recognition of granular media filtration`s value after the escape of Altona city from a cholera epidemic because of the use of slow sand filtration.
1892	First use of sand filter in America to reduce the rates of mortality.
1897	G.W. Fuller found that good sedimentation and coagulation can produce better filtration.
1902	The first supply of drinking water in Belgium by using the Ferrochlor process. Ferrochlor process is the mixing of ferric chloride and calcium hypochlorite that can produce disinfection and coagulation.
1903	The first application of lime and iron process of treating water.
1906	The first usage of ozone as a disinfectant in France.
1911	The publishing of “Hypochlorite treatment of public water supplies” that recognized the importance of using chlorination at the water treatment process.
1942	The first set of drinking water standards been adopted by U.S. PHS
1974	Safe drinking water act(SDWA)passage

Table 4.2: Water treatment systems that been used at the twentieth century. (Crittenden, et al., 2005).

	Method of treatment	Agent/objective
1	Mechanical separation	• Using gravity like sedimentation • Using screening like filters , screens and scrubbers • Using adhesion like filters and scrubbers
2	Coagulation	• Chemical treatment is used to gather matters into groups which make it easier to be removed by mechanical separation but without change the water chemical nature
`	Chemical purification	•
4	Poisoning process	• Using ozone • Using copper sulfate • The object of Poisoning process is to kill and poison objectionable organism without adding poisonous or substances objectionable to water users.
5	Biological process	• Objectionable organism death by producing unfavorable conditions and antagonistic organism • Organic matter oxidation
6	Aeration	• By evaporation of gases that cause odors and objectionable taste • By carbonic oxygen evaporation • By supplying specific amounts of oxygen that used for chemical purification specially the support of growth of water purifying organisms.
7	boiling	• Used in households to protect from disease carrying water

4.4 Benefits of grey water

The use of treated grey water shouldn`t be viewed from economic point of view only because it has significant environmental and social benefits that contribute in implementing sustainable development.

1. Reducing the stress on potable water

Using treated grey water conserve the fresh water resources. Many activities don't need fresh water and can be achieved by using treated water like irrigation and car washing. Replacing the usage of fresh water with treated grey water would save money and save water natural resources, (Sustainable Earth Technologies, 2013).

In addition, at drought and scarcity periods, grey water can be used in lawns and gardens irrigation. (Grey water Reuse Guidelines, 2012). Using treated grey water in toilets flushing can save third of fresh water resources (Environment agency, 2011).

2. Reducing the strain on treatment plant or septic tank

Grey water compromise 50-80% of wastewater and contain less pathogens and nitrogen. Reducing waste water flow into the septic tank can extend its capacity and service life. Also reducing the flow to the treatment plant can increase the treatment effectiveness and reduce the cost. (Ludwig, 2009).

The usage of treated grey water increases the durability of septic tanks. In addition domestic waste water flow can be reduced so the effectiveness will be higher in municipal treatment systems on Treatment plants and septic tanks.

3. High quality purifications

Grey water treatment plants produce high quality purified water which protects the ground water and natural resources (Oasis design, 2013).

4. Replacing septic tank in small areas

Some sites that have soil problems like soil with slow site percolation, it is not feasible to use a septic tank so it can be substituted with grey water treatment plants that reduce the cost significantly. Also it is feasible to use water treatment systems instead of using drainage system that reaches to far areas.

5. Less chemicals and energy consumption

As less waste water and fresh water need to be pumped and treated, energy reduced and chemical use reduced too which lead to burden reduction on infrastructure (Sustainable Earth Technologies, 2013). Using grey water would save third of the domestic water which will reduce the bills significantly (FBR, 2013).

The usage of treated grey water in irrigation will encourage the reduction of toxics dumped into the drain. Also the use of grey water reduces the plumping of fresh water into the buildings and also reduces the waste water pumping from buildings (Ludwig, 2009).

6. Recharging ground water

One of the good characteristics of grey water that it been purified effectively at the upper soils region which is biologically active. This character protects the quality of groundwater and natural surface. Top soil is considered as most powerful purification engine that can discharge waste water deeply into the subsoil. Excess treated water that used in irrigation recharge groundwater.

7. Plant growth

Using treated grey water in irrigation promotes the plants flourish and growth. Oasis design (2013) .According to FBR (2013), grey water contains a portion of nitrogen estimated to be one-tenth of the whole quantity in the black water that can be filtered easily by plants biological activities. Grey water is considered as a fertilizer source if used in irrigation because of its richness in nitrogen, phosphorous and potassium (FBR, 2013)

8. Nutrients reclamation

Disposal of waste water into oceans and rivers cause nutrients loss and increase the threat of erosion. On the other hand nutrients reclaim from grey water would reduce erosion and keeps fertility of land. Oasis design (2013).

9. Awareness increment of natural cycle

The usage of treated grey water increases the awareness and feeling of responsibility of wise consuming of resources.

10. Environmental benefits

Gulyas (n.p.) stated that reducing water demand would reduce gas chlorine that contributes to ozone-depleting.

Increment of grey water quantities increase water availability for irrigation purposes which increase forestall and agricultural production.

4.5 Limitations of grey water use

There are some reasons making the usage of grey water difficult or un-feasible at certain times or all the time.

1. Inadequate space: grey water treatment plant needs apace which sometimes is not available at areas where the neighbors are too close or the yard is small or not existing. In reachable drain pipes: sometimes the plumbing system is entombed by a concrete slab which makes it unfeasible to access grey water.

2. Inappropriate soil: soil that has percolate problems like being impermeable or being extremely permeable. In that case the treatment system will need special adaptation. Some Acid-loving plants would not survive with treated grey water irrigation because of low pH and Alkalinity .It was found that soils irrigated with grey water would be more salinity that one's irrigated with fresh water which can affect the crop`s growth ( Holger,n.p.) .Grey water would be contaminated with boron that is element of detergents. High concentrations of boron would affect the crop`s growth.

3. Inappropriate climate: in some cold regions grey water treatment cannot be used at freezing periods as well as the very wet regions where using grey water for irrigation purposes is un- benefitable.

4. Permit hassles or legality concerns: in some industrial countries the legal issues of grey water treatment is not clear yet however there is a movement to promote

systems and increase experience of the systems. Some systems still considered un-legal in some regions but in another regions it is legal and under tax system.

5. Health concern: grey water systems considered un legal because of health concern however it have been proved that the health threat that result from grey water is insignificant. Increment in health potential and pollution potential in case of un-proper treatment (Grey water Reuse Guidelines, 2012).Grey water systems that don`t incorporate disinfection processes can contain viruses. Gulyas (n.p.)

6. Poor cost/benefit ratio: in some cases the ecological and economical value of using grey water is less than its benefits and this is usually results because of the legal requirements that makes only the complex systems are permitted. This is common if the cost of professional installed systems compared to the cost of owner installed systems.

7. Inconvenience: grey water systems require more involvement by user than sewer system or septic tank.

8. Inadequate combined waste water flow: the use of all grey water in different applications reduces the municipal sewers flow which is already designed for high flow. This can lead to move toilets waste insufficiently through the municipal system.

9. Unsuitable development: sometimes developers pursue grey water systems because soil quality not allowing using septic tanks so they prefer it to develop property that is otherwise unbuildable

4.6 Health and Environmental concerns

At the second half of nineteenth century, it was found by Dr. John Snow that the cause of cholera epidemic is the water contamination un-like the common belief at the middle of that century that the cholera transmitted by miasma breathing or breathing vapors resulted from victims decaying. After a short time, it was demonstrated by William Budd that the transmittance of typhoid is by contaminated drinking water. After ten years of Dr. Snow`s discovery, disease germ theory articulated by Louis Pasteur .At late 1880s, it was clearly known that many of the epidemic diseases were waterborne. At the end of nineteenth century, the benefits of conventional water treatment system (flocculation/filtration/ sedimentation /coagulation) demonstrated by Fuller.

Chlorination developed at the twentieth century as a mean of bacteriological control. At the first forty years of that century, there was a focus on implementation of chlorine disinfection and conventional water treatment for the supplies of surface water. During 1940 to 1950, the majority of the water in developed countries considered as microbiologically safe because of the use of complete treatment systems. During the period from 1940 to 1960 it was discovered that viruses are also responsible of some diseases at the fecal-oral route. In 1960 the potential of anthropogenic harm starts to be a concern so U.S Public health service (U.S. PHS) developed tests to realize the anthropogenic compound`s total mass in the water using the extraction and adsorption of carbon .

After that there been a concern regarding the use of man-made organic compounds and it harmful effect thus many regulations had been designed to eliminate the excessive formation of chemical byproducts that used in the disinfection process. Later it was found that pathogenic protozoa can transfer from animals to human and it has a great resistance to treatment which causes a stress on improving the water disinfection to control DBPs (disinfection byproducts).After all the previous findings it was clearly realized that two parts of treatment are required; first: better pathogens physical removal, secondly: better disinfection process (Crittenden et al., 2005). At the current century, new issues emerged that increase the challenging of water quality engineering like identification of new disinfection byproducts (like N-nitrosodimethylamine NDMA), new pathogens (like Helicobacter pylori and noroviruses) and plenty of chemicals (like detergents and personal care products). In warm regions, gray water can cause health risk and negative aesthetic effects as the high ambient temperature increase the degradation of organic matter and promote the growth of pathogens. In order to avoid the risk associated with gray water re use, it is recommended to use the treated gray water directly on site through a reliable conveyance treatment and storage system. (Friedler, et al., 2005)

4.7 Physical and chemical properties of grey water

The physical parameters of grey water are color, turbidity, temperature and suspended solids content. High temperatures are not recommended as it increases the microbial growth. Fibers, hair resulted from laundry and raw animal fluids and Food particles sourced from kitchen sinks are examples of grey water suspended solids. Suspended solids and turbidity measures indicate colloids and particles content in grey water that can lead to treatment installation clogging like sand filters and pipes. Solid phase stabilization can be caused by the combination of surfactants resulted from detergents and colloids. Agglomeration prevention of colloidal matter will reduce the solid matter settling and pre-treatment efficiency. Infiltrating grey water to the soil reduces the pollutants sorption capacity. pH, hardness and alkalinity of infiltrating water are used to determine Infiltrating effect on soil capacity and used to measure clogging potential.

Measurements of COD, BOD and nutrient concentration offers valuable data about grey water. COD and BOD content indicate the oxygen depletion potential resulted from organic matter degradation during storing and transportation which lead to sulphide production risk. XOCs and heavy metals (like: Cr, Ni, Hg, Pb, Fe, Al) content is also important. Jefferson, et al. (2004) described the main characteristics of grey water:

1. Extremely variable in organic concentration.
2. High ratio of COD/BOD ratio
3. Imbalance in nutrient macro and micro equally divided between phosphorus and nitrogen
4. Low ratio of suspended solids to turbidity
5. Majority of particles size is 10–100 µm
5. 3 log of coliforms concentration
6. No proof of known pathogenic organisms

4.7.1 Turbidity

Turbidity of water is usually caused by suspended particles that lead to reduce the water clarity. The definition of turbidity is "the optical property that makes the light absorbed and scattered rather than transmitted constantly without any change in light flux or direction through the water or liquid. As illustrated in figure 4.1, in order to measure turbidity, a light source is needed and a sensor is also needed for scattered light measuring.

Turbidity is a measurement is used to compare different sources of water or the treatment facilities also it is used to regulatory compliance and process control. The increment of turbidity is an indicator of the increment of water constituent's level (like: giardia cysts, bacteria and cryptosporidium oocytes. Turbidity is always expressed by NTU (nephelometric turbidity units). In fresh water turbidity is 0.3 NTU; most of the treatment systems produce less than 0.1 NTU turbidity treatment level.

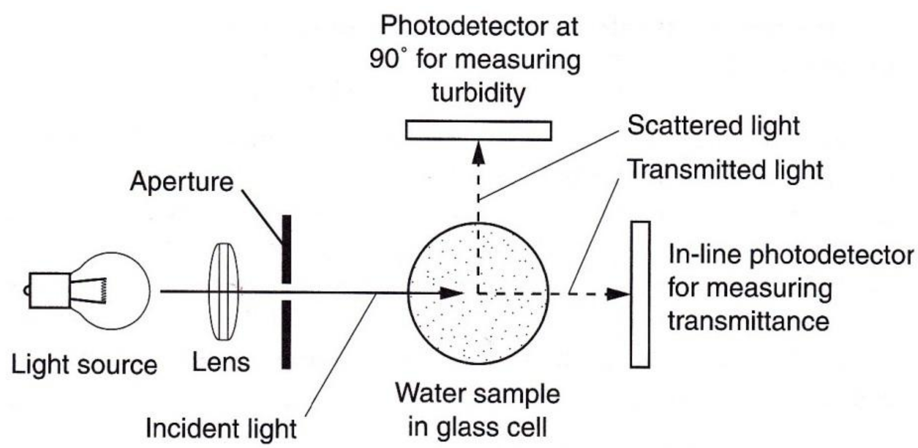

Figure4.1: Measuring turbidity and absorbance by spectrophotometer. (Crittenden, et al., 2005).

4.7.2 Particles

Particles are defined as a solid that is finely divided that is larger than the molecules though is difficult to be individually distinguished by unaided eye but particles clumps can be encountered. Particles potential in water is so important because it influence the treatment process and its health associated impact in regards to pathogen – associated particles. The classification of particles depends on its size, origin, and charge characteristic, properties of the interface between water and solids and the chemical structure of the solids.

4.7.3 Color

The importance of water color is that it is indicating the organic content that includes the fulvic and humic acid, turbidity and metallic ions. The water color categorized to apparent color and true color. Turbidity causes the Apparent color while dissolved species cause true color. Unfiltered samples are used to measure the apparent color while to measure the true color filtered samples is used. In order to assess the potable water color, a visual comparison is implemented to a solution from concentrations of a standard platinum-cobalt or serial dilutions solution. By the pH of the solution, the water color is measured in color units (c.u.).The difficulty of that comparison in water treatment process is it that when the color is in low levels it is hard to distinguish between low values. If the water contains constituents like industrial waste for example so the water color will be unusual and cannot be match the standards of platinum-cobalt. Instrumental methods are used to measure three parameters related to chromaticity which are hue (green, yellow...), saturation (deep, pale, etc.,) and luminance.

4.7.4 Temperature

Water temperature has an influence on most parameters that have a direct impact on the engineering design. The parameters that can be affected by water temperature are: viscosity, density, surface tension, vapor pressure, saturation value of gasses, solubility, and rates of chemical, biological and biochemical activities.

4.8 Grey water system elements

The basic function of grey water system is to collect water, divide it and then distribute its flow at specific planted areas like garden or green roof. In general all the systems are consisting from the following (Ludwig, 2009):

1. Source: examples of the source of grey water are usually such as but not limited to the showers, sinks, bath tubs and washing machines.

2. Plumbing system: plumbing system is mainly consisting of the pipes that transfer the grey water from the building to outside.
3. Flow tank, filter and tank: these elements are optional but useful in facilitating the distribution of plumbing however it adds cost and complexity to the systems.
4. Distribution system: this system transfer and distribute the treated grey water among plants.
5. Receiving planted areas: examples of this element are plants, soil, roots and mulch basins.
6. People: people are considered as one of the grey water system as they generate the grey water, design the system and maintain it.

4.9 Water treatment processes Selection

The most critical issue when choosing the water treatment technology is the water source and the intended use of the water. Another important factor in water treatment is the total dissolved solids (TDS) level. If the TDS level is less than 1000mg/l, the water is considered fresh water and if the TDS level is between 1000 to 10000mg/l, the water is considered brackish water. Fresh water can be used for drinking while brackish water should be treated before it has been used in special applications (Crittenden, et al., 2005).

There is a wide range of Water treatment systems like home treatment unit, treatment plant for community and industrial facilities. There are steps should be followed in order to select the suitable water treatment plants which are:

1. Quality characteristics of water source and definition of treatment standards and goals.
2. Pre design studies followed by pilot testing of plant and design development criteria
3. Detailed design of the selected strategies
4. Construction
5. Operation and maintenance

These steps should be achieved by the engineers of various disciplines including but not limited to; architecture, microbiology, chemistry and geology. There are many important factors should be considered when selecting treatment processes illustrated in table4.3.

Table 4.3: Grey water treatment processes factors, (Crittenden, et al., 2005).

	Factor	comment
1	Process applicability	Evaluation of process applicability is depending on past experience however if new conditions faced so it is important to implement a pilot plant studies
2	flow range Applicability	The system should be flexible to operate with different flow ranges. For example in high population areas, it is not suitable to use slow sand filters as it can operate properly with large flow rates.
3	flow variation Applicability	Unit operations usually operate ideally with a relatively constant flow rate however the system should be flexible to operate with variable flow rates.
4	characteristics of Raw-water	Raw material type has an influence on the types of treatment processes and it requirements.
5	un affected and Inhibiting constituents	It should be considered the type constituents that can inhibit the treatment processes
6	Climatic constraints	Temperature have an influence on the physical treatment process and at the same time affects the reaction rate between of most processes
7	Process sizing based on process loading criteria or reaction kinetics	Governing reaction kinetic and kinetic coefficient affects the reactor sizing. This data is derived from literature review and experience.
8	Process sizing based on process criteria or on mass transfer rates	Mass transfer coefficient affects the reactor sizing. This data is derived from literature review and experience.
9	Process sizing based	Some processes have certain sizes that should be

	on redundancy requirements and size availability	considered from beginning, some are too big and some are so small.
10	Performance	Quality of treated water
11	residuals Treatment	Estimation should be done to measure the residuals quantities.
12	processing of Residuals	Constraints should be considered when choosing the residual processing system.
13	Environmental constraints	Environmental factors can restrict the installation of some processes .some processes affect the location of plants as it is impact its delivery.
14	Environmental protection	This section related to the environmental threats associated with some processes and how can be avoided Like chemical spills and discharges.
15	Chemical requirements	Amount and resources of chemicals needed should be considered and the influence of using specific types of chemicals on the treated water quality.
16	Energy requirements	Energy cost and requirements should be considered from design stage.
17	Other resources requirements	Investigations should be done to check if there any addition resources are needed to install the system successfully.
18	Personal requirements	Number of people needed to operate the system and the level of skills that they need it.
19	Maintenance and operating requirements	Maintenance and operating requirements, its cost and spare parts that should be available.
20	Ancillary process	Supporting ancillary process that needed and its influence on treated water quality.
21	Reliability	Long term reliability of the system ,
22	Complexity	The complexity of operation in emergency conditions,

		training required to operate the system
23	Compatibility	System can be expanded in future or installed with existing facilities.
24	Adaptability	Modification and upgrading felicity to meet any requirements needed in future.
25	Economic life cycle assessment	Initial cost, long term costs and maintenance cost should be considered. The plants with less capital cost can be more costly over years.
26	Security	Water treatment plants should be secured .all the methods to secure the plant should be considered.
27	Land availability	Availability of sufficient spaces, to install the system and expanded it in future, availability of buffer zone of landscape to reduce the impacts.

According to Pidou, et al. (2007), there are five categories for grey water treatment systems depending on treatment type. The systems are:

1. Simple treatment system:
2. Chemical treatment system:
3. Physical treatment system:
4. Biological treatment systems
5. Extensive treatment technologies

Most of the systems installed with sedimentation stage or screening below or/and a disinfection stage (like UV Chlorine).it was found that the biological systems are the most common used water treatment technology followed by extensive and physical system. Sand filters and simple systems have a limited influence on grey water quality; membranes are perfect at solid removal but limited in organic fraction tackling. Biological and extensive systems are better in organics removal and grey water treatment in general. The best performance can be achieved through the use of variable methods to treat all grey water fractions.

4.9.1 Simple treatment system

Usually simple systems have two phase systems depending on sedimentation or coarse filtration that are used to get rid of large solids then implement disinfection. This system provides a limited grey water treatment in regards to solids and organics and its operational cost is low. It was reported that the simple treatment systems remove 70% of chemical oxygen demand (COD), 56% of suspended solids (SS) and 49% of turbidity (Pidou, et al. , 2007).on the other hand it had been reported that this system is effective in micro-organism removal at disinfection phase as the coliform residuals are below 50/cfu/100ml in treated grey water. Simple treatment systems are usually used in small scale buildings like individual houses and also used to treat grey water with low strength that been produced from showers, baths , and hand basins.

4.9.2 Physical treatment system

There are two categories of physical treatment systems; membranes and sand filters. Sand filters can be used alone or can be combined with disinfection only or with disinfection with activated carbon .Sand filters are used to get rid of course at grey water but it produce limited treatment for different grey water`s fractions. In order to improve micro-organisms removal, sand filters are combined with disinfection. It was found that the usage of sand filters combined with disinfection and activated carbon doesn’t have a significant removal of solids or turbidity however it have a good removal of micro-organism. It was reported that the coliform concentrations in treated grey water are around 0 to 4 cfu/100 ml.

Membrane systems have a limited organics removal however it is excellent in suspended and dissolved solids, turbidity and SS removal .They removes up to 100% turbidity and SS concentrations reported to be less than 10 mg/l which comply with strictest standards. Membrane core size has a direct influence in the achieved treatment.

Fouling is the most important issue when using membrane as this will influence system operations and cleaning costs. It was found that the fouling increase if the organic matter concentrations increase. In order to eliminate fouling, a pretreatment process using sand filter or screening can proceed membrane phase. The operations of physical treatment include the following: Screening ,Reduction of Coarse solids, Equalization of flow, Flocculation and mixing ,Gravity separation ,Removal of grit ,Sedimentation ,Flotation, Transfer of oxygen ,Aeration and Stripping and volatilization of volatile organic compounds.

I. Screening

Screening is the first unit in waste water treatment plants. Screen is defined as a device that retains solids found in wastewater .The main objectives of removing solids is that these solids can cause damage to the process equipment, it can reduce the reliability and effectiveness of treatment processes and it can cause contamination to waterways. Any aspects should be considered when choosing the screening of treatment plant like: required screening degree, health and safety of screening, odor potential and handling, transportation and disposal requirements. In general there are two types of screens: fine screens and coarse screens. Coarse screens openings range from 6-150mm while fine screens openings are less than 6mm.There is also micro screens that can be used to remove fine solids with openings less than 50µm.

II. Reduction of Coarse solids

Macerators and comminutors can be used to replace screens by grinding the coarse solids to screen channel. Mechanically cleaned screens with conjunction of grinders are used to grind screenings that been resulted from the treatment system. The advantage of these grinders, Macerators and comminutors is that it reduces the offensiveness of handling and disposal of screenings.

III. Equalization of flow

Flow Equalization is a method to cope flow rate variations problems occurred at operation period, reduce cost of treatment plant and to increase its performance. The benefits that can be gained from flow equalization are: Enhancing biological treatment, improving the sedimentation tanks at the biological treatment, improving filter performance and improving chemical feed control in the chemical treatment.

IV.Flocculation and mixing

Mixing unit is one of the most important units of the water treatment plants. Mixing is including: Mixing substances, miscible liquids blending, Particles flocculation, Heat transfer and Liquid suspensions mixing.

There are two types of flocculation depending on the size of particle: micro flocculation & macro flocculation .The advantages of flocculation process are: promoting the removal of BOD and suspended solids ,conditioning the water that contains industrial waste, promoting the performance of secondary tanks after activated sludge process and pretreatment filtration for secondary effluents.

V. Gravity separation

The most common used tool to remove colloidal and suspended material from waste water is gravity separation. Sedimentation is a terminology used to describe the methodology of removing particles that are heavier than water using gravity theory. Sedimentation is used to remove of TSS and grit in the settling basins, removing chemical floc at chemical coagulation process and removing biological floc at sludge basins.

VI. Removal of grit

Grit chambers are used to the purpose of grit removal and located before the sedimentation tanks and after the bar screens in treatment plants.

VII. Sedimentation

Sedimentation process is used to remove settleable solids to reduce the quantity of suspended solid .it is used usually as preliminary stage in the treatment system to enable the removal of 50-70 % of suspended solids and 25-40% of BO(Tchobanoglous, et al. ,2003).

The choice of sedimentation unit is depending on the regulations of authorities, site conditions, and engineer experience.

VIII. Flotation

Flotation process is used mainly to separate the liquid particles and the solids from the liquid phase by introducing bubbles of air to the water. When the bubbles introduced to the water it attached to the particles and by the floatable force the combination rise to the water surface to be collected by skimming processes. Flotation advantage in comparison to sedimentation is the fine particles can be removed completely and in shorter time .inorganic chemicals like ferric and aluminum and organic polymers can be added in order to enhance the flotation and collecting processes.

IX. Transfer of oxygen

Oxygen transfer is a terminology to describe the transfer of oxygen from gas phase to liquid phase. The quantity of oxygen affects drastically the treatment processes like the aerobic digestion, biological filtration and activated sludge. Sufficient oxygen quantities can be introduced to the water by introducing air into the water or by using the form of droplets.

X. Aeration

Aeration systems are used to fulfill two requirements in waste water treatment plants: first, to introduce oxygen or air to the system .Second, to actuate the water mechanically which promote air solution from atmosphere. The choice of the suitable aeration system is depending on cost, function and reactor geometry .There are three main types of aeration systems which are: diffused air system, high purity oxygen systems and mechanical aeration systems.

XI. Stripping and volatilization of volatile organic compounds

There are two mechanism cause the release of VOCs from waste water treatment plants: Volatilization and gas stripping .Volatilization is a terminology to describe the release of VOCs to the atmosphere from the waste water surface .The main reason to VOC`s release is that it partitioned between water and gas phase until reaching the equilibrium concentration.

In order to control the release of VOCs the following strategies should be followed: first, Elimination turbulence points. Second, Source control and finally, covering the treatment facilities. Covering the treatment facilities can lead to serious problems like mechanical parts corrosion, treatment of off gases that contains VOCs and confined maintenance spaces.

I. Membrane filtration

Membrane technology is physicochemical separation processes using the variation of permeability as a mean of separation mechanism. The principle of membrane treatment is depending on pumping the water against membrane surface which result in producing product stream and waste stream. Membrane is usually consisting of less than 1 mm thick of a semi permeable synthetic material .When the treatment process starts the permeable components move through the membrane while the impermeable materials held on the side of feeding water. As a result the product stream is free from any impermeable materials while the waste stream is concentrated with these materials. In municipal water treatment there are four types of membranes are used: ultra filtration (UF), microfiltration (MF), reverse –osmosis (RO) and Nano-filtration (NF).

Membrane technology offers a permanent particles barrier for solids with size greater than the membrane material size .On the other hand in membrane system; the energy demand is higher than that for depth filter.

One of the problems that are related to membrane system is the poor quality of treated water because over time gray water can generate organic compounds and become anaerobic which cannot be rejected by membrane system. Cost is another constrain related to membrane system and constraint its viability. Pollutant species fouling on the surface of membrane lead to increment of the membrane hydraulic resistance so the energy demand of membrane permeation increase.

4.9.3 Chemical treatment system

Chemical unit processes referred to the use of chemical reactions as a mean in order to treat waste water. A usually chemical process is used with conjunction of physical and biological processes in order to achieve the targeted quality of treated water. The principal of chemical treatment processes include the following as illustrated in table 4.4 : Chemical coagulation, Chemical precipitation, advanced oxidation processes, Chemical oxidation, Ion exchange and Chemical neutralization, Chemical disinfection, stabilization and scale control The most important processes within the chemical treatment are: Disinfection , Phosphorus precipitation and Particulate coagulation. There are many Disadvantages of chemical processes that should be considered from the beginning. One of the important disadvantages in chemical treatment the usage of chemicals which lead to increment in dissolved constituent's content in the water (Tchobanoglous, et al. ,2003).For example solving the problem of particulate sedimentation by adding chemical to enhance its removal increase the total dissolved solids (TDS) in water.

Another important disadvantage of chemical treatment is the sludge handling and disposal. Cost is an important consideration in chemical water treatment as it is related to the energy cost which will affect the end user.

I. Chemical coagulation

There are two categories to describe the particles in water: colloidal and suspended particles. Usually the suspended particles are the particles that are larger than 1.0µm and its removal can be achieved by gravity sedimentation. Colloidal particles size is range from 0.01µm to 1.0µm.Chemical coagulation terminology is used to describe the mechanism of chemical destabilization and all the reactions involved in it.

Coagulant is a chemical used to disrupt the colloidal particles in water. Coagulation is suitable to treat low strength grey water only while cannot achieve the require quality when used to treat high and medium strength grey water. Ion exchange resins and coagulants with chemical treatment solutions are limited to treat water that is used in the urban environments (Pidou, et al. 2008).

Table 4.4: chemical processes Applications. (Tchobanoglous, et al.2003).

Process	Application
Advanced oxidization processes	• Removal of refractory organic compounds
Chemical coagulation	• The chemical destabilization of particles in wastewater to bring about their aggregation during perikientic and arthakinetic flocculation
Chemical disinfection	1. Disinfection with chlorine ,chlorine compounds ,bromine, and ozone 2. Control of slime growth in sewers 3. Control of odors
Chemical neutralization	• Control of PH
Chemical oxidation	1. Removal of BOD, grease, etc. 2. Removal of ammonia 3. Destruction of microorganism 4. Control of odors in sewer, pump station and treatment plants 5. Removal of resistant organic compounds
Chemical precipitation	1. Enhancement removal of total suspended solids and BOD in primary sedimentation facilities 2. Removal of phosphorus 3. Removal of heavy metals 4. Physical-chemical treatment 5. Corrosion control in sewers
Chemical scale control	• Control of scaling due to calcium carbonate and related compounds
Chemical stabilization	• Stabilization of treated effluents
Ion exchange	1. Removal of ammonia ,heavy metals , total dissolved solids 2. Removal of organic compounds

II. Chemical precipitation

The principle of Chemical precipitation is depending on adding chemicals that change the solids physical state in order to facilitate its removal. Chemical precipitation is used to: improve the primary settling facilities performance, phosphorus removal, heavy metal removal and as a step in independent chemical – physical waste water treatment.

Many chemicals can be used as a precipitant in order to get clear water however the clarification degree depends on the chemical quantity, mixing times and the process control. Chemical precipitation can remove 80-90% of total suspended solids (TSS), 50-80% BOD removal and 80-90% bacteria removal (Tchobanoglous, et al. 2003).

III. Chemical precipitation for phosphorus removal

Phosphate Incorporation into TSS and the removal of those solids is the way that is used to remove the phosphorus. Phosphorus can be incorporated into chemical precipitation or into biological solids. Chemical precipitation is usually achieved by adding multivalent metal ions salts like iron, calcium and aluminum,

In phosphorus removal there are many factors affecting the choice of chemical like: suspended solids concentration, influent phosphorus concentration, cost of chemicals, alkalinity, sludge facilities, chemical supply reliability and compatibility with the other treatment systems.

IV. Chemical precipitation for dissolved substances and heavy metals removal

The common chemicals that can be used in dissolved substances and heavy metals removal are carbonate, sulfide and hydroxide. The metals that should be removed from water are barium , copper , cadmium , arsenic , zinc , nickel and selenium.in general metals can be precipitated by sulfides or by hydroxides however in waste water treatment the hydroxides is the common by adding caustic or lime .

V. Chemical oxidation

There are two basic strategies to reduce the microbiological contaminations which are; removing contaminations and inactivating contaminations.

Chemical oxidization involves oxidizing agents to change the chemical composition of compounds. Chemical oxidization is used to reduce the residual organics concentration, ammonia removal, odors control and bacterial reduction .It is used commonly to improve the non-biodegradable organic compounds treatment, reduce the organic and inorganic compounds toxicity and to eliminate restrained influence of organic and inorganic compounds to the microbial growth.

VI. Chemical neutralization, stabilization and scale control

The term neutralization is used to describe the process of removing the excess alkalinity or acidity of water by using opposite composition chemicals. Treated water could have a high or less PH which require the neutralization before discharging the water into the environment. The chemicals that can be used to increase the PH are calcium oxide , calcium hydroxide , calcium carbonate , sodium hydroxide , sodium carbonate , sodium bicarbonate , magnesium oxide , magnesium hydroxide , dolomitic quicklime and dolomitic hydrated lime while the chemicals that can be used to reduce the PH are carbonic acid ,sulfuric acid and hydrochloric acid.

4.9.4 Disinfection

Disinfection terminology is used as a description of two activities: primary disinfection and secondary disinfection.

Primary disinfection means inactivating the microorganism that is in water. Secondary disinfection means keeping disinfection residual in the distribution system of treated water. (Crittenden, et al. 2005).

There are five agents that are commonly used in disinfection: UV light, Ozone, free Chlorine, chlorine dioxide and combined chlorine (combination of chlorine and ammonia). UV light depends on using electromagnetic radiation while the other four agents are chemical oxidants. The strongest agent is the ozone and it is started to be commonly used because it have the ability to control the odor and taste compounds like methyl isoborneol and geosmin.

Chlorine forms of disinfection agents usually used in serpentine, baffled contact chambers or at long pipelines. Ozone is usually introduced in bubble champers .ultraviolet light disinfection is usually used in proprietary reactors where short circuiting is a concern in that type of disinfection. When medium –pressure UV lamps are used; proprietary pressure vessels are usually used.

I. Free and combined chlorine disinfection

When introducing chlorine into water it dissolves and rapidly reacts with the water to form hydrochloric acid and hypochlorous acid. The hydrochloric acid is strong and completely ionized which reduce the alkalinity and PH of water. The desired PH is 7 or slightly less.

If ammonia added to the water, chlorine acts and forms three chloramine species depending on the quantity of chlorine added. The three chloramine species are: Trichloramine dichloramine and monochloramine,

Usually there are two forms of chlorine: gas and sodium hypochlorite solution. In small systems chlorine used in the form of calcium hypochlorite.

II. Chlorine dioxide

Alost no organic byproducts have been identified in Chlorine dioxide thus it been used in Europe widely. It produces two types of inorganic byproducts: chlorite and chlorate ion. It is mainly used in low-TOC waters that don’t need a high dose to overcome oxidant demand. It was found that the usage of chlorine dioxide causes a “cat urine “odor thus California State banned its use.

Usually in water treatment applications, chlorine dioxide is generated by sodium chlorine solution with a concentration of 25% or less. There is a safety concern related to the usage of sodium chlorite which is the uncontrollable release of chlorine dioxide. Another concern is related to sodium chlorite as a salt which is the crystallization. At high concentrations and low temperature sodium chlorite crystallized which obstruct the water flow through the plumbing system. Dried sodium chlorite is a fire hazard that can cause fires if it contacts combustible materials. Stratification is another concern related to sodium chlorite that can be occurred in the holding tanks.

III. Ozone

Ozone word means smell and it is origins from Greek word ozein. It has a pungent smell at a concentrate above 0.1 ppm and it is harmful to expose to it as it is strong oxidant. At concentrations that are above 23% it can be explosive and it decays under ambient conditions. It cannot be stored in vessels and transferred to the treatment plant like chlorine gas. When it is dissolved into the water, ozone starts to decay and form hydroxyl radical.

Usually ozone has two ways in reaction: first, using the direct oxidation second, by the hydroxyl radical action that generated from its decay. Appling ozonation in water treatment systems required the additions of two components to system which are:

1. Mass transfer device to achieve the ozone dissolving in water.
2. Contact chamber to create a place for the disinfection reaction.

IV. Ultraviolet light

The popularity of using ultraviolet in waste water disinfection is because it doesn’t produce toxics like chlorine. Ultraviolet light is a terminology used to describe the radiation of electromagnetic that has wavelengths between 100-400 nm as shown in figure 4.2. UV disinfection system is usually employing three types of lamp technologies: 1.low intensity, low pressure lamps 2. high intensity ,low pressure lamps 3.high intensity ,medium pressure lamps .The common used lamps are the low intensity ,low pressure lamps however the other two types still new technologies that can achieve higher UV output.

Ultraviolet has many advantages like : no need for chemical addition to the water , high effectiveness in vast pathogens range like protozoans and chlorine-resistant viruses, fast contact times(less than 60s), low operating and capital costs, minimum maintenance and simple and safe operation . UV systems are not used widely because its efficiency is influenced by suspended solids that can absorb or scatter the light which make chemical treatment is recommended.

UV disinfection effectiveness is depending at two factors: micro-organisms sensitivity and radiation dose amount that micro-organisms get. Grey water quality is a key factor to achieve a successful disinfection.

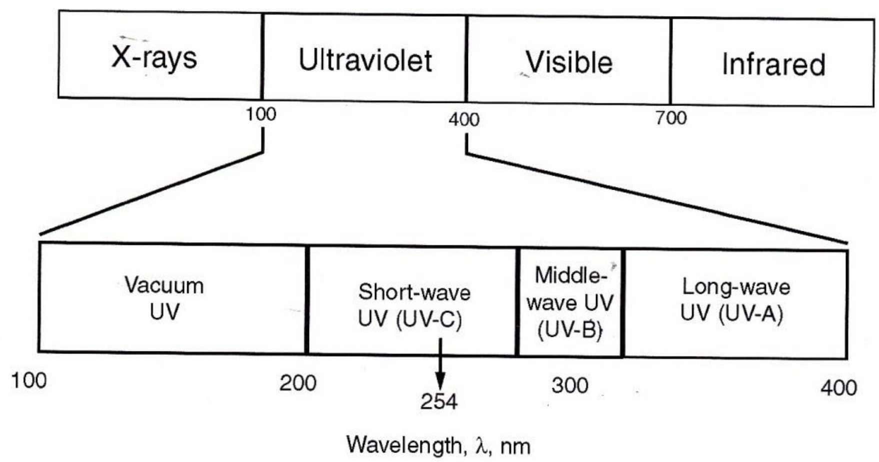

Figure 4.2: UV light. (Crittenden, et al., 2005).

The photons of UV light damaging the organism directly with nucleic acids. The nucleic acids comes in two forms: nucleic acid (RNA) or deoxyribonucleic acid (DNA). Nucleic acid (RNA) leads the metabolic progressions in the cell while deoxyribonucleic acid (DNA) assists as the databank of cell life. UV light is damaging DNA of cells which prevents the organism reproduction.

4.9.5 Biological treatment systems

Biological treatment is used to treat the biodegradable constituents in the waste water. The main objectives of this type of treatment are:

1. transformation of particulates and dissolved biodegradable constituents in to acceptable products
2. incorporating and capturing non-settleable and suspended colloidal solids into biological biofilm or floc
3. Removing nutrients like phosphorus and nitrogen especially for water intended to be used in irrigation as these two nutrients can stimulate the aquatic plants growth.
4. removing specific compounds and organic constituents

Bacteria are the main microorganism that is used in the biological technology in order to remove particulate and dissolved carbonaceous BOD however there are many types that can be used like fungi, protozoa, algae and rotifers. Microorganism is used to oxidize and convert the carbonaceous organic matter into simple products and extra biomass. Microorganisms are used to remove phosphorus and nitrogen and with some type of bacteria it could dioxide ammonia into nitrate and nitrite. There are two types of biological process; attached growth process and suspended growth process. In order to design the treatment plant successfully, the designer should understand the microorganism types, its reaction, environmental factors that can influence its nutritional needs and performance.

I. Suspended growth process

In this type of biological treatment, proper mixing methods should be used to maintain the microorganism in liquid suspension. Activated sludge process is the most common treatment process used for water treatment. It was named by this name because it is producing microorganism activated mass that has the ability to stabilize the waste using aerobic conditions. Activated sludge process can form floc particles with a size ranging from 50-200µm. these floc can be removed in the clarification step by gravity settling.

II. Attached growth process

In this type of biological treatment, the microorganisms are removing the nutrients and organic materials which are attached to the inert packing material. The terminology biofilm is used to describe this nutrients and organic materials. The packing materials which are usually used gravel, slag, plastic, rock, sand and red wood.

There are a variety of biological processes in grey water recycling that been used. Biological processes like: rotating biological contactors, sequencing batch reactors, fixed film reactors, anaerobic filters, biological aerated filters and membrane bioreactors. Regardless type and numbers of processes, biological systems provide an excellent solid and organics removal.

It is rarely to use biological system alone, usually it is proceeded by physical pre-treatment (screening, or sedimentation) or/and followed by disinfection. Biological treatment systems can be combined with activated carbon, sand filters, membranes in process like MBRs or constructed wet lands. Full scale biological systems usually are used in big buildings like multistory buildings, stadiums and student residence.

The benefits of physical and biological treatment processes have been combined in a small foot print system like membrane bio reactor (MBR) and biologically aerated filters (BAF).Both systems have the ability to produce high quality effluents. BAF combine fixed film biological reactor with depth filtration while MBR combine a microfiltration membrane with sludge reactor.

There are two ways to configure the MBR system either placing the membrane within the reactor (submerged MBR) or external to the reactor (side stream MBR).both configurations have similar biological performance but they differ in the membrane permeation. The main disadvantage of MBR system is the fouling that is result from materials build up that depends on blocking the flow of effluent the across the membrane. Advantages of if compared to conventional systems are (Ottosson, 2003):

1. Requires small space
2. Consumes less energy
3. Controls in a better way the organic matters and microbes in the process effluent
4. Produces better water quality

All biological systems achieved a turbidity level below 8 NTU and SS below 15mg/l. In order to achieve the best micro – organism removal disinfection stage can be combined to the system however it was found that MBRs can achieve an excellent microorganism removal without the need to apply a disinfection phase. MBRs achieve a faecal and coliforms concentration 5-log, corresponding residual concentration below 30cfu/100ml, BOD concentration of 3mg/l, turbidity 3NTU and SS 6mg/l. The dis-advantage of biological systems is that its performance can be affected by the fluctuation of grey water flow and strength in the small scale systems.

6.9.6 Extensive treatment technologies

Extensive treatment technologies always compromise of constructed wet lands like ponds and reed beds that proceeded by sedimentation and followed by sand filter. Sedimentation used to remove big particles in the grey water and sand filter is used to remove small particles carried by treated water. Many plants can be used in reed beds planting. The common plant used in reed beds planting is phragmites australis however it is reported that this kind of plants is noxious. Other plants that can be used as founded by researchers are: *Veronica Beccabunga, Iris Pseudocorus, Juncus Effuses, Glyceria Variegates, Caltha Palustris, Iris Versicolor, Menthe Aquatic and Lobelia Cardinalis.*

Extensive treatment technologies achieve BOD concentration below 10mg /me, turbidity concentration 8 NTU and SS concentration 13mg /me however it was reported that these systems achieve a poor removal of micro- organism. Faecal concentration was reported to be 3.6 log and total coliforms concentration 3.2 log and the residual concentration is above 10^2 cfu/100 ml.it was found that the average HRT is 4.5 days for Extensive treatment technologies. The advantages of Extensive treatment technologies are: Environmentally friendly system, Low operating costs and Inexpensive

As a conclusion , sand filters and simple technologies have a limited effect on grey water treatment, membrane have a good ability to remove solids but failed to tackle the organic fraction , biological systems and extensive technologies are a good ability to treat grey water in general and to remove organics in particular. Although there is lack of information regarding chemical systems, it was reported that it can achieve a good treatment with short retention times. Systems that include a disinfection phase can achieve the best microorganism removal however MBRs can achieve the microorganism removal without the need to a disinfection phase.

Another parameter that can affect the choice of grey water system is the space. Biological, physical and chemical systems always require smaller area than extensive technologies.

4.10 Regulatory process for water quality

There are no international regulations to control grey water treatment and its quality, however some countries issued their own regulations to match their needs (Crittenden, et al., 2005). The published standards always focus on the microbial content as the grey water could have a human health potential risk, thus it includes the treatment parameters of solid fractions and organics like bio chemical oxygen demand (BOD) , turbidity and suspended solids(SS)(Pidou et al. 2007).

The importance of water quality regulations and standards is that it helps in the selection of raw-water source, helps in the proper selection of treatment criteria and system, and provides alternatives and solutions to modify the existing water treatment plants, provides an idea of the treatment cost and helps in residuals management.

Many reports and publications have been prepared over the years regarding water quality criteria and its usage in many beneficial uses. The first report "water quality criteria" was published in 1952 by California state water pollution control board in conjunction with California institute of technology and was revised by McKee and Wolf in 1963 and republished on 1971.Later, many references issued by federal agencies in order to response to SDWA and federal water pollution control act. These references are:

1. Water quality criteria (NAF & NAS, 1972).this criteria prepared and issued by national academy of science and national academy for engineering for US. EPA.

2. Water quality criteria (US. EPA, 1972) .this criteria prepared by national technical advisory committee in 1968 and reprinted by US. EPA.
3. Quality criteria for water (US. EPA, 1976a), this criteria published by US. EPA.

In 1993, world health organization (WHO) developed guidelines for drinking water quality that is not mandatory however any countries adopted WHO guidelines in their national standards. WHO guidelines include: health based standards, measurement, monitoring, waterborne pathogens and microbial removal, radionuclides, chemical constituents and aesthetic characteristics.

4.11 Regulatory process for water quality in Abu Dhabi Emirate

Abu Dhabi Emirate recognized the importance of water, nutrients and energy sources so it creates Plan Abu Dhabi 2030. Abu Dhabi 2030 is an environmental policy to develop sustainable infrastructure technologies that are managing energy , water and waste.

The main aim of the regulations is to provide clear framework to manage reclaimed water in many activities in order to create safe environment. Water reuse activities in Abu Dhabi should be approved by regulations and supervision bureau as shown in table 4.5. The approved reuse activity should confirm not causing any Public Nuisance, public health and safety harmful and water environment pollution. After approving the reuse activity, the entity that is intending to use treated water should clarify the performance and operation of treatment, disposal and end user systems and the waste water quality.

A monitoring programmer should be developed as part of the safety plan to confirm the treatment performance and operation effectiveness by installing metering system to measure flow rate, volume and composition. In case of failure in complying with the regulations, entity will have a penalty not less than 250,000 DH in the first time and 500,000 DH in the second time. The standards of using treated water in irrigation are derived from Annex 1 of WHO 2006 Guidelines for the safe use of Wastewater in Agriculture1 as illustrated in table 4.6 and table 4.7.

Table 4.5: Approved re use activities using treated reclaimed water. (Regulations and supervision bureau,2009)

Approved-end-use Public health	Public health standards	Irrigation standards	Remarks
Irrigation of urban areas	P I	Required	Golf courses, sports facilities, public open spaces, and Parks, with unrestricted access for public.
Unrestricted irrigation of agricultural areas.	P II	Required	Agricultural activities which produce raw edible crops which is grazed directly. With controlled public access.
Restricted irrigation of agricultural and forestry areas	P III	Required	Agricultural activities which produce industrial crops, crops that should be processed before consumption and landscaping or forestry activities, With limited public access.

Table 4.6: Microbiological public health standards using treated reclaimed water. (Regulations and supervision bureau, 2009)

Parameter	unit	Assessment criteria	Public health standards		
			P I	P II	P III
Faecal Coliforms	CFU/100ml	MAC	< 100	< 1000	-
Intestinal Enterococci	CFU/100ml	MAC	< 40	<200	-
Helminth Ova	Number / l	MAC	< 0.1	< 1	< 1

Table 4.7: Public health standards using treated reclaimed water. (Regulations and supervision bureau, 2009)

Parameter	unit	Assessment criteria	Public health standards		
			P I	P II	P III
pH		average	6-8	6-8	6-8
BOD5 (ATU)	Mg/l	MAC	10	10	30
Total Suspended Solids	Mg/l	MAC	10	20	30
Turbidity	NTU	MAC	5	10	n/a
Residual Chlorine	Mg/l	average	0.5 to 1	0.5 to 1	n/a
Dissolved Oxygen	Mg/l	average	≥ 1	≥ 1	≥ 1

4.12 Global experience of gray water reuse

U.S., Australia and Japan are reusing grey water in high profile. Each country has a different reason to adopt grey water reuse. For example Japan adopts gray water reuse because of its small land space compared to its high population density. Jordan, USA, Australia and KSA are suffering from drought conditions. In Germany gray water is used for toilet flushing and irrigation.

Currently, conventional activated sludge plants have been adopted on large site treatment systems. This adaptation is suitable for garden surface irrigation because its effluent standard is chlorinated effluent that contains not more than 20BOD/30SS.Using treated water in crops irrigation is an acceptable practice in many MENA countries like Tunisia, Morocco, Egypt and Jordan however it is costly. Recycled water will be a dominate irrigation source in MENA countries By this century as many countries reclaiming their waste water like Tunisia one-eighth and Jordan one-quarter.

MENA population compromise 5% of the overall world's population however it is suffering from Water scarcity as freshwater resources less than 1% of the world's resources. MENA climate is semi-arid and arid with low rain fall rates. Irrigation is the most water consumer in MENA countries and varies from 70% to 90%.the domestic water use varies from 5% to 20% only. Water delivery systems considered as inefficient and the loss mainly resulted from supply and delivery systems that reaches to 60%.Domestic and irrigation water are subsidized and the cost is low which promote the consumers waste and no incentives for water saving. Potable water is used in gardens irrigation. In order to solve the water scarcity in MENA area, many countries adopt the usage of treated water like Kuwait, Qatar, UAE and Bahrain. GCC countries are using 400 million cubic meter of treated water in irrigation urban landscaping and non-edible crops.

In United Arab Emirates, fresh water available per capita annually is 61 m3 /capita while the annual withdrawal is 954 m3 /capita. The annual withdrawal by domestic, industrial and agriculture sectors are 24%, 10% & 67 % respectively (Bakir, 2001).
The use of Reused treated wastewater in UAE is 108,000,000m3/yr. The annual withdrawal by agriculture sector is 7.7% and the total withdrawal of treated wastewater is 5.1%.

Abu Dhabi Emirate developed Masdar Initiative in April 2007 to create the world’s first car-free city, zero-waste and zero carbon. Masdar project has four targets which are: achieve economy diversify in Abu Dhabi, locate UAE as a sustainable technologies developer, solving environmental problems and expand Abu Dhabi role in the international energy markets. As the climate of Abu Dhabi is harsh so water systems efficiency is a key element in the contribution of sustainability plan of Masdar. Masdar City water demand reduced to 60% and 80% of the water will be recycled to be used in irrigation and household activities (Stilwell & Lindabury, 2008).

4.13 Landscape Irrigation

The use of treated waste water in irrigation became important in last millennia however its quality importance recognized recently. High rates of evapotranspiration in arid zones make the chemical and physical characteristics have a special concern. The quality of irrigation water varies greatly depending on the quantity and type of dissolved salts.

The increment of evapotranspiration increases the salt deposition in water. Soil mechanical and physical properties like permeability, soil structure and stability of aggregate are influenced greatly by the ions exchange in irrigation water. In order to use treated water in irrigation, soil and plants should be considered. University of California committee of consultants developed guidelines for water quality intended to be used in irrigation as illustrated in table 4.8.

According to Tchobanoglous, et al. (2003), there are four parameters that have a major influence on the irrigation water quality: ion toxicity, Salinity, Water infiltration rate and other problems.

- **Specific ion toxicity**

High concentrations of specific ion toxicity cause declination of crop growth. The ions that affect plant drastically are boron, chloride and sodium. The most toxicity ion is boron which is resulted from the used detergents or industrial waste. Chloride and sodium are resulted from using water softeners.

- **Salinity**

Salinity is the most important parameter to determine the suitability of water in irrigation and can be done by measuring the electrical conductivity. Electrical conductivity measures the total dissolved solids (TDS) levels in water and expressed by decisiemens per meter (dS/m).
Salts concentration in water have a great influence on the growth of plants in three ways: first Soil particle dispersion (caused by low salinity and high sodium), second Ion toxicity (caused by ions concentration), third Osmotic effects (caused by dissolved salt levels).

Evapotranspiration increase the salt levels in the root zone which increase the plant expand more than the available energy. The practical way to solve this problem is to establish a net to downward the salt and water flux through the root zone with a proper drainage system. Irrigation water should fulfill the standard illustrated in table 4.09.

Table 4.8: Guidelines of irrigation water quality (Tchobanoglous, et al. 2003).

Potential irrigation problem	units	Degree of restriction on use		
		none	Slight to moderate	severe
Salinity				
ECw	dS/m	<0.7	0.7-3.0	>3.0
TDS	Mg/l	<450	450-2000	>2000
Permeability (influence water infiltration rate .evaluation using SAR and ECw or adj RNA together)				
0-3		ECw≥0.7	0.7-0.2	<0.2
3-6		≥1.2	1.2-0.3	<0.3
6-12		≥1.9	1.9-0.5	<0.5
12-20		≥2.9	2.9-1.3	<1.3
20-40		≥5.0	5.0-2.9	<2.9
Specific ion toxicity:				
Sodium				
Surface irrigation	SAR	<0.3	3-9	>9
Sprinkler irrigation	Mg/L	<70	>70	
Chloride				
Surface irrigation	Mg/L	<140	140-350	>350
Sprinkler irrigation	Mg/L	<100	>100	
Boron	Mg/L	<0.7	0.7-3.0	>3.0
Miscellaneous				
nitrogen	Mg/L	<5	5-30	>30
Bicarbonate	Mg/L	<90	90-500	>500
PH	unit	Normal ranges 6.5-8.4		
Residual chlorine	Mg/L	<1.0	1.0-5.0	>5.0

Table 4.9: irrigation water quality (Jubran & Hizon ,1999)

Soluble salt	Water quality
Below 0.25	Excellent
0.26-0.59	Good
0.60-1.49	fair
1.50-2.00	poor
Above 2.00	Excessively salty

- **Water infiltration rate**

High sodium levels cause deterioration of soil physical conditions (soil permeability reduction, water logging and crust formation). Poor water infiltration rate makes the irrigation difficult .to solve this problem soil needs to be rearranged or excavated. Sodium adsorption rate (SAR) is usually used to predict the infiltration**.** High SAR values mean high sodium rates.

- **Other problems**

Irrigation system clogging is a serious problem that is resulted from biological growth in the emitter orifice, supply line and sprinkler head. Usually clogging problem occurred in drip irrigation systems. The ideal systems are totally enclosed systems that reduce the exposure to spray drift or treated water. Chlorinated treated water that has residuals of chlorine more than 5g/l can cause damage to vegetation when water sprayed on foliage directly.

Chapter 5: Methodology

Chapter 5: Methodology

5.1 Introduction

This chapter outlines the different methodologies used to investigate the performance of green roofs, pros and cons of each methodology, the selected methodology, data collection and simulation program.

5.2. Comparison between different methodologies

Many researches with different methodologies have been carried out in order to investigate the thermal behaviors of green roofs and their contributing in reducing the building`s cooling loads. Methodologies that been used are: theoretical analysis, field investigation, case study analysis and simulation analysis.

Field investigation and Case study analysis methodologies were used more than other methodologies like simulation analysis however recently there is a tend to use simulation analysis methodology for many reasons will be discussed in details in the current section. Researches did investigate many parameters that could influence the performance of green roofs like: planting density and type, water content and soil thickness.

Parizotto &Lamberts (2011) used a case study analysis to compare the thermal performance of three types of roof; ceramic roof, green roof and metallic roof. They used graphical figures to present the comparison in regards to water content, substrate layers, drainage, relative humidity heat flux and external surface temperature

Fioretti, et al. (2010) investigated two case studies with two special methodologies. In the first case study, they investigated bare roof and green roof in Marche polytechnic universities at fall and summer seasons. In the second one; they investigated the performance of two green roof systems with different layers of planting in university of Genova. They used graphical figures to present the comparison in regards to air temperature, Dry bulb temperature, heat fluxand external surface temperature.

The two researches that adopt case study methodology had realistic results that are based on realistic local climate conditions.

The most important issue with this methodology is that the parameters that would be investigated should be specific as they are depending on distributing monitoring systems and sensors over specific locations. However this method is realistic, it has many cons like: needs long time over seasons, needs green roof installation on buildings with structural loads, needs instruments, sensors and manpower over the research. In addition, building`s results cannot be used for another building as they depend on climate, orientation, building activities, building types, finishes and heights, Occupancy and shadow of adjacent buildings. Also to bear on mind that monitoring systems should be under observation as they could have errors.

Sailor (2008), adapted simulation methodology by using Energy Plus program to investigate different design`s alternatives in regards to moisture and heat transfer within the layers of green roof system. He selected the weather file of two cities; Chicago and Houston to show the monthly energy reduction that been occurred.

Wong, et al. (2003), adapted simulation methodology also by using DOE-2 program. They investigated the cooling loads and energy consumption occurred in a building with green roof. Their results were shown in graphics to illustrate building loads, surfaces temperature and energy consumption.

Computer simulation methodology can be easily used with different weather files for different location at any period of time within the year. The pros of this methodology are that: not consuming long time, modification and changes can be applied into the parameters easily; energy consumption and cooling loads can be shown hourly, don’t need instruments and sensors and don’t require travelling. In addition, orientation and building scale can be changed, On the other hand, cons of this type of methodology that it could have some human errors specially at time of data feeding and plant`s biological process and evapotranspiration cannot be investigated . Sailor (2008) stated that drainage layer and protection membrane influence cannot be investigated in the same model and required a separate model.

Tsang & Jim (2011) used the theoretical analysis methodology by collecting their data at summer season from a field experiment. They conducted a Sensitivity analysis to show results of dry bulb temperature, wind speed and relative humidity,

Barrio (1998) adapted the theoretical analysis methodology by implementing a theoretical model to investigate the different parameters that influence green roof performance. Sensitivity analysis was also conducted to show the results of heat transfer, meteorological data, energy flows and heat storage. Feng, et al. (2011) adapted the theoretical analysis methodology .an experiment was conducted after the analysis to justify the green roof`s energy balance. Results were shown in photos and graphics in regards to outdoor temperature, relative humidity and indoor temperature.

Theoretical analysis methodology is considered complicated as it depend on applying different equations related to different parameter that should be integrated to find out the parameters interaction. Another dis advantage to this methodology is that it needs always to be validated by another methodology. In addition; field investigation should be carried out to find out measurements that can be applied into the equations.

Santamourisa, et al. (2007) used experiment methodology that followed by simulation methodology. The simulation methodology used to produce a validation to the experiment results like outdoor temperature, relative humidity and indoor temperature.

Onmura, et al. (2001) used experiment methodology that followed by simulation methodology. The experiment depends on wind tunnel installation. Lazzarin, et al. (2005) adopt the experiment methodology that followed by a numerical model. The numerical model is used to produce validation to the experiment`s results like surface temperature and air temperature.

Experiment analysis methodology depends on the experiment type and conditions. If the experiment conducted in controlled environment (like the experiment of Onmura, et al. ,2001) that have similar conditions like local climate conditions so the experiment should be validated by another methodology. On the other hand, if the experiment conducted by installing realistic green roof, the results will be realistic.

Experiment methodology consumes time and effort. Also it needs installing sensors and monitoring systems which could have some errors. When starting an experiment by installing green roof researchers need to confirm that the building doesn't been affected by reflected solar radiation or shadows by adjacent buildings.

5.3 Selection of method

Based on the previous methodologies' pros and cons, the best methodology to be used is the computer simulations methodology. Computer simulations methodology saves time and offers flexibility in changing parameters, orientation, location and building design. Simulations methodology has the ability to produce results related to any season and at hourly rates. It provides a realistic analysis to the best thickness and parameters of green roof to be used before installing the layers into any building while the other types of methodologies requires the green roof installation to investigate its thermal performance. Theoretical methodology should be followed by an experiment to validate its results. Case study and experiment methodologies are costly and consuming time and effort.

Nowadays, there is a wide range of simulation programs that can be used to simulate and investigate the thermal performance of green roofs. Sailor (2008) stated that there is a weakness in these programs in analyzing the performance of drainage layer and protection membrane however the technologies` quick development can help in solving this weakness.

Theoretical analysis methodology will follow the simulation methodology in order to solve the weakness of IES program in considering the effect of soil`s evaporation and plant`s transpiration. The theoretical analysis methodology will consider all the parameters that IES failed to consider that are related to plants and soil. Soil`s parameters that will be considered are:

1. Surface resistance of substrate to mass transfer.
2. Aerodynamic resistance to mass transfer.
3. Soil`s vapor pressure.
4. Evaporative resistance coefficient of substrate.
5. Water`s volumetric volume in substrate.
6. Soil`s temperature.

Plant's parameters that will be considered are:

1. Stomatal resistance to mass transfer .s/m
2. Air`s vapor pressure that in contact with the leaves of plant
3. solar irradiance
4. Plant temperature
5. Plant`s leaf area index
6. Average temperature of plants

Theoretical analysis methodology has the ability to integrate different parameters that cannot be achieved by other mythologies which enables the observation of the interaction between them. In order to improve the theoretical analysis, the measurements that used will be obtained from IES program and from experiments done by others.

5.4 UAE Meteorological data

United Arab Emirates is located in the Arabian Peninsula within the countries of Middle East. UAE has borders with Oman and Saudi Arabia as shown in figure 5.1. It is consisting from the federation of seven emirates; Abu Dhabi, Umm Al Quwain, Ajman, Dubai, Sharjah, Fujairah and Ras Al Khaimah. UAE is located at 23° 49 north, 54° 20 East with an area estimated by 83,600km^2.

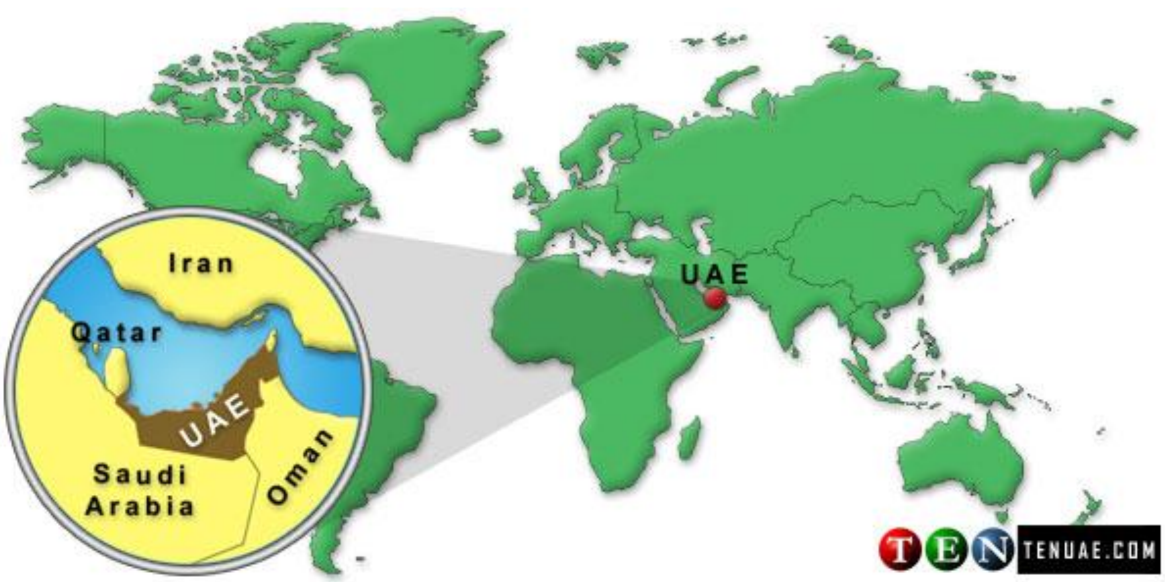

Figure 5.1: United Arab Emirates location. (TENguide ,2009).

Abu Dhabi Emirate is the capital that has the largest area that been estimated by 67,340 km². the city of Abu Dhabi is located on an island with T-shape at the center of the Arabian Gulf`s western coast. The climate in UAE is an arid tropical climate, thus in summer the weather is dry and hot in the desert while in the coastal areas it is hot and humid.

The average humidity in the coastal areas is 50%-60% however in summer it increases to reach 90%.in summer, the average temperature is 40°c while in winter it is 26°c. at day time. The temperature and rainfall of UAE illustrated in table 5.1.The rain fall season is usually in March and February however sometimes it rains at early periods. The annual average rain fall is estimated to be less than 6.5cm.

Table 5.1: Mean monthly rainfall and mean monthly maximum temperature (Aspinall, n.p.)

	Jan	Feb	Mar	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Temperature in °C	24	25	29	33	38	39	40	40	39	35	30	26
Rainfall in mm	11	38	34	10	3	1	2	3	1	2	4	10

5.5 Case study building

A residential building was selected in order to investigate the thermal behaviors of different green roof and living wall types on the building energy consumption. The building is a representative building of the type is most used in Abu Dhabi and located in a densely urban area in the city that has a meager area for open spaces and extensively covered by high-rise buildings and roads. This case study by this building suggests green roof and living walls as a passive cooling and energy saving method in Abu Dhabi city. The building latitude is 24°29'13.36"N and longitude is 54°22'19.17"E and is located in the center of Abu Dhabi city as shown in figure 5.2.The building is residential building, consisting of ground floor (refer to figure 5.3) used as a showroom and containing some services spaces and 16 typical floors (refer to figure 5.4) that contain six apartments in each floor.

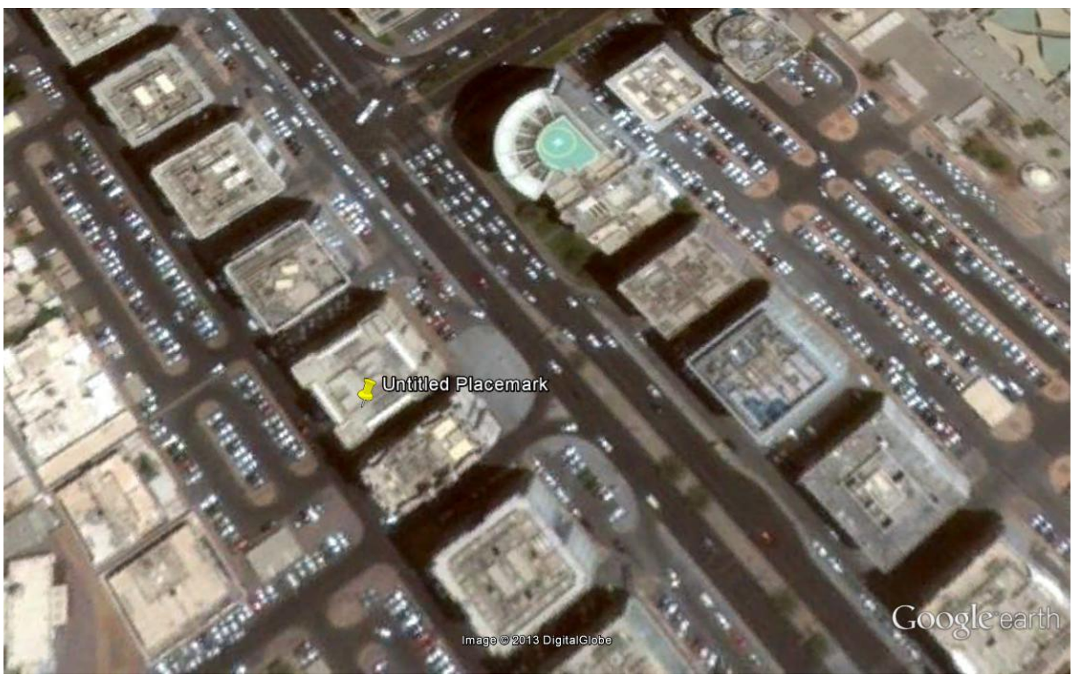

Figure 5.2: Buiding location in Abu Dhabi(Google maps,2013)

The ground floor area is equal to 929 m² while the typical floor area is equal to 1035 m². The building facades constructed using conventional materials like brick and simple double glass. Floors constructed using concrete slab and marble tiles while the roof consisting from concrete and conventional insulation materials.

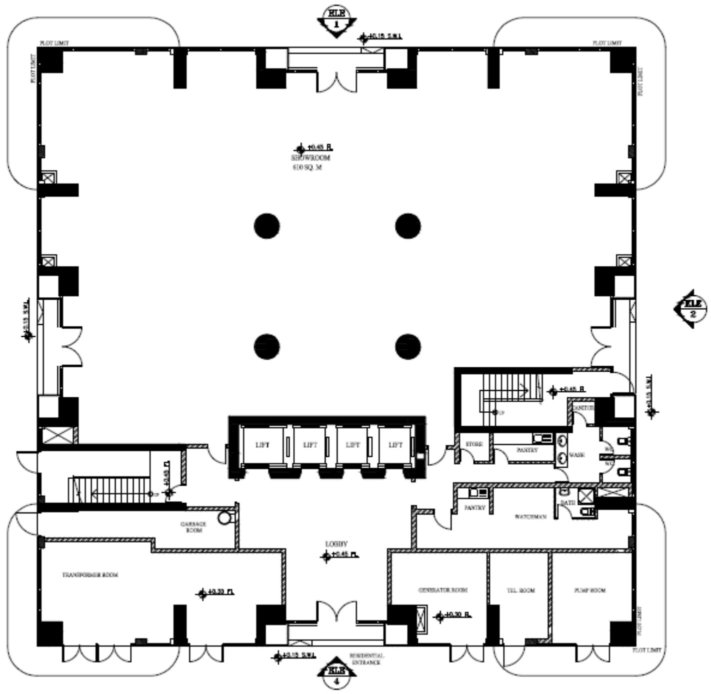

Figure 5.3: Ground floor plan. (Image source: CAD drawing)

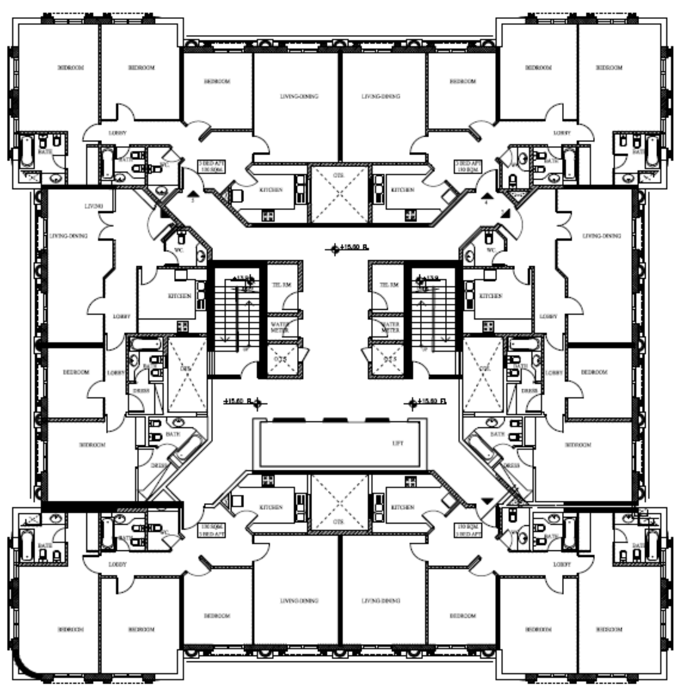

Figure 5.4: Typical floor plan.(Image source: CAD drawing)

5.6 Green roof

A sketch (as shown in figure 5.5) can help in designing the green roof system by presenting the building, boundaries and planted areas. To assess grey water resource, calculations should be done for the designed building depending on the population and the water fixtures. The slope of the system from beginning to the end should be considered and should be not less than 2%to enable transferring the water to the planted areas.

Green roofs benefits had been discussed in the first chapter. Roofs require special considerations in design as they are exposed directly to the solar radiation. In order to achieve the target of using green roofs in reducing heat gain into buildings, many layers and different membranes are used. Green roof in general is consisting from the following layers as discussed in the first chapter; however the U value of each layer has been illustrated in table 5.2.

I. Plants: plants that will be used are native and indigenous plants in order to promote the natural systems.
II. Soil: 8°slope will be implemented to promote drainage system. Soil thickness will be 200 mm in extensive green roof while in intensive green roof it will be 20 mm.
III. Filter fabric:
IV. Drainage layer:
V. Root barrier:
VI. Insulation layer this layer should be impervious. materials that can be used is Extruded polystyrene
VII. Water proofing layer: will be consisting from three layers with a thickness of 30mm.
VIII. Structure: Reinforced concrete:

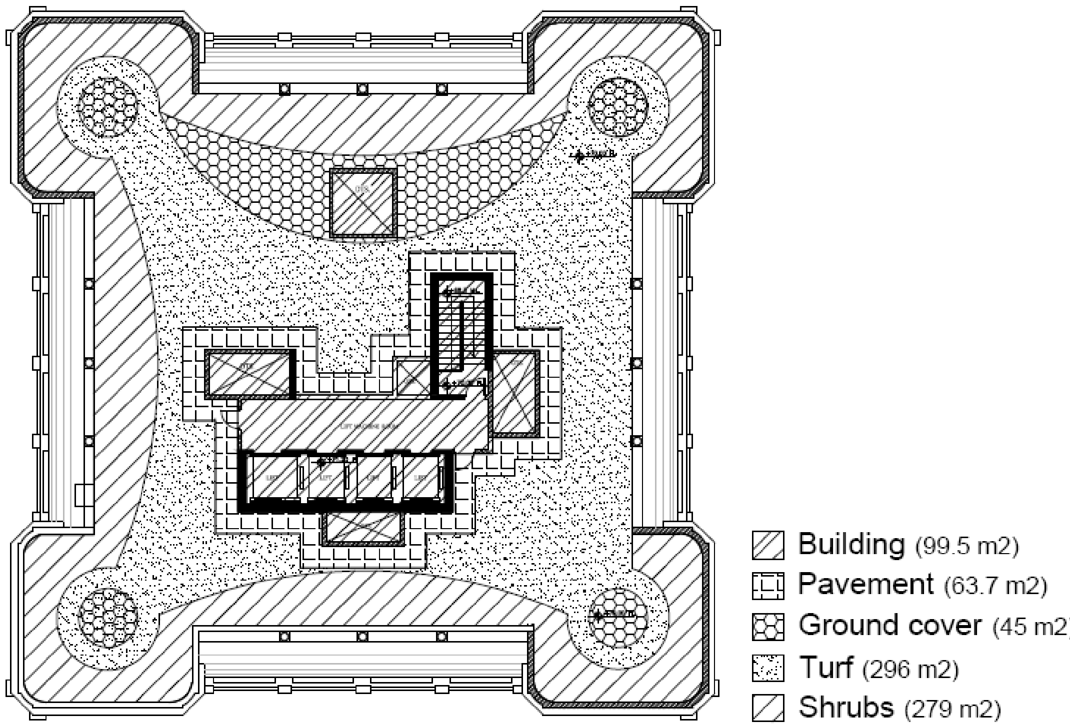

Figure 5.5: Green roof plan.

Table 5.2. Green roof`s Layers U values. (Colorado Energy, 2011)

	Layer	Thickness	U value
1.	exterior air film	-	-
2.	soil	9.8''	0.29
3.	Cavity	4.7''	
4.	polyurethane board)	2.36''	0.0250
5.	Polystyrene	0.5''	0.03
6.	Insulation layer	3''	0.0759
7.	Waterproofing membrane	2"	0.0250
8.	CMU (concrete masonry unit)	7.87''	1.13
9.	interior air film	-	-

5.7 Green walls

The system that is intended to be used in the research is a wall system. The system is modular system, flexible and can be used on the external walls at hot climate regions. The system is consisting of the following components as shown in figures 5.6, 5.7 and 5.8 while the U value of wall`s layers has been illustrated in table 5.3:

1. 1 ft² stainless panels.
2. Growing Medium:
3. Plants.
4. Irrigation system and sensors.
5. Stainless Steel Frame mounted on the façade.

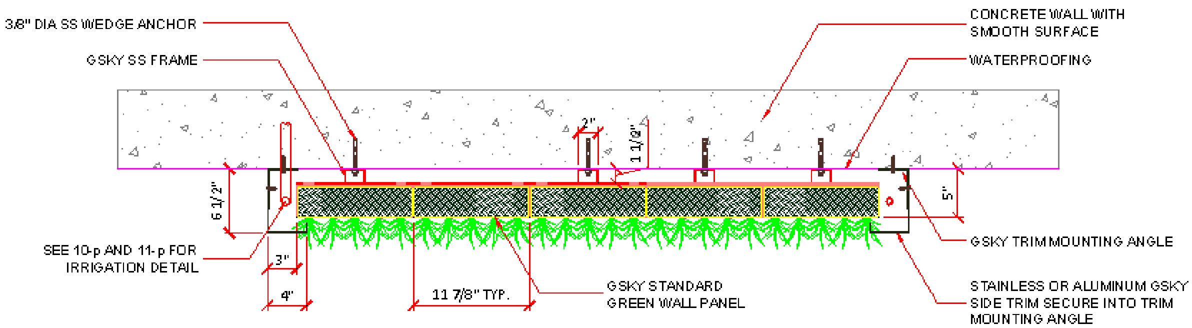

Figure 5.6: Green walls plan. (GSKY Green Wall Panels, 2010).

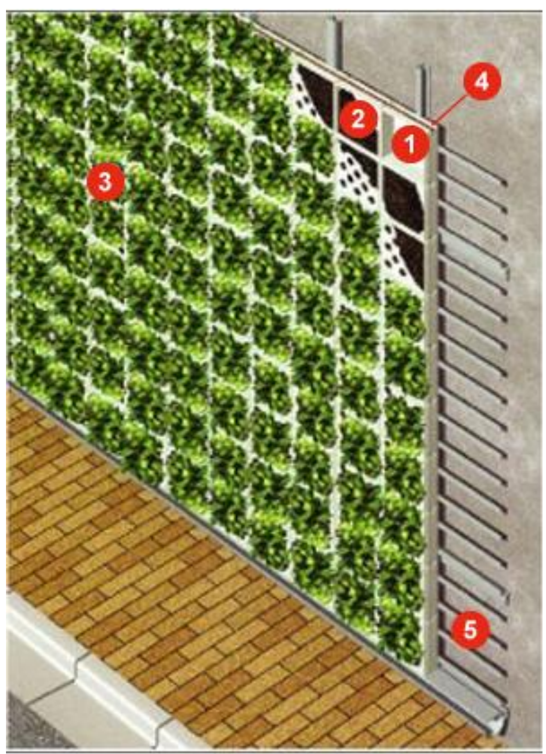

Figure 5.7: Living wall system. (GSKY, 2010)

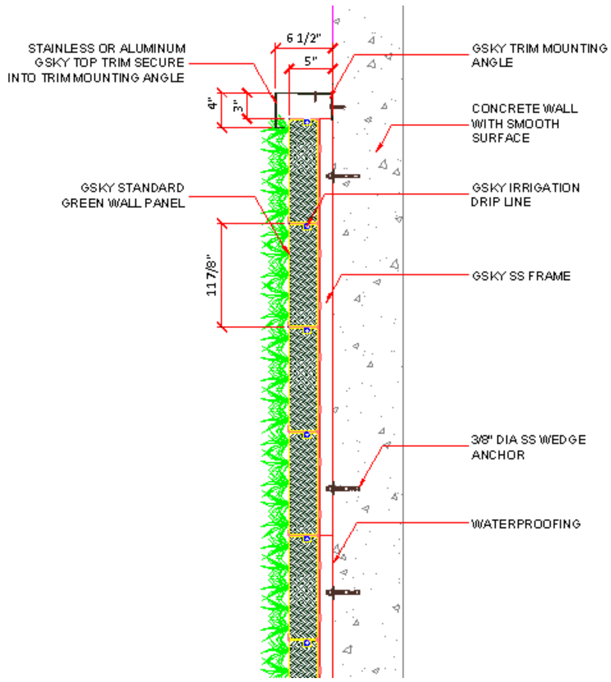

Figure 5.8: Green walls section. (GSKY Green Wall Panels, 2010).

Table 5.3: Living wall`s layers U values. (Colorado Energy, 2011)

	Layer	Thickness	U value
1	exterior air film	-	-
2	soil	5.9’’	0.29
3	air space	1.5’’	-
4	Waterproofing membrane(Fiberglass)	6.5"	0.04
5	CMU(concrete masonry unit)	7.87’’	0.84
6	Air Space	0.4’’	-
7	0.5” drywall	0.6’’	0.42
8	interior air film	-	-

5.8 Simulation Program

The software that will be used to investigate the performance of green roof and living wall is the IES Virtual Environment (VE).IES is a thermal load and energy analysis simulation program. The program is depending on the input of user in regards to mechanical systems, building's physical make-up etc. It has the ability to calculate the cooling, heating, ventilating, lighting and other energy loads.

In order to find out the end user`s annual energy, Two building models were created. The first model is the base case which is the building with conventional facades and roof. The U values implemented to the base case are as stated by ASHRAE standard and ESTIDAMA prescriptive pathway.

5.8.1 Climate Data and Peak Design Conditions

As the study case is a building located in Abu Dhabi city, the weather file that is used is for Abu Dhabi which is within the IES Weather Database. The IES Weather Database is using Abu Dhabi International Airport`s IWEC data.

Basically, this weather file is offered by the United States Department of Energy (US DOE) that uses that data for 18 years of DATSAV3 hourly weather data. The figures 5.9, 5.10, 5.11 and 5.12 below show the monthly temperature and relative humidity, solar radiation and Psychometric chart for Abu Dhabi, plotted using the hourly IWEC data from Abu Dhabi International Airport.

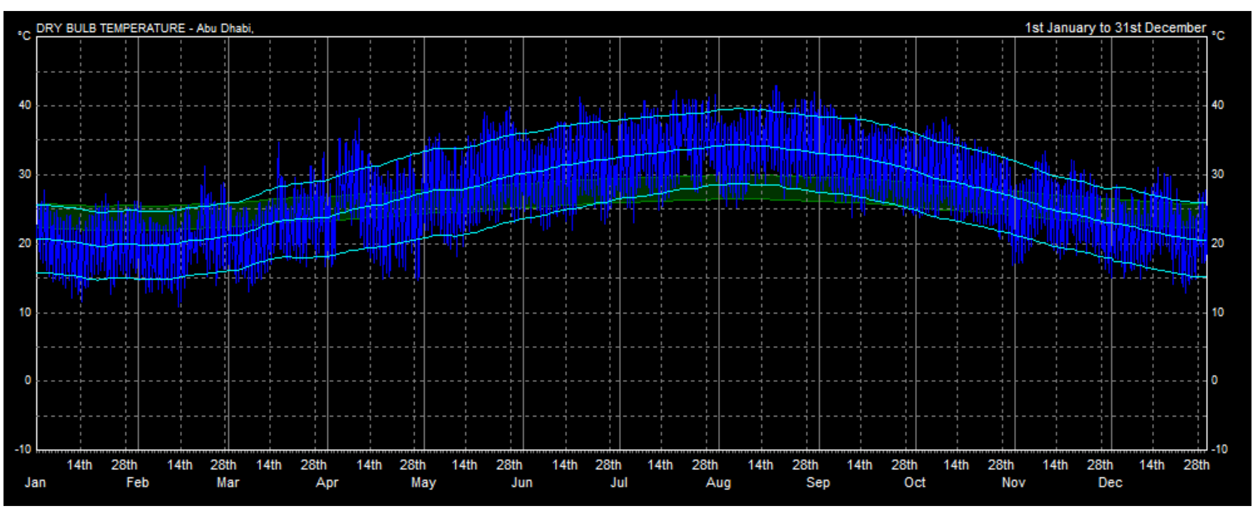

Figure 5.9: Monthly diurnal Dry Bulb Temperature (weather tool, Ecotect 5.5)

The temperature in summer is ranging between 10° C to 47° C. Comfortable conditions was found to be in winter as temperature at day time is around 24° C while at night is 13° C. there is a relatively high proportion of diffuse radiation; however clear sky is predominate in Abu Dhabi.

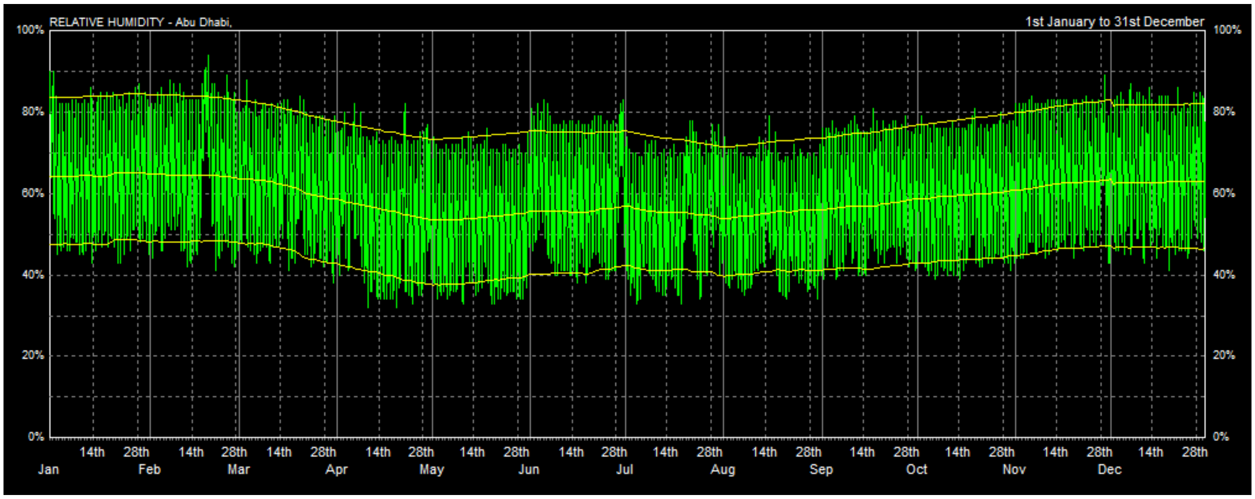

Figure 5.10: Monthly relative humidity.(Weather tool, Ecotect 5.5)

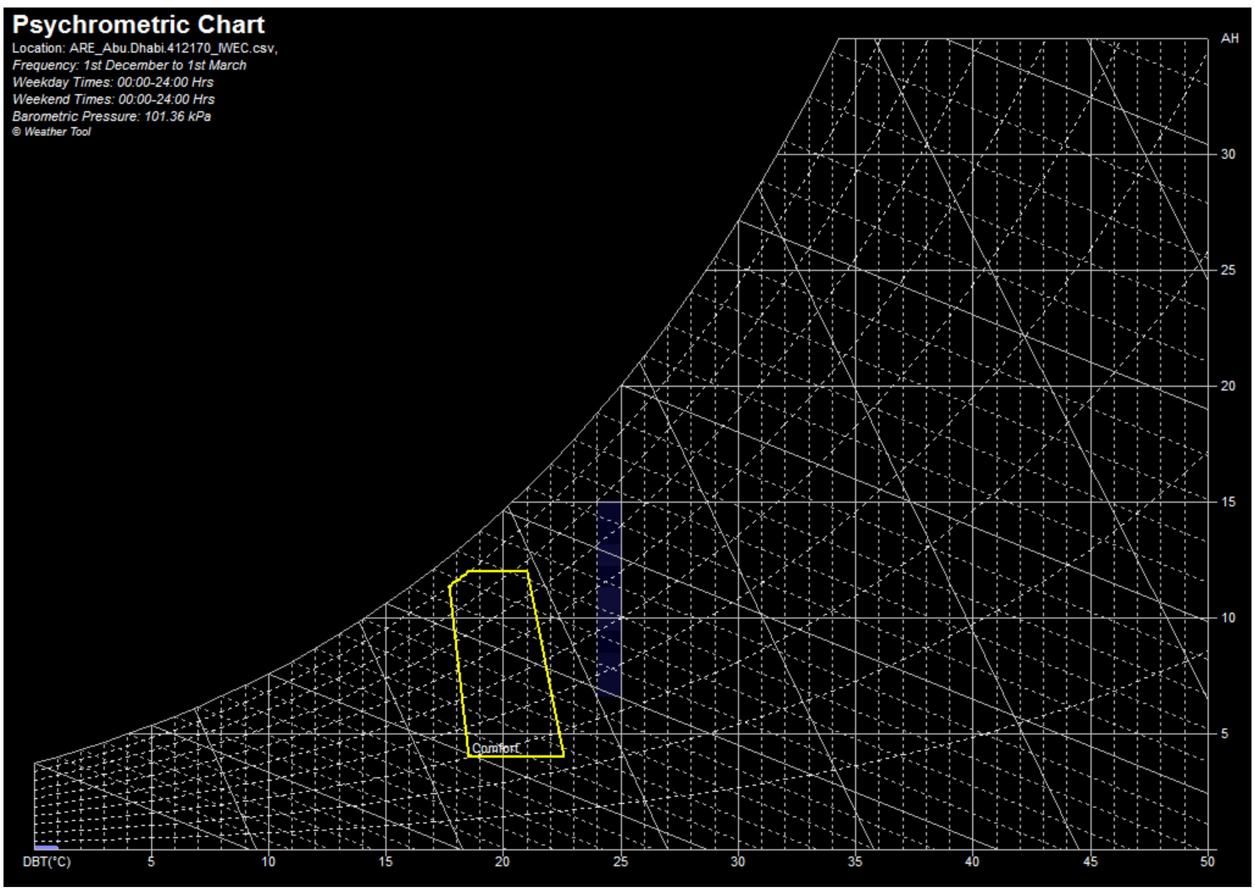

Figure 5.11: Psychometric chart of Abu Dhabi. (Weather tool, Ecotect 5.5)

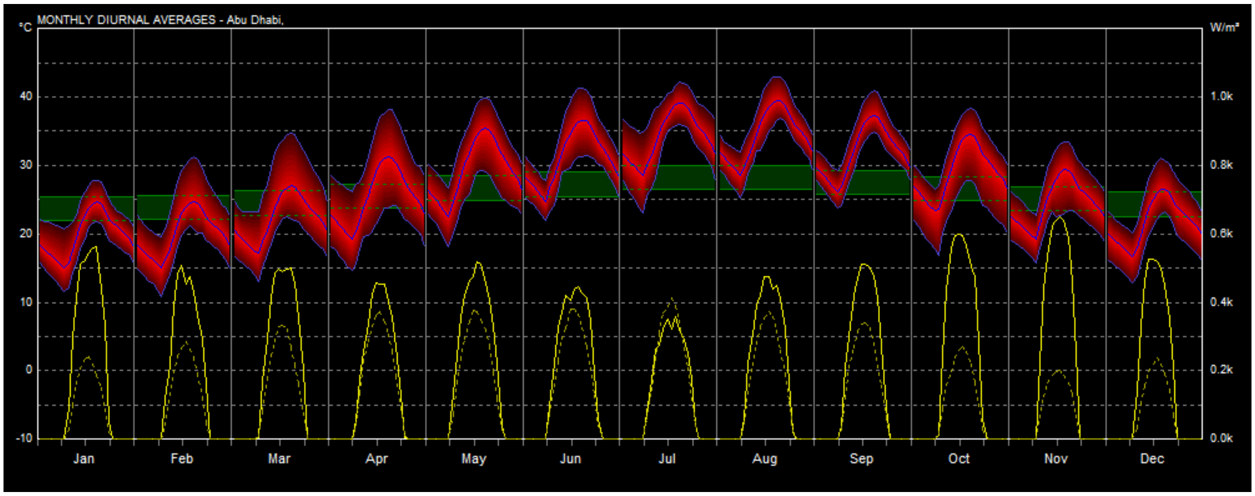

Figure 5.12: Annual diurnal solar radiation profiles.(Weather tool, Ecotect 5.5)

5.8.2 Model Build

The thermal model, built within the IES Virtual Environment, divided into six thermal zones depending on cooling requirements, occupancy, internal gains and ventilation flow rates:

- bedrooms +living +dressing
- Kitchens
- Toilets
- Services +store
- Staircase
- Showroom

5.8.3 Building Geometry

To limit the size and complexity of model, the 3D model was simplified by limiting the number of zones and identical floors were modeled using floor multipliers. Spaces with similar use and internal loads were combined into one thermal zone. The simplified zoning diagram is shown below in figure 5.13 and figure 5.14.

Both baseline building and proposed design share the same geometry and zone layout except the construction templates are based on ESTIDAMA prescriptive requirement and proposed facade design respectively. The proposed design glazing area is less than the maximum allowed ESTIDAMA prescriptive requirement for housing building, and hence the fenestration area and layout is kept same for both the models.

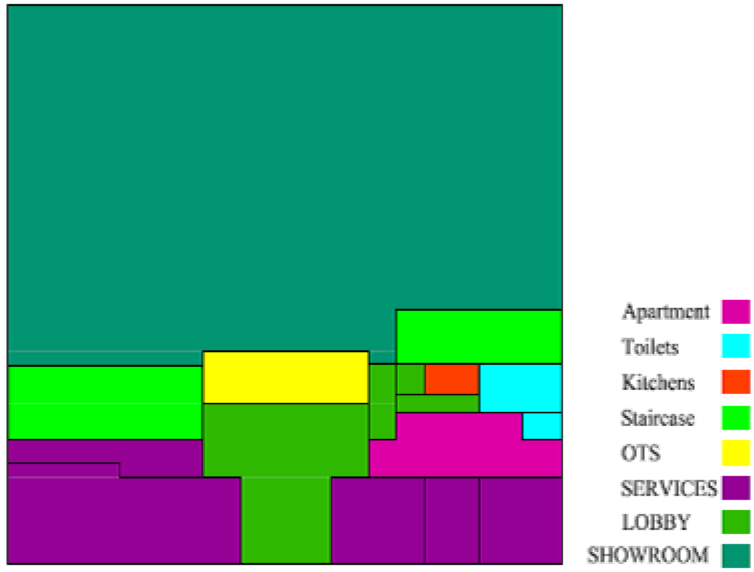

Figure 5.13: Thermal zoning diagram at ground floor.

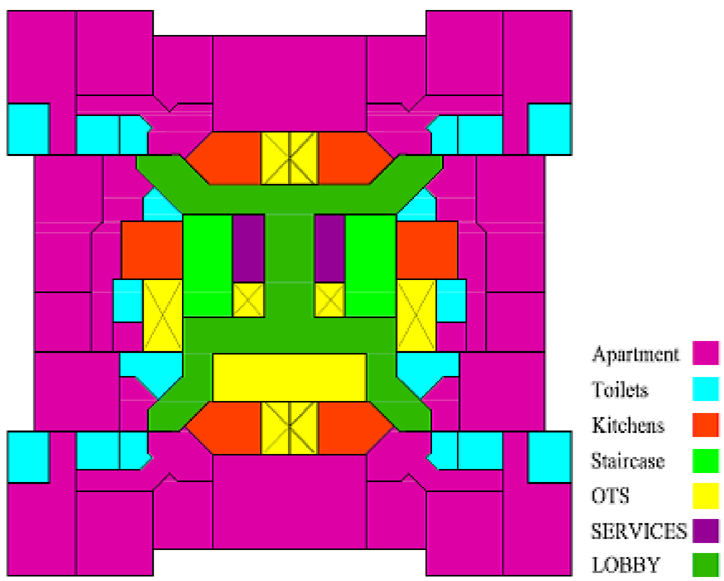

Figure 5.14: Thermal zoning diagram at typical floor.

5.8.4 Building Envelope Performance

The following facade performance values(as shown in table 5.4) divided into U values for the base case based on American Society of Heating, Refrigeration and Air conditioning Engineers (ASHRAE) and ESIDAMA prescriptive pathway; and design case U values for two types of green roofs and living walls) which calculated according to the green envelope parameters .the first type of green roof is type A is an extensive green roof that has a substrate thickness of 10 cm while the other type B is an intensive green roof that has a substrate thickness of 25 cm.

Table 5.4: Envelope Performance.

Element	Base case(according to Estidama 2011)	Design case
External wall U value(w/m²k)	0.30	living wall =0.15
External roof U value(w/m²k)	0.20	Green roof type A=0.15 Green roof type B=0.13
Floor U value(w/m²k)	1.65	1.65
Glass U value(w/m²k)	2.00	2.00
Percentage of glass to wall	30%	30%
Building Air Leakage l /s/m2	3.64	3.64

5.8.5 Internal Gains

Internal gains were defined in the thermal model to account for the non HVAC energy consumption including building lighting, plug loads and building occupancy. Variation profiles were defined in conjunction with the internal gains to represent the building usage and occupancy patterns in order to predict the annual energy use from building operation. Table 5.5 below summarizes the inputs for different zones. The zone inputs are same for baseline design and proposed design.

Table 5.5: Internal gains.

space	People m²/person	Fluorescent lighting w/m²	Computer w/m²	Infiltration ach	cooking	Cooling set point
bedrooms +living +dressing	10	15.000	10	0.25	-	21
Kitchens	10	15.000	-	0.25	20	21
toilets	10	15.000	-	0.25	-	21
Services +store	-	15.000	-	0.25	-	21
Staircase	-	15.000	-	0.25	-	21
showroom	10	15.000	10	0.25	-	21

5.8.6 Internal Conditions

I. Temperature and humidity

The assumed temperature set point for apartments is 21°c and humidity is 30-70% based on Abu Dhabi weather file (Ecotect).(Refer to Psychometric chart of Abu Dhabi).

II. Ventilation rates

Ventilation rates used according to ASHRAE standardas following:

- Residential 14.2 L/s/person via Mechanical Ventilation.
- Kitchen Exhaust 15 ac/hr.
- Toilet Ventilation 10 air changes/hour extract.
- Showroom 10 L/s/person via Mechanical Ventilation.
- Services rooms10 air changes/hour extract.

5.9 Theoretical analysis methodology

As mentioned in section 5.3, IES program will be used to investigate the thermal performance of green roofs and living walls however according to the fact that there is no explicit model for green roofs in IES, soil evaporation and plants transpiration cooling effects will not be considered during the simulation.

According to the important effect of soil evaporation and plants transpiration on the thermal performance of green roofs, a theoretical analysis methodology will follow IES simulation to find out the final energy consumption of green roofs.

The theoretical analysis methodology will be basically based on the findings of Tabares-Velasco and Srebric (2012) who developed a model for green roof`s heat transfer that is considering substrate, sky and plants by using a set of equations. The researchers conducted an experiment in order to validate the data that been resulted from the theoretical methodology that proofed the accuracy of the model.

Two different types of green roofs will be used with different soil thickness and different plant types depending on each green roof type. The first green roof (type A) will be an extensive green roof with soil thickness of 10cm and Ground cover. Ground cover is selected based on the low thickness of the green roof its low water demand. The second green roof (type B) will be an intensive green roof with soil thickness of 25cm and a variation of plants. Thickness of green roof (type B) enables the usage of wide range of plants for investigation so the plants will be selected with different leaf area index and different water demand like turf, ground cover and shrubs (refer to Appendix 2 for desert and native plants that suit the harsh climate of UAE).

5.9.1 Soil evaporative cooling

$$QE = \frac{p.\ Cp}{\gamma\ (r_{substrate} + r_a)} \cdot (e_{soil} - e_{air})$$ (Tabares-Velasco & Srebric, 2012) ……….…..(1)

Where,

P is atmospheric pressure, KPa

Cp is the air`s specific heat J/Kg. K
γ is the psychometric constant
r substrate is the surface resistance of substrate to mass transfer
ra is aerodynamic resistance to mass transfer .s/m
e soil is the soil`s vapor pressure, KPa
e air is the air`s vapor pressure, KPa

$$r_{substrate} = c1 + c2\left(\frac{VWC}{VWC_{sat}}\right)^{c}$$ (Tabares-Velasco & Srebric, 2012) …………….(2)

Where,
c1, c2&c3 are the evaporative resistance coefficient of substrate

VWC is the water`s volumetric volume in substrate

VWC_{sat} is the water`s volumetric volume in substrate at saturated conditions.

$$e_{soil} = 0.6108.\exp\left[\frac{17.27 \times (T_{soil} - 273.15)}{T_{soil} - 273.15 + 237.3}\right]$$ (Tabares-Velasco & Srebric, 2012)……..(3)

Where,

T soil is the soil`s temperature, K

$$\gamma = Cp\ .Pa/0.622\ I_{fg}$$ (Tabares-Velasco & Srebric, 2012) ……………………….. (4)

Where,
Cp is the air`s specific heat J/Kg. K
Pa is the atmospheric pressure KPa
I*fg* is the enthalpy of water vaporization J/KG

5.9.2 Plants transpiration cooling

$$Q_T = LAI\ \frac{p.\ Cp}{\gamma\ (r_s + r_a)}.\ (e_{s,\ plant} - e_{air})$$ (Tabares-Velasco & Srebric, 2012) …………….(5)

Where,
P is atmospheric pressure, KPa
Cp is the air`s specific heat J/Kg. K
γ is the psychometric constant
ra aerodynamic resistance to mass transfer .s/m
rs is stomatal resistance to mass transfer .s/m
$e_{s, plant}$ is the air`s vapor pressure that in contact with the leaves of plant, KPa
e air is the air`s vapor pressure, KPa

$$r_s = \frac{r_{stomatal;min}}{LAI}(f_{solar})(f_{VPD})(f_{vwc})(f_{temperature})$$ (Tabares-Velasco & Srebric, 2012) …(6)

Where,

$r_{stomatal;min}$ is the minimum value of stomatal resistance to mass transfer
f_{solar} is solar irradiance
f_{VPD} is vapor pressure
f_{vwc} is volumetric water content in substrate
$f_{temperature}$ is plant temperature
LAI is plant`s leaf area index,

$$e_{s, plant}=0.6108.\exp\frac{17.27.(T_{plants}-273.15)}{T_{plants}-273.15+237.3}$$ (Tabares-Velasco & Srebric, 2012)…..(7)

Where,
T_{plants} is the average tempreture of plants,k

Chapter 6: Results and Discussion

Chapter 6: Results and Discussion

6.1 Introduction

Green envelope and grey water treatment systems were discussed widely in the previous sections .This section contains the results and discussion of green envelope simulation, grey water calculation and irrigation calculation.

Grey water generation is measured based on occupancy number in each apartment while irrigation demand measured mathematically based on EPA equation that depends on Landscape water requirement, evapotranspiration, landscaped area, rainfall and distribution system uniformity.

The main building components that always affected by heat gain are roof, windows and walls respectively. Thus proper design for the green envelope (green roof and living walls) will improve building performance significantly; however their form design should be optimized to uniform the load distribution at each component. Building performance was evaluated and tested against base building designed according to ASHRAE standard.

Green envelope performance measured by simulation program that compares between a conventional building with conventional roof and facades and a model that incorporates green roof and living walls. Graphics and summarized results can be found at the current section while the spread sheets of simulation`s results can be found in Appendix 1.

6.2 Irrigation calculations

6.2.1 Green roof irrigation demand

Grey water systems depend mainly on the current conditions of the context like site grey water resources, climate and irrigation. Currently there is no grey water network utility in Abu Dhabi so installing grey water treatment system in the building and use it in irrigation and bathroom flushing will have achieve great advantages to environment and the city. It is more rewarding if the system will be used for a new construction as it will be better integrated to the systems of the building. In that case coordination between the architect, landscape designer and plumbing engineer should be done at the designing phase. The integration of grey water system can affects the building location and the water features.

In order to calculate landscape water demand, it is essential to divide the landscape into hydrozones based on the type of plants and vegetation. Water demand of each hydrozone should be calculated in order to find out the sum of water demand for the whole landscape area. In case of using different irrigation systems, different hydrozones should be established as the irrigation demand influenced by the irrigation performance.

Landscape water demand calculations depend on local evapotranspiration (ETo), hydrozone area, irrigation distribution system uniformity (DULQ), rainfall (Ra) and landscape coefficient (KL). Landscape coefficient is used in modifying ETo of different plants, location of planting and plants density. Landscape coefficient is calculated based on the equation:

KL = Ks x Kmc x Kd………………………………………………………..……… (8)

Where:

KL =landscape coefficient

Ks = estimation of plants water demand

Kmc =estimation of microclimates effect on water demand

Kd = estimation of plants density effect on water demand

Kmc and Kd values range from 0.5 to 1.4 so EPA assumed that Kmc and Kd equal to 1 in order to reduce calculations complexity , thus KL = KS . Table 6.1 shows the water demand (ks)for different plants.

Table 6.1: plants water demand (ks). (The drip store, 2010)

Ks, a landscape coefficient Vegetation	High	Average	Low
Trees	0.90	0.50	0.20
Shrub	0.70	0.50	0.20
Ground Cover	0.90	0.50	0.20
Mixed	0.90	0.50	0.20
Turf Grass	0.80	0.75	0.60

The first step in water demand calculations is ETo calculation which is basically depending on plant water demand. Native plants have very low ETo while plants that need high amounts of irrigation have a high ETo value. There is no information about ETo of Abu Dhabi plants so it will be assumed 11.22 inches based on research by Al-Nuaimi et al. (2003).

According to EPA (2009), 25 % of average rainfall over 30-year should be calculated toward the needs of plant .The incorporation of rainfall water can lead to more conservative design for landscape.

It is rarely to find irrigation systems with 100% efficiency according to many climatic factors which create some areas with lack of irrigation .For example wind and landscape design have influence on water sprayed from nozzles. In order to solve this problem, irrigation systems are designed to distribute more amount of water than designed. Using the value of lower-quarter distribution uniformity (DULQ) of irrigation system can help in solving that problem depending on irrigation system. Distribution uniformity is the measurement of water uniformity over a landscape area depending on site conditions.

According to Al-Nuaimi et al. (2003), there are variable values of average evapotranspiration ET0 in UAE based on the location. In general the highest annual ETo in UAE is 2124 mm and the maximum monthly value of ETo is 285 mm (11.22 inches) and occurred in July. The average rainfall is 9.92mm (0.44 inches)

In order to improve soil absorption, drip irrigation will be used to deliver the needed water to shrubs. Drip irrigation systems have the ability to reduce water irrigation consumption by 50% if compared to sprinkler systems however they still not effective in irrigating turf grass areas (North Carolina Cooperative Extension Service, 1996). The best time to irrigate plants is night time as there is less evaporation occurs and plants can use water more efficiently. The irrigation systems that will be used are:

•Drip-system: for groundcover and shrubs.

• Fixed Spray: for turf grass areas.

DULQ of drip irrigation system (drip pressure compensating) is 95% and DULQ for fixed spray system is 75 %(Irrigation Association, 2005).

According to EPA (2009) Landscape Water calculations are based on the following equation:

$$LWR = \frac{1}{DULQ} \times [(ETo \times KL) - Ra] \times A \times Cu \quad \ldots\ldots (9)$$

Where:

LWR= Landscape water requirement for each hydrozone. (Gallons/month)

DULQ = percentage of lower quarter distribution uniformity (dimensionless)

ETo = evapotranspiration (inches/month)

A = Landscaped area (square feet)

Cu = Conversion factor (0.6233 for results in gallons/month)

KL = Landscape coefficient

Ra = Allowable rainfall

I. Green roof type A (Extensive green roof) calculations

With reference to table: 3.2, extensive green roof needs no irrigation or minimal quantity of irrigation however ground cover will be used in order to apply the required calculations(refer to appendix 02for desert plants and ground covers that can be used with minimal irrigation and tolerate to the harsh climate of UAE). The depth of extensive green roof type A is assumed to be 10 cm so ground cover will be used to cover the whole area of the roof which is 610 m² as ground cover have shallow roots and at the same time have a low Ks coefficient (refer to table 6.1).

Appling to equation 9:

(Ground cover`s ks is 0.20; Area is 610 m²and DULQ is 95%)

$$LWR = \frac{1}{95} \times [(11.22 \times 0.20) - 0.44] \times 6566\ (610m2) \times 0.6233$$

=77.52 Gallons/month

=9.8 L/day

II. Green roof type B (Intensive green roof) calculations

Thickness of green roof (type B) enables the usage of wide range of plants for investigation so the plants will be selected with different leaf area index and different water demand like turf, ground cover and shrubs (refer to figure5.6for green roof design &Appendix 2 for desert and native plants that suit the harsh climate of UAE).

Shrubs and ground cover irrigation demand:

(Shrubs and ground cover ks are 0.20; Area is 314 m² according to green roof design in figure: 5.5)

Appling to equation 9:

$$LWR = \frac{1}{95} \times [(11.22 \times 0.20) - 0.44] \times 3379.868\ (314m2) \times 0.6233$$

=40.21 Gallons/month

Turf irrigation demand:

(Turf ks is 0.60, Area is 296 m² according to green roof design in figure: 5.5)

Appling to equation 9:

$$LWR = \frac{1}{75} \times [(11.22 \times 0.60) - 0.44] \times 3186.12(296m2) \times 0.6233 \quad \text{turf}$$

=166.6 Gallons/month

The total monthly irrigation demand for green roof type B is:
40.21 + 166.6 =206.8 Gallons/month
=26 liter/day

6.2.2 Living wall irrigation demand

Hopkins et al. (2010) stated that the required irrigation for a modular container living wall system is 5 liters/ m^2/day.

Based on that:
Each façade of the building is 21m length (excluding windows openings) and the height is 73 m.

Area of each façade is 21 m X 73 m (height) =1533 m^2
Irrigation demand for each façade is 1533 m^2 X 5 liters/ m^2 =7665 L/day
Total irrigation demand for the four facades is:
7665 L X4= 30660 L/day

6.3 Grey water calculations

According to EAD (2009), Gray Water Estimation Procedure in residential depends on occupancy number however there are two main equations. First equation depends on estimating the number of occupants in each dwelling by assuming the First bedroom has two occupants and any extra room will have one occupant only. The second equation depends on estimating grey water generated by each occupant.

Bathtubs, wash basins and showers generate 95L/day (25 gpd)/occupant while Laundry generates 57L/day (15 gpd)/occupant. The building is consisting from ground floor and 16 typical floors. Ground floor is a showroom .Each typical floor is consisting from six apartments, two apartments are 2 bedroom and the other four apartments consisting from 3 bedrooms.

3 bedrooms apartment calculations:

Number of occupants = 2 +1+1 = 4

Estimated gray water=4 x (95+57) =608 L/day

4 apartments x456=2432 L/day

2 bedrooms apartment calculations:

Number of occupants = 2 +1 = 3

Estimated gray water=3 x (95+57) =456 L/day

=3x (25+15) =120 gpd

2 apartments x456=912 L/day

So each floor`s occupants generate grey water= 2432 +912

=3344 L/day

Total grey water generated by all the typical floors =3344 x 16

=53504 L/day

Ground floor calculations:

Grey water calculations in shopping centers are based on the area of the space not the number of persons. The equation of grey water calculations is: 0.23L/day/0.1 m^2.

$$\frac{610 \text{ (area of showroom) } X0.23 \text{ liters}}{0.1} = 1402 \text{ liters /day}$$

Watchman room calculations:

1 x (95+57) =152 L/day

Total grey water generated =53504 +1402+152

=55052 L/day

6.4 Simulation results

The average temperature in Typical Summer Day time is 39°C while the average relative humidity is 60%.By assuming the indoor air temperature is 21°C constantly based on thermal comfort of Abu Dhabi psychometric chart (refer to figure 5.12).

Energy demand is created in order to keep that indoor temperature constant. Thus, energy demand estimation for space cooling is based on the heat flow within the roof system.

6.4.1 Case 1: Base Case Building

Conventional building (base case) modeled with conventional materials as real using brick and simple double glass. Floors constructed using concrete slab and marble tiles while the roof consisting from concrete and conventional insulation materials. However the U values that been applied are based on ESTIDAMA prescriptive requirement. Glazing area is less than the maximum allowed ESTIDAMA prescriptive requirement for housing building, and hence the fenestration area and layout is kept same for both the models.

With reference to figure 6.1, the annual energy consumption by case 1 is 4,185(MWh) while the annual cooling load is 2,905 (MWh) and its electricity consumption is2,905 (MWh) as illustrated in figure 6.2 .Co2 emissions were also measured and found to be 2,164,079 (kgCO2/h). Chillers load for the whole building is 5,379.6(MWh) and the cooling plant sensible load is 4,896 (MWh).

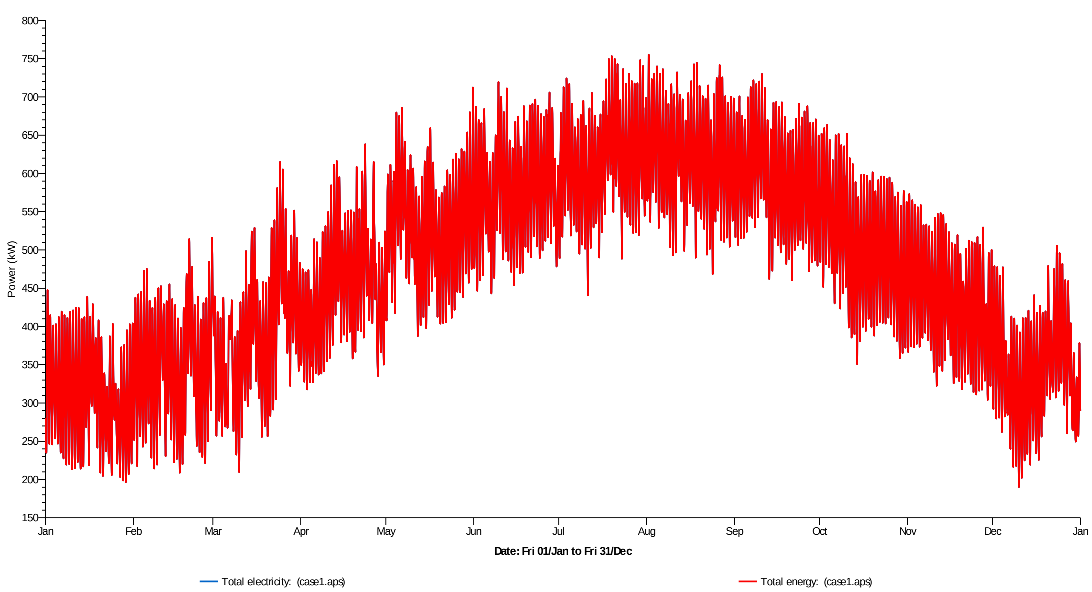

Figure 6.1: Total electricity and total energy consumption (case 1).

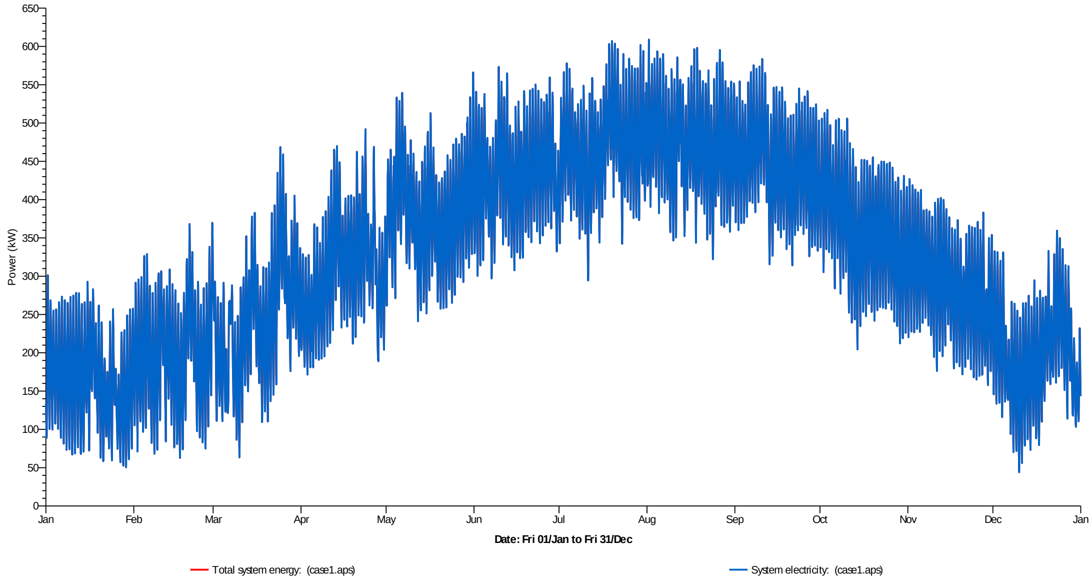

Figure 6.2: Total system electricity and total energy consumption (case 1).

The sixteenth floor was simulated to find out the green envelope influence on its cooling loads. The cooling plant sensible load of the 16th floor is 383.11 (MWh) as showed in figure 6.3 while the external conduction gain is 226.1(MWh) as showed in figure 6.4. The external roof`s conduction found to be 118.77(MWh) while the external walls` conduction found to be 101.448 (MWh).

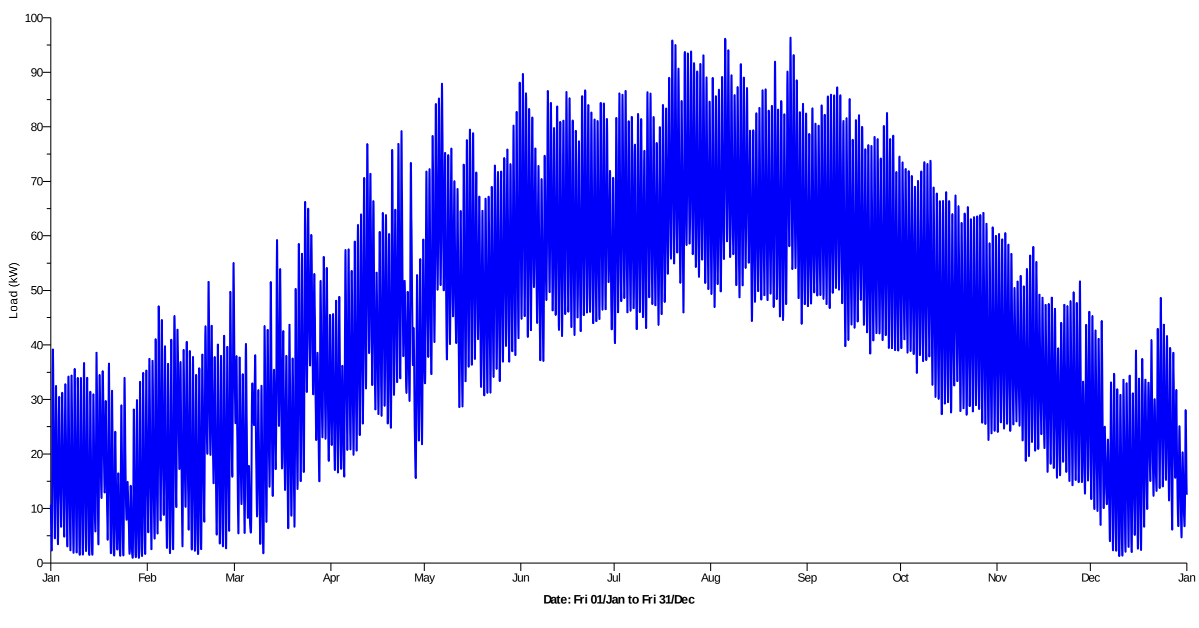

Figure 6.3: Cooling plant sensible load of the 16th floor(case 1).

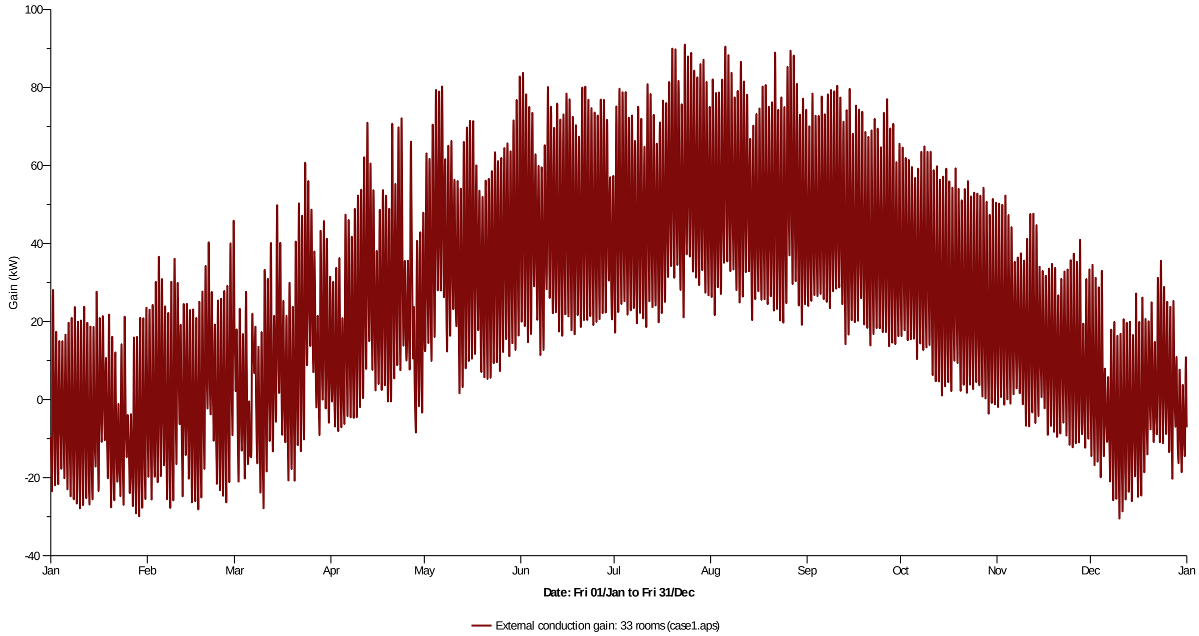

Figure 6.4: External conduction gain (case 1).

6.4.2 Case 2: Proposed building with green roof type A

In case 2, the proposed building modeled with extensive green roof that has a substrate thickness of 10 cm. Figure 6.5 illustrates the annual energy consumed by case 2which is 3,542 (MWh) while the annual cooling loads is 2260.71MWh.Co2 emissions found to be 1,830,991(kgCO2/h). Chillers load for the whole building is 4186.5(MWh) and the sensible cooling plant Load is 3607.34(MWh).

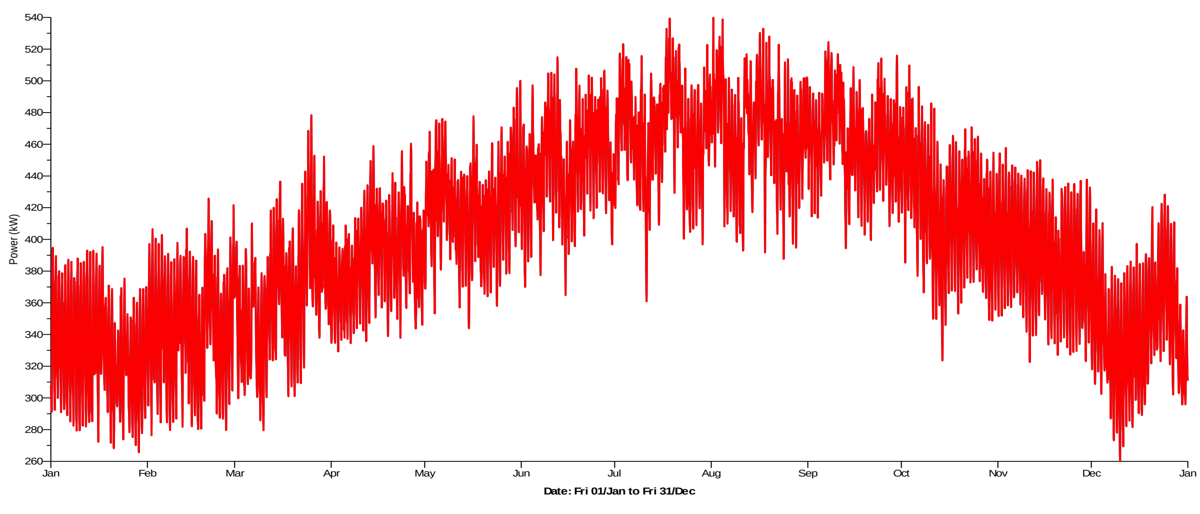

Figure 6.5: Total electricity and total energy consumption (case 2).

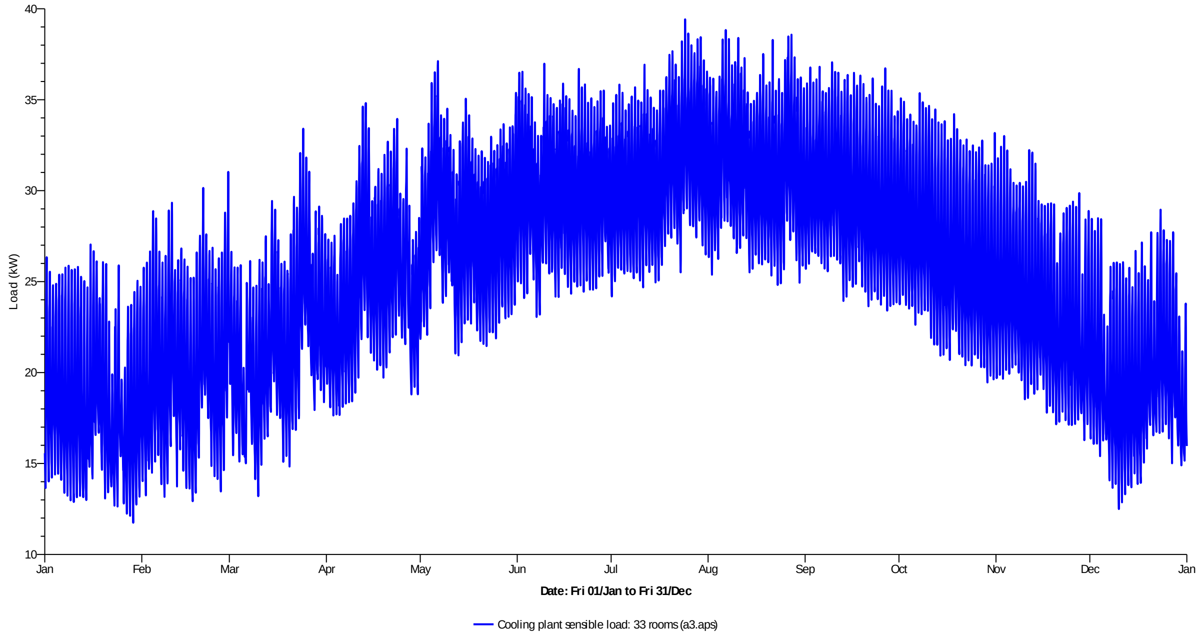

Figure 6.6: Cooling plant sensible load of the 16^{th} floor(case 2).

The cooling plant sensible load of the sixteenth floor is 223 (MWh)as illustrated in figure 6.6and the External conduction gainsare120.76 (MWh) as shown in figure 6.7.The external roof`s conduction found to be 7.0(MWh) while the external walls` conduction found to be 101.448 (MWh).

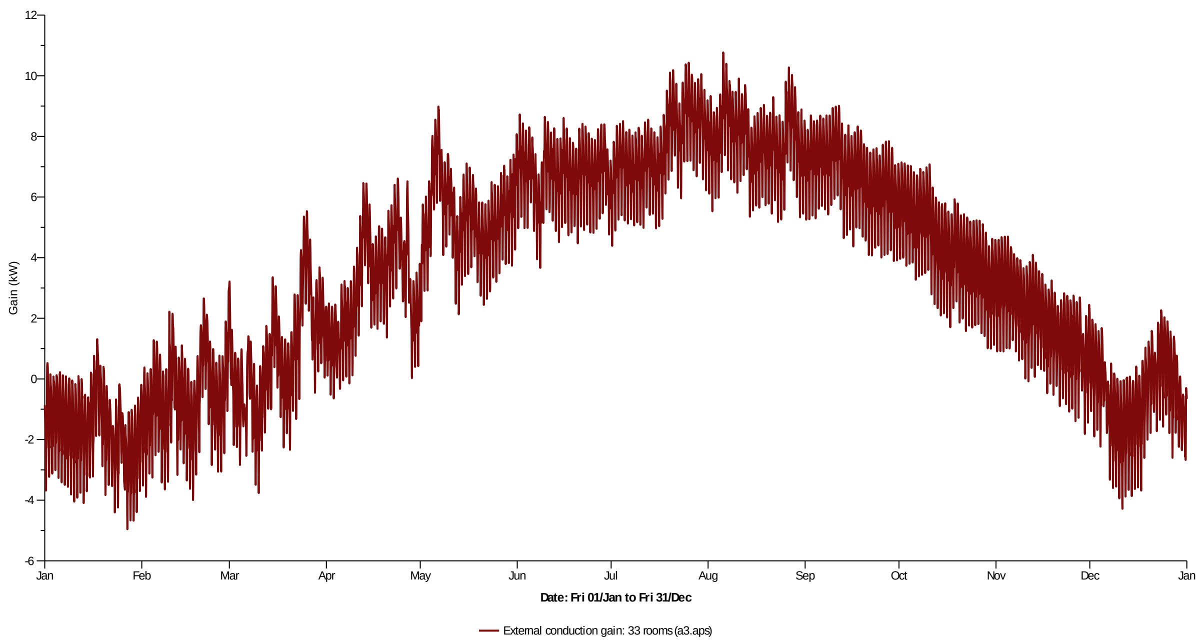

Figure 6.7: External conduction gain (case 2).

6.4.3 Case 3: Proposed building with green roof type B

In case 3, the proposed building modeled with intensive green roof that has a substrate thickness of 25 cm. The annual energy consumed by case 3 is 3533.52 MWh as shown in figure 6.8while the annual cooling load is2252.6 (MWh).Co2 emissions are 1,826,898 (kgCO2/h). Chillers load for the whole building is4171.84 (MWh) and the sensible cooling plant load is 3591.5(MWh).

Figure 6.9 illustrates thecooling plant sensible load for the sixteenth floor which is 219.9 (MWh) while the External conduction gain is 120.2053 (MWh) as illustrated in figure 6.10.The external roof`s conduction found to be 6.4 (MWh) while the external walls` conduction found to be 101.448 (MWh).

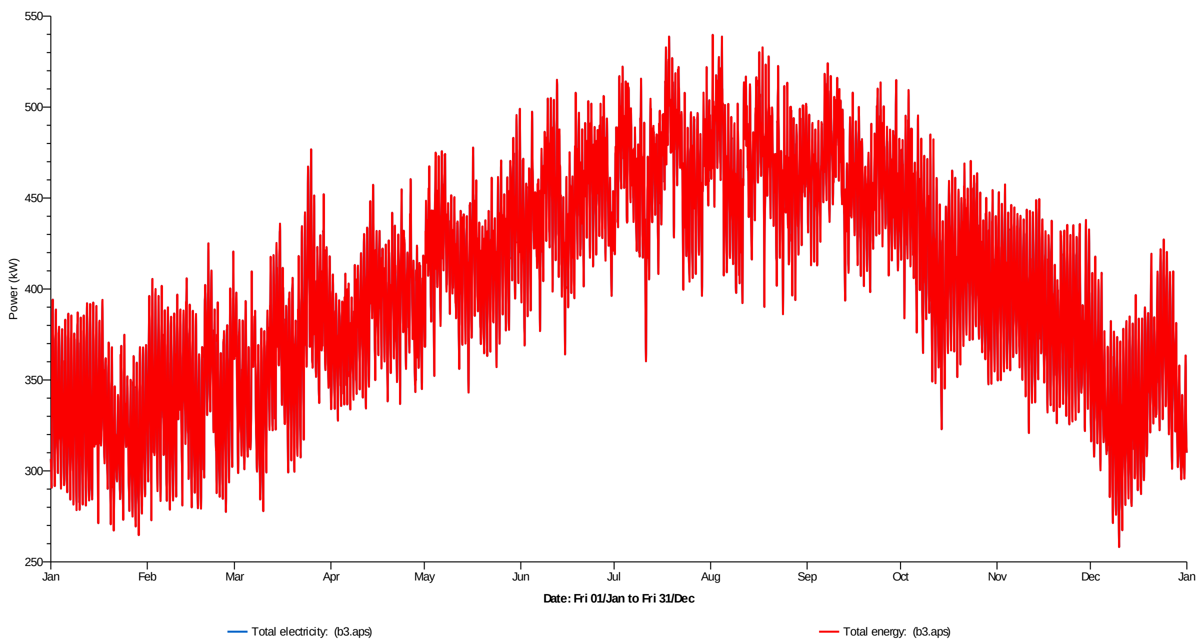

Figure 6.8: Total electricity and total energy consumption (case 3).

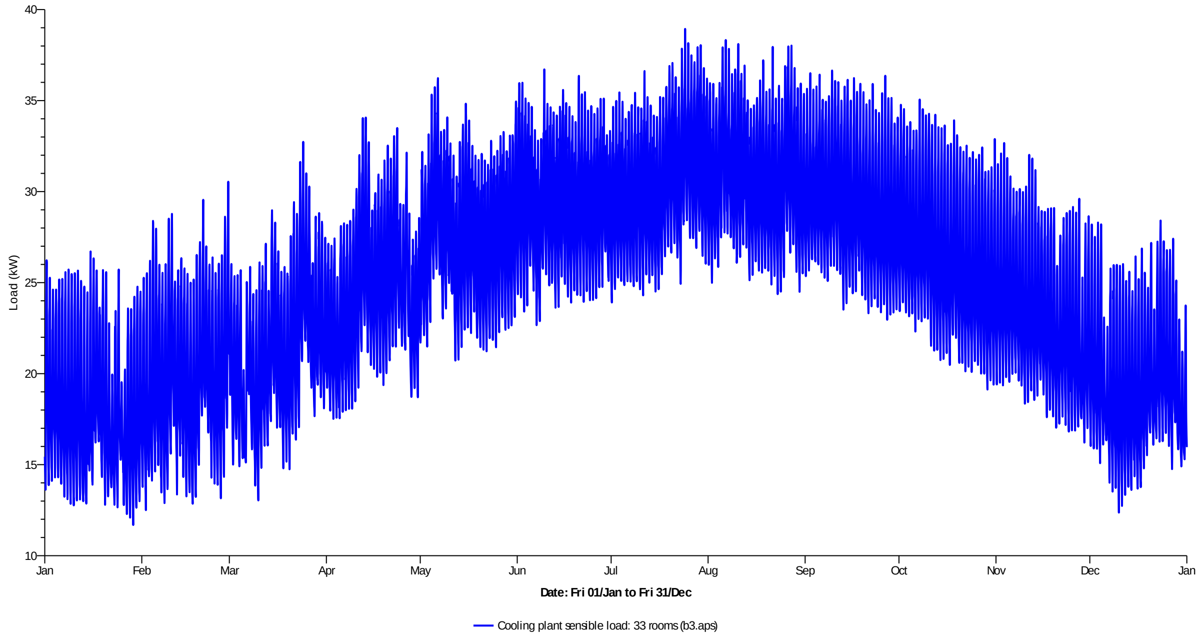

Figure 6.9: Cooling plant sensible load of the 16th floor(case 3).

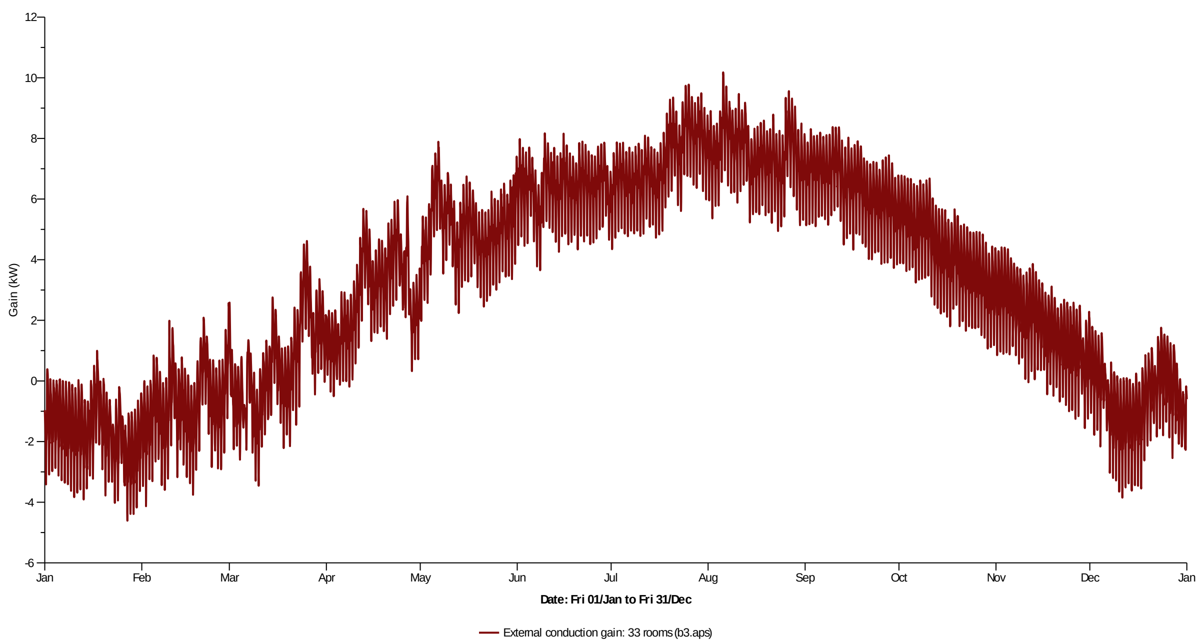

Figure 6.10: External conduction gain (case 3).

6.4.4 Case 4: Proposed building with living walls

In case 4, the proposed building modeled with living walls and conventional roof construction. The annual energy consumed by case 4 as shown in figure 6.11 is 3586.6 (MWh) while the annual cooling load is 2305.8MWh.Co2 emissions are

1,854,302(kgCO2/h). Chillers load is 4270(MWh) and the sensible cooling plant load is 3697.4(MWh).

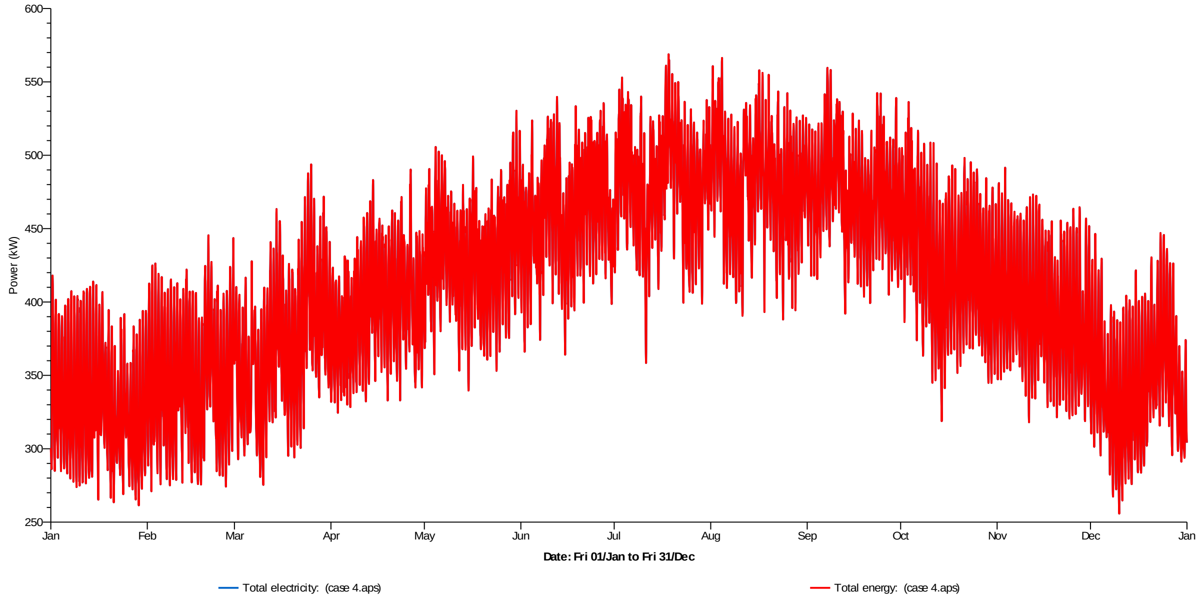

Figure 6.11: Total electricity and total energy consumption (case 4).

The cooling plant sensible load for the sixteenth floor is 384.4 (MWh) as shown in figure 6.12 while the External conduction gain has been illustrated in figure 6.13and equal to134.5 (MWh).The external roof`s conduction found to be 118.7685 (MWh) while the external walls` conduction found to be 6.5474 (MWh).

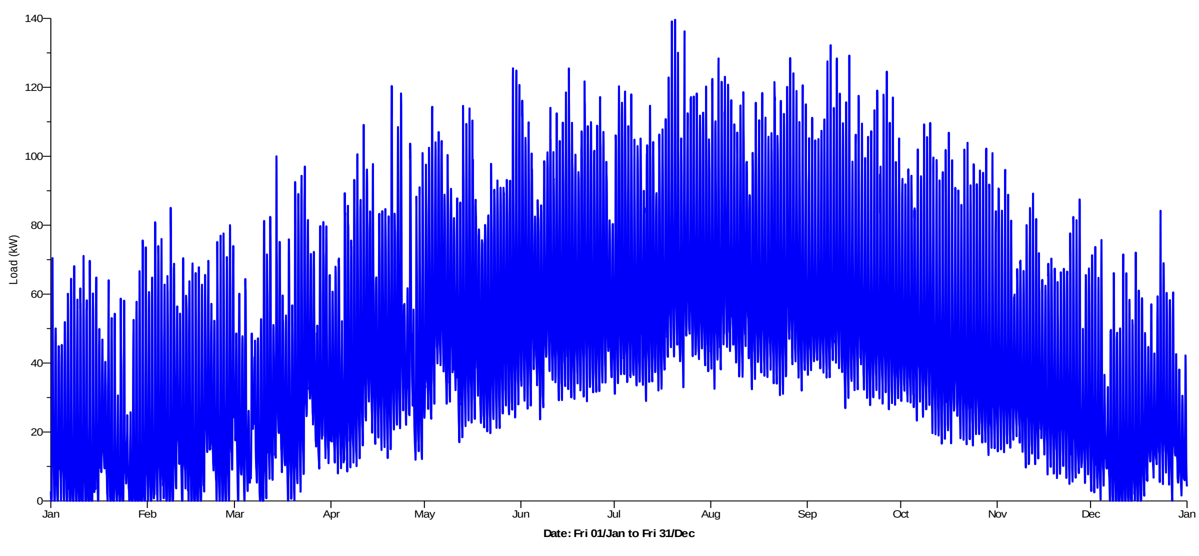

Figure 6.12: Cooling plant sensible load of the 16th floor(case 4).

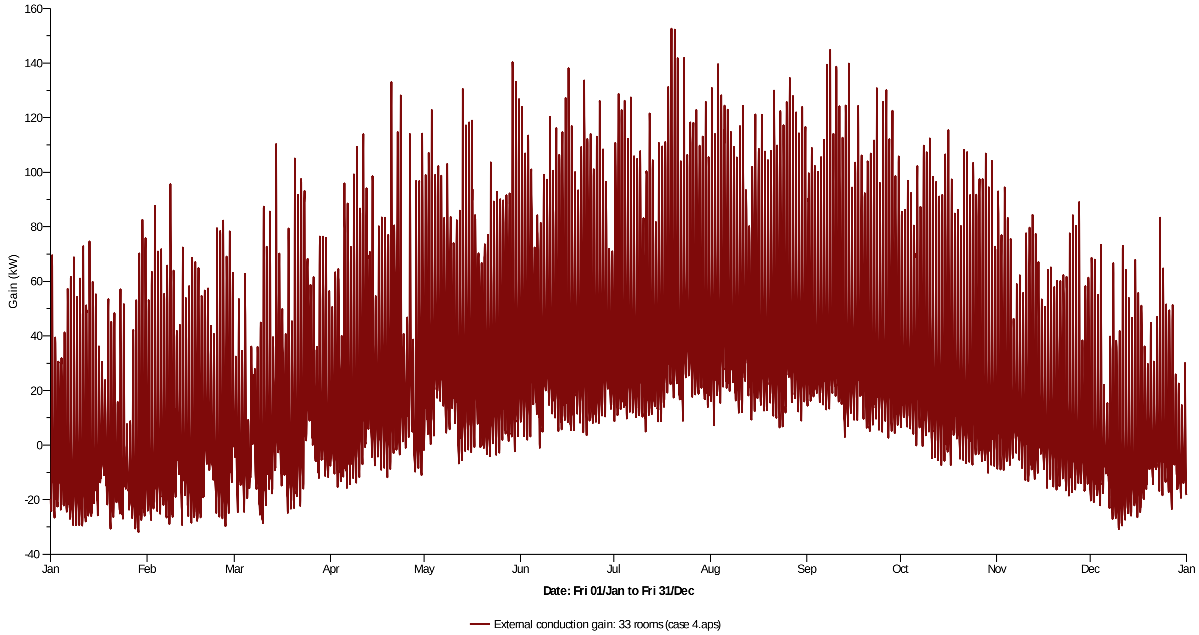

Figure 6.13: External conduction gain (case 4).

6.4.5 Case 5: Proposed building with living wall and green wall type B

Case 5 is the last simulation case where the proposed building modeled with intensive green roof that has a substrate thickness of 25 cm and living walls. The annual energy consumed by case 5 is 3478.67 (MWh) as shown in figure 6.14while the annual cooling load is 3481.31 (MWh).Co2 emissions found to be1,798,413 (kgCO2/h). The chillers load for the whole building is4069.81 (MWh) and the sensible cooling plant load is 210(MWh).

The sensible cooling plant load for the sixteenth floor is 210 (MWh)has been illustrated in figure 6.15 while the external conduction gain is 16.38 (MWh)has been illustrated in figure 6.16.The external roof`s conduction found to be 7.1439 (MWh) while the external walls` conduction found to be 7.8312 (MWh).

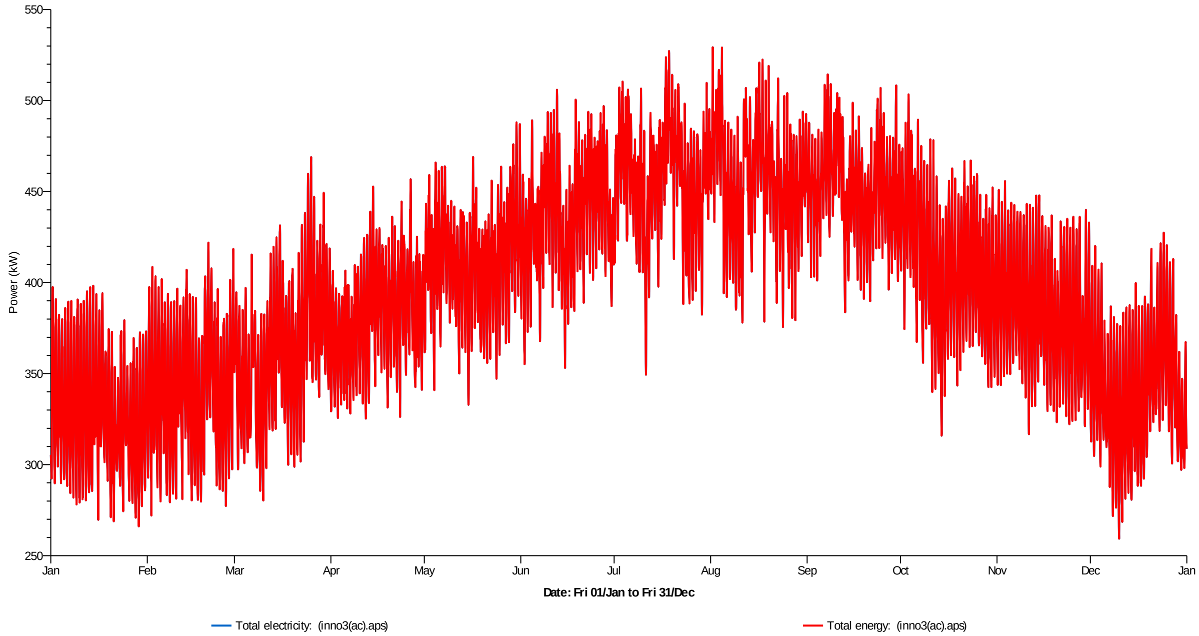

Figure 6.14: Total electricity and total energy consumption (case 5).

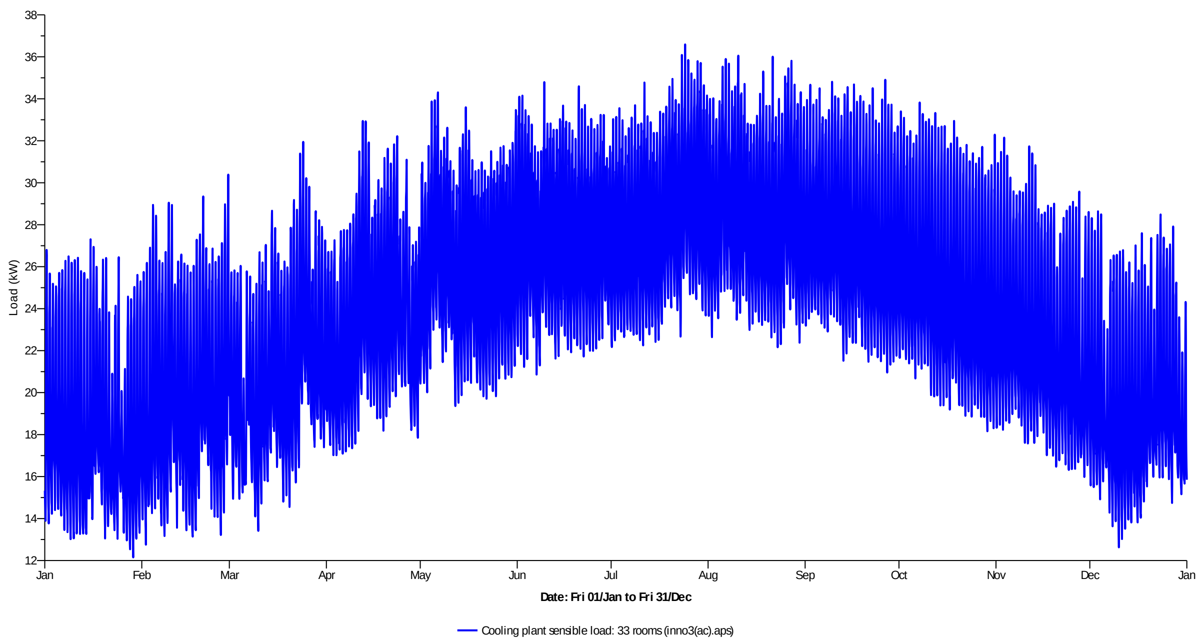

Figure 6.15: Cooling plant sensible load of the 16th floor(case 5).

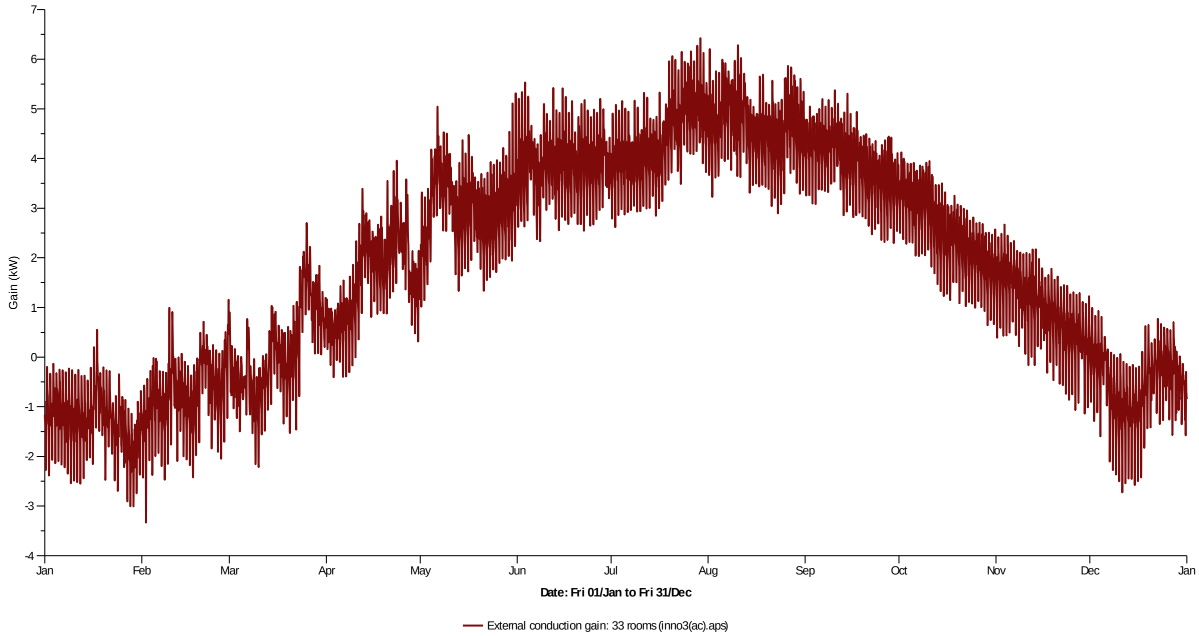

Figure 6.16: External conduction gain (case 5).

6.5 Evaporative cooling.

6.5.1 Green roof type A & B (Soil evaporation calculations)

Applying to equation 2 (refer to section 5.10):

$$r_{substrate} = c1 + c2\left(\frac{VWC}{VWC_{sat}}\right)^{c3}$$

$$= (0+34.5)\left(\frac{0.2}{0.6}\right)^{-3.3}$$

$$=11648.4$$

Where c1=0, c2=34.5, c3=3.3, VWC=0.2 & VWC_{sat}=0.6 (Velasco and Srebric, 2012)

Applying to equation 7(refer to section 5.10):

$$e_{soil} = 0.6108.\exp\left[\frac{17.27 \times (T_{soil} - 273.15)}{T_{soil} - 273.15 + 237.3}\right]$$

$$e_{soil} = 0.6108.\exp\left[\frac{17.27 \times (314.2 - 273.15)}{314.2 - 273.15 + 237.3}\right]$$

$$e_{soil} = 7.7$$

Where T_{soil} =314.2 k(Velasco and Srebric, 2012)

Applying to equation 4(refer to section 5.10):

γ= Cp .Pa/0.622 I*fg*
(998) x 101.3 / (0.622) (146640)
101097.4/91210.08=1.108

Where Pa is 101.3KPa and Cp is 998 J/Kg. K (ThermExcel ,2003)

Applying to equation 1(refer to section 5.10):

$$QE = \frac{p.\ Cp}{\gamma\ (r_{substrate} + r_a)} \cdot (e_{soil} - e_{air})$$

$$QE = \frac{(101.3 \times 998)}{1.108(11648.4 + 142)} (7.7 - 2.513)$$

QE = 40.2 w/m²

Where,

e_{air} is 2.513 (NOAA ,2009).

p is 101.3KPa and Cp is 998 J/Kg. K (ThermExcel ,2003)

r_a is 142 s/m (Tabares-Velasco & Srebric,2012)

In order to find out the evaporation reduction in MWh to match the results of IES, the following calculations done:

QE_{total} (W/h) = QE w/m² x area of roof x sum of yearly hours of sun rise…..…. (10)

Sum of yearly hours of sun rise is assumed to be 12 hour per day x 365 day=4380 hours

Applying to equation 10:

=40.2 w/m² x 620 m² (area of green roof)x 4380 hours

=109167120 w/h

QE_{total} =109 MWh(For both green roof types)

6.5.2 Green roof type A &B (Plants transpiration calculations)

I. Green roof type A

Applying to equation 7(refer to section 5.10):

$$e_{s,\,plant}=0.6108.\exp\frac{17.27.\,(T_{plants}-273.15)}{T_{plants}-273.15+237.3}$$

$$e_{s,\,plant}=0.6108.\exp\frac{17.27.\,(325.5-273.15)}{325.5-273.15+237.3}$$

$e_{s,\,plant}=13.8$

Where, T_{plants} =325.5 k (Velasco and Srebric, 2012)

Applying to equation 6(refer to section 5.10):

$r_s = \frac{600}{2}(1)(202.3)(1.3)(1.9)$.........21

=149904.3

Where, $r_{stomatal;\,min}$=600, f_{solar}=1, f_{VPD}=202.3, f_{vwc}=1.3and $f_{temperature}$=1.9(Velasco and Srebric, 2012) andLAI=2 (Turner et al., 1999)

Applying to equation 5(refer to section 5.10):

$$Q_T = 2\,\frac{(101.3 \times 998)\ .\ (13.8-2.513)}{1.108(149904.3+142)}$$

Q_T = 13.47

Where, e_{air} is 2.513 (NOAA ,2009).

r_a is 142 s/m (Tabares-Velasco & Srebric,2012)

Applying to equation 10:

=13.74w/m² x 620 m² x 4380 hours

=37312344 w/h

QE_{total} =37 MWh (For green roof type A)

II. Green roof type B

Grass:

Applying to equation 6(refer to section 5.10):

$$r_s = \frac{600}{3}(1)(202.3)(1.3)(1.9) \ldots\ldots\ldots 21$$

$=99936.2$

Where, LAI=3 (Turner et al., 1999)

Applying to equation 5(refer to section 5.10):

$$Q_T = 3\,\frac{(101.3 \times 998) \;.\; (13.8 - 2.513)}{1.108(99936.2 + 142)}$$

$$Q_T = \frac{3396872.6}{110886.6}$$

$Q_T = 30.6$

Applying to equation 10:

$=30.6\ w/m^2 \times 296m^2$ (area of grass)x 4380 hours

=39672288 w/h

QE_{total} =39 MWh

Shrubs:

Applying to equation 6(refer to section 5.10):

$$r_s = \frac{600}{5}(1)(202.3)(1.3)(1.9) \ldots\ldots\ldots 21$$

$=59961.7$

Where,LAI=5 (Turner et al., 1999)

Applying to equation 5(refer to section 5.10):

$$Q_T = 5\left(\frac{\mathit{101.3\ x}\ 998)\quad .\ (13.8\ -\ 2.513}{1.108(59961.7+142)}\right) \quad \text{............ ....(20)}$$

$$Q_T = \frac{5661454.4}{66594.8}$$

$Q_T = 85$

Applying to equation 10:

$=85\ w/m^2 \times 279m^2$(area of shrubs) x 4380 hours

=103871700 w/h

QE_{total} =103 MWh

Ground cover:

Applying to equation 6(refer to section 5.10):

$$r_S = \frac{600}{2}(1)(202.3)(1.3)(1.9)$$

=149904.3

Where, LAI=2 (Turner et al., 1999)

Applying to equation 5(refer to section 5.10):

$$Q_T = 2\left(\frac{\mathit{101.3\ x}\ 998)\quad .\ (13.8\ -\ 2.513}{1.108(149904.3+142)}\right)$$

$$Q_T = 2\ \frac{(\mathit{101097.4})\quad (11.2)}{1.108(150046.3)}$$

$$Q_T = \frac{2264581.7}{166251.3}$$

$Q_T = 13.6$

Applying to equation 10:

=13.6 w/m² x 45m² (area of ground cover) x 4380 hours

=2680560w/h

QE total =2 MWh

So QE total for green roof type B is: 39+103+2=144 MWh

6.5.3 Green roof type A &B (Total soil`s evaporation and plants transpiration)

From previous calculations the total soil`s evaporation and plants transpiration of green roof type A is:
37+109=146 MWh

Total soil`s evaporation and plants transpiration of green roof type B is:
109 +144 = 253 MWh

Table 6.2: Annual energy consumption (Researcher, 2013)

	Consumption	Case 1	Case 2	Case 3	Case 4	Case 5
1.	Annual energy (MWh) by IES	4186	3542	3533.5	3586.6	3478.6
2.	Soil evaporative and plants transpiration cooling (MWh)	-	146	253	-	253
3.	Net annual energy (MWh) (1-2=3)	4186	3396	3280.5	3586.6	3225.6
4.	Percentage of reduction compared to case 1		18.8%	21.6%	14.3%	23

6.6 Comparison between all cases

Five cases have been evaluated using the IES simulation program. The first case is the base case, case 2 is the proposed building with extensive green roof (type A) that has a growing medium depth 10 cm, case 3 is the proposed building with intensive green roof (type B) that has a growing medium depth 25 cm, case 4 is the proposed building with living walls and finally case 5 which is the proposed building with green roof (type B) and living walls.

The simulation and the theoretical methodology proved that Energy efficiency can be improved by green roof systems and living walls by its contribution in reducing the annual heat gain compared to the base case. The reduction of energy consumption is resulted from the reduction of cooling loads of the building depending on each case.

With reference to figure 6.17and figure 6.18, Green roof type B was more effective in reducing the annual energy consumption by21.6%comparing to green roof system type A which reduced it by 18.8% because of the increment of soil thickness and evaporation influence of the soil.

Also it is important to note the effect of the plants used in both types and its influence in reducing the energy consumption. As shown previously in section 5.10, leaf area index (LAI) has an influence on the stomatal resistance to mass transfer of plants which affects the flux of plant`s transpiration (QT). It was proofed by section 6.5.2 calculations that the increment of leaf area index (LAI) of plants increases QT which increase the cooling effect greatly. For example ground cover has a LAI equal to 2 and achieved QT is 13.6 MWh, grass that has a LAI equal to 3 and achieved QT is 39 MWh while shrubs has a LAI equal to 5 and achieved QT is 103 MWh .

Case 4(living walls) was also effective although the roof that been simulated is a conventional roof that achieved14.3 % reduction in the annual energy consumption because of the facades area that is covered by soil and plants that is much larger than the roof area. The best reduction achieved by the combination of green roof type B and living wall to reach 23% as the whole envelope covered and insulated from solar radiation.

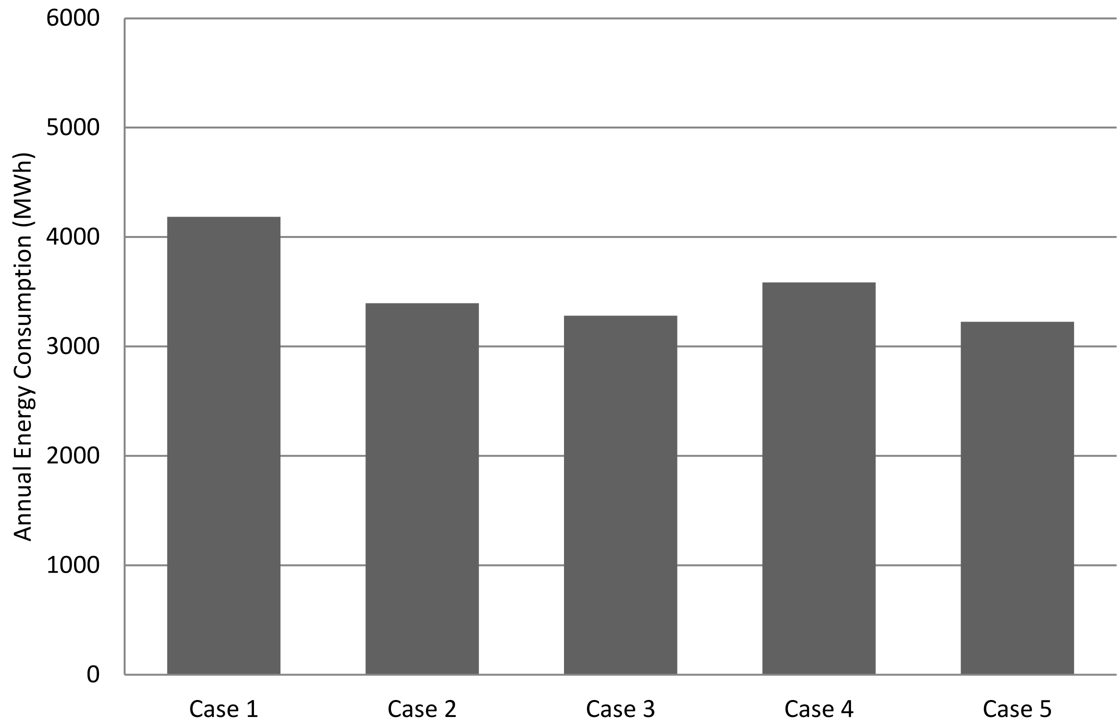

Figure 6.17: Annual energy consumption of all cases.

Cooling loads reduction contributes in energy demand reduction for space cooling in buildings. Although vegetation and water content were not considered during the simulation, the different systems with different soil thicknesses and different locations contribute in the cooling loads reduction. As showed in figures 6.19 and figure 6.20, Green roofs(type A and type B) contributed in reducing the annual cooling loads by approximately 22.17 % and 22.5 % respectively which proof that the increment in soil thickness would promote the thermal mass , insulation and moisture retention that contribute in heat gain reduction. However, type 3 (green walls) achieved a significant reduction reached 20.6 %. The best reduction was achieved by the combination of green roof type B and living wall to reach 24.35%.

There are many factors that affect the sensible cooling load like external facades, roofs, people, Air infiltration, Lights, appliances and internal walls. The reduction by case 2 is 26.3 % while case 3 achieved a reduction of 26.6 % which proofs that the soil thickness increment lead to increment in the reduction of sensible cooling plant load. Case 4 (living wall) reductions noted to be 23.5 % while case 5 achieved the best reduction by 29% as a good insulation for the whole envelope by greenery.

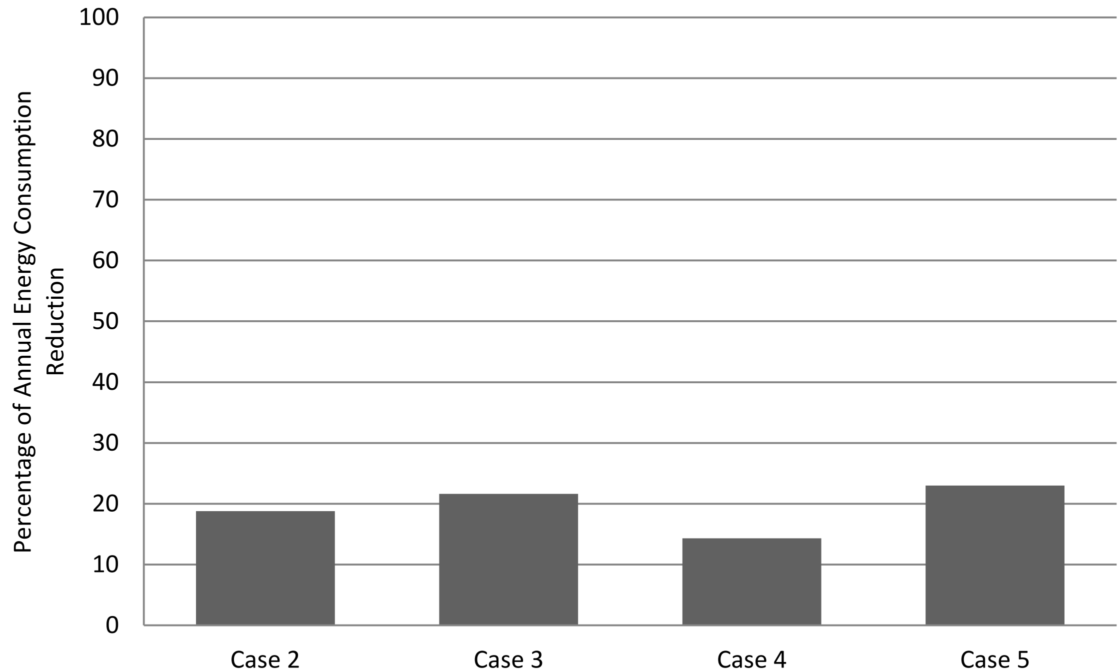

Figure 6.18: Percentage of annual energy reduction of all cases.

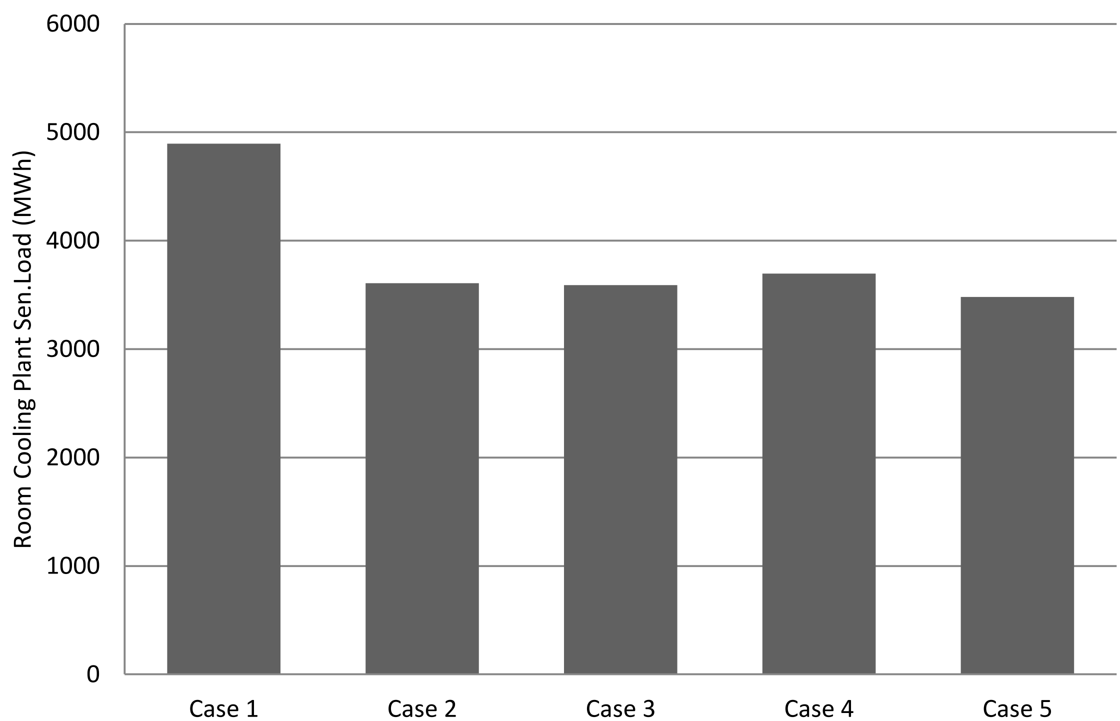

Figure 6.19: Cooling load of all cases.

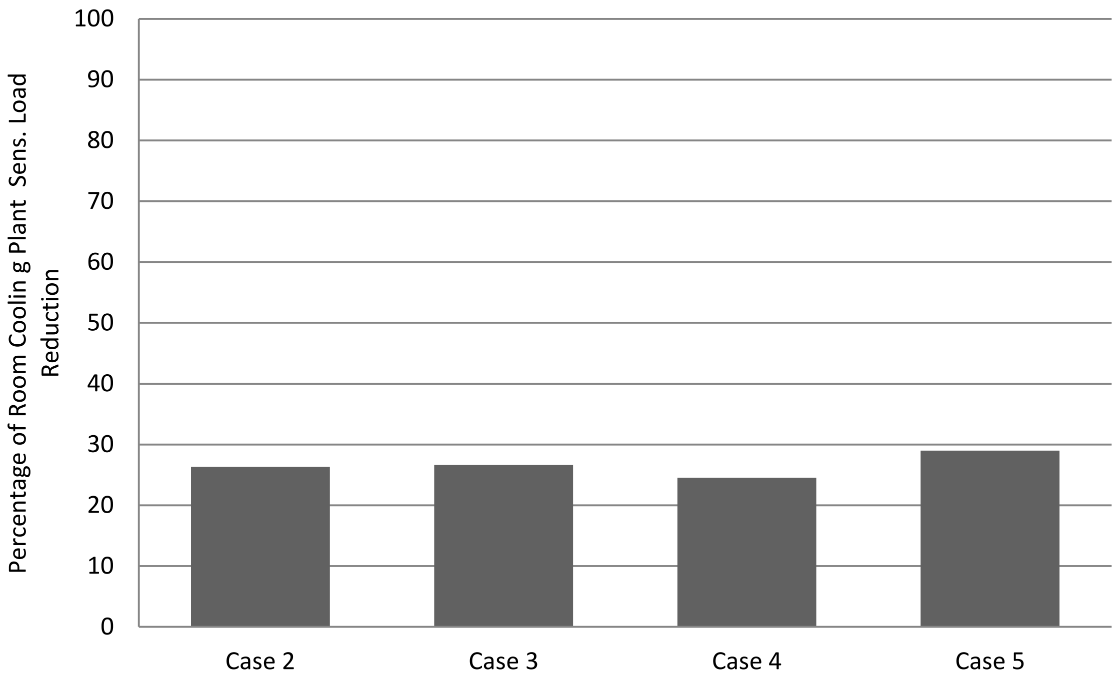

Figure 6.20: percentage of cooling load reduction of all cases.

The external conduction gain is the sum of the heat conducted through the building envelope like roof, facades, floors, doors and windows. For a better understanding for the external conduction of the different cases and as the heat conducted through different elements of the envelope so the external conduction gain detailed and investigated through walls and roof for each case.

The external conduction gained by the roof was the same in case 1(base case) and case 4(living walls case) which is equal to 118.8(MWh) as the roof in both cases is conventional roof while roof conduction in case 2 (green roof A) is 6.4(MWh) with a reduction equal to 94.1% because of the green roof layers that reduce the heat conducted through the roof. The roof conduction in case 3 (green roof b) and case 5(green roof and living walls) was the same and the best 7.0(MWh) with a reduction equal to 94.6%.The increased reduction in roof conduction gain in case 3 and case 5 is resulted from the increment of soil layer thickness.

The external conduction gained by the walls was the same in case 1(base case), case 2(green roof A) and case 3 (green roof b) which is equal to 101.4(MWh) while walls conduction in case 4 (living walls case) and case 5 (green roof and living walls) is 6.5(MWh) with a reduction equal to 93.5% because of the greenery cover that insulated the facades.

Based on the previous and as showed in figures 6.21 and 6.22, both green roofs (type A and type B) reduced the External conduction gain by46.5% and 46.8 respectively resulted from covering the roof only with greenery, however, case 4(living walls) reduce the gain by 40.5% by covering the walls only by greenery while case 5 was the best by a reduction that reached 92.8% that resulted from covering both the roof and facades by greenery.

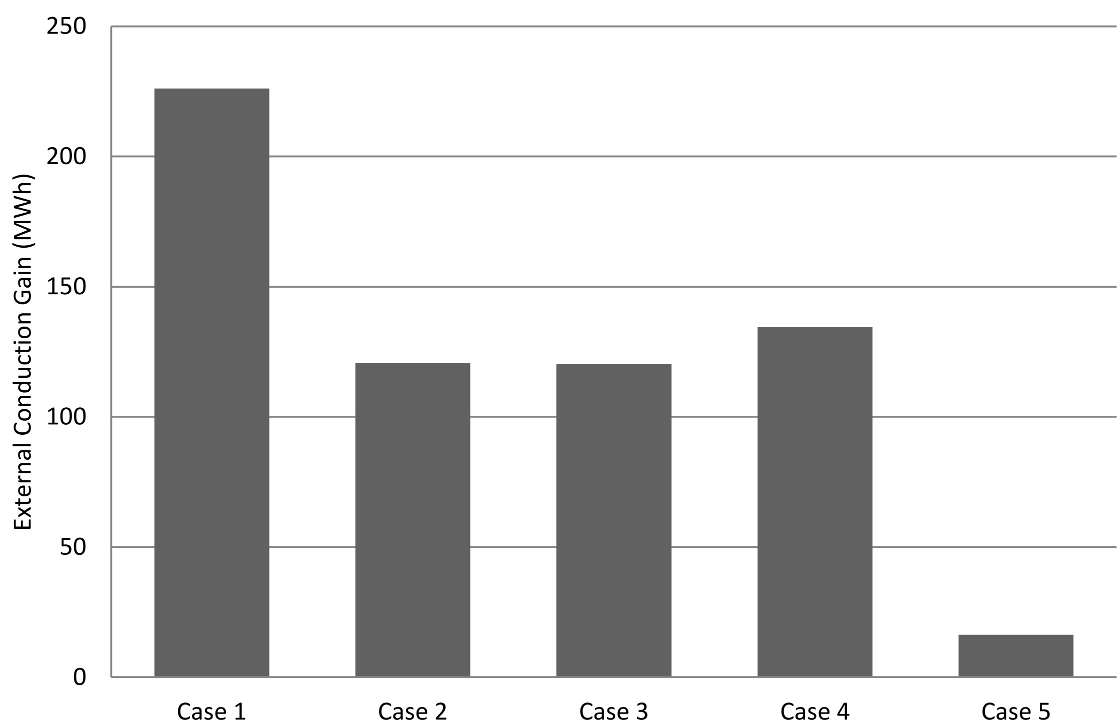

Figure 6.21: External conduction of 16th floor at all cases.

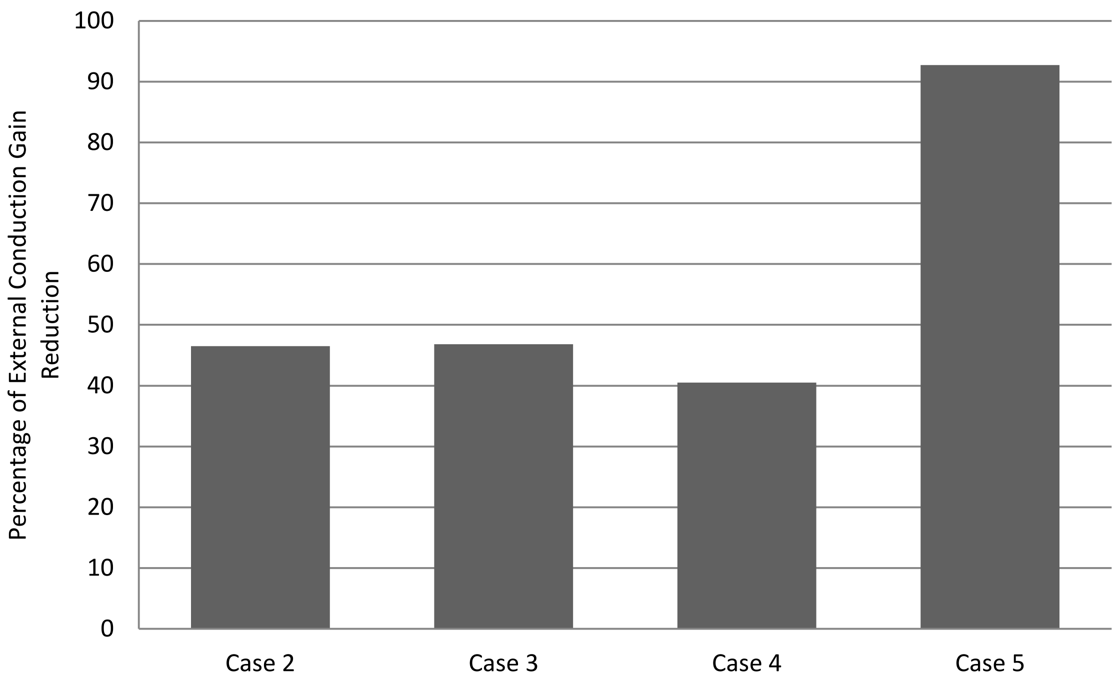

Figure 6.22: percentage of External conduction reduction of 16th floor at all cases.

As a result of reducing the cooling loads of the building that been discussed previously, chillers load have been reduce too. Both green roofs (type A and type B) achieved a reduction in chillers load by 22.1% and 22.5% respectively. The reduction achieved by case 4(living walls) is 20.6% while the best chillers load reduction in the sixteenth floor achieved by the combination of green roof and living walls to reach 24.35% (refer to figures 6.23 and 6.24).

From previous results it is obvious that green roofs can contribute in reducing building`s cooling load however this reduction is varying from the whole building load and the last floor load which make installing green roofs in low rise buildings more efficient than high rise buildings unless combined with living walls.

As a consequence for the reduction in the cooling loads and the energy consumption, the co2 emissions reduced significantly. Green roof type B was more effective in reducing the co2 emissions by 15.6% comparing to green roof system type A which reduced it by 15.3% case 4(living walls) has a similar achievement to the two types of green roofs by 14.3%. The best reduction has been achieved by the combination of green roof type B and living wall to reach 17 %.(refer to figures 6.25 and 6.26).

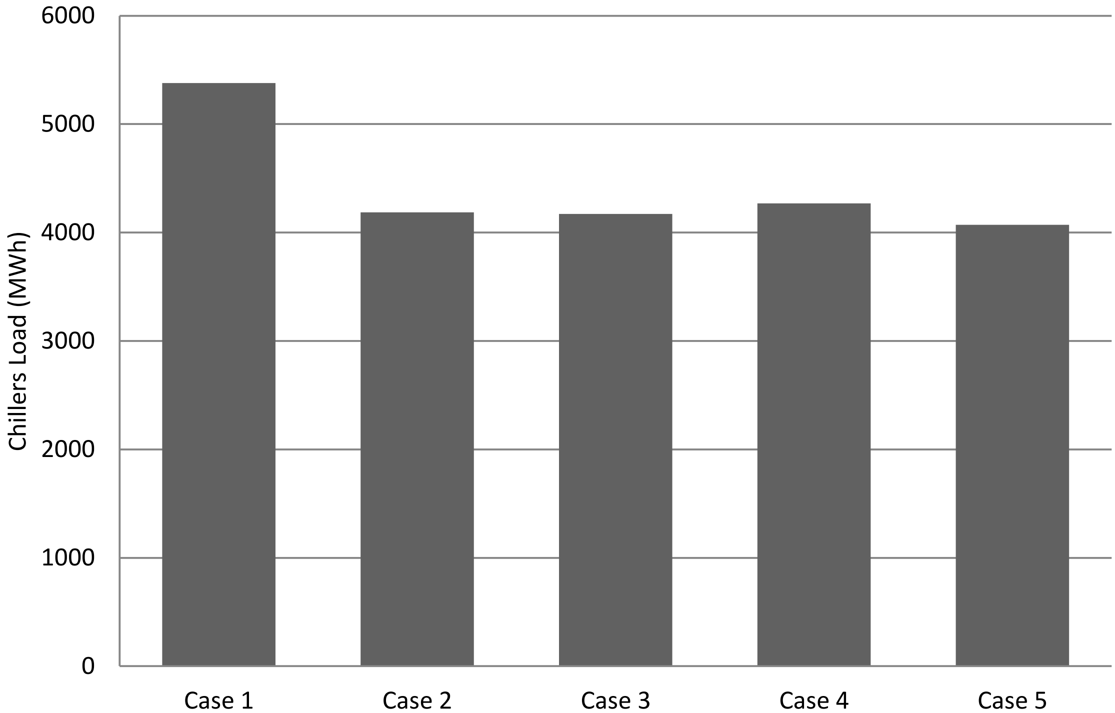

Figure 6.23: Chillers load at all cases.

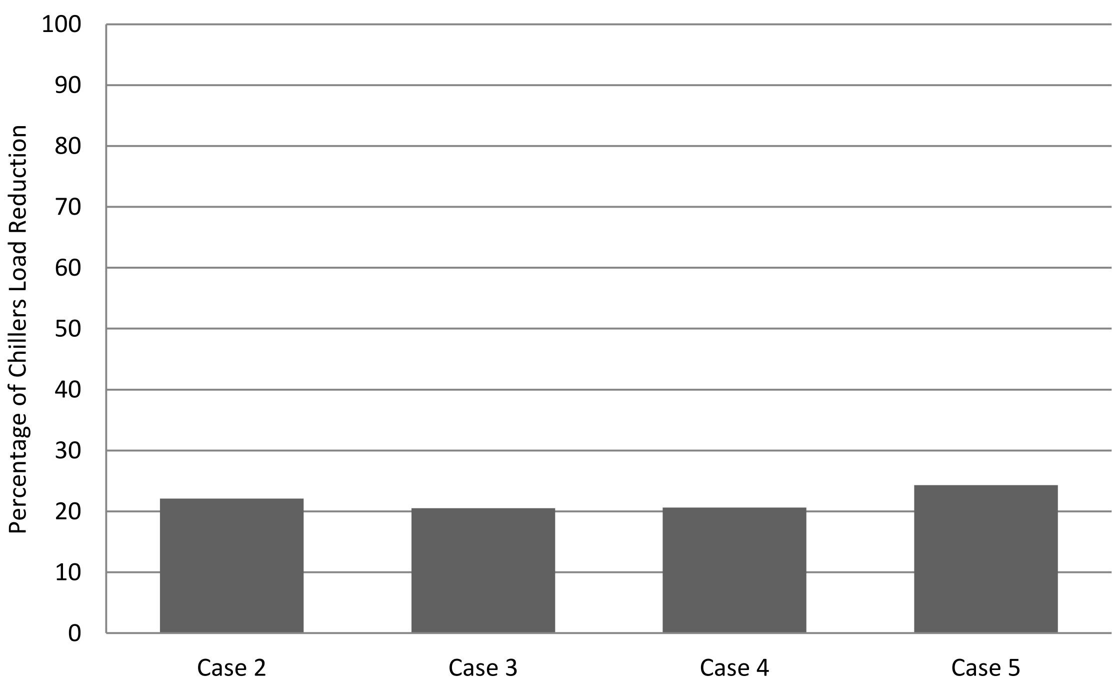

Figure 6.24: Percentage of chillers load reduction at all cases.

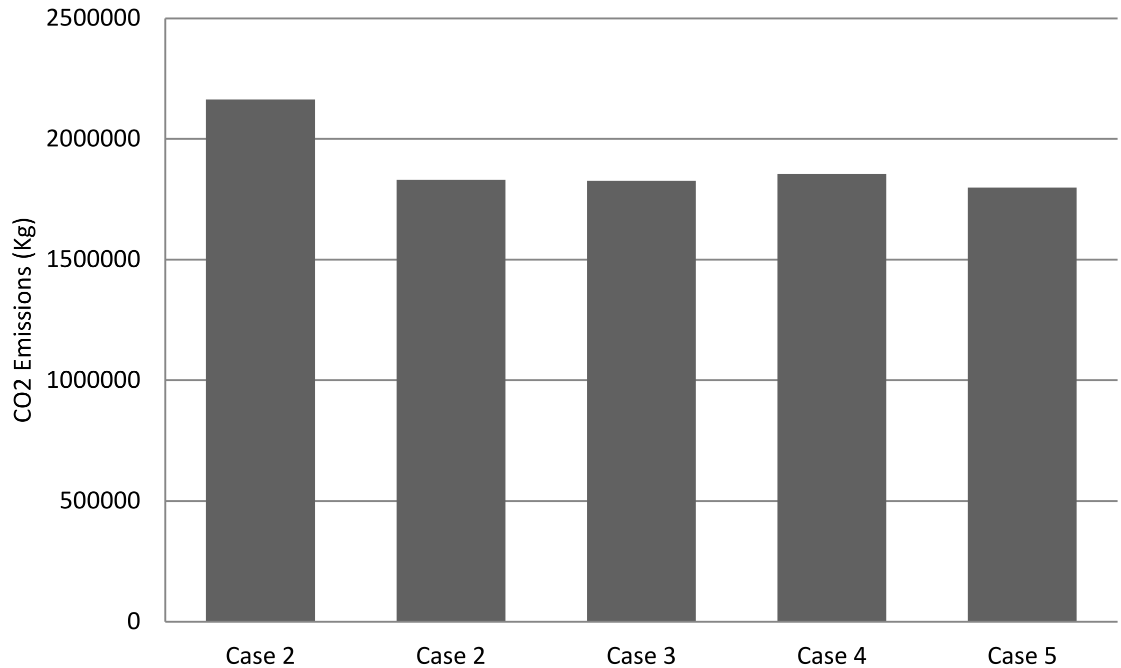

Figure 6.25: CO2 emission at all cases.

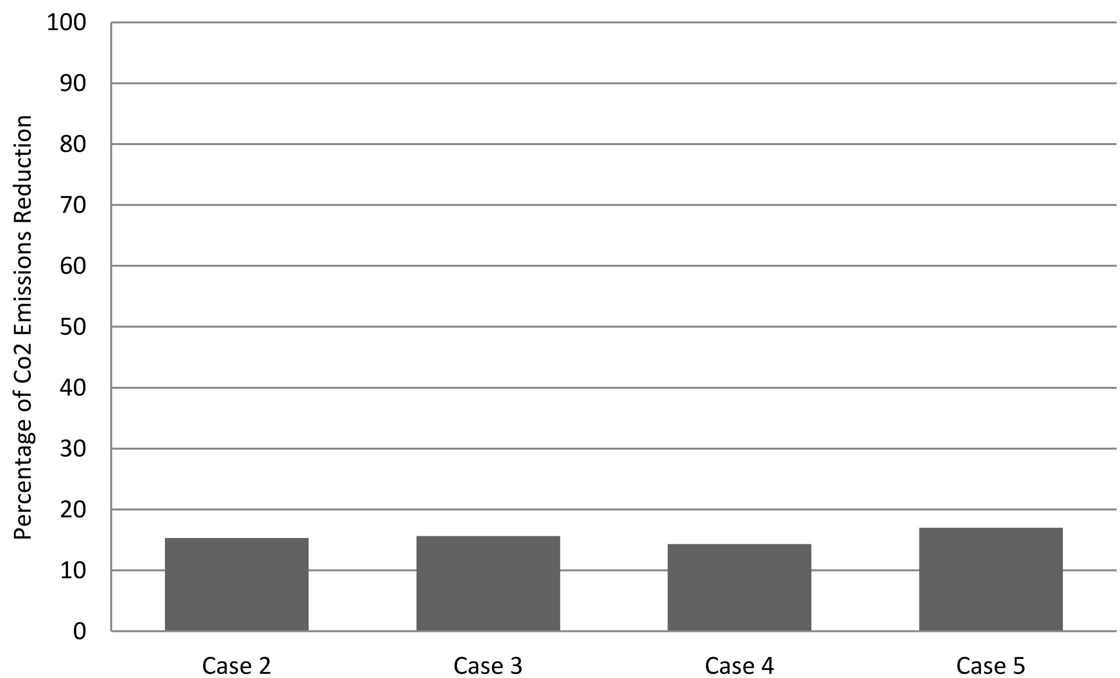

Figure 6.26: Percentage of CO2 emission reduction at all cases.

The water demand of green envelope irrigation is also varying based on the location and type of greenery. In case 2(green roof type A) the irrigation demand was calculated to be 9.8L/day while in case 3(green roof type B) the water demand was 26 liter/day. Case 4(living walls) water demand is 30660 L/day While case 5(green roof and living walls) water demand is 30686L/day.

With a comparison to the total treated grey water generated within the building which is 55052 L/day, we can find that case2 (green roof type A) consumed 0.018% while case 3(green roof type B) consumed 0.047%,Case 4(living walls) consumed 55.6% and case 5(green roof and living walls) consumed 55.74%

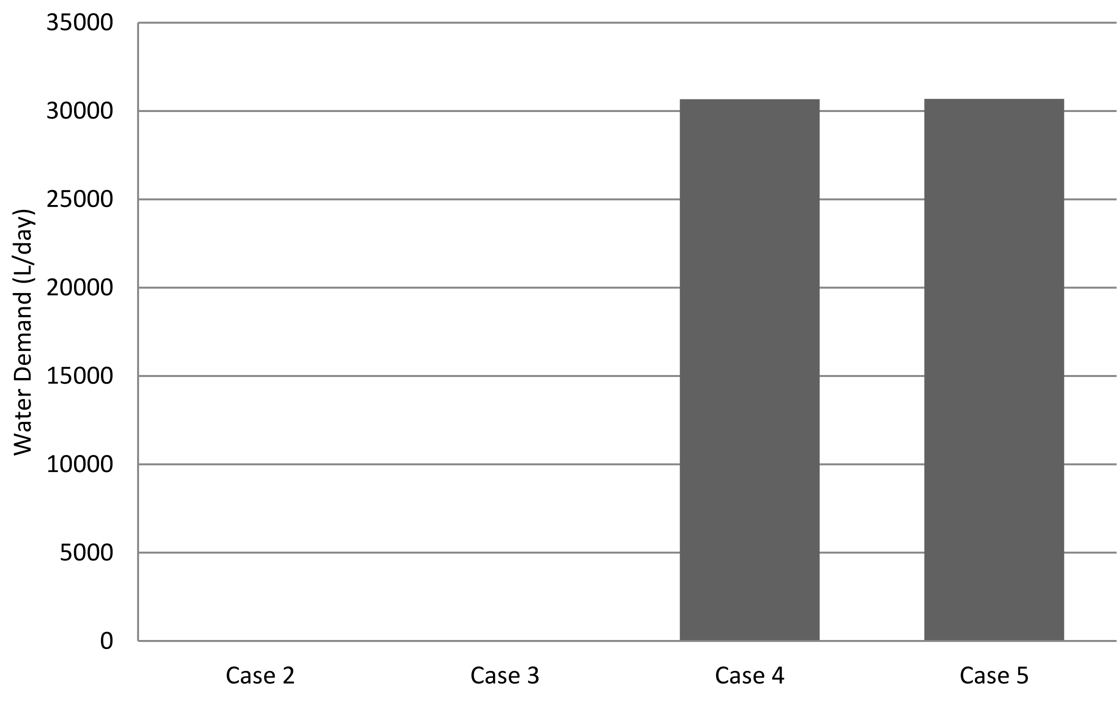

Figure 6.27: Water demand in at all cases.

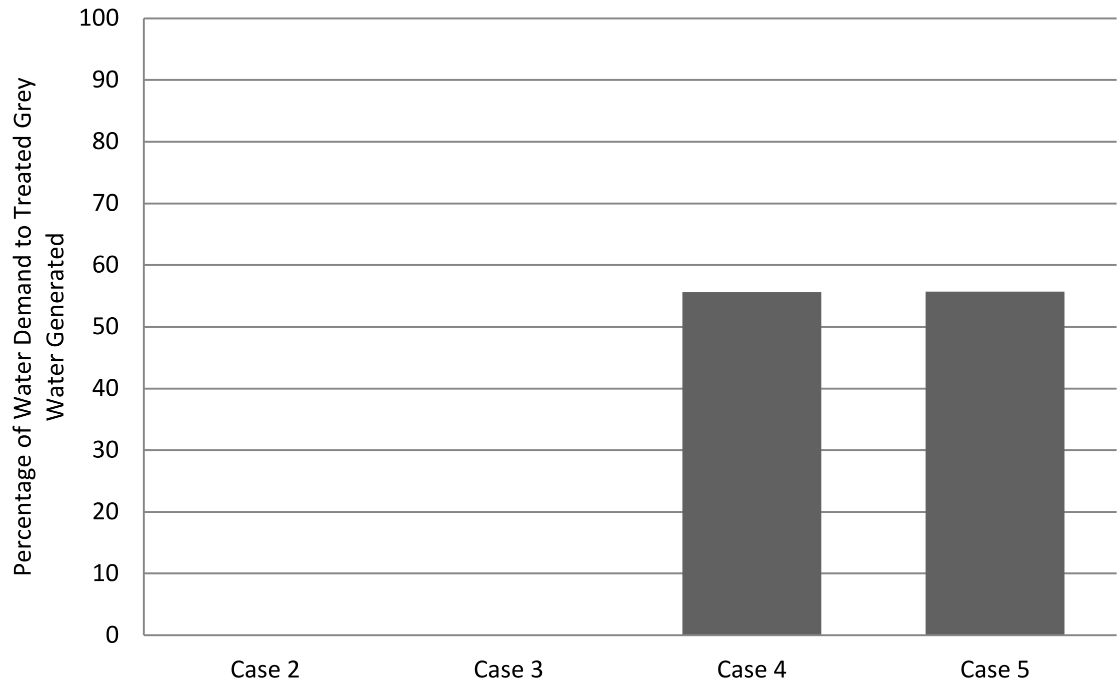

Figure 6.28: Percentage of water demand to treated grey water generated.

Chapter 7: Conclusion and Recommendations

Chapter 7: Conclusion and Recommendations

7.1 Conclusion

Contemporary world is suffering from climatic problems resulted basically from urbanism human destruction to the natural resources .Built environment have a drastic influence on the global environment. Green roofs, green walls and grey water treatment can have a major role in eliminating environment damage.

This dissertation discussed many opportunities to create green building and green urban using treated grey water which will reduce the stress on potable water significantly. The technologies that been discussed in this dissertation focus on how to create green areas in a limited, unusable spaces like roofs and walls using innovative approaches. It shows the integration between hard structural materials and soft natural vegetation.

The usage of green roof and living walls in high rise building reduced the cooling loads by 24.35% comparing to the base case. The energy use of the whole building dropped by 23% compared to the base case while the CO_2 emissions dropped by 17%. The increment of soil thickness and plants leaf area index (LAI) reduce the cooling loads and the total energy consumption greatly.

Irrigation is the success key to implement green roofs and living walls so the approach was to treat grey water resulted from the building and use it to irrigate green areas within the building itself. It was important to find that the irrigation water demand is 55.7 % of the overall treated grey water that been generated within the building .This low percentage enables the use of the extra treated water in toilet flushing which can compensate the capital cost of grey water treatment systems by reducing the consumption of potable water that used in toilet flushing and irrigation activities.

I believe that the integration of green roofs, green walls and treated grey water can reduce the cooling loads and the potable water consumption significantly. Green walls, green roof and water treatment systems can do much and their integration will produce a powerful synergy with increased benefits to the planet. The success of this synergy depends on the integrated design achieved by all parties involved in the design like architects, structural engineers, environment engineers…etc.

7.2 Recommendations

The clearest trend that was observed is that generally there is a gap between the amount of researches related to green roofs and that related to living walls all over the world. Green roofs and living walls are still new trend in the Middle East area and especially in UAE. It was noticed that there is a lack in data regarding Abu Dhabi context related to green envelope effects like cooling energy consumption, ecological benefits and surface temperatures. Additional obstacle faced during conducting the research is that there is inadequate botanical information about plants that is suitable to be used on living walls or green roofs in Abu Dhabi like native and desert plants and their irrigation requirements. Also there was no Cost-benefit analysis that is not available for living walls in general and for green roofs in Abu Dhabi practically

It is recommended to conduct a Coherent estimation of green envelopes contribution in the mitigation of Urban Heat Island. In addition it recommended to conduct researches that clarify Abu Dhabi`s native plants botanical information, thermal behaviors and water demand.

It is highly recommended to conduct researches with different methodologies to investigate the living wall tolerance in UAE and its thermal behaviors,

A Cost-benefit analysis for living walls and for green roofs in Abu Dhabi practically and in UAE in general is recommended in order to encourage stakeholders, developer, designers and policy makers to subsidize their incorporation into the different types of buildings.

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Appendix 1(Grey water systems)

Closed water loop tool as shown in figure 1.1, is a method within water demand management implementation that can be incorporated into all scales like institution, industry, community, neighborhood and household. Water flow with different qualities can be feed into closed water loop to be treated to be used in different applications. All the water quantity can be used twice before sending it out of the loop. The wastewater generated after the water usage is classified based on the type and level of contaminations content. Wastewater flow is recycled and treated water kept in the loop to be used in another applications. At residential buildings, the water with high quality is kept to be used for hygiene requirements, food preparation and drinking while Grey water is treated in the loop and used for toilet flushing and landscaping. Kitchens and toilets Wastewater is treated in special septic tank and then flushed into surface wetlands. Sub-surface wetland can be established in the building landscape and used in irrigation of ornamental plants.

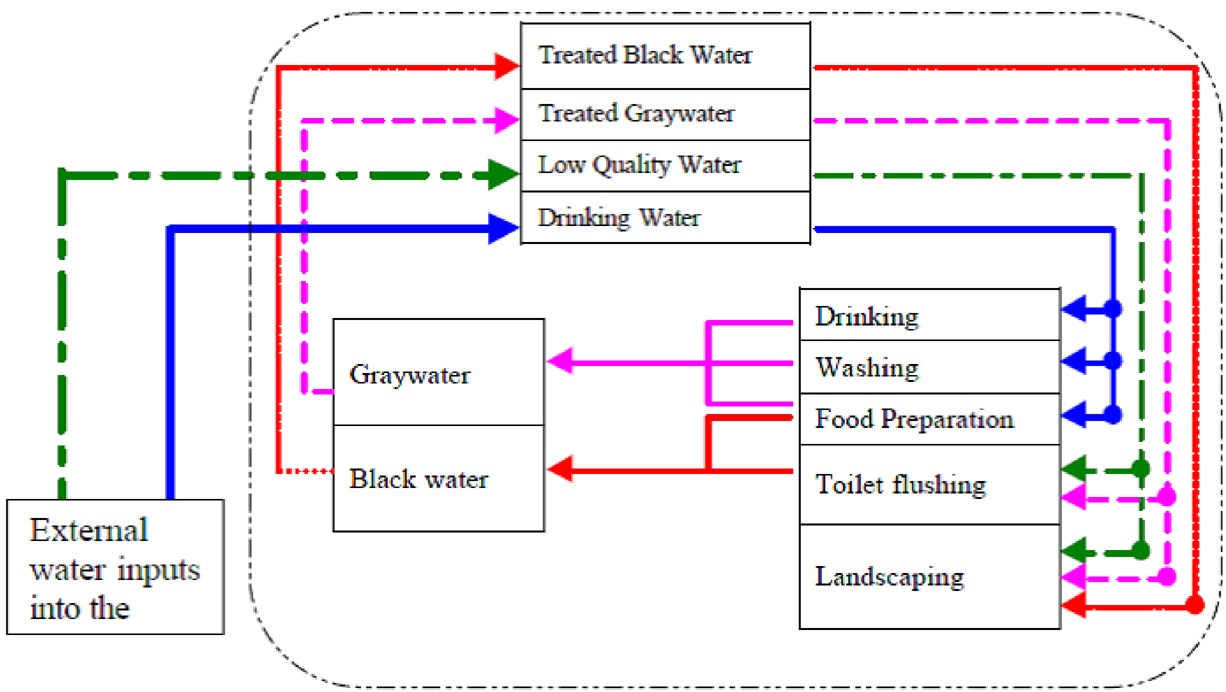


Figure 1.1: Water closed loop to be installed in a residential building. (Bakir,2001).

Gross et al. (2008), investigated the performance of seven small grey water treatment systems. The systems that had been investigated are: electrolysis and sand filtration system, 'Bio-Clear' system, vertical-flow constructed wetland (VFCW), filtration, horizontal-flow CW (HFCW), tuff filter and recycled VFCW. If the recycled VFCW designed properly to treat grey water for small communities or households, it is will cost less and require less tech treatment system and can be operated by unskilled operators.

Garcia-Perez et al. (2011), investigated the performance of RVFCW and found that it is has high efficiency in organic matter decomposition and suspended particles and pathogens removal. They planted corn crops and in the constructed wetland that proofs its ability to reduce phosphorus compound significantly and grow properly.

1.1 Recycled vertical flow constructed wetland (RVFCW) System

Recycled vertical flow constructed wetland (RVFCW) System is consisting from a combination of trickling filter, water recycling and vertical flow constructed wetland. The system is efficient in grey water treatment, low cost, doesn't need skill operators and have environmental effects on plant and soil over time.

The system has the ability to remove 80% of chemical oxygen demand, all the suspended solids and three to four orders of fecal coliforms after 8 hours of operation (Gross et al., 2007).In addition, generated treated water has no negative effect on soil and plants. According to feasibility analysis investigated the return over investment of the system; it was found that it is three years.

The system as shown in figure 1.2 is consisting from two containers placed on each other. the upper container is a VFCW with area approximately 1 m2 and consisting from three layers bed ;first layer thickness is 15 cm and consisting of planted organic soil, second layer thickness is 30 cm and consisting of plastic or turf, the last layer thickness is 5 cm and consisting of limestone pebbles. The second lower container is usually used as a reservoir. Raw grey water flowed into a sedimentation tank to settle the coarse material only and then the water pumped into the plants root zone at VFCW , then it filtered down in to the reservoir through the three-layer filter bed .the water kept recycling from the reservoir to the VFCW by using a centrifuge pump operating according to a known rate.

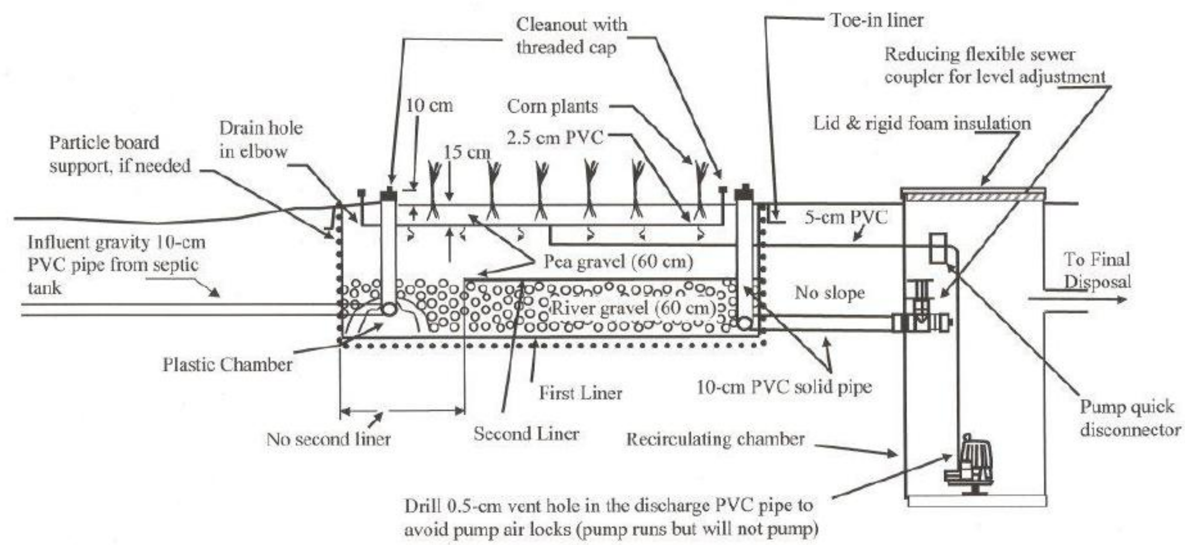


Figure 1.2: Section at recirculating vertical flow constructed wet land. (Garcia-Perez et al., 2011).

Water generated from the reservoir can be used in irrigation directly or can be filtered by a secondary sedimentation or a disinfection treatment before used in irrigation. To avoid clogging and overflow An overflow pipe should be installed from the upper container to the lower one.

Introducing raw grey water into the root zone of VFCW unit eliminates mosquitoes, bad odors and diseases. After that the root zones the water flow through porous media to the reservoir which enhance aeration that promotes the degradation of organic matter and nitrification.

Water recycling from the reservoir to the upper container the by the pump helps in dilute the new raw grey water which eliminate organic overload risk .one of the advantages of RVFCW system is that it is flexible and can tolerate to flow variation by keeping the bed and wetland operating and wet.

Recycling rate calculated based on water quality needed, dimensions of bed and flow rate of waste water. As a rule of thumb graded gravel with layer of sharp sand is usually used in most VFCW as a bed medium.

VFCW design parameters

VFCW design parameters are: Depth, area, retention times and BOD of the effluent are the main parameters when designing a VFCW. There are some VFCW sizing models however the common design is based on ‘‘rules of thumb’’ experience. To calculate the area of the system, the following equation can be used:

$$A = \frac{Q\,(\ln Ci - \ln Ce)}{KBOD} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where A is the area needed (m2)

Q is the flow rate of water (m3 /d)

Ce is the concentration of outlet (mg/ l)

Ci is the concentration of inlet (mg /l)

k is the first-order areal rate constant (m /d) ,usually estimated to be 0.16 m /d

BOD concentration target (Ce) according to table 4.7(Regulations and supervision bureau standards, 2009) is 10 mg/l. Water flow of the residential building apartments is 55052 L/day. And by assuming that the Ci the BOD influent concentration is 39 (mg/l) (refer to Pidou et al. 2007) and the recirculation rate is 400 l/h, area will be 610 m^2. The depth range of RVFCW is 0.5-0.8m.

$$A = \frac{Qd\,(\ln Ci - \ln Ce)}{KBOD}$$

Q =55052 L/day= 55.052 m^3/day

K=0.16 m /d

(Ce)= 10 mg/l Table (according to table 2.15, Regulations and supervision bureau, 2009)

Ci =39 (mg/l),

Appling in equation (1)

$$A = \frac{55.052\ (\ln 39 - \ln 10)}{0.16}$$

$$A = \frac{55.052\ (3.66 - 2.30)}{0.16}$$

$$A = \frac{55.052\ (1.363)}{0.16}$$

A =469 m^2 =21x21 m

The area is too big to be implemented on a building roof, thus Membrane Bioreactors systems will be used.

1.2 Membrane Bioreactors systems

1.2.1 Treatment units:

Membrane Bioreactors as shown in figure 1.3and figure 1.4 are consisting from the combination of conventional biological treatment and membrane filtration which produce high quality of treated grey water. Membrane Bioreactors achieve advanced levels of suspended solids, nutrient and organic removal. Membranes that used in the system are submerged in an aerated biological reactor and have porosities that are ranging 0.035 microns to 0.4 microns which produce high quality filtered water that eliminates the need to a filtration and sedimentation processes. Elimination of sedimentation process promotes biological process operation and reduces the tankage requirements and at the same time enables the future upgrading by adding plants without the need for extra tanks. Membrane bioreactors have many advantages that make it favorable if compared to other modern grey water systems like Sequencing Batch Reactor (SBR) and Extended Aeration (EA) specially if there is space limitation and in areas that considered environmentally sensitive. MBRs are usually costly if compared to other conventional treatment systems however they provide the best quality of treated grey water ,operates properly at fluctuating influent flows periods and don't require large area. Fitzgerald (2008) summarized the advantages of MBRs versus EA and SBR systems:

1. 4-8 hours Hydraulic Retention Time (HRT) vs. 16-24 hours
2. 15-365 days of Solids Retention Time (SRT) without any negative impact on the process
3. 10-15,000 mg/L MLSS
4. 20-40% less in Sludge Yield comparing to other systems
5. 25% less Footprint
6. Best effluent quality
7. Giardia/Crypto barrier
8. Less odor
9. Simple
10. Less sensitive to flow variations
11. Can be expanded by Modular
12. MBR systems are economically feasible in high rise buildings over 20 floors high. (Friedler& Hadari, 2006).

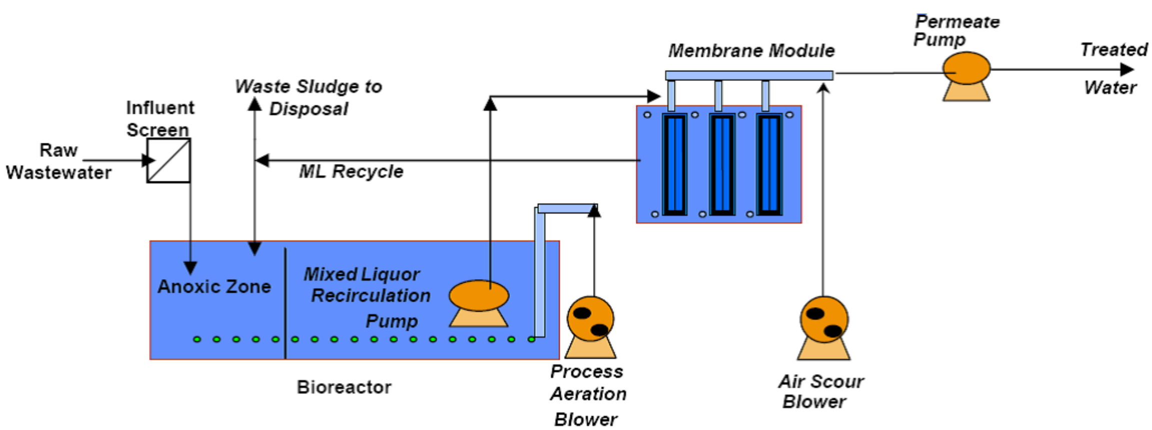


Figure 1.3: Membrane Bioreactors systems.(Fitzgerald, 2008).

1.2.2 Ancillary Processes

There are few ancillary processes that can be combined into the bio reactors systems to improve the quality of treated water like:

I. Primary Treatment
II. Disinfection
III. Sludge Stabilization

I. Primary Treatment

Designers used to combine grit removal and screening processes to conventional systems which increase the cost of the system. These processes can be useful in case if used in large systems that can compensate its cost. Screening is essential in MBR systems with a size of <3 mm in order to protect membranes from breakage or undue wear.

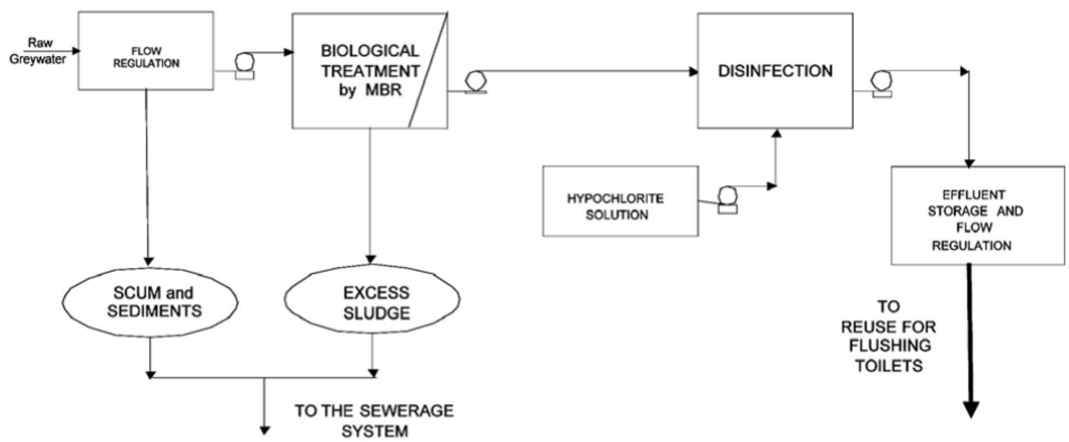


Figure 1.4: Membrane Bioreactors systems. (Friedler& Hadari, 2006).

II. Disinfection

Disinfection process is recommended by using many processes detailed in section 4.9.4. In small treatment plants like buildings treatment system, Ultraviolet (UV) disinfection system are used to eliminate residual chlorine however UV tubes needs monitoring and cleaning.

III. Sludge Stabilization

Aerated sludge holding tank is usually used to perform Sludge stabilization in warm climate regions. Its configuration and size are depending on disposal means and the chosen biological system.

Appendix 2: Plants

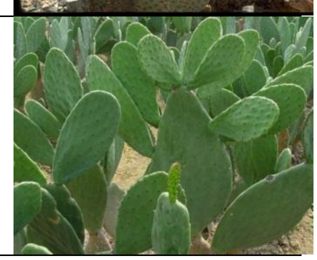
Table 1.1: Plants. (Jubran & Hizon, 1999)

Item	Spread	Foliage /flower color	Flower season	Drought tolerate	Water need	
Shrubs						
Acacia armata	3-5 m	Light green /rich yellow	Spring	high	low	
Acacia ehrenbergiana	1-5	Dull green/bright yellow	Winter to summer	high	low	
Avera javanica	0.2-0.8	Grey green /white	Year around	high	low	
Atriplex halimus	2-3 m	Silvery white/ white or greenish		high	low	
Calotropis procera	2-3 m	Grey green/ greenish white		high	low	

Callistemon lanceolatus	4 m	Coppery to vivid green/ crimson		high	low	
Capparis spinosa		Deep green/ white	Spring to summer	high	low	
Cortaderia sellona	2 m	Grey green/ white to chamios		high	low	
Dipterygium glaucum		Pale green/yello w	Spring	high	low	
Dodonaea viscosa		Shiny green /greenish-yellow		high	low	

Leptadenia pyrotechnica		Green/ greenish		high	low	
Ground cover						
Baileya multiradiata	0.15-0.2 m	White/golden yellow		high	low	
Cenchrus ciliaris		Reddish green/pink or purple	summer	high	low	
Heliotropium curassavicum	0.6	Blue-green/white		high	low	
Lycium arabicum	1.0 m	Greyish-green/ greenish, whitish		high	low	
Pennisetum setaceum	1.2 m	Pale to dark purple/pink or purplish	Year around	high	low	
Senecio cineraria		White/yellow	Year around	high	Low	

succulents						
Caralluma retrospiciens	0.45 m	Dark red	Year around	high	low	
Carpobrotus edulis	1-2 m	Grey green/white , yellow, etc	Year around	high	low	
Echinocactus grusonii	1m	Light green/ yellow	spring	high	low	
Euphorbia lactea	2-3 m	Dark green		high	low	
Euphorbia milii	0.3-0.4 m	Green/red	Year around	high	low	
Euphorbia tirucalli	3-4 m	Light green		high	low	

Kalanchoe blossfeldiana	0.45 m	Dark green/Red	winter	high	low	
Lampranthus roseus		Grey green/pink	Year around	high	low	
Mammillaria seitziana		Green/rose		high	low	
Mesembrya-nthemum crystalinum		Grey green/ white		high	low	
Opuntia basilaris		Bluish coppery/purple to rose	Spring and summer	high	low	
Opuntia dillenii		Bright green/yellow	Spring and summer	high	low	

Appendix 3: Total Energy Consumption (MWh)

	Total energy (MWh)				
	case 1	case 2	case 3	case 4	case 5
Date					
Jan 01-31	231.7002	244.1395	244.1532	244.3373	244.655
Feb 01-28	233.4613	230.442	230.3969	231.6211	229.588
Mar 01-31	290.9317	271.9491	271.8756	274.3004	269.8452
Apr 01-30	326.5186	278.4955	278.4119	283.0572	274.3552
May 01-31	394.5042	312.8904	312.7632	319.1499	306.0202
Jun 01-30	417.1371	322.0193	321.8847	329.1397	314.2203
Jul 01-31	458.2082	348.0769	347.9246	356.1025	338.9994
Aug 01-31	460.89	348.2249	348.0971	356.3241	339.1279
Sep 01-30	426.4982	332.2263	332.1304	339.0812	324.5634
Oct 01-31	377.675	311.076	311.0253	315.8628	305.5636
Nov 01-30	312.7287	279.9185	279.9012	282.1324	276.9852
Dec 01-31	255.5867	255.0897	255.0875	255.5494	254.6315
Summed total	4185.84	3534.548	3533.652	3586.658	3478.555

Appendix 4: Room Cooling Plant Sensible Load (MWh)

	Room cooling plant sens. load (MWh)				
	case 1	case 2	case 3	case 4	case 5
Date					
Jan 01-31	204.3914	231.2897	229.3082	229.6375	230.3113
Feb 01-28	232.2027	227.9496	226.0753	228.5067	224.4579
Mar 01-31	302.6778	265.8794	264.5662	269.4117	260.505
Apr 01-30	384.5605	289.5188	288.3475	297.638	280.2343
May 01-31	496.5804	334.0383	333.098	345.8723	319.6121
Jun 01-30	530.3549	340.5816	339.8498	354.3597	324.5211
Jul 01-31	584.0543	364.2909	363.487	379.8423	345.6368
Aug 01-31	591.8329	367.2879	366.2473	382.7003	348.3083
Sep 01-30	528.2153	340.6036	339.4801	353.3826	324.3458
Oct 01-31	454.0013	322.1836	320.7019	330.3765	309.7786
Nov 01-30	340.8724	276.6357	275.2174	279.68	269.3849
Dec 01-31	246.1247	247.0841	245.1295	246.0395	244.2169
Summed total	4895.869	3607.3428	3591.509	3697.447	3481.313

Appendix 5: Chillers Load (MWh)

	Chillers load (MWh)				
	case 1	case 2	case 3	case 4	case 5
Date					
Jan 01-31	227.6208	252.5164	250.6817	251.0227	251.6107
Feb 01-28	250.3775	246.4374	244.7021	246.9693	243.2046
Mar 01-31	337.3085	303.2356	302.0196	306.5094	298.2594
Apr 01-30	409.7087	321.7066	320.6221	329.2242	313.11
May 01-31	529.1097	378.6071	377.7369	389.5648	365.2498
Jun 01-30	577.521	401.8051	401.1276	414.5625	386.9344
Jul 01-31	647.079	443.5951	442.8513	457.9947	426.323
Aug 01-31	652.0471	444.1341	443.1705	458.405	426.5609
Sep 01-30	594.8558	421.1414	420.1009	432.9732	406.0876
Oct 01-31	497.944	375.8909	374.519	383.4767	364.4046
Nov 01-30	384.1715	324.6936	323.3801	327.512	317.9799
Dec 01-31	271.8548	272.7403	270.9308	271.7856	270.0857
Summed total	5379.599	4186.503	4171.843	4270	4069.811

Appendix 6: External conduction gain (MWh)

	External conduction gain (MWh)				
Date	case 1	case 2	case 3	case 4	case 5
Jan 01-31	-3.5901	-3.1658	-3.1	-1.7738	-0.96
Feb 01-28	1.777	-0.108	-0.1353	1.3637	-0.496
Mar 01-31	7.3813	3.0153	2.949	4.8131	0.082
Apr 01-30	17.2746	8.8483	8.774	10.5406	1.1397
May 01-31	28.5184	15.4362	15.3224	16.9153	2.2247
Jun 01-30	32.8593	18.1173	17.9867	19.4906	2.7779
Jul 01-31	37.9865	21.082	20.9387	22.403	3.2523
Aug 01-31	38.5148	21.6479	21.5479	22.6033	3.4247
Sep 01-30	32.0672	18.0267	17.9718	18.777	2.8119
Oct 01-31	22.3454	12.538	12.5426	12.9755	1.8497
Nov 01-30	10.7586	5.8529	5.8891	6.1892	0.69
Dec 01-31	0.2141	-0.5248	-0.4818	0.2531	-0.416
Summed total	226.1071	120.766	120.2053	134.5507	16.381

Appendix 7: Total CO2 emissions (kg)

	Total CE (kgCO2)				
Date	case 1	case 2	case 3	case 4	case 5
Jan 01-31	119789	126739	126227	126322	126487
Feb 01-28	120700	119600	119115	119748	118697
Mar 01-31	150412	140899	140560	141813	139510
Apr 01-30	168810	144242	143939	146341	141842
May 01-31	203959	161942	161698	165001	158212
Jun 01-30	215660	166604	166414	170165	162452
Jul 01-31	236893	180085	179877	184105	175263
Aug 01-31	238280	180235	179966	184219	175329
Sep 01-30	220500	172002	171711	175305	167799
Oct 01-31	195258	161183	160800	163301	157976
Nov 01-30	161681	145076	144709	145862	143201
Dec 01-31	132138	132386	131880	132119	131644
Summed total	2164079	1830991	1826898	1854302	1798413