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Sustainable Development & Eco – Roof

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Abstract: ***The analytical preview of the elements, definitions and historical background for the research. It started with identifying the global problems and methods of solution through sustainability concepts and the method of applying these concepts in building roof design. Then it continues with the study of the building and its elements, and the study of historical development of the sustainable cities. The research focuses on types of buildings roofs, and studies comprehensive definition of Eco-roof and accompanying theories and systems. The many acres of flat rooftop space in most cities can become additional green spaces while also mimicking the natural environment in a way that restores ecosystems, combats the urban heat island effect, controls storm water runoff, and conserves energy. There should now be enough evidence and successful examples worldwide to be able to convince more legislators, planners, architects, landscape architects, engineers, developers and builders that green roofs have real benefits, at local and city-wide scales. It is predictable that attitude towards green roofs will change and that they will become more commonplace and mainstream following further adoption of new guidelines on urban design by central and local government. Green roofs will make the cities, homes, and workplaces of the future, greener, cleaner, cooler, and more tranquil, with people sharing space with nature. Problems: Sustainable roofing design presents a feasible design strategy for microclimate amelioration and energy conservation in buildings which in return will build sustainable cities. Previous field and modeling studies in various climatic zones indicate that an individual Sustainable roof can reduce roof surface temperature by 15–45 °C, near-surface air temperature by 2–5 °C and building energy consumption by up to 80%. In an extremely compact tropical city such as Cairo with severe shortage of ground-level green spaces and intense UHI effects, Sustainable roof could bring significant benefits. Large-scale installation of greenery on the spatially concentrated roofs and podiums & passive roof cooling solutions forming an elevated sustainable network could compensate for the green-space deficit, mitigate urban climate and improve quality of life. Objectives: The Research aim at reaching a practical design strategy for building roof design as a step for sustainable & environmental building developments for improving building performance & energy efficiency, which in return will affect the indoor air quality creating a comfort atmosphere for the building uses. Research Contents: History & Origin of Roof ideas, Concepts related to environmental treatments to the building roof Building Envelope, Sustainable Roofing Systems, Energy efficiency, Result and Recommendation***

Keywords: Eco-roof, global energy, green roofs, passive cooling, Sustainable roofs

1. Introduction

This chapter is concerned with the theoretical study, definitions and historical background for the thesis subject. It starts with identifying the global problems and methods of solution through sustainability concepts and the method of applying these concepts in buildings roof design. Then it continues with the study of the building envelope and its elements, and the study of historical development of the building envelope. The chapter focuses on residential and commercial buildings as an urban design element, and studies their relations with other city elements, and studies comprehensive definition of Eco-roof and accompanying theories. Then the chapter is concerned with the evaluation and assessment methods, first through rating systems, second, through computer simulation, and finally, through equipment monitoring. This chapter is the theoretical study sector which is the basic foundation for the coming chapters.

1.1 Background

Cities have become major contributors to global energy consumption and greenhouse gas (GHG) emissions. The urbanization process causes local climate change through excessive anthropogenic heat release and modification of land biophysical properties. The resultant urban heat island (UHI) effects and aggravating human heat stress have become key environmental issues in city management. Cities can be designed to be climate-conscious and energy-efficient to contribute to urban sustainability and address global climate-change issues at the local level.

Sustainable roofs present a feasible design strategy for microclimate amelioration and energy conservation in cities. Previous field and modeling studies in various climatic zones indicate that an individual Sustainable roof can reduce roof surface temperature by 15–45 °C, near-surface air temperature by 2–5 °C and building energy consumption by up to 80%. In an extremely compact tropical city such as Cairo with severe shortage of ground-level green spaces and intense UHI effects, Sustainable roof could bring significant benefits. Large-scale installation of greenery on the spatially concentrated roofs and podiums forming an elevated green network could compensate for the green-space deficit, mitigate urban climate and improve quality of life. Previous assessments of sustainable-roof thermal effects are largely restricted to the individual building scale.(23)

Figure 1: Hanging Gardens of Babylon

Figure 2: Turf roof – Iceland
Source: Sustainable roofs Research by David Stater – Online document Accessed February 2014

Sustainable roofs are not a new phenomenon. They have been standard construction practice in many countries for hundreds, if not thousands, of years, mainly due to the excellent isolative qualities of the combined plant and soil layers.

Two modern advocates of Sustainable roof technology were the architects Le Corbusier and Frank Lloyd Wright. Although Le Corbusier encouraged rooftops as another location for urban green space, and Wright used Sustainable roofs as a tool to integrate his buildings more closely with the landscape, neither was aware of the profound environmental and economic impact that this technology could have on the urban landscape. Until the mid-20th century, Sustainable roofs were viewed mainly as a vernacular building practice. However in the 1960‘s, rising concerns about the degraded quality of the urban environment and the rapid decline of green space in urban areas, renewed interest in Sustainable roofs as a "green solution" was sparked in Northern Europe. New technical research was carried out, ranging from studies on root-repelling agents, membranes, drainage, lightweight growing media, to plant suitability.(3)

1.2 History & Origin of Roof ideas

The earliest known Sustainable roofs were turf roofs, a Nordic tradition still practiced today in many parts of Norway and Iceland. Turf was a durable and readily available building material known to have an insulating effect. There are several remaining examples of relatively sophisticated earth-sheltered and turf-roofed structures dating as far back as the Bronze Age, 3, 000 years ago.

Sustainable roofs are not a new phenomenon. They have been standard construction practice in many countries for hundreds, if not thousands, of years, mainly due to the excellent isolative qualities of the combined plant and soil layers.

Sustainable roofs date back to thousands of years. Despite the recorded existence of roof gardens, little physical evidence has survived but history reveals the purposes of vegetated roofs were diverse. These purposes include the insulating qualities, and an escape from the stress of the urban environment.

The origins of Sustainable roofs began thousands of years ago. The most famous Sustainable roofs were the Hanging Gardens of Babylon. They were considered as one of the Seven Wonders of the Ancient World, were constructed around 500 B.C. They were built over arched stone beams and waterproofed with layers of reeds and thick tar.

Plants and trees were then planted. In more recent times, people used sod to cover their roof tops for the purpose of insulation, it kept their homes cool in summer and warm in winter. Modern Sustainable roofs may have had their "roots" in ancient times but technological advances have made them far more efficient and expensive than their ancient counterparts. (58)

Modern green roofs are made of a system of layers placed over the roof to support soil medium and vegetation. This is a relatively new phenomenon and was developed in Germany in the 1960s, and has spread to many countries, since then. Sustainable roofs are also becoming increasingly popular in the United States, although they are not as common as in Europe.

Currently, Sustainable roofs are becoming more common in the United States, although other countries are farther along in the adoption of Sustainable roof systems. In Germany for example, it is estimated that 14% of all flat roofs are green .Before human development began causing wide scale disturbance, soil and vegetation managed storm water and solar energy effectively. Since that is no longer the case, Sustainable roofs have become one aspect of effective storm water and solar energy management. The introduction into the U.S. urban environment only occurred recently, gaining popularity in the last few decades. (58)

Further advancements came from Germany in the 1960‘s where still new materials were developed to create the Sustainable roof we still use today.

1.3 Problems

Here are two global events converging to create the most significant crisis of modern times. The first of these is global warming. The second major event threatening our planet is the escalating consumption of energy and resulting depletion of fossil-fuel resources.

Figure 1.3: Guinigi Tower, Lucca, Italy
Source: Sustainable roofs Research by David Stater - Online document - Accessed February 2014

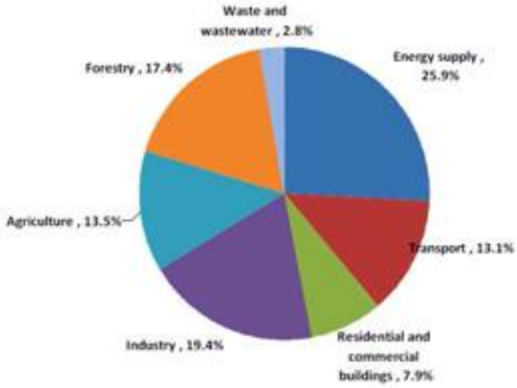

Figure 1.4: Worldwide GHG emissions by sector in 2004 Source: 4th IPCC assessment report, climate change mitigation, 2007.

1.3.1 Global Warming

There is considerable scientific evidence that the earth's temperature is rising and will continue to do so as a result of human activities. These activities include particularly the burning of fossil fuels- coal, oil and gas- for our buildings and our transportation, manufacturing and agricultural systems and they result in increased greenhouse gases (GHG), which contributes to global warming, see Fig. (1.4). Climate change affects us all- we should act to reduce its impact by changing from fossil-fuel-based systems to renewable-energy-based ones.

a) The likely negative impacts of global warming include:

1) Disastrous sudden results like increased storms, flooding, droughts, and the probable destruction of the ecosystems,
2) Slow rate results, as the spread of diseases affecting human health, impairment of crops and plants, also affecting the living environment of human beings. In urban areas, there is a "heat island" effect resulting from the production and accumulation of heat in the urban mass. Cities can be several degrees warmer than their surroundings. The heat island effect will lead to temperature rises being more marked; air pollution in cities may increase; drainage systems may need to be altered to cope with periods of higher rainfall.

Global warming will probably lead to social, political and economic disturbance. It seems wise to stand for what is known as the "precautionary principle", which maintains that we should take action now to avoid possible serious environmental damage even if the scientific evidence for action is inconclusive, and design our cities to reduce their CO2 production significantly despite the welfare caused by the over emissions. [(101)]

There will naturally be environmental costs if the standards of the wealthy are maintained while at the same time meeting the basic needs of the poor. These environmental costs, furthermore, will increase dramatically if the living conditions in developing countries improve. It is one earth that we inhabit, and its environmental, social, economic and political problems have no borders.[(102)]

The technology to reduce climate change is largely available. We need more solutions, more government support and more individual initiative.

1.3.2 Urban Heat Island Effect (UHI)

An urban heat island (UHI) is a metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The phenomenon was first investigated and described by Luke in the 1810s, although he was not the one to name the phenomenon.

The temperature difference usually is larger at night than during the day, and is most apparent when winds are weak. UHI is most noticeable during the summer and winter. The main cause of the urban heat island effect is from the modification of land surfaces, which use materials that effectively store short-wave radiation.

Waste heat generated by energy usage is a secondary contributor. As a population center grows, it tends to expand its area and increase its average temperature. The less-used term heat island refers to any area, populated or not, which is consistently hotter than the surrounding area.

Monthly rainfall is greater downwind of cities, partially due to the UHI. Increases in heat within urban centers increases the length of growing seasons, and decreases the occurrence of weak tornadoes.

The UHI decreases air quality by increasing the production of pollutants such as ozone, and decreases water quality as warmer waters flow into area streams and put stress on their ecosystems.

Not all cities have a distinct urban heat island. Mitigation of the urban heat island effect can be accomplished through the use of Sustainable roofs and the use of lighter-colored surfaces in urban areas, which reflect more sunlight and absorb less heat. Despite concerns raised about its possible contribution to global warming, comparisons between urban and rural areas show that the urban heat island effects have little influence on global mean temperature trends.

Causes

There are several causes of an urban heat island (UHI). The principal reason for the nighttime warming is that the short-wave radiation is still within the concrete, asphalt, and buildings that was absorbed during the day, unlike suburban and rural areas. This energy is then slowly released during the night as long-wave radiation, making cooling a slow process. Two other reasons are changes in the thermal properties of surface materials and lack of evapotranspiration (for example through lack of vegetation) in urban areas. With a decreased amount of vegetation, cities also lose the shade and cooling effect of trees, the low albedo of their leaves, and the removal of carbon dioxide.

Materials commonly used in urban areas for pavement and roofs, such as concrete and asphalt, have significantly different thermal bulk properties (including heat capacity and thermal conductivity) and surface radiative properties (albedo and emissivity) than the surrounding rural areas. This causes a change in the energy balance of the urban area, often leading to higher temperatures than surrounding rural areas.

Other causes of a UHI are due to geometric effects. The tall buildings within many urban areas provide multiple surfaces for the reflection and absorption of sunlight, increasing the efficiency with which urban areas are heated. This is called the "urban canyon effect". Another effect of buildings is the blocking of wind, which also inhibits cooling by convection and pollution from dissipating. Waste heat from automobiles, air conditioning, industry, and other sources also contributes to the UHI. High levels of pollution in urban areas can also increase the UHI, as many forms of pollution change the radiative properties of the atmosphere. As UHI raises the temperature of cities, it will also increase the concentration of ozone in the air, which is a greenhouse gas. Ozone concentrations will increase because it is a secondary gas, aided by an increase in temperature and sunlight.

Some cities exhibit a heat island effect, largest at night. Seasonally, UHI shows up both in summer and winter. The typical temperature difference is several degrees between the center of the city and surrounding fields. The difference in temperature between an inner city and its surrounding suburbs is frequently mentioned in weather reports, as in "68 °F (20 °C) downtown, 64 °F (18 °C) in the suburbs". Black surfaces absorb significantly more electromagnetic radiation, and causes the surfaces of asphalt roads and highways to heat. "The annual mean air temperature of a city with 1 million people or more can be 1.8–5.4°F (1–3°C) warmer than its surroundings. In the evening, the difference can be as high as 22°F (12°C).

b) Why Do We Care About Heat Islands?

Elevated temperature from urban heat islands, particularly during the summer, can affect a community's environment and quality of life. While some heat island impacts seem positive, such as lengthening the plant-growing season, most impacts are negative and include:

- Increased energy consumption: Higher temperatures in summer increase energy demand for cooling and add pressure to the electricity grid during peak periods of demand. One study estimates that the heat island effect is responsible for 5–10% of peak electricity demand for cooling buildings in cities.
- Elevated emissions of air pollutants and greenhouse gases: Increasing energy demand generally results in greater emissions of air pollutants and greenhouse gas emissions from power plants. Higher air temperatures also promote the formation of ground-level ozone.
- Compromised human health and comfort: Warmer days and nights, along with higher air pollution levels, can contribute to general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality.
- Impaired water quality: Hot pavement and rooftop surfaces transfer their excess heat to storm water, which then drains into storm sewers and raises water temperatures as it is released into streams, rivers, ponds, and lakes. Rapid temperature changes can be stressful to aquatic ecosystems.

c) What Can Be Done?

Communities can take a number of steps to reduce the heat island effect, using four main strategies:

- Increasing tree and vegetative cover
- Creating Sustainable roofs(called "rooftop gardens" or "eco-roofs")
- Installing cool—mainly reflective—roofs
- Using cool pavements.

Typically heat island mitigation is part of a community's energy, air quality, water, or sustainability effort. Activities to reduce heat islands range from voluntary initiatives, such as cool pavement demonstration projects, to policy actions, such as requiring cool roofs via building codes. Most mitigation activities have multiple benefits, including cleaner air, improved human health and comfort, reduced energy costs, and lower greenhouse gas emissions.

1.3.3 Energy Crisis

Fossil fuels are currently the most economically available source of power for both personal and commercial uses. In 2005, more than 3/4 of total world energy consumption was through the use of fossil fuels. Petroleum led with over 43.4 percent of the world's total energy consumption, followed by natural gas (15.6 percent) and coal (8.3 percent). Long thought to be inexhaustible, fossil fuels have been used extensively since the Industrial revolution.

However, many believe that the world is using fossil fuels at a non-regenerative rate (See Fig 1.5). Some experts believe that the world has already reached its peak for oil extraction and production, and that it is only a matter of time before natural gas and coal vanish.(103)

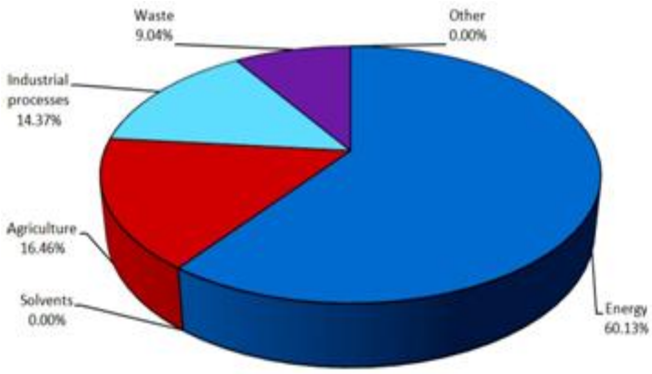

Figure 1.9: Inverse relation between rate of oil discovery and production.

Source : http: //seekingalpha.com/article/310502-getting-ready-for-peak-oill Accessed February 2014

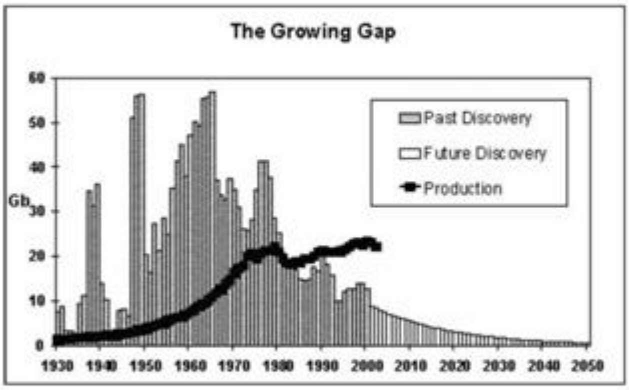

Figure 1.10*:* GHG emissions in Egypt by sector.
Source: Emissions Summary for Egypt - Online document, Accessed February 2014

1. 3.4 Environmental Problems in Egypt

Egypt had a good share of these problems being part of the world. These problems are a share from other countries, plus the contribution Egypt shares as a polluting country.

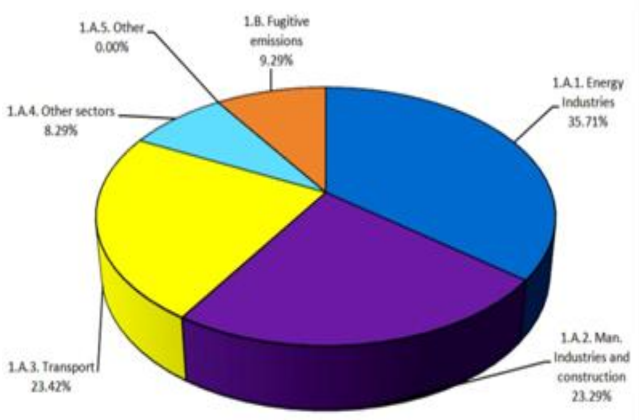

Figure 1.11: Breakdown of GHG emissions in Egypt within the energy sector.
Source: Emissions Summary for Egypt - Online document Accessed February 2014

A) Climate Change and Rising Sea Level

Climate change poses significant risks through sea level rise on the coastal zone, which is already subsiding at approximately 3-5mm/year around the Nile delta. Analyses of current climatic trends reveal a warming trend in recent decades with country averaged mean temperature increases of 1.0°C, 1.4°C and 2.5°C projected by 2030, 2050 and 2100. Higher temperatures in the semi-arid regions with resulting evaporative losses coupled with increasing water demands will likely result in decreasing water availability from the Nile. There is also some possibility of significant decline in Nile stream flow under climate change as a result of changes in precipitation. Coastal zone and water resource impacts have also serious implications for agriculture: sea level rise will adversely impact prime agricultural land in the Nile delta, while the intensive irrigated agriculture upstream would suffer from any reductions in Nile water availability. Therefore, climate change is a serious development concern for Egypt. Given that Egypt‘s population, land-use and agriculture, as well as its economic activity are all constrained along a narrow T-shaped strip of land along the Nile and the deltaic coast, it is extremely vulnerable to any adverse impacts on its coastal zones and water availability from the Nile.[32]

B) GHG Emissions

Egypt ranks 31st in total emissions with 221.1 million tons of CO2 emitted yearly making Egypt responsible for 0.59% of global emissions. Egypt ranks 94th in terms of per capita emissions with 3 tons of CO2 per person.

C) Water Crisis

Water resources in Egypt are becoming scarce. Surface-water resources originating from the Nile are now fully exploited, while groundwater sources are being brought into full production. Egypt is facing increasing water needs, demanded by a rapidly growing population, by increased urbanization, by higher standards of living and by an agricultural policy which emphasizes expanded production in order to feed the growing population. The per capita water resources is expected to drop from a current value of about 922 m3 per year to about 337 m3 per year in 2025, this could mean that up to 60 per cent of the agricultural land will not be irrigated. [34]

1.4 Concepts related to environmental treatments to the building roof Building Envelope

The building envelope is defined in this context as those elements of the building that form the boundary between the indoor environment of a building and the external environment in which it is located for example, the floor, walls, roof, windows, etc.

1.4.1 Building envelope and energy performance

The building envelope is in a sense a filter between the internal and external environments. It serves to protect the indoor spaces from undesirable impacts such as excessive cold, heat, radiation, and wind, while allowing desirable impacts to pass through such as cool breezes on a hot day, warmth from the sun on a cold day, daylight, etc.

The building envelope directly influences the energy performance of a building in the following ways:

- Resisting undesirable heat transfer.
- Allowing desirable heat transfer.
- Providing heat storage (delayed heat transfer).
- Allowing daylight penetration.
- Preventing undesirable light penetration (glare).
- Allowing desirable ventilation.
- Preventing undesirable ventilation.

There are two different approaches to envelope design in relation to building energy performance.

One approach seeks to isolate the interior of the building as much as possible from the external environment. Insulation is used extensively in all the envelope elements to reduce heat transfer as far as possible. Such buildings rely entirely on air conditioning systems to provide heating or cooling to maintain comfort conditions. This is often referred to as an ‗active‘ approach to building energy design.

Another approach to building energy design is referred to as ―passive" design. This seeks to encourage beneficial interactions between the building and the outside environment, while reducing as far as possible the undesirable interactions. In climates such as that of Botswana, where the average daily temperature is generally close to indoor comfort conditions, this approach tends to make use of thermal mass to reduce the extremes of day and night temperature. Careful use of both insulating and conductive materials as appropriate for different elements of the building prevent or encourage heat transfer when it is useful, and controlled ventilation allows air movement through the building to provide fresh air and help to keep the temperature in the comfort zone.

When successful, this approach can allow the external environment to address some or all of the internal loads, reducing the energy required by mechanical systems.

Cooling of the building takes place when heavy elements such as walls absorb heat from the building during the day and release it to outside at night. Ventilation of the building when the outdoor air is cool can also help to cool the building. In winter heat from the sun can be stored in the walls and released into the building at night when heating is needed. When it fails, this approach can lead to high energy consumption if mechanical systems are required to pump heat into or out of thermal mass elements that conflict with the desired internal temperature. Generally buildings such as residential houses with relatively low levels of internal heat gain from occupants, lights and equipment, can be designed using passive principles to achieve comfort conditions for most of the year with little or no mechanical heating or cooling.

Buildings with high levels of internal heat gain such as office blocks will generally require mechanical systems to maintain comfort conditions, but there are significant opportunities to reduce the energy consumption with careful design.

In the design of energy efficient buildings dominated by internal heat gains particular attention should be given to matching the mechanical systems to the internal loads, and to ensure that control systems are designed and operated to avoid conflict between the mechanical systems and the thermal mass elements of the envelope and internal structure. (29)

1.4.2 Passive cooling approaches

Passive cooling is considered an alternative to mechanical cooling that requires complicated refrigeration systems. The building envelope is a critical component of any facility since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, walls, windows, doors, construction details and ground surfaces the envelope controls the flow of energy between the interior and exterior of the building.

The building envelope can be considered the selective pathway for a building to work with the climate- responding to heating, cooling, ventilating, and natural lighting needs. (U.S. Department of Energy, 2004)

There are four key approaches for achieving thermal comfort in cooling applications: envelope design, natural cooling sources, hybrid cooling systems, and adapting lifestyle.

Envelope design as a means of passive cooling is the integrated design of building form and materials as a total system to achieve optimum comfort and energy savings. An optimal design of the building envelope may provide significant reductions in cooling loads-which in turn can allow downsizing of mechanical equipment Natural cooling sources including air movements, evaporative cooling, and earth coupled thermal mass can also provide thermal comfort. Hybrid cooling systems are whole building cooling solutions employing a variety of cooling options (including air-conditioning) in the most efficient and effective way. They take maximum advantage of passive cooling when available and make efficient use of mechanical cooling systems during extreme periods. Adapting lifestyle involves adopting living, sleeping, cooking and activity patterns to adapt to and work with the climate rather than using mechanical cooling to emulate an alternative climate. The general design principles of passive cooling are the reduction or elimination of external heat gains during the day with sound envelope design, and allow lower nighttime temperatures and air movement to cool the building and its occupants.

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The general design principles of passive cooling are the reduction or elimination of external heat gains during the day with sound envelope design, and allow lower nighttime temperatures and air movement to cool the building and its occupants. (30)

1.4.2.1 Development of a passive cooling strategy

Passive cooling techniques can reduce the peak cooling load in buildings, thus reducing the size of the air conditioning equipment and the period for which it is generally required. The important cooling concepts like shading are discussed in details:

A) Solar shading

Among all other solar passive cooling techniques solar shading is relevant to thermal cooling of buildings especially in a developing country owing to their cost effectiveness and easy to implement.

Rural India and developing countries in Middle-east region has witnessed a steep rise masonry houses with RCC roofs. However the availability of electric power in the villages especially during summer is limited. These RCC roofs tend to make the indoor temperature very high around 41°C:

This is due to high roof top temperature of around 65°C in arid regions. Solar shading with locally available materials like terracotta tiles, hay, inverted earthen pots, date palm branches etc. can reduce this temperature significantly.

Scientists in India evaluated the performance of solar passive cooling techniques such as solar shading, insulation of building components and air exchange rate. In their study they found that a decrease in the indoor temperature by about 2.5°C to 4.5°C is noticed for solar shading. Results modified with insulation and controlled air exchange rate showed a further decrease of 4.4°C to 6.8°C in room temperature. The analysis suggested that solar shading is quite useful to development of passive cooling system to maintain indoor room air temperature lower than the conventional building without shade. [106] **Shading by overhangs, louvers and awnings.**

Well-designed sun control and shading devices, either as parts of a building or separately placed from a building facade, can dramatically reduce building peak heat gain and cooling requirements and improve the natural lighting quality of building interiors. The design of effective shading devices will depend on the solar orientation of a particular building facade. For example, simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high.

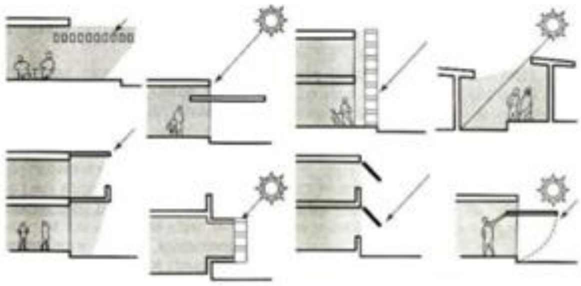

Figure 1.4: Different types of shading

Shading of Roof

Shading the roof is a very important method of reducing heat gain. Roofs can be shaded by providing roof cover of concrete or plants or canvas or earthen pots etc. Shading provided by external means should not interfere with night-time cooling.

A cover over the roof, made of concrete or galvanized iron sheets, provides protection from direct radiation. Disadvantage of this system is that it does not permit escaping of heat to the sky at night-time.

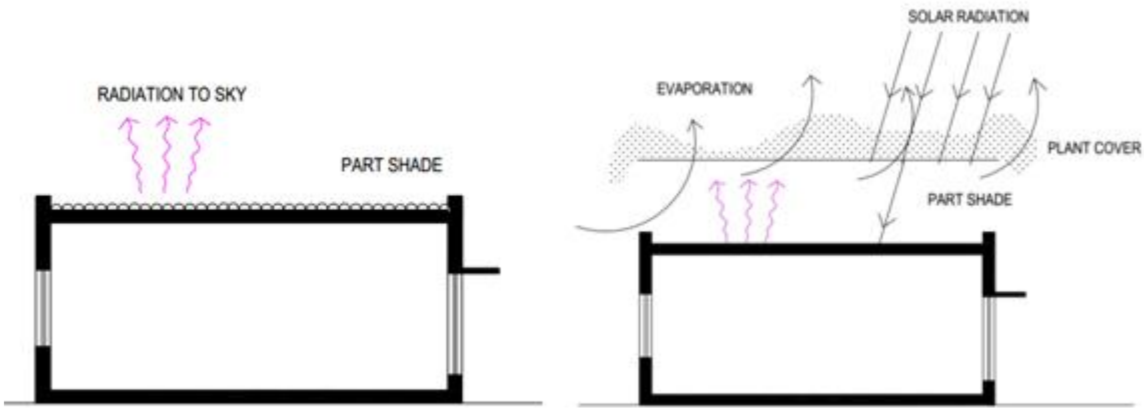

Figure 1.5: Roof Shading by solid cover

A cover of deciduous plants and creepers is a better alternative. Evaporation from the leaf surfaces brings down the temperature of the roof to a level than that of the daytime air temperature. At night, it is even lower than the sky temperature.

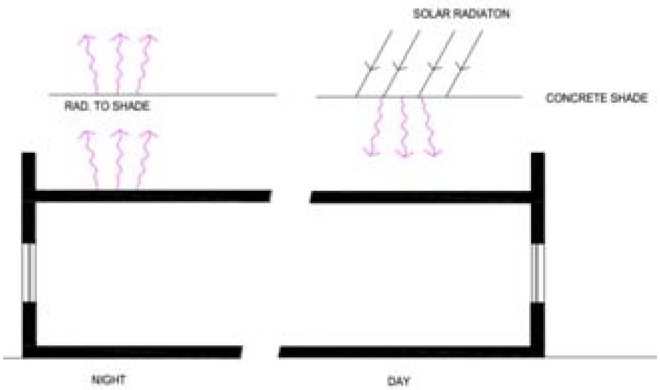

Figure 1.6: Roof shading by plant cover

Covering of the entire surface area with the closely packed inverted earthen pots, as was being done in traditional buildings, increases the surface area for radiative emission. Insulating cover over the roof impedes heat flow into the building. However, it renders the roof unusable and maintenance difficult. Broken china mosaic or ceramic tiles can also be used as top most layer in roof for reflection of incident radiation.

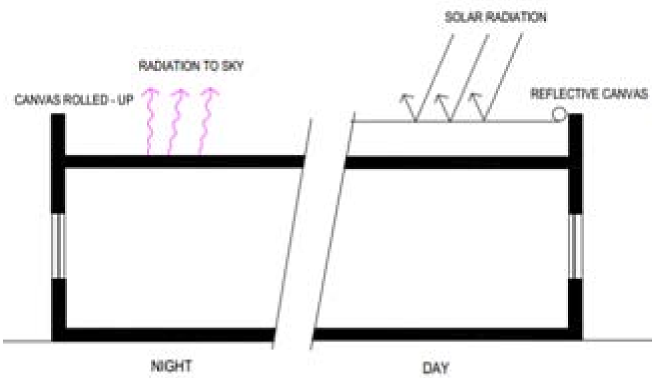

Figure 1.6: Roof Shading by earthen pots

Another inexpensive and effective device is a removable canvas cover mounted close to the roof. During daytime it prevents entry of heat and its removal at night, radiative cooling. Fig. 1.7 shows the working principle of removable roof shades. Painting of the canvas white minimizes the radiative and conductive heat gain. Ref. (107)

B) Radiative cooling

The roof of a building can be used both as a nocturnal radiator and also as a cold store. It is often a cost-effective solution. During the night the roof is exposed to the night sky, losing heat by long-wave radiation and also by convection. During the day, the roof is externally insulated in order to minimize the heat gains from solar radiation and the ambient air. The roof then absorbs the heat from the room below.

- **Diode roof**

The diode roof eliminates the water loss by evaporation and reduces heat gains without the need for movable insulation. It is a pipe system, consisting of a corrugated sheet-metal roof on which are placed polyethylene bags coated with white titanium oxide each containing a layer of pebbles wetted with water. The roof loses heat by long-wave heat radiation to the sky and by the evaporation of water which condenses on the inside surface of the bags and drops back onto the pebbles. By this means, it is possible to cool the roof to 4°C below the minimum air temperature. [(67)]

- **Roof pond**

In this system a shallow water pond is provided over highly conductive flat roof with fixed side thermal insulation. The top thermal insulation is movable. The pond is covered in day hours to prevent heating of pond from solar radiation. The use of roof pond can lower room temperature by about 20°C. While keeping the pond open during night the water is cooled by nocturnal cooling. The covered pond during the day provides cooling due to the effect of nocturnally cooled water pond and on other side the thermal insulation cuts off the solar radiation from the roof. The system can be used for heating during the winter by operating the system just reverse. The movable insulation is taken away during day so the water of pond gets heated up by solar radiation and heating the building. The pond is covered in night to reduce the thermal losses from the roof and the hot water in the pond transfers heat into building. ([67)]

1.4.2.2 Walls and Roofs

The building envelope is a critical component of any facility since it both protects the building occupants and plays a major role in regulating the indoor environment. Consisting of the building's roof, walls, windows, doors, construction details and ground surfaces the envelope controls the flow of energy between the interior and exterior of the building.

The building envelope can be considered the selective pathway for a building to work with the climate- responding to heating, cooling, ventilating, and natural lighting needs.

For buildings dominated by cooling loads, it makes sense to provide exterior finishes with light colors and high reflectivity or wall-shading devices that reduce solar gain considering the impact of decisions upon neighboring buildings. A highly reflective envelope may result in a smaller cooling load, but glare from the surface can significantly increase loads on and complaints from adjacent building occupants. Reflective roofing products help reduce cooling loads because the roof is exposed to the sun for the entire operating day.

Wall shading can reduce solar heat gain significantly using roof overhangs, window shades, awnings, a canopy of mature trees, or other vegetative plantings, such as trellises with deciduous vines.

In new construction, providing architectural features that shade walls and glazing should be considered. In existing buildings, vegetative shading options are generally more feasible. Building walls, roofs, and floors of adequate thermal resistance is essential to provide human comfort and energy efficiency. Passive evaporative cooling design can also be used on roofs through roof spray or roof ponds, and Insulating materials in walls and roofs are very beneficial for energy saving and efficiency. Incorporating solar controls on the building exterior can also have a significant impact to reduce heat gains which will studies in chapter two.

1.4.3 Sustainable roofs as a key step in climate change mitigation

A Sustainable roof is either a vegetated landscape built up from a series of layers that are installed on the roof surface as ‗loose laid‘ sheets or modular blocks or a passive "cool roof" approach, where the roof is designed to absorb less of the sun's heat and therefore stay at a cooler temperature . This approach will always benefit in hot climates, but will also benefit in any climate where summer heat gain on the roof outweighs winter heat loss.

Sustainable roofs are constructed for a number of reasons - as a space for people to visit, as an architectural feature, to add value to the property or to achieve particular environmental benefits (e.g. storm water management, biodiversity, thermal insulation).

Vegetation on Sustainable roofs as one approach is planted in a growing substrate (a specially designed soil-like medium) that may range from 50mm to over a meter in depth, depending on the weight capacity of the building‘s roof and the aims of the design. Sustainable roofs will do best if they have some irrigation, although it is possible to create a Sustainable roof that survives lives without any irrigation (but be aware that there will be periods of die back).

The cool roof approach to creating a cool roof is to use light colored roofing, but beware that light colored composition (asphalt) roofing isn't generally as reflective as light colored metal roofing.4 An even more effective approach in hot climates would be to use a roofing that is coated with a material that has high emissivity and low absorption (high reflectance) essentially building a solar collector in reverse. High emissivity coatings will increase winter heat loss, so usually don't make sense in cold climates.

Not only are Sustainable roofs a key climate change mitigation strategy, they also help with energy consumption.

Sustainable roofs help maintain a buildings temperature by regulating temperature variability –insulating it from cold weather in the winter and absorbing the heat in summer. This reduces central heating and air-conditioning costs.

Often known as roof gardens, they break up the monotonous grey jungle of cities, creating green spaces, and encouraging biodiversity. Since the industrial revolution, smog and heat levels – known as the urban heat island effect – have increased in major cities. Sustainable roofs, with their intense vegetation, help control the rise in temperature and make the air cleaner.

Sustainable roofs have traditionally been categorized as extensive or intensive. Extensive Sustainable roofs are lightweight with a layer of growing substrate that is usually less than 200mm deep. Extensive Sustainable roofs generally have lower water requirements and grow smaller sized plants. Intensive Sustainable roofs are generally heavier, with a deeper layer of growing substrate that can support a wider variety of plants. Because of this they can have greater needs for irrigation and maintenance, compared to extensive roofs. Traditionally extensive Sustainable roofs were seen as light weight, non-publicly accessible, spaces whilst intensive Sustainable roofs were designed as amenity spaces for people. Over time the Sustainable roof at Council House, Little Collins Street, Melbourne boundaries between these types of roofs have blurred, and terms like semi-intensive or semi-extensive have been introduced to describe roofs that are a blend of both categories.

Other descriptions of Sustainable roofs include Brown roof or Eco-roof, which are generally lightweight, with shallow, substrate and minimal access and maintenance. They are typically associated with low growing plants - generally succulents. Biodiversity roof - lightweight roof, with a focus on using native vegetation. May be designed for a particular species of invertebrate, bird, mammal, or plant. Roof garden or Podium roof - heavier, deep substrate, designed for access by people, and requires regular maintenance and are built directly on a structure with considerable weight loading capacity, such as a car park.[18]

Figure 1.7: Sustainable roof at Council House 2, Little Collins Street, Melbourne
Source: Victoria's Guide to Sustainable roofs, walls & facades - Online document
Accessed February 2014

1.5 Sustainable Roofing Systems

1.5.1 Green Roofs (Living roofs)

1.5.1.1 Origin

Green roofs involve growing plants on rooftops, thus replacing the vegetated footprint that was destroyed when the building was constructed (Getter and Rowe 2006). The earliest documented roof gardens were the Hanging Gardens of Semiramis in what is now Syria, considered one of the seven wonders of the ancient world. In the 1600s to 1800s, Norwegians covered roofs with soil for insulation and then planted grasses and other species for stability. Germany is recognized as the place of origin for modern-day green roofs (Getter and Rowe 2006). These were developed to help with protection for radiation on the roof, and even used as fire protection.

In the 1970s, growing environmental concern, especially in urban areas, created opportunities to introduce progressive environmental thought, policy, and technology in Germany. These innovations and technologies were quickly embraced. The use and understanding of green roofs have allowed the formation of building laws that now require construction of green roofs in many urban centers. Green-roof coverage in Germany alone now increases by approximately 13.5 million square meters (m2) per year. Today, similarly elaborate garden projects are designed for high-profile international hotels, business centers, and private homes.

Greens roofs are classified into two categories, intensive and extensive. Intensive green roofs involve intense maintenance and include shrubs, trees, and deeper planting medium. Extensive green roofs have less maintenance and usually consist of shallower soil media, different plants such as herbs, grasses, mosses, and drought tolerant succulents such as sedum (Getter and Rowe 2006). The creation of green roofs, whether they are intensive or extensive, has beneficial effects to the environment and on the UHI.

1.5.1.2. Types of green roof

The term green roof is used to describe both ornamental roof gardens and roofs with more naturalistic plantings or self-established vegetation. Green roofs consist of three types of construction, design, and cost: intensive, simple intensive, and extensive. The intensive roof is closest to what is known as a roof garden. It has the appearance of a garden or park that you would see at ground level. Because of the amount of weight needed for a growing medium, plants, water, and visitors, these gardens are usually constructed over reinforced concrete decks. Because of the expense of roof structure upgrades these roofs are usually not an option for green roof retrofits, but if implemented at the design phase they can have a dramatic affect on the architecture of a building while adding green roof benefits to the structure.

Figure 2.1: The ACROS Building, Fukuoka, Japan is an intensive green roof

The second type is referred to as a simple intensive green roof. This roof is vegetated with lawns or ground covering plants, and requires regular maintenance, including irrigation, feeding and cutting. Demands on building structure are much more moderate than that of the intensive roof, making it much more affordable and a possible choice for retrofit green roofs.

It is, however, more expensive and complex than extensive green roofs. These roofs are usually not meant to be accessible but they are often designed to be overlooked. A structure with a tiered roof system would be a great candidate for a roof of this type.

Figure 2.2: The School of Art and Design in Singapore is an example of a simple-intensive green roof

The third type is the extensive green roof. This type requires minimal maintenance and is usually not irrigated, although in some cases it can be during the time when plants are being established. The extensive roof has a very shallow planting media (low weight, sometimes soil-less) which helps minimize the cost and the structural load on the roof. This makes it an ideal candidate for retrofit green roofs. There are also disadvantages. The low- weight synthetic planting media is more susceptible to winds, drought, and high temperatures associated with an elevated surface. With this in mind, plant selection must consist of hardy, low-height drought resistant plants like succulents, herbs, and grasses. This roof would only be accessible for maintenance. (1)

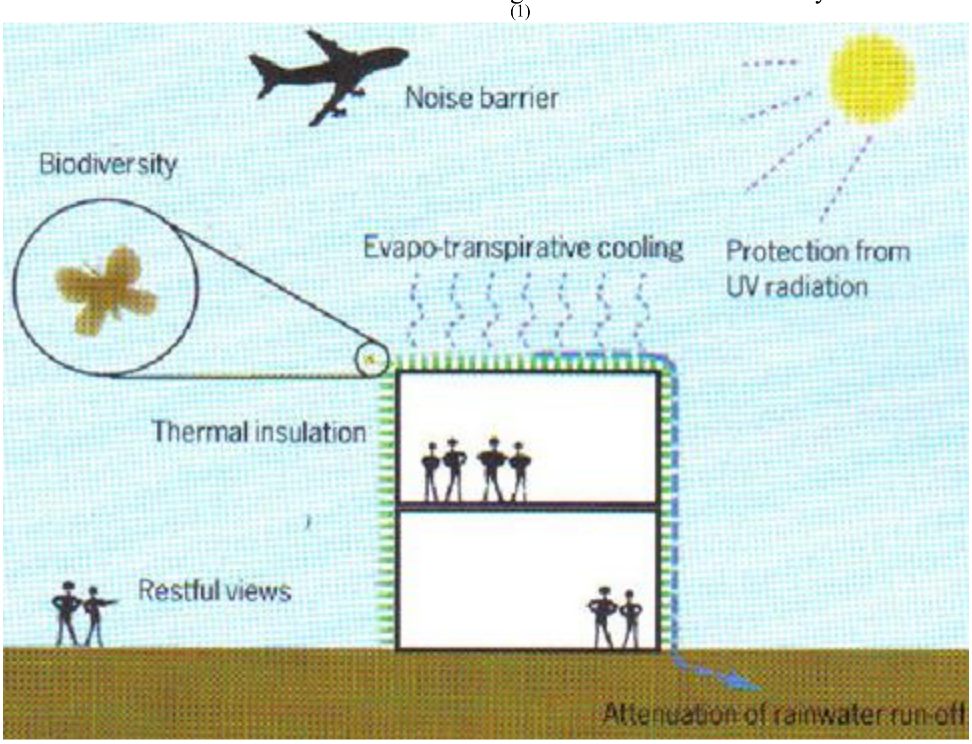

Figure 2.3: Canary Wharf, London, an extensive green roof.

1.5.1.3 Benefits of green roof

Green roofs have multiple benefits, one of which is shadowing the surfaces of roofs, which can reduce heat gain by nearly 100 percent. A green roof forms a buffer zone between the roof and the sun's radiation and shades the roof, preventing its surface from heating up and increasing outdoor and indoor air temperatures (FEMP 2004). Green roofs provide many other benefits such as storm-water management, improving roof membrane longevity, summer cooling of interior space, support of wildlife diversity, improvement in air quality, aesthetic views, and reduction of the UHI effect.(42)

Figure 2.5: Eco - roof benefits
Source*:* Green Roofs Research by David Stater - Online document - Accessed February 2014

Green roofs benefits are generally bio-physical, that is they provide ecosystem services like flood control and temperature moderation. Amenity and having rehabilitative properties are additional and important social benefits offered by green roofs. Several authors classify specific benefits offered by green roofs and the commonly mentioned include the following:

- Retain storm water and act as possible detention sites.
- Reduce pollutant levels in storm water.
- Provide insulation, reducing heating and cooling costs for the building.
- Influence urban microclimates.
- Reduce the urban heat island effect.
- Offer noise reduction (as a result of the insulating effects).
- Improve urban air quality and absorb greenhouse gases.
- Promote biodiversity and increase habitat.
- Provide amenity and rehabilitative services.
- Improve aesthetic quality of buildings and the urban environment.
- Provide opportunities for urban agriculture.

Life-Cycle Assessment

- Longer roof membrane
- Embodied energy and recycled content
- Reduce energy costs 10 percent to 30 percent

1.5.2 Cool roofs

1.5.2.1 Ventilation Cooling Strategies
In climates where it regularly cools of during the night, an especially when there is at least a gentle breeze, the house temperature can be lowered significantly overnight (assuming of course that you don't have a lot of thermal mass that was heated during the day). Taller buildings (i.e. two stories or more) can use the stack effect, e.g. by opening a vent high in the building the hot air in the house will rise up and out. The cooler it is out, and the taller the vent, the stronger the air movement. If there is not enough stack effect pressure, an attic fan can supply the same pressure.

By designing the house with good cross ventilation, any nighttime breeze will both provide cooler night air in a horizontal direction, but help force air out any ceiling vents.

Since the ground temperature in most areas stays relatively cool (typically below 60 degrees), we can use the ground as a thermal mass also by using a pipe under the house to draw cold air out of the ground. Transferring too much heat will cause heating of the ground around the pipe, rendering it as ineffective as any other thermal mass, so the usual cautions apply.

1.5.2.2 Evaporative Coolers
When the relative humidity is low, passive cooling can be increased by evaporating water (such as the body's perspiration system, or the cooling towers used in the Middle Eastern countries), which takes advantage of the additional heat absorbed by the evaporating water. Depending on the demand, an evaporative cooler can easily use 30-50 gallons of water a day. Since they work best in dry climates, and water tends to be scarce in dry climates, they're use it limited to areas where there is plentiful source of water. Their main advantage is that they use less energy, there disadvantage is the increase in water usage, and sometimes increasing the room humidity too much.

The typical evaporative cooler used in the US is the "swamp cooler" which usually sits on the roof, or in a wall and has a fan that blows air over a wet, sponge like material. Water evaporates into the air, cooling the air, but also increasing its humidity, typically above 70% relative humidity.

1.5.2.3 Reflective Roofs:
Reflective roofs involve either laying down a white membrane or spraying a white paint on top of a roof, which gives roughly the same effect. With the right insulation, white roofs can be a good investment. Of course, they won't stay the same white color over time and will lose some of their reflectivity. You also have to consider neighbors and the effect that a highly reflective roof can have on them. Otherwise, they can be a very effective way of reversing the heat island effect at a reasonable cost, and saving some investment on cooling. Storm water runoff, of course, isn't addressed by this approach, but there are other water management approaches a building owner can use instead.

1.5.2.4 Photovoltaic Roofs:
Roofs are becoming a hot destination for solar panel installations.

―The cells themselves are more efficient if you have a white membrane because you are keeping the roof cooler. And by it being cooler you can get more energy from it, " he explains. ―On the other hand, black membranes are more able to handle the high heat, and PVs will generate heat."

1.5.2.5 High-Performance Roofing:
High-performance roofing can best be described as more intelligent design in roofing — using elements of each type of roofing described above to function in the best possible manner given the environment in which a building exists. Paroli offers one interesting example — putting white paint around the air intakes, so you keep that area of the roof cool instead of incurring the overall expense of putting in a new cool membrane roof.

Sustainable roofing as a ―cradle to gradle" approach — understanding that while much will be recycled (cradle) in replacing a roof some things will end up in the garbage (grave). The point of designing a high-performance roof is very similar — to aim for heightened durability and longevity, while taking into account the environment and energy savings at the same time.

Installing a new, more sustainable roof can add great environmental benefits. And he stresses that there are many ways to reach that ultimate goal. At the same time, he points out that the fundamentals are what matter most – keep the building dry and well insulated

1.6 Energy Efficiency

Sustainable roofs increase the energy efficiency of the building envelope and reduce a building‘s energy demand on space conditioning and therefore greenhouse gas emissions, through direct shading of the roof, evapotranspiration and improved insulation values.

Sustainable roofs are particularly effective in reducing heat entry into the building in the summer. The plants shade and cool the roof. The insulation value is in both the plant and the growing medium. Water in the plants and the growing medium evaporates and further cools the roof. The growing medium also acts as a thermal mass that stores solar energy during the day and releases it at night. Green roofs are less effective in preventing heat leaving the building in the winter due to the limits of the same thermal mechanisms.

Sustainable roofs have a substantial thermal mass and a moderate insulation value. These combined properties significantly reduce diurnal temperatures at the boundary between green roof and building structure (the diurnal temperature being the daily maximum to minimum temperature range).

The diurnal temperature range for a conventional construction ‗warm-roof' waterproof layer can be very large; for example, the surface of a typical bitumen waterproof layer may exceed 50°C during a sunny summer‘s day, whilst falling to just above 0°C at night. A roof with a low level of insulation below the waterproof layer will allow the space below to heat up quickly in hot, sunny weather. The increased internal temperatures in the floor below the roof contribute to making the internal building environment uncomfortable for the building‘s occupants.

Overheating can lead to increased use of air-conditioning, which in turn will lead to an increase in energy consumption. During cold weather, the opposite effect applies, resulting in a demand for extra heating of the floor directly below the roof and, hence increased energy consumption. The energy used for heating and cooling has a financial as well as an environmental impact.

The green roof has the same energy providers as a conventional roof, but it has the additional energy consumers of evapotranspiration and photosynthesis. Unlike a conventional roof, the green roof is a living system that reacts to the environment in a number of important ways:

- Water is stored within the substrate and is used in evapotranspiration by the vegetation layer; this process utilizes a considerable proportion of the incoming solar radiation in comparison to a non-green roof the green roof has a large thermal mass, which stores energy and delays the transfer of heat to or from the building fabric
- Plants absorb solar radiation for photosynthesis
- Plants have a higher albedo (solar radiation reflectivity) than many standard roof surfaces.

The use of a green roof compared to conventional surfaces can have a significant impact on the energy balance within a given building and on the immediate environment surrounding the building. This is particularly relevant if a building has poor insulation and poor ventilation, which can lead to more use of air conditioning and therefore increased energy use.

Studies have shown that the membrane temperature beneath a green roof can be significantly lower than where the membrane is exposed. Table 2 shows the average temperatures under the membrane of a conventional roof and that of membrane under green roofs in a study undertaken at Nottingham Trent University.

Table 1: Study of Temperatures under Membranes of a Conventional and a Green Roof

	Winter	Summer
Mean Temperature	0°C	18.4°C
Temperature under membrane of conventional roof	0.2°C	32°C
Temperature under membrane of green roof	4.7°C	17.1°C

Source: *www.greenroofs.co.uk - Accessed February 2014*

Although green roofs do provide potential energy savings by improving building insulation characteristics, these are often considered difficult to assess due to the varying climatic conditions throughout the winter months, and will be minimal on already well-insulated buildings.[9]

1.6.1 Storm Water Management

Many local governments are interested in water sensitive urban design (WSUD) which embraces a range of measures that are designed to avoid, or minimize, the environmental impacts of urbanization by reducing the demand for water and the potential pollution of natural waterways (City of Melbourne 2009). WSUD is based on the idea of treating storm water before it enters a waterway or before it is re-used for another purpose.

The importance of integrated water cycle management in Victoria has been highlighted by the recent establishment of the Office of Living Victoria with a $50m commitment from the state government to support innovative rainwater, storm water and recycled water projects (OLV 2013).

Green roofs absorb and retain water and are therefore one strategy for controlling storm water runoff in urban environments (DDC 2007). Green roofs influence run-off by intercepting and retaining water from the early part of the storm, and limiting the maximum release rate of run-off in larger storms (Newton et al. 2007). Water is stored in the substrate, used by the plants, or retained in plant foliage and on the substrate and evaporates (Oberndorfer et al. 2007, cited in City of Sydney 2012, Newton et al. 2007 and DDC 2007). Additional water storage capacity is available in green roof systems which have a drainage layer. In addition to helping slow and reduce storm water run-off, green roofs can also filter particulates and pollutants (Carter & Jackson 2007 and Frazer-Williams et al. 2008, cited in Tolderlund 2010). This is important in urban areas where run off can be polluted from contaminants that are picked up on the way, such as motor oil, animal droppings and pesticides (Tolderlund 2010).

A number of elements influence the extent to which a green roof or vertical wall can control the volume of water running off from a site. The vertical depth of the growing medium and drainage layer, consistency and porosity of the growing medium, structure of the drainage layer, and slope of the site are all important elements of a rooftop‘s ability to slow water. The type of plant species and type of drainage system are important factors to consider when designing a green roof system for water treatment .The run off diversion for green roofs is also influenced by the weather conditions of the region. The length, intensity and frequency of rain events influence a green roof‘s ability to retain water. ([7])

1.6.2 Air Quality

Green roofs also filter out fine, airborne particulate matter as the air passes over the plants. Airborne particulates tend to get trapped in the surface areas of the greenery. Rain washes it into the growing medium below. Plants also absorb gaseous pollutants through photosynthesis and sequester them in their leaves (later to become humus). Studies show that treed urban streets have 10-15% fewer dust particles than found than similar streets without trees.

In Frankfurt Germany, for example, a street without trees had an air pollution count of 10-20, 000 dirt particles per liter of air and a treed street in the same neighborhood had an air pollution count of less than a third of that amount. Based on data from trees, one estimate suggests that a grass roof with 2, 000 m2 of unmown grass (100 m2 of leaf surface per m2 of roof) could cleanse 4, 000 kg of dirt from the air per year (2 kg per m2 of roof). This estimate, is probably high since the lower portion of the grass layer is too dense to be in direct contact with the air. However, even if the amount were 1/10th of what trees could remove, 10 m2 of grass roof could still take out the significant amount of 2 kg of dirt every year. (Ref.3) (p. 9)

1.6.3 Noise Attenuation

There are few research studies indicating the benefits of sustainable roofs at muffling and attenuating urban noise. At the British Columbia Institute of Technology (BCIT), Connelly and Hodgeson studied the noise attenuation capacity of two 33 m2 extensive green roof reference plots relative to a control section of conventional flat roof to determine the differences.

While the study had to be performed outside in open air, rather than in an acoustically controlled environment, the background noise was minimized by careful timing of the testing during calm periods and at night. The study found that the green roof plots reduced noise transmission by 5 to 13 decibels (dB) over the low to mid frequency range and by 2 to 8 dB over the mid to high frequency range.

1.7 Examples & Analysis

1.7.1 International Examples

1.7.1.1 Chicago City Hall Building

Chicago‘s City Hall shares a 12-story building in downtown Chicago with Cook County‘s administrative offices (FEMP 2004). The overall roof measurements are about 38, 800 square feet, with 22, 000 square feet of green roof The first interesting effect, the reduction in heat flow resulting from the green roof, was observed during the first winter.

The snow lasted for an extended period of time on the green roof, as observed by engineers in the city‘s environment Department, while the snow on the adjacent buildings roof melted in just two weeks, indicating reduced heat flow on the green roof (FEMP 2004). Actual data have been collected for this particular rooftop to show temperature reduction.

City Hall along with 12 other public buildings and through a unique combination of mayoral commitment, policy development and implementation, and incentive, have incorporated more than 300 green roofs that are establishing roots in this densely developed Midwestern city, adding more than 3 million square feet of vegetation (Berkshire 2007). Through the development of these projects the city continues to encourage green roof incorporation through a number of activities:

- The Building Green/Green Roof Policy
- The Green Permit Program
- Green Roof Grant Program
- Fostering Green Roof Products and Services
- The Green Roof web site
- The Green Roof Improvement Fund (GRIP)
- Streamlining City Effects

The result of these projects and initiatives is to create a well-established, healthy, and vital green roof market and ultimately make green roofs a more standard building feature, but also to ensure a healthy future for the city as a whole. As it stands, Chicago currently has the most green roof space of any city in North America.

Besides Chicago other cities have studied the effects of the UHI and green initiatives but only on a smaller scale or by computer aided analysis. These studies have helped in understanding the benefits of green roofs and have helped in defining the purpose and scope for this project, by creating interest in finding out how the benefits of green roofs have an effect on an entire city and not just in one or two particular areas.

Figure 3.1: Chicago city hall green roof

Figure 3.2: Chicago city hall green roof

1.7.1.2 ACROS Fukuoka Prefectural International Hall

Argentine-born, U.S. architect Emilio Ambasz transposed a nearly 100, 000-square-meter park in the city center onto 15 stepped terraces of the ACROS, "Asian Crossroads over the Sea, " Fukuoka Prefectural International Hall. The design for ACROS Fukuoka proposes a powerful new solution for a common urban problem: reconciling a developer's desire for profitable use of a site with the public's need for open green space. The plan for Fukuoka fulfills both needs in one structure by creating an innovative agro-urban model.

The Takenaka Corporation website states, "Emphasizing continuity of the planting zone with Tenjin Central Park, and to represent the landscape from the park as an image of a mountain instead of the low vegetation which has a tendency to occur in the vicinity of buildings in city areas, a staircase-shaped rooftop garden was adopted. Regarding the building as a mountain, and with the beauties of nature as a theme, a space configuration and vegetation configuration was adopted which represents the changes of the four seasons.

"Its north face presents an elegant urban facade with a formal entrance appropriate to a building on the most prestigious street in Fukuoka's financial district. The south side of the Hall extends an existing park through its series of terraced gardens that climb the full height of the building, culminating at a magnificent belvedere that offers a breath-taking view of the city's harbor. Underneath the park's fifteen one-story terraces lies over one million square feet of multipurpose space containing an exhibition hall, a museum, a 2000-seat proscenium theater, conference facilities, governmental and private offices, as well as several underground levels of parking and retail space. The structure is steel-framed reinforced concrete, the building has 14 floors above ground and 4 floors below ground, and the total floor space area is 97, 252 m2.

Along the edge of the park, the building steps up, floor-by-floor, in a stratification of low, landscaped terraces. Each terrace floor contains an array of gardens for meditation, relaxation, and escape from the congestion of the city, while the top terrace becomes a grand belvedere, providing an incomparable view of the bay of Fukuoka and the surrounding mountains. Growing media depths range between 12 and 24".

A stepped series of reflecting pools upon the terraces are connected by upwardly spraying jets of water, to create a ladder-like climbing waterfall to mask the ambient noise of the city beyond. These pools lie directly above the central glass atrium within the building, bringing diffused light to the interior through clerestory glazing separating the pools. Each year during the famous week-long Don Taku festival, the encircling balconies inside the atrium allow for a panoramic view as the procession passes through the building, while outside the stepped garden terraces become an inviting outdoor amphitheater for the entire city.

A large "stone" like wedge at the foot of the terraced park pierces a V-shaped entrance into the building, revealing rough-hewn stone suggestive of geologic strata underlying the surface vegetation and likening the building to a massive block cut from the earth. This wedge shaped element also doubles as ventilation exhaust for the underground floors below and as a raised stage for performing artists.

The opposite side of the building faces onto the most important financial street of Fukuoka. Composed of striped glass, with every floor so angled as to reflect the passersby below, it softly de-materializes the mass of the building. The facade rakes outwardly from the vertical with each successively higher floor, creating the effect of an awning over the sidewalk. These overhanging eaves use the building design itself rather than an applied device to provide cover to pedestrians.

The final stepped layers at the top create the effect of a large 45° cornice overhang at the street's edge, defining the public entrance while enhancing the building's urban presence.

Figure 3.3: The ACROS Building, Fukuoka, Japan is an intensive green roof example

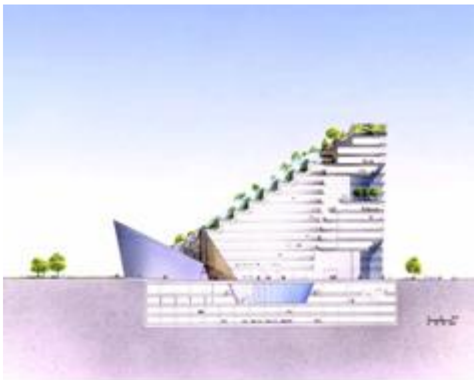

Figure 3.4: The ACROS Building, Fukuoka, Japan is an intensive green roof example

1.7.2 Regional Examples

Green Mat campaign in UAE

Dubai Municipality has teamed up with suppliers to launch a public awareness campaign to encourage ‗green' roofs in the Emirate.

1.8 Checklist for considerations before starting a Sustainable roof

INSPECTION CHECKLIST

General Roof Conditions	
Item	Remarks
Debris on Roof	
Drainage	
Physical Damage	
Attic Conditions	
Structural Deformation	
Other	

Flat / Membrane Roof	
Item	Remarks
Condition of Coating	
Granular Loss	
Punctures	
Cracks / Alligatoring	
Blisters / Fishmouths	
Ponding	
Other	

Sloped Roof	
Item	Remarks
Roof Material	
Condition of Surface	
Deformed Edges	
Shingle: Buckled	
Curled	
Missing Tabs	
Granular Loss	
Other	
Metal: Corrosion	
Fasteners	
Other	

Roof Features	
Item	Remarks
Fascia	
Soffit	
Flashing	
Gutters / Drains, etc.	
Skylights	
Chimneys / Vents	
Fall Arrest Anchors	
Control Zone Access	
Drains / Vents	
Other	

Ceiling Conditions	
Item	Remarks
Cracks	
Water Staining	
Water Leaks	
Seasonal Change	
Other	

Exterior Wall Surfaces	
Item	Remarks
Deformed Finish	
Surface Deterioration	
Staining	
Other	

Interior Wall Surfaces	
Item	Remarks
Cracks	
Water Staining	
Water Leaks	
Deformed Finish	
Seasonal Change	
Window Leaks	
Door/Window Alignment	
Other	

Summary/Comments (Highlight areas of concern and any rapid degradation in roof system)

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