International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:7, No:7, 2013

Air Conditioning Energy Saving by Rooftop Greenery System in Subtropical Climate in Australia

M. Anwar, M. G. Rasul, and M. M. K. Khan

***Abstract*—**The benefits of rooftop greenery systems (such as energy savings, reduction of greenhouse gas emission for mitigating climate change and maintaining sustainable development, indoor temperature control etc.) in buildings are well recognized, however there remains very little research conducted for quantifying the benefits in subtropical climates such as in Australia. This study mainly focuses on measuring/determining temperature profile and air conditioning energy savings by implementing rooftop greenery systems in subtropical Central Queensland in Australia. An experimental set-up was installed at Rockhampton campus of Central Queensland University, where two standard shipping containers (6m x 2.4m x 2.4m) were converted into small offices, one with green roof and one without. These were used for temperature, humidity and energy consumption data collection. The study found that an energy savings of up to 11.70% and temperature difference of up to 4°C can be achieved in March in subtropical Central Queensland climate in Australia. It is expected that more energy can be saved in peak summer days (December/February) as temperature difference between green roof and non-green roof is higher in December-February.

***Keywords*—**Extensive green roof, Rooftop greenery system, Subtropical climate, Shipping container.

I. Introduction

NATURAL cooling techniques have been used over the centuries until mechanical air conditioning system has introduced. This air conditioning system is the easiest but expensive option for people to control hot humid temperature in summer. Countries in the sub-tropical zone face high temperature and humidity all year round. Energy situation becomes alarming for many of the countries due to the demand for electric power increase day by day whereas the means of production remain limited. Energy consumption by buildings has become a major issue because of growing concern about CO_2 and other greenhouse gas emissions and scarcity of fossil fuels. Buildings energy efficiency is critically important in addressing climate change because of increased CO_2 emissions. The energy used by buildings accounts for approximately 20% of Australia's greenhouse gas emissions [1].

The majority of Australia's electricity is produced using coal, accounting for 68.2% of total electricity generation in 2010-11 [2]. This is because coal is the cheapest and readily available energy source in Australia. These power plants ultimately produce substantial greenhouse gases which are one of the major causes for global warming and climate change. Nowadays climate change is predicted as one of the greatest challenges for all developed and developing countries including Australia. About 40-45% of total energy is consumed in building sector in Europe [3] whereas Rahman [4] has estimated that about 40% energy is expended in Australia. Building sector is responsible for approximately 42% of the world's total annual energy consumption [4] and conservation of energy in building design and operations could save up to 30% of total energy consumption [5].

The energy efficient building has some implications that depend on regulations, economics, energy demand and the environment. An efficient building applies energy efficient technologies while operating as per design. It will effectively reduce energy usage while ensuring consistent supply of the amenities and features appropriate for that kind of building. And it can be operated in such a manner as to have a low energy use compared to other similar buildings. Green roof is one of the promising energy efficient approaches.

Green roofs are well known for their wide range of environmental, ecological, social and economic benefits [6], [7]. Some of the vital features of using green roofs are mitigation of urban heat island effect, reduction of building energy consumption, retention of storm water runoff from roof surface, cooling of buildings in summer and enhancement of roof life results in longevity of roof and energy efficiency and reduction of air and noise pollution. This system consists of several layers along with suitable plants for specific climates, affixed in a structure. A green roof normally has several layers such as vegetation layer, substrates, drainage system and water proofing membrane. Irrigation system can be optional depending on climatic condition.

In a green roof, plant absorbs large amount of solar energy through biological functions and remaining solar radiation affects the internal temperature of the building is much less than that of a bare roof. Only 13% of total solar radiation is transmitted into soil and other 27% reflected and 60% absorbed by the planted roofs [8]. Both plants and layers of green roof add insulation value with existing building insulation. Del Barrio [9] has stated that green roof reduces the heat flux through the roof which does not act as cooling device rather as insulation.

Based on the depth of planting medium and maintenance, there are two main classifications of green roofs: intensive and

M. Anwar, corresponding author, is with the School of Engineering and Technology, Central Queensland University, Bruce Highway, Rockhampton, QLD 4701, Australia (e-mail: m.anwar@cqu.edu.au).

International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:7, No:7, 2013

extensive. These two are applicable for different purposes. Intensive green roofs can support deeper rooting complex vegetation like groundcovers, small trees and shrubs as it has a deep soil layer. Intensive roofs involve a greater load of more than 150 kg/m^2 and have more than 200mm of substrate and require maintenance in the form of weeding, fertilizing and watering [10]. For heavy load it is very hard to retrofit in existing structure. Extensive green roofs have a thin substrate layer with low level planting like sedums or lawns which are expected to provide full coverage of the vegetated roof. It can be distinguished by being low cost, lightweight (50-150 kg/m^2) and with thin material substrate of up to 200mm. Table I shows the basic differences of extensive and intensive green roof system.

TABLE I
DIFFERENCE BETWEEN EXTENSIVE AND INTENSIVE GREEN ROOFS

Topics	Extensive green roof	Intensive green roof
Substrate	100-200 mm	>200 mm
Weight	50-150 Kg/m^2	>150 Kg/m^2
Plant option	Sedums, Succulents, Herbs with shallow rooting	Perennial, Lawn, Trees and shrubs with deeper rooting
Maintenance	Low	High
Irrigation	Low	High
Fertilization	Low	High
Energy efficiency	Low	High
Installation	Easy to retrofit in existing structure.	Difficult to retrofit.
Storm water retention	Low capacity	High capacity
Cost	Low	High
Technical expertise	Minimum	Higher
Structural support	Lower	Greater

This paper investigates the energy saving from air conditioning in Rockhampton, Queensland by comparing a building with and without a green roof. Two 6 meter long shipping containers have been converted into office building. Both are identical, insulated and well decorated. Both containers have a window or box type air conditioner fitted on western wall. Both air conditioners are running for 24 hours at a set temperature (24°C) to keep the interior temperature under control. An experimental bed of green roof has been set over one shipping container whereas other container has bare roof.

II. METHODOLOGY

A. Description of the Site

The green roof setup has been installed in the sustainable precinct of Central Queensland University, Rockhampton, Australia. Rockhampton is situated 40km inland from the Coral Sea and north of the Tropic of Capricorn in Central Queensland. It is located at 23°22'S, 150°32'E and has a population of 70,000 people [11]. It lies within the cyclone risk zone and it is subjected to summer thunderstorms. The city experiences a Subtropical Climate with an annual average rainfall of 805mm [11]. It has a usual summer or wet season from December to March and a winter or dry season between June and September. Temperatures range from 22°C- 32°C in the summer and 9°C-23°C in the winter although the temperatures can exceed 40°C in summer or drop below 0°C in winter [11]. Typical winds are predominately southeast winds however during the spring and summer late afternoon, sea breezes from the Northeast usually come in. Fig. 1 shows yearly climatic condition of Rockhampton.

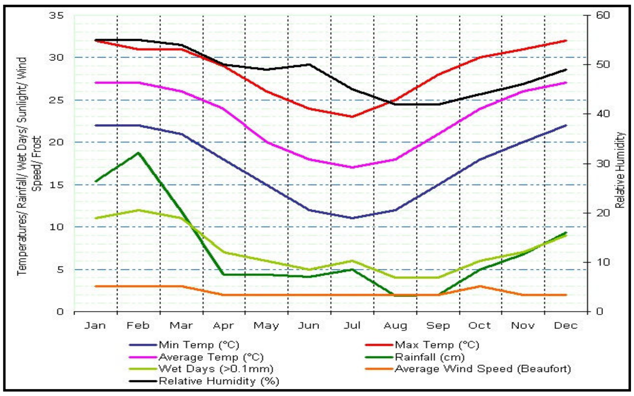

Fig. 1 Rockhampton climate graph [12]

B. Experimental Setup

The experimental setup was installed on a standard 6 meter long shipping container. For this experiment, two identical containers were used as an office building. One container had the setup on the rooftop and other one is bare roof. Both containers were painted in green colour. As per the roof design, both containers had an entrance, a window and a box type air-conditioner. For excess rain water runoff, the containers were set with a 3° pitch from North to South side. Dimensions of both containers are 6m long, 2.44m wide and 2.44m high. The roof area of the container is approximately 15m^2. Both the containers have single sliding 5mm dark grey float toughened glass door and window along with aluminum frame. Dimensions are 2133mm x 1828mm and 914mm x 914 mm respectively. Both hand rail and stairs are built as per Australian Standard (AS 1657-1992) which ensures safety while working on the rooftop. The following Fig. 2 shows the schematic diagram of the experimental green roof setup.

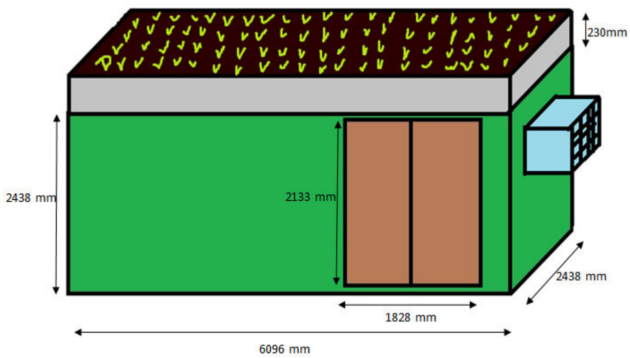

Fig. 2 Schematic diagram of experimental green roof [13]

Both containers are set in an open and flat ground which has minimum shading effect. The site of the facility is an open and flat ground, therefore has minimal shading effect. Water, electricity and internet supplies are available in this location. Nearest bureau of meteorology (BOM) is about 13km away from this sustainable precinct.

C. Green Roof System

As there is not enough research and resources available for extensive green roof in subtropical climatic conditions, many factors need to be considered while designing. The green roof will face harsh sun in hot and humid weather and it is installed on top of steel structure which is highly thermal conductive. Depth of substrate could be an important factor, as thin substrate dries up very quickly and too thick substrate cannot be classified as extensive green roof. Williams [14] reported a less popularity of extensive green roof technology in Australia due to shallow substrate which dries up very quickly and technical difficulties for growing plants in a dry and variable climate.

The experimental green roof set up has several layers. A corrugated steel sheet is affixed with the container steel roof ensuring smooth water runoff. A gutter is placed in the south side along with the roof to collect the runoff water. A galvanized aluminium bracket with 5mm thickness and 230 mm high has been used for holding the green roof materials. The bottom layer of any green roof is waterproofing membrane. GRT HP 700 is a single component, UV stable and polyurethane waterproofing system which has been used in this experiment. The second layer from the bottom is drainage system. ElmichVersicell® lightweight drainage module has been used. It not only protects the waterproofing membrane but also captures high volume of water. ElmichVersidrain® 25P drainage sheet is also used for its cost effective water management purpose and effective capillary irrigation system. It has high capability of water storing into the cells coupled with high discharge capacity. The third layer from bottom is geotextile. Geotextile prevents fine particles of growing media entering into the drainage system. A needle punched geotextile filter fabric is used in this setup. The fourth layer from the bottom is substrate. A substrate needs to be lightweight, natural, biological organic based, long lasting sustainable media that does not slump and remains robust for 2 years. For that reason Enviroganics® Bioganic Earth substrate has been used in this experiment. It has component mixtures such as peat moss, composted sawdust, coco peat, washed sand, fertilizer and water retaining crystals ensures high water storage capability. Average substrate thickness for extensive green roof is 200mm and dry weight is 300kg/m^3 and fully irrigated green roof weight is 450kg/m^3[15].

In subtropical climate, green roof plants tolerate severe sun and hot temperature along with change in humidity and moisture. Even it could be a difficult task to select plant on top of steel structure. A few research resources are available for extensive green roof in subtropical climate but choosing a suitable native plant is a big challenge. To cover the risk a variety of local native plants have been chosen, such as Rhoeo, Scaevola, HelichrysumItalicum, Callistenon Captain Cook, Dianella little jess, EremophilaMaculata both purple and aurea. All the plants shown in Fig. 3 were planted in early February 2013. A time controlled irrigation system ensures watering garden once in every day.

Fig. 3 Extensive green roof plants

D. Description of Equipment and Measurement Period

The data has been collected from both the containers (green roof and non-green roof) during February 2013 to April 2013. Both indoor temperature and relative humidity data have been collected from inside the containers. Temperature at different layers is collected from outside green roof top. All data are logged in every 30 minutes interval. Air conditioning energy consumption data has been continually logged into the data acquisition system. Following tools have been used in the experimental facility to record data.

1. HOBO U10 Temp & RH Logger

For indoor temperature and relative humidity, HOBO U10 temperature data logger is used. It is small size and can store large amount of data. One HOBO logger is kept inside each container. All data are logged in every 30 minutes interval.

2. BTM-4208SD 12 CH Temperature Recorder

12 Channel temperature recorders were used to measure layer temperature of the green roof structure. K type different shape probes were used to measure temperature at different layers which is shown in Fig 4.

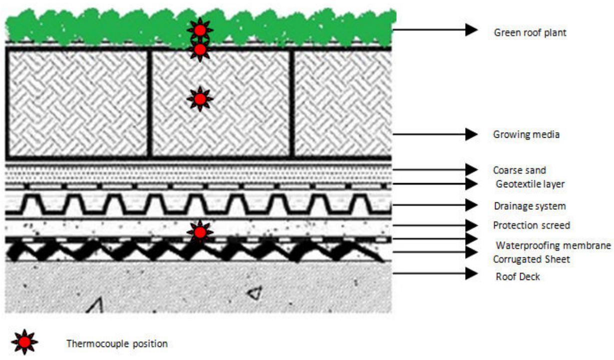

Fig. 4 An extensive green roof with different layers

3. G4400 BLACKBOX Fixed Power Quality Analyzer

Energy consumption of air conditioning for both green roof and non-green roof was measured using G4400 Blackbox. One Blackbox was connected with each air condition. It has been used for its accurate detection and isolation of power quality events. It can store onboard all the waveforms of every network cycle for up to one year at up to 1024/cycle resolution. PQSCADA Power Quality Management Suite software has been used to analyse, compare, configure and control of time synchronized data by the BlackBox device. This device can be connected either via TCP/IP/RTU/GPRS wireless. Data were analyzed remotely over Central Queensland University network.

III. Results and Discussion

A. Thermal Performance of Green Roof

For better understanding of thermal performance, four K type thermocouple sensors were placed in different layers of green roof setup. The 1st thermocouple position was on the steel roof surface of the container block. The 2nd thermocouple position was in the mid-level of substrate or soil. The 3rd thermocouple was set on top of the soil and the last one was placed on the shade of a plant just 40mm above the soil top. Temperature profile of different layers of green roof for a typical hot day in April is shown in Fig. 5.

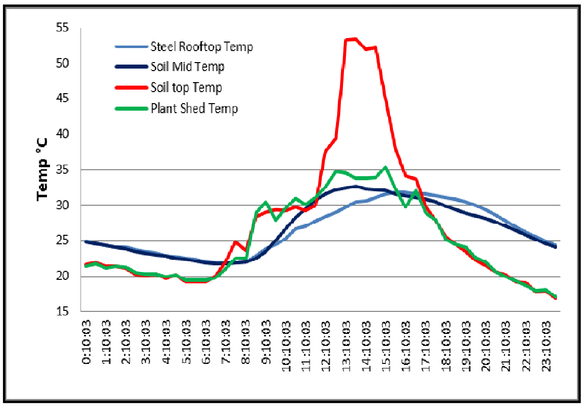

Fig. 5 Temperature profile of different layer in a typical day of April

It is evident that green roof layers have a lower temperature compared with the outdoor air temperature during day time. The maximum temperature of the soil top was found to be 53.4°C whereas the maximum air temperature and steel rooftop temperature was recorded as 30.5°C and 31.8°C respectively. A significant temperature drop (about 40.45%) can be observed over different layers of green roof from the soil top layer.

The soil top layer temperature does not stay hot all day long. It started picking up the temperature from 7 am and due to the sub-tropical harsh sun it got maximum of 53.4°C at 1:40 pm. As day progresses it becomes cooler from 5 pm until the following morning. Table II shows a change in temperature over a week period. As the soil top releases its heat to atmosphere and underneath layers, it cools much quicker than other layers. Fig. 6 shows the comparison between maximum and minimum temperature at different layers.

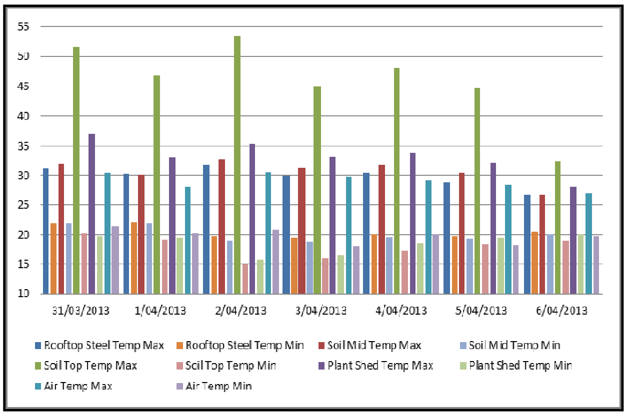

Fig. 6 Temperature comparison at different layers of Green roof

Soil top layer got both maximum and minimum temperature in every day. This indicates that during the summer time interior temperature of green roof will be lower than the outside air temperature and in the winter time internal temperature will be higher than the outside air temperature. A green roof does not act as a cooling device rather as insulation. It can reduce the surface temperature and the attenuation of temperature fluctuations. Without increasing the thickness of substrate or insulation value, a green roof can shield off maximum 87% of solar radiation whereas bare roof receives 100% direct exposure [9].

TABLEII
CHANGE IN TEMPERATURE AT DIFFERENT LAYERS IN GREEN ROOF

Date	Maximum temperature in°C			Minimum temperature in °C		
	Green rooftop	Steel structure top	Change in %	Green rooftop	Steel structure top	Change in %
31/03/13	51.6	31.1	**39.73**	20.2	21.8	**-7.92**
01/04/13	46.8	30.3	**35.26**	19.1	22	**-15.18**
02/04/13	53.4	31.8	**40.45**	15	19.7	**-31.33**
03/04/13	44.9	30	**33.18**	16	19.4	**-21.25**
04/04/13	48.1	30.4	**36.80**	17.3	20	**-15.61**
05/04/13	44.6	28.9	**35.20**	18.4	19.8	**-7.61**
06/04/13	32.3	26.7	**17.34**	19	20.5	**-7.89**

Temperature of the green roof shown in Fig. 7 is higher than the non-green roof from 12:00 am midnight to 8:40 am in the morning. The difference ranges from 0.5°C to 0.7°C. From 8:50 am to 7:50 pm, the non-green roof absorbs much more solar energy than the green roof. As an example, for the maximum day temperature of 31.7°C [11] the non-green roof got a maximum temperature of 42.75°C which indicates direct solar energy absorption. The maximum temperature difference occurs at 3:10 pm which is 4°C. This temperature difference could be significant during the peak summer time of December to February.

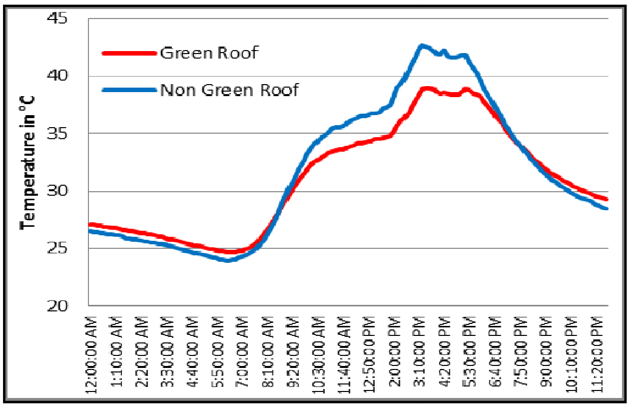

Fig. 7 Temperature profile of green roof and non-green roof without air condition in a typical summer day

B. *Energy Saving From Green Roof*

Reduction of cooling energy requirements of a building leads to the reduction of energy consumption of that building. Application of green roof can reduce the cooling energy consumption of a building. A study on different types of roofs for a five story commercial building in Singapore shows that the installation of green roof on the exposed roof could result in savings of up to US$ 3,625 (shrubs) compared to a typical flat roof, which could save up to US$ 375 (shrubs) [16]. Fig. 8 shows the comparison of daily energy consumption of an air conditioning employed in both green roof and non-green roof container in a typical summer day in Rockhampton.

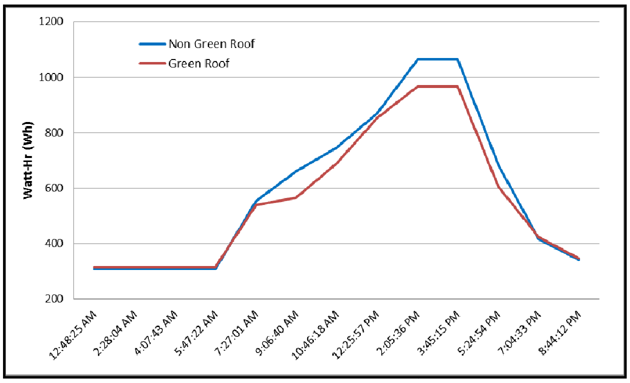

Fig. 8 Comparison of air conditioning energy consumption in a typical day of March

Fig. 8 compares the maximum energy usage of both air conditioners during first week of March and April. As both air conditions are set at 24°C, energy consumptions are highly dependent on the outdoor air temperature. For an example, rainfall of 14.2mm was recorded on 7th April and maximum temperature was 22.9°C and maximum air conditioning energy consumption of green roof was 372.75 Wh. On 7th March, rainfall recorded only 0.2mm, maximum temperature was 29.7°C and maximum energy consumption was 901.66 Wh. From Fig. 9, it can be seen that for day 1, 3, 4 and 5; outdoor air temperature in March was lesser than that of April.

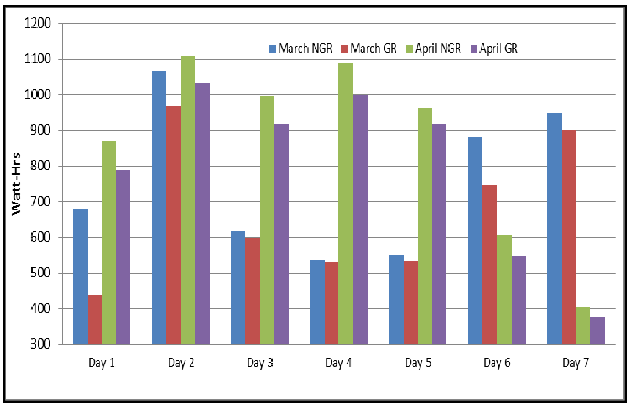

Fig. 9 Maximum energy consumption in a week

Daily total energy consumption in a week can be shown in Fig. 10. There is a substantial difference between green roof and non green roof, although this consumption varies with outdoor temperature. The more outdoor temperature, air condition need to work more to set back its temperature at 24°C.

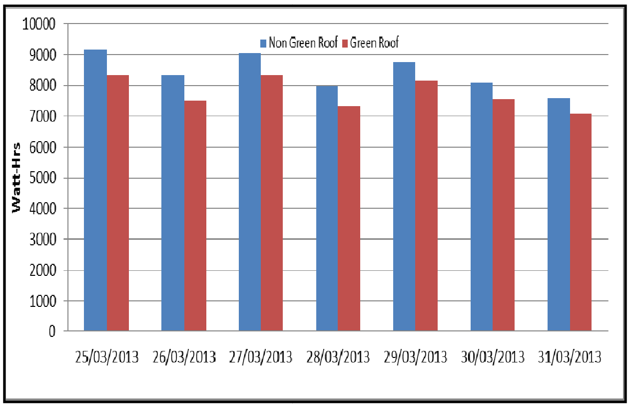

Fig. 10 Daily total energy consumption in March

Fig. 11 shows the weekly energy consumption data of both green roof and non-green roof. In all cases, the consumption for air conditioning of non-green roof is much higher than that of green roof.

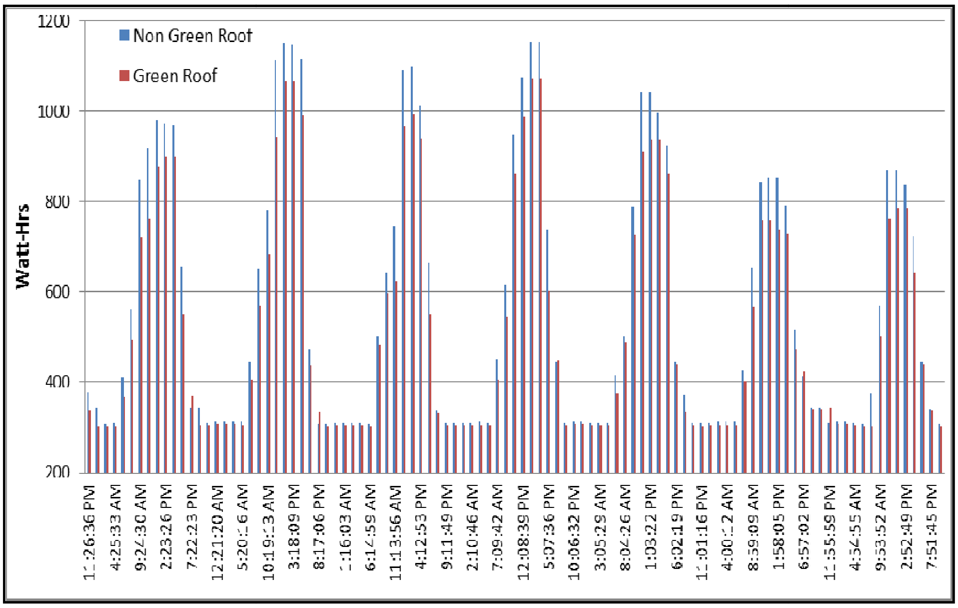

Fig. 11 Energy consumption pattern over a week

Hourly energy consumption comparison on day 2 of both March and April is shown is Fig. 12. On 2nd March there was rainfall of about 100mm and maximum temperature of 28.2°C. On 2nd April the maximum temperature was recorded as 30.5°C. Maximum energy consumption for Green roof and non-green roof in 2nd March was 967.92Wh and 1064.21Wh respectively and minimum was 304.44Wh and 308.03Wh respectively. For 2nd April maximum energy consumption for green roof and non-green roof was 1031.21Wh and 1108.65 Wh respectively and minimum was 303.34Wh and 309.81Wh respectively. It can be clearly said that the difference in energy consumption relates to temperature and rainfall of the respective day. The extent of heat loss through evapotranspiration is dependent on the moisture content of the soil. A drainage cell layer has been used into this green roof setup, which holds excess water eventually reduces temperature at bottom layer.

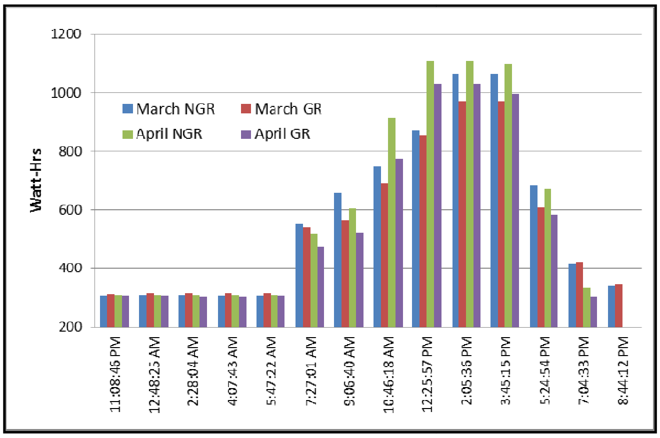

Fig. 12 Energy consumption on 2nd Day of March and April

Total air conditioning energy consumption of first five days of March and April is shown in Table III. A maximum savings of 11.70 % can be observed in 1st March. It is expected that more amount of energy can be saved in summer (December-February).

TABLEIII
ENERGY SAVING FROM GREEN ROOF

Month	Date	Total Energy Consumption		Difference	Saving
		Non Green Roof (Wh)	Green Roof (Wh)	(Wh)	(%)
March	01/03/13	6170	5448	722	11.70
	02/03/13	7944	7108	836	10.52
	03/03/13	6214	5601	613	9.86
	04/03/13	5582	5023	559	10
	05/03/13	5552	5014	538	9.69
April	01/04/13	6896	6232	664	9.62
	02/04/13	8230	7351	879	10.68
	03/04/13	8106	7286	820	10.12
	04/04/13	8015	7263	752	9.38
	05/04/13	7582	6878	704	9.28

IV. CONCLUSIONS AND RECOMMENDATION

Rooftop greenery systems have positive thermal and visual impacts on buildings and residents. Moreover, it can significantly reduce air-conditioning energy consumption cost. Less demand for air conditioning will impact on total energy production and eventually accounts for less greenhouse gas emission. The main purpose of this study was to determine if a green roof is a feasible means to reduce air conditioning electricity consumption, in a climate similar to Rockhampton (Australia). The result exhibits the effectiveness of greenery system in cooling energy saving and reducing indoor air temperature. For any typical summer day in Rockhampton, the difference in indoor temperature of green roof and non-green roof ranges from 0.5°C to 4°C [13] and up to 11.70% of total energy saving can be achieved. This study also shows a significant reduction in temperature (max. 40.45%) through the roof layers with the installation of rooftop garden. Any reduction in temperature in building cooling eventually can save thousands of dollars over the year.

This study provided good understanding of the benefits of rooftop greenery system, however, two weeks' worth of analysis is not enough and more days of energy metering are required to form more consistent results. Although both shipping containers are identical and decorated as an office space, but in reality there is no occupancy at any time. Outside steel walls are highly thermal conductive and it gets both hot and cold very quickly. During hot day time, the sun faced wall temperature gets higher than all other three walls and even the green rooftop. In cold night time, the steel walls releases heat back to atmosphere very quickly and gets cooler than the interior air temperature. This illustrates that in winter time, people can use green roof to get comfortable warmer condition inside the room; eventually saving energy by reducing heating load. Again about 11.70% cooling energy saving can be achieved by implementation of green roof system in a building structure. Authors are working on modeling and simulation of extensive green roof on both shipping container and an institutional building in Central Queensland University, Rockhampton, Australia. The model is being developed using Designbuilder [17] and will be validated with the measured performance data.

REFERENCES

[1] Buildings (2013) retrieved from http://www.climatechange.gov.au/en/what-you-need-to-know/buildings.aspx accessed on April 20, 201.
[2] Energy in Australia 2012, Department of Resources Energy and Tourism, available from http://www.abares.gov.au.
[3] T. Markis, J.A. Paravantis, Energy Conservation in small enterprises, Energy and Buildings 39, 2007, pp. 404-415.
[4] M.M. Rahman, M.G. Rasul and M.M.K. Khan (2008), Energy Conservation Measures in an Institutional Building by Dynamic Simulation Using DesignBuilder, Proceedings of the 3rd IASME/WSEAS International Conference on Energy & Environment (EE'08), Paper Number: 565-266, pp. 192-197, University of Cambridge, Cambridge, UK, February 23-25.
[5] J.A. Clarke, Assessing Building Performance by Simulation, Building and Environment 28, 1993, pp. 419-427.
[6] T. Emilsson, Vegetation development on extensive vegetated green roofs: Influence of substrate composition, establishment method and species mix. Ecol. Eng. 33, 2008, pp. 265-277.
[7] J. Mentens, D.Raes, M.Hermy, Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning 77 (3), 2006, pp. 217-226.
[8] E. Ekaterini, A.Dimitris, The contribution of a planted roof to the thermal protection of buildings in Greece, Energy and Buildings 27(3), 1998, pp. 29-36.
[9] E.P. Del Barrio, Analysis of the green roofs cooling potential in buildings, Energy and Buildings 27, 1998, pp. 179–19.
[10] ZinCo GMBH, Green Roofs: Recommended Standards for Designing and Installation on Roofs, 6th edition, Zinco GmbH, Germany, 2000.
[11] Bureau of Meteorology, (BOM), Australia, Climate data online retrieved from http://www.bom.gov.au/climate/data.
[12] Climate data online retrieved from http://www.rockhampton.climatemps.com/
[13] M. Anwar, M.G. Rasul and M.M.K. Khan (2013), Thermal Performance Analysis of Rooftop Greenery System in subtropical climate of Australia, 7th WSEAS International Conference on Renewable Energy Sources 2013, April 2-4, 2013, Kuala Lumpur, Malaysia.
[14] N.S.G. Williams, J.P.Rayner, Green roofs for a wide brown land: Opportunities and barriers for rooftop greening in Australia. Urban Forestry & Urban Greening 9, 2010, pp. 245-251.
[15] Elmich, Sustainable eco-friendly landscapes and architectural products, 2013, available from http://www.elmich.com.
[16] N.H. Wong, Y. Chen, C.L.Ong, A.Sia, Investigation of thermal benefits of rooftop garden in the tropical environment. Build. Environ. 38, 2003, pp. 261–270.
[17] DesignBuilderDocumentation. (2012), DesignBuilderUser Manual, Version 3.0. UK:DesignBuilder Software Limited.