Performance Assessment of Rooftop Greenery System in an Institutional Building in Subtropical Climate in Australia

M. ANWAR*, D. STEELE, M.G. RASUL, M. M. K. KHAN
Central Queensland University
Centre for Plant and Water Science, Faculty of Sciences, Engineering and Health
Rockhampton, Queensland 4702
AUSTRALIA
* m.anwar@cqu.edu.au

Abstract: - Energy consumption in Building sector is one of the major contributors to Australia’s stationary energy greenhouse gas emissions. The greening of buildings is essentially one of the ecological measures. Green roofs have been around for centuries as used on domestic houses in Northern and Western Europe. There has been significant development of extensive green roofs in Western Europe and North America in last two decades mainly through retrofitting to existing buildings. In comparison with other developed countries, Australia has been slow in adapting green roofs. The main reason is lack of relevant and reliable research to provide confidence in the economic and environmental benefits of green roofs. Beside that green roof’s design and performance varies with each region, orientation, structure and microclimate. Because of this uncertainty and lack of tested exemplars, designers and developers hesitate to use them. The objective of this paper is to analyze the performance of an extensive green roof by modelling using DesignBuilder Energyplus; state of the art Building simulation software, on an institutional building in Rockhampton, Queensland (Australia) for cost saving in cooling energy. The result showed that an energy saving of up to 6% can be achieved for a four storied building in subtropical Queensland (Australia).

Key-Words: - Rooftop greenery system, Extensive green roof, Subtropical climate.

1 Introduction

Demand for electric power increases day by day whereas the means of production remain limited; energy situation is becoming alarming for many countries. Countries are in the inter-tropical zone and are thus subjected to high temperatures and humidity all year round. These climates lead people to use of air conditioners mostly. Though air conditioning is very energy consumer, it is the easiest solution to reach thermal comfort during the hot season. The electric power produced from fossil energies such as coal, oil, gas, uranium will disappear in the coming decades and then it will become too expensive to operate air conditioning systems. Energy usage has been recognized as an essential component of greenhouse emissions. Efficient operation of the built environment has the potential to contribute to both energy and greenhouse gas reduction. The majority of Australia’s electricity is produced using coal, accounting for 77 % percent of total electricity generation in 2008-2009 [1]. This is because coal is a relatively low cost energy source in Australia. About 32% of Queensland’s annual electrical energy has been consumed for space cooling in both residential and commercial complex [2]. Those greenhouse gases cause the global warming and climate change. Markis and Paravantis [3] has reported that the amount of energy expended in the building sector in Europe was about 40-45% of total energy consumption whereas Rahman et al. [4] estimated that about 40% of the total energy’s end user is the building sector in Australia. Rahman et al. [4] also reported that building sector is responsible for approximately 42% of the world’s total annual energy consumption and nearly 30% of energy consumption could be saved by conservation of energy in building design and operations [5].

Nowadays green roof is one of the most promising energy conservation measures. As the amount of green areas in cities fallen, green roof plays a vital part by increasing vegetated surface. A green roof is a roof surface, which is partially or completely covered with vegetation and growing medium over a waterproof membrane. A green roof is a layered system comprising of a waterproofing membrane, growing medium and the vegetation layer itself. Green roof also include a root barrier layer, drainage layer and an irrigation system depends on the climate [6].
As plants absorb large quantities of solar energy through biological functions in a green roof, the remaining solar radiation that would affect the internal temperature of the building is much less than that of a bare roof. Of the total solar radiation absorbed by the planted roofs, 27% is reflected, 60% is absorbed by the plants and the soils and 13% is transmitted into soils [7]. With a green roof, the insulation value is in both the plants and the layer of substrates. Even without considering the increased thickness of soil due to additional layers of soil and drainage, the plants layer can shield off as much as 87% of solar radiation while a bare roof receives 100% direct exposure. Del Barrio [8] has reported that green roofs do not act as cooling device rather as insulation, reducing the heat flux through the roof.

There are two main classifications of green roofs: intensive and extensive. Depending on the depth of planting medium and maintenance, these classifications have been done. These two are appropriate for different purposes. Intensive green roofs can support plants and bushes as it has a deep soil layer but require maintenance in the form of weeding, fertilizing and watering. Generally intensive green roofs can support complex vegetation like groundcovers, small trees and shrubs which has deeper rooting. Intensive roofs involve a greater load of more than 150 kg/m² and have more than 200 mm of substrate with higher amount of organic material than extensive systems [9]. A green roof with a substrate depth of 110-150 mm can be regarded by different authors as intensive or extensive. Intensive green roof require strong roof structure and that’s why it is very difficult to retrofit in existing building. Intensive green roof is relatively expensive than extensive system. Extensive green roofs have a thin substrate layer with low level planting, typically sedum or lawn. They are planted with smaller plants which in the final stage are expected to provide full coverage of the vegetated roof. Extensive roofs are intended to be self sustaining and require minimal maintenance. It can be distinguished by being low cost, lightweight (50-150 kg/m²) and with thin material substrate of up to 100 mm. Extensive green roof structure is similar to conventional roof coverings. Williams and Rayner [10] showed a poor uptake of extensive green roof technology in Australia due to technical difficulties for growing plants in shallow substrates in a dry and variable climate. Some fertilization is often recommended for commercial products. It can be established in various ways: through prefabricated vegetation mats, shot planting, seed sowing and spontaneous self-established vegetation. This paper investigates the practicality of using a green roof in Rockhampton (Australia) by comparing a building with and without a green roof. This was done by creating a model of a green roof on an institutional building in Central Queensland University’s campus in Rockhampton using the DesignBuilder software package created by DesignBuilder Software Ltd [11].

Rockhampton is situated 40km inland from the Coral Sea and boasts a population of approximately 60,000 people. It’s located at 23°22’S, 150°32’E [12]. Rockhampton, being on the Tropic of Capricorn experiences a Subtropical Climate with an annual average rainfall of 800mm [12]. It has a usual wet season of December to March and a dry season between June and September. Temperatures range from 32°C- 22°C in the summer and 23°C- 9°C in the winter however occasionally the temperatures can exceed 40°C or drop below 0°C [12]. Typical wind patterns consist of mostly of southeast winds however during spring and late summer coastal sea breezes from the Northeast usually come in the afternoons.

2 Methodology

2.1 Model Description

The models of information technology building ’19’ have been constructed. The photograph of of building 19 is shown in Figure 1. This is a four storied building. The air conditioning in building 19 was installed in 1993 by Parkinson Air Conditioning. It consists of two air cooled chiller units that supply chill water to fan coil unit located throughout the building. Chilled water is pumped from the chillers to each of the units which condition the air for their selected zones. Most air conditioning systems run from 8am-6pm with the exception of the computer labs and the server rooms on the ground floor which runs 24/7. The models were created in Designbuilder [11] following a few specific stages as outlined below:

Stage 1: Trace exterior walls along imported DXF floor plan of the ground floor.

Stage 2: Interior partitions as per the floor plan were inputted to create individual rooms and windows and doors were placed in their actual locations.

Stage 3: The first two stages were repeated for the next few levels with their own files which were exported into the ground floor file and
combined with the ground floor to form the building.

Stage 4: Materials and environmental data was then inputted into the model with all the variables inputted into DesignBuilder a calculation can easily be made to give data such as energy consumption, operative temperatures, humidity, cooling load and heating load. Figure 2 shows the DesignBuilder model of Building 19 of Central Queensland University.

![Building 19 of Central Queensland University](image1)

![DesignBuilder model of Building 19 of Central Queensland University](image2)

### 2.2 Building Materials and Environmental variables

The building materials data are inputted into DesignBuilder after the main structure has been formed giving objects such as walls, floors, internal partitioning and roofing thermodynamic properties to be used in the calculations. After the materials were inputted, environmental variables such as air-conditioning set temperatures, office equipment, personnel density and lighting were inputted to accurately represent the building being occupied. The data used to simulate a green roof in DesignBuilder represents an extensive green roof with DesignBuilder allowing many variables to accurately model a variety of roofing solutions. The data used in the simulations was DesignBuilders default values for an extensive green roof which was collected by DesignBuilder Software Ltd. In order to establish the credit of a green roof, actual data of building 19’s air conditioning electricity consumption needed to be gathered. Typical summer data was supplied by Facilities Management at Central Queensland University of the electricity consumption of building 19 [13]. The atmospheric data required by DesignBuilder to run the simulation is the maximum, minimum and maximum wet bulb temperatures. Considering the electricity data gathered for building 19 was recorded on the dates mentioned above, temperature data was collected for these dates from the Australian Bureau of Meteorology database and inputted into DesignBuilder accordingly.

### 3 Results and Discussion

Average temperatures, energy balance, cooling load, average building humidity and mechanical and natural ventilation flow rate are shown in Figures 3 and 4. The middle graph (cooling load) and the graph below it (average building humidity) are the only graphs where a noticeable difference between the two roof types can be seen. The humidity data shown in the graphs represents the average humidity of an entire building. It can be seen that when the HVAC system is turned on at 8am the relative humidity levels of the buildings typically experience a sudden increase then drop. This is because the buildings internal temperature decreases however the moisture content of the air takes longer to drop and so with the decreasing saturation temperature of the building the relative humidity increases until the HVAC’s dehumidifiers remove the excess moisture. The opposite is also true and more pronounced in the results. As the buildings internal temperature increases due to the systems being turned off the saturation temperature also increases however the moisture content increases at a slower rate thus decreasing the relative humidity. Whilst the changes are very subtle there are noticeable differences between the humidity levels over the models with and without a green roof. This difference is usually a decrease. It can be seen from Figures 3 and 4 the humidity levels are lower just as the HVAC system is turned on in the green roof model.
Temperature and Heat Gains-Building 19

Fig. 3 Non green roof DesignBuilder output data

Fig. 4 Green roof DesignBuilder output data
The actual, non-green roof and the green roof power consumption are shown in Figure 5.

![Figure 5: Power consumption data of Building 19 in a typical summer day in February](image)

It can be seen from Figure 5 that the building 19 data produced by the DesignBuilder simulation did not entirely match the actual recorded electricity data, it varies 20%. As can be seen in the results, in the times when the HVAC system is turned off (8pm-6am) the model data shows very little power consumption compared to the actual data. There are a few rooms on the ground floor that house computer equipment that needs to be cooled 24 hours a day meaning that the HVAC system must remain on during this time. According to the model, these rooms are being cooled but it seems the model does not account for the HVAC system needing the roof mounted chillers functioning and hence a large portion of power consumption is missing. The model only outputs the required cooling load given by the calculated latent and sensible heat gains in the rooms and does not output the power of a HVAC system cooling the room.

Table 1 shows building 19’s simulation results of each day’s power consumption figures in kWh as well as the peak power draws on the two roof types and the difference between their energy consumptions.

Table 1: Simulated power consumption in summer of building 19

<table>
<thead>
<tr>
<th>Day in Summer</th>
<th>Actual Consumption (KWh)</th>
<th>Normal Roof Consumption (KWh)</th>
<th>Normal Roof Energy Peak (KW)</th>
<th>Green Roof Consumption (KWh)</th>
<th>Green Roof Energy Peak (KW)</th>
<th>Energy Saving (KWh)</th>
<th>Energy Saving %</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>2605.94</td>
<td>2663.69</td>
<td>709.51</td>
<td>2648.69</td>
<td>694.54</td>
<td>15.00</td>
<td>0.5632</td>
</tr>
<tr>
<td>February</td>
<td>2309.93</td>
<td>1532.17</td>
<td>404.46</td>
<td>1442.50</td>
<td>389.10</td>
<td>89.67</td>
<td>5.8526</td>
</tr>
<tr>
<td>March</td>
<td>2657.16</td>
<td>2306.87</td>
<td>582.38</td>
<td>2280.14</td>
<td>564.61</td>
<td>26.73</td>
<td>1.1586</td>
</tr>
</tbody>
</table>
At the rate the university pays for electricity this gives a saving of $4.50 per day. As there is more than 1.5 m air gap between the roof and ceiling of the building 19, the result in energy savings is not significant. Table 1 shows that there is a reduction of at most approximately 15 kW in the peak power draw suggesting that the green roof can potentially reduce the power capacity requirements of a HVAC system and could be a consideration when designing such systems.

4 Conclusions and Recommendation
Greenery systems for buildings represent a promising technology that has the proven potential to provide multiple private and public benefits. They have positive thermal and visual impacts on buildings and residents. Moreover, greenery systems can pay back their costs in energy savings alone and thus, in effect, earn money. The main purpose of this study was to determine if a green roof is a feasible means to counter the first problem mentioned, hence to reduce air conditioning electricity consumption, in a climate similar to Rockhampton (Australia). Actual electricity consumption figures for the HVAC system in building 19 were supplied by Central Queensland University facilities management to assist in the analysis. The simulation data outputted by DesignBuilder from the model was very usable and gave output data that was fairly consistent and allowed for some conclusions to be drawn.

1. The average building humidity for building 19 was reduced a small but notable amount due to the implementation of a green roof.
2. The green roof reduced energy consumption more on the colder of the three days in February simulated, suggesting the green roof saves more energy in a colder less humid climate.
3. There was a maximum power rate of power consumption reduction of 56% due to the green roof from the building 19 results from the February simulation.
4. There was a maximum saving of 90kWh from the output data which equates to a saving of $4.50 at the rate at which Central Queensland University pays for electricity.
5. There was a maximum reduction of approximately 15kW of peak power loading for the air condition system of building 19.

From the above analysis it is easy to see that three days worth of analysis in not enough and more days of energy metering are required to form more consistent results. Also, there needed to be more accuracy in the data inputted into DesignBuilder to give further conclusive evidence to the practicality of a green roof in Rockhampton (Australia).

References:
[13] Extensive Rooftop Greenery Modelling by David Steele, Engineering Project Implementation, Central Queensland University, Rockhampton, Australia, June 2011