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Performance Evaluation of Hybrid Green Roof System in a Subtropical Climate Using Fluent

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Abstract

Energy disaster is one of the major obstacles in the progress of human society. There are some on-going researches to overcome this for a sustainable environment. Green roof system is one of them which assist to reduce energy consumption of the buildings. The green roof system for a building involves a green roof that is partially or completely covered with vegetation and plant over a waterproofing membrane. Green roofs provide shade and remove heat from the air through evapotranspiration, reducing temperatures of the roof surface and the surrounding air. This paper reports the thermal performance of hybrid green roof system for a hot and humid subtropical climatic zone in Queensland, Australia. A thermal model is developed for the green roof system using ANSYS Fluent. Data were collected from two modelled rooms, one connected with green roof system and other non-green roof system. The rooms were built from two shipping containers and installed at Central Queensland University, Rockhampton, Australia. Impact of air temperature on room cooling performance is assessed in this study. A temperature reduction of 0.95˚C was observed in the room with green roof which will save energy cost in buildings. Only 1.7% variation in temperature was found in numerical result in comparison with experimental result.

Keywords

Thermal Performance; Green Roof; Subtropical Climate; ANSYS Fluent

1. Introduction

Total world energy consumption is rising with a significant amount each year. The total world energy consumption refers to the total energy used by all of human society. Population and income growth are the key drivers behind this growth of energy demand. By 2030 world population is projected to reach 8.3 billion, which indicates an additional 1.3 billion people will need energy and world income in 2030 is expected to be roughly doubled the 2011 level [1]. Total world energy use rises from 524 quadrillion British thermal units (Btu) in 2010 to

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630 quadrillion Btu in 2020 and to 820 quadrillion Btu in 2040 [2]. This energy consumption will grow by 56% between 2010 to 2040. Much of this energy consumption occurs in the countries outside the organization for economic cooperation and development (OECD), known as non-OECD. Energy use in non-OECD countries increases by 90% while in OECD countries it is 17%.

Four major sectors such as commercial, industrial, residential, and transportation are responsible for this energy consumption. Rapid growth in global demand for Australia's energy resources has driven growth in domestic production. However, the share of domestic consumption in Australian energy production has declined, from an average of 49% in the 1980s to an average of 42% in the 1990s, and has continued to decline, to an average of 34% over the past decade [3]. According to the Department of climate change and energy efficiency (Australia), the Australian residential sector energy consumption in 1990 was about 0.28 quadrillion Btu (electricity, gas, LPG and wood) and that by 2008 had grown to about 0.38 quadrillion Btu and is projected to increase to 0.44 quadrillion Btu by 2020 under the current trends. This represents 56% increase in residential sector energy consumption over the period 1990 to 2020.

There are many options to reduce the energy consumption. Green roof system is seen as a viable option to save energy. Green roofs assist a building in different forms such as absorbing rainwater, providing insulation, making a habitat for wildlife and helping a lower urban air temperature and mitigate the heat island effect. Green roofs are a recognized part of modern building in Europe. Australian examples are less common but in 2007 a national organization was formed to promote green roofs and Brisbane City Council included green roofs in its proposed action plan for dealing with climate change [4]. Green roofs are well known for their wide range of environmental, ecological, social and economic benefits [5,6]. 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 [7]. Both plants and layers of green roof add insulation value with existing building insulation. Del Barrio [8] has stated that green roof reduces the heat flux through the roof which does not act as cooling device rather as insulation.

Hydrological performance of extensive green roofs was investigated in New York City [9]. Three full-scale green roofs were monitored in the City, representing the three extensive green roof types. A mathematical model was developed for evaluating cooling potential of green roof and solar thermal shading in buildings [10]. A control volume approach based on finite difference methods was used to analyse the components of green roof such as green canopy, soil and support layer. Thermal properties and energy performance of the green roof was analysed by Niachou *et al.* [11]. A model of the energy balance of a vegetated rooftop was developed and integrated into Energy Plus building energy simulation program [12]. This green roof module allows the energy modeller to explore green roof design options including growing media thermal properties and depth, and vegetation characteristics such as plant type, height and leaf area index. Although there are a few researches on green roof system, but no credible researches on hybrid green roof system using air conditioning are practiced in Australia as well as in the world. In these view, the main aim of this study is to investigate the thermal performance of green roof system in combination with air conditioning.

2. Green Roof System

Green roof is a rooftop garden, park or meadow that carries a host of environmental and economic benefits. It absorbs heat and acts as insulators for buildings, reducing energy needed to provide cooling. A green roof replaces traditional roofing with a lightweight, living system of soil, compost, and plants. By using soil and plants on rooftops in place of hard roofing materials, the homeowners can extend the life of the roof two or three times more. Hybrid green roof system is a green roof system in combination with any other treatment such as air conditioning. There are two types of green roof systems: extensive and intensive. Extensive green roof is more common between the two categories which employs a shallow growing medium of five inches or less. The plants chosen for extensive roofs usually include succulents and moss. The design of extensive green roofs is geared towards low maintenance and limited irrigation. The extensive green roof system has been used in this present study. At most, maintenance occurs one to two times a year with limited access to the roof [13]. Intensive roofs use hardier plants that require a growing medium of at least 6 - 12 inches. Roofs of this system can assist the multiple functions such as providing an outdoor garden space for food production. Intensive roofs involve a greater load of more than 150 kg/m^2 and have more than 200 mm of substrate and require maintenance in the form of weeding, fertilizing and watering [14]. **Figure 1** shows the green roof cross section.

The cost of constructing a safe and effective green roof depends on the building and its existing roof structure. An estimated cost of installing a green roof is $10 per square foot for simpler extensive roofing, and $25 per square foot for intensive roofs (Environmental Protection Agency, USA). Annual maintenance costs for either type of roof may range from $0.75 to $1.50 per square foot.

3. Experimental Set Up and Measurement

Two identical shipping containers with a dimension of 5.63 m × 2.14 m × 2.26 m were used in this study as modelled rooms. They were installed in the sustainable precinct at Central Queensland University, Rockhampton, Australia for the experimental measurement. An experimental bed of green roof has been set over one shipping container whereas other container has bare roof. An air conditioner was installed in both the containers to increase the efficiency of the green roof system. Temperature of both the air conditioner was set at 24˚C to provide optimal comfort and energy savings. The experimental set up of the green roof system has been shown in **Figure 2**.

For excess rain water runoff, the containers were set with a 3˚ pitch from North to South. Both the containers have single sliding 5 mm dark grey float toughened glass door and window along with aluminium frame. Both hand rail and stairs are built as per Australian Standard (AS 1657-1992) which ensures safety while working on the rooftop. **Figure 3** shows the schematic diagram of the experimental green roof setup.

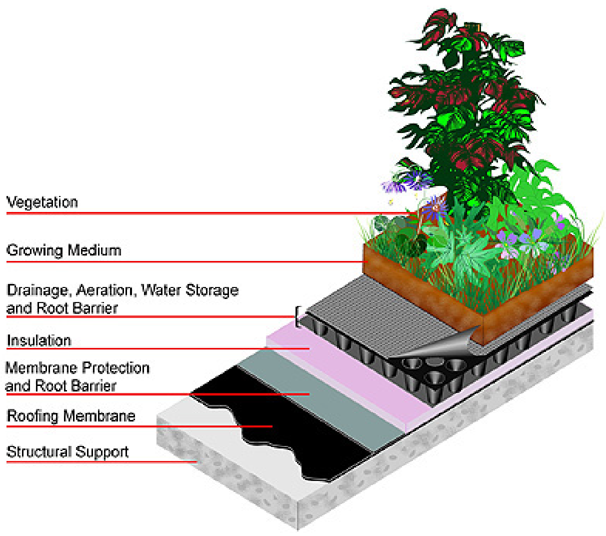


Figure 1. Green roof cross section.

Figure 2. Experimental set up.

Data Collection

Through a suite of experimental design, experimental tests and field investigation, the cooling performance was assessed against air temperature. Air temperature was measured to investigate their impact on cooling performance of the system. Indoor average air temperature and indoor top room temperature were collected using the measuring tools from both the containers. The data of the months of December, 2012 and January, 2013 were collected for this study. Temperature profile of both green roof and non-green roof systems on one of the hottest day (26th February 2013) have been shown in **Figure 4**.

4. Modelling Approaches

Green roof problem has been solved numerically by using the CFD code "Fluent in ANSYS 13.0", which uses the finite volume method for discretization of the computational domain. Standard $k-\varepsilon$ turbulence model was used to develop the green roof model. The model satisfies certain mathematical constraints on the Reynolds stresses and consistent with the physics of turbulent flows. The modelling equations were described in ANSYS Fluent theory guide [16].

4.1. Geometry of the Model

A 2D geometry for this model was created in DesignModeler which is shown in **Figure 5**. The geometry consists of a room with dimension of 5.63 m × 2.14 m × 2.26 m.

4.2. Mesh Generation

A typical mesh is presented for green roof system in **Figure 6**. This mesh was generated using DesignModeller

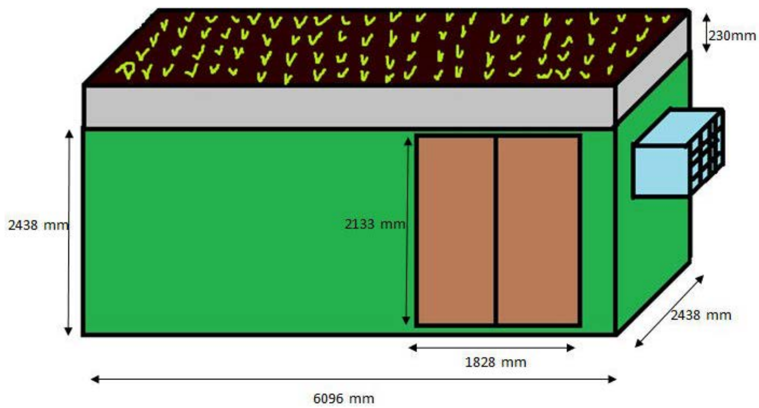


Figure 3. Diagram of experimental green roof [15].

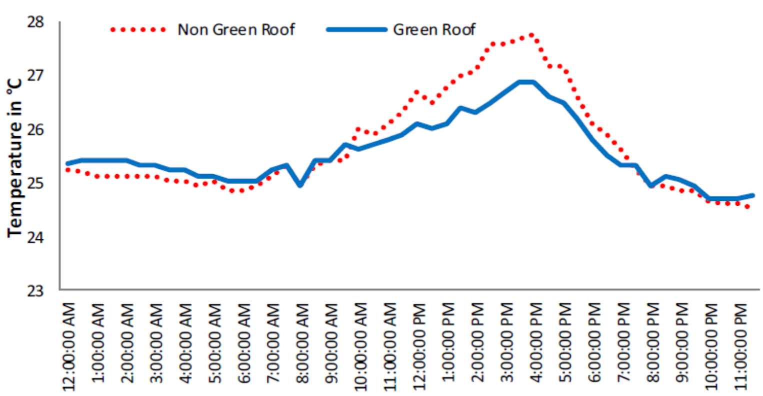


Figure 4. Temperature profile of both green roof and non-green roof systems in summer (26th February 2013).

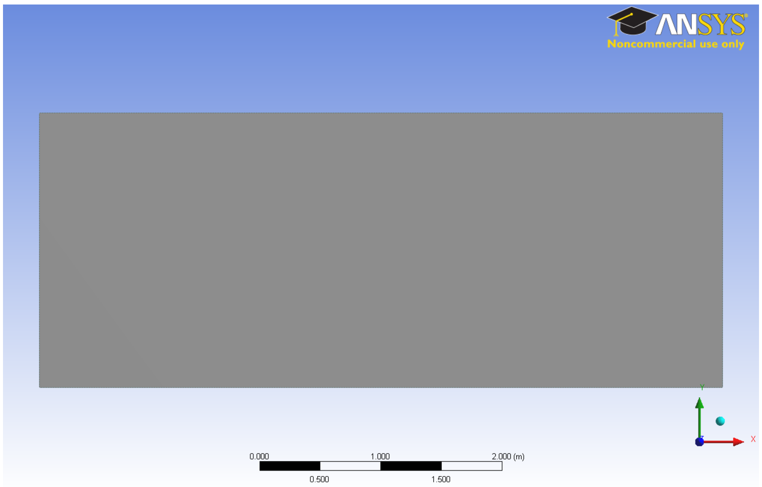


Figure 5. Model geometry in DesignModeler.

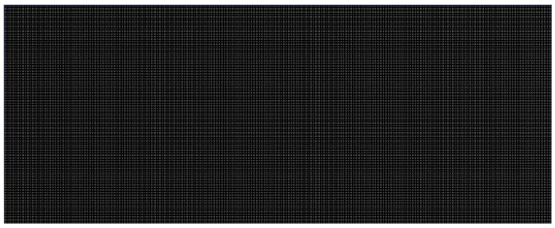


Figure 6. A typical 2D mesh.

in ANSYS 13.0. A number of cells, namely 127,340, were created in the meshing to get an accurate result as a large number of cells may result in long solver runs and a small number of cells may lead to inaccurate results. Cell zone condition for the surface body was defined as fluid. All the zones used in the geometry were defined such as inlet and room wall. No slip boundary conditions were applied on the pipe walls and room walls.

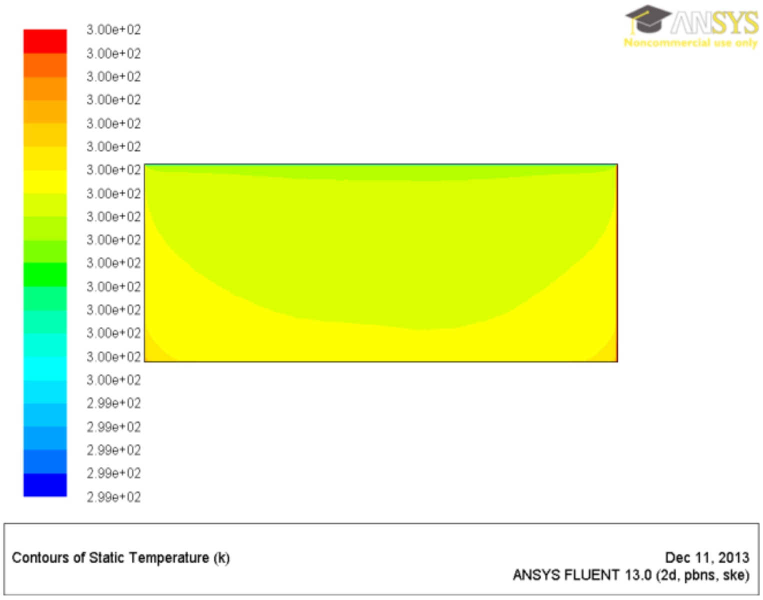
4.3. Solver Approach

A 2D pressure-based-segregated solver was used for the green roof modelling. The solver uses a solution algorithm where the governing equations are solved sequentially. The pressure semi-implicit with splitting operators (simple) was adopted for the numerical calculations. The simple algorithm uses a relationship between velocity and pressure corrections to enforce mass conservation and to obtain the pressure field [17]. It uses a segregated approach where the equations are solved in sequential steps letting to the iterative process the care of non-linearity as well as the coupling between the equations [18].

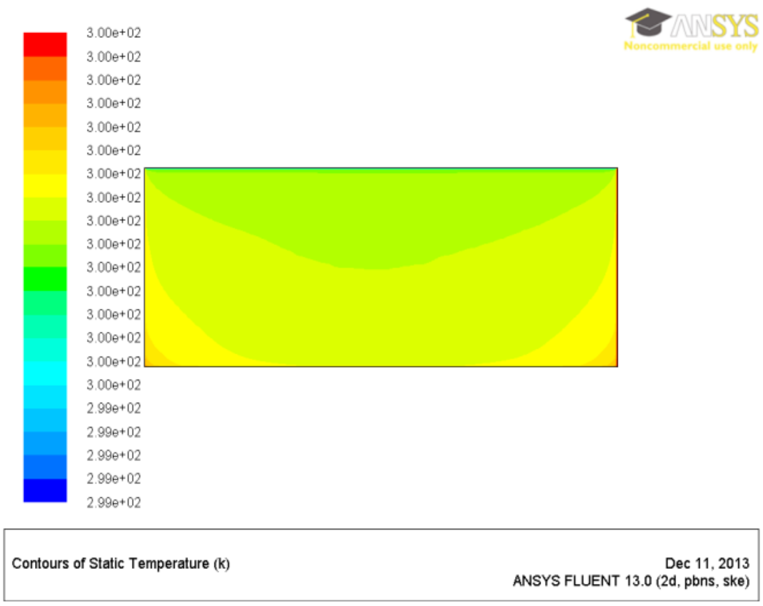
Spatial discretization of second-order upwind scheme was used for momentum, turbulent kinetic energy and turbulent dissipation rate as the discretization of the viscous terms is always second-order accurate in Fluent. Moreover, the second-order upwind differencing scheme was used to overcome numerical diffusion. The standard initialization in the entire domain used in this study allows setting the initial values for the flow variables and initializing the solution using these values.

5. Results and Discussion

Experimental results were obtained for air temperature at different points in both the modelled rooms. The air temperature was measured using HOBO Pendant Temp Logger. The average room temperatures of 299.54 K (26.39˚C) and 300.95 K (27.8˚C) were measured in the modelled rooms of green roof and non-green roof respectively. Performance of the green roof system was also calculated numerically at different iterations of 10,000 and 15,000. Temperature profiles have been shown at these iterations in **Figure 7**. The thermal variables for the boundary and cell zone conditions were imposed on the boundaries of the model. Average maximum room air



(a)



(b)

Figure 7. (a) Temperature profile at the iteration of 10,000; (b) Temperature profile at the iteration of 15,000.

temperature of 299.23 K (26.08˚C) collected from the top of the green roof room was imposed at the top wall of the room.

The numerical results for the maximum predicted room temperature of using green roof system was found to be 300 K (26.85˚C) as shown in **Figure 7(b)**. This predicted temperature is minimum 0.95˚C less than the measured temperature of 300.95 K (27.8˚C). The results obtained in this study were validated at different points by comparing the numerical data predicted by Fluent with the measured data collected from the modelled room containers. The maximum room temperature of 300 K (26.85˚C) predicted by Fluent which is shown in **Figure 7(b)** was compared with the measured room temperature of 299.54 K (26.39˚C) of green roof system. The difference between the numerical data predicted by Fluent and the experimental data was found to be within 1.7% of the measured maximum room temperature.

6. Conclusion

Thermal performance of green roof system was measured in this study by developing a CFD model for a subtropical climate in Queensland, Australia. Standard $k-\varepsilon$ turbulence model was used to develop the model. The impact of air temperature was assessed on the room cooling performance using simulation. The simulation result shows a minimum temperature reduction of approximately 0.95˚C in the room. The developed model was validated at different points of the room with the measured data, and only 1.7% temperature variation was found between numerical result predicted by Fluent and the experimental result. Further investigation is being undertaken in this study.

References

[1] (2013) BP Energy Outlook 2030. London.

[2] (2013) International Energy Outlook 2013.

[3] (2012) Energy in Australia, Department of Resources Canberra, Australia.

[4] http://www.yourhome.gov.au/technical/fs513.html

[5] Emilsson, T. (2008) Vegetation Development on Extensive Vegetated Green Roofs: Influence of Substrate Composition, Establishment Method and Species Mix. *Ecological Engineering*, **33**, 265-277. http://dx.doi.org/10.1016/j.ecoleng.2008.05.005

[6] Mentens, J., Raes, D. and Hermy, M. (2006) Green Roofs as a Tool for Solving the Rainwater Runoff Problem in the Urbanized 21st Century. *Landscape and Urban Planning*, **77**, 217-226. http://dx.doi.org/10.1016/j.landurbplan.2005.02.010

[7] Ekaterini, E. and Dimitris, A. (1998) The Contribution of a Planted Roof to the Thermal Protection of Buildings in Greece. *Energy and Buildings*, **27**, 29-36.

[8] Del Barrio, E.P. (1998) Analysis of the Green Roofs Cooling Potential in Buildings. *Energy and Buildings*, **27**, 179-193. http://dx.doi.org/10.1016/S0378-7788(97)00029-7

[9] Carson, T.B., Marasco, D.E., Culligan, P.J. and McGillis, W.R. (2013) Hydrological Performance of Extensive Green Roofs in New York City: Observations and Multi-Year Modelling of Three Full-Scale Systems. *Environmental Research Letters*, **8**, 36-48. http://dx.doi.org/10.1088/1748-9326/8/2/024036

[10] Kumar, R. and Kaushik, S.C. (2005) Performance Evaluation of Green Roof and Shading for Thermal Protection of Buildings. *Building and Environment*, **40**, 1505-1511. http://dx.doi.org/10.1016/j.buildenv.2004.11.015

[11] Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, T. and Mihalakakou, G. (2001) Analysis of the Green Roof Thermal Properties and Investigation of Its Energy Perofrmance. *Energy and Buildings*, **33**, 719-729. http://dx.doi.org/10.1016/S0378-7788(01)00062-7

[12] Sailor, D.J. (2008) A Green Roof Model for Building Energy Simulation Programs. *Energy and Buildings*, **40**, 1466-1478. http://dx.doi.org/10.1016/j.enbuild.2008.02.001

[13] Cutlip, J. (2006) Green Roofs: A Sustainanable Technology.

[14] ZinCo GMBH (2000) Green Roofs: Recommended Standards for Designing and Installation on Roofs. 6th Edition, Zinco GmbH, Nuertingen.

[15] Anwar, M., Rasul, M.G. and Khan, M.M.K. (2013) Thermal Performance Analysis of Rooftop Greenery System in subtropical climate of Australia. *Proceedings of the* 7*th WSEAS International Conference on Renewable Energy Sources*, Kuala Lumpur, 2-4 April 2013.

[16] (2011) ANSYS Fluent Theory Guide 13.0.

[17] (2013) Fluent 6.2 User's Guide. http://cdlab2.fluid.tuwien.ac.at/LEHRE/TURB/Fluent.Inc/fluent6.2/help/pdf/ug/fl62ug.pdf

[18] Ahmed, S.F., Khan, M.M.K., Amanullah, M.T.O., Rasul, M.G. and Hassan, N.M.S. (2013) Thermal Performance Analysis of Earth Pipe Cooling System for Subtropical Climate. *Proceedings of the* 12*th International Conference on Sustainable Energy technologies*, Hong Kong, 26-29 August 2013.