SIMULATING THE ENERGY PERFORMANCE OF GREEN ROOFS FOR NINGBO'S CLIMATE

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ABSTRACT
A passive means of lowering the energy demand and improving indoor thermal comfort in buildings is the application of green roof components. The complexity between the heat and moisture exchanges in green roof layers and the large variations of green roof types make the need for experimental or simulation assessments necessary in order to quantify the energy benefits from green roofs. In terms of simulation assessments, the current treatment of green roofs in simulation programs is either over-simplistic, for example by ignoring heat and moisture exchanges such as the evapotranspiration, or the more advanced models have limitations and require inputs that are rarely available in practice. In this paper a combination of experimental and modelling techniques are used to assess the potential heating and cooling load reductions from the application of green roofs in the subtropical climate of Ningbo in China. Experimental measurements of weather data and of temperatures across the layers of an existing green roof in Ningbo are taken and are then fed in the ESP-r whole building simulation program to modify the boundary conditions of the roofs on building models and run an integrated assessment for the energy performance of buildings with green roofs. The method provides a generalised assessment for the energy performance of green roofs in Ningbo by overcoming the limitations of existing green roof simulation models.

KEYWORDS
Green roofs, energy savings, integrated energy simulation, measuring boundary conditions

INTRODUCTION
Building energy regulations have been updated across the world and are requesting for measures in buildings that could reduce energy consumption. A potential technique for lowering the energy consumption of buildings is the application of green roofs. The benefits from green roofs are not limited on only lowering the energy demand. Green roofs are linked with other socio-economic issues such as storm water management (Mentens et al. 2006, Teemusk and Mander 2007), mitigation of urban heat island (Alexandri and Jones 2008, Susca et al. 2011), enhancement of biodiversity (Brenneisen 2003), improvements on air quality (Yang et al. 2008), etc. The advantages of green roofs have been discussed by many researchers in the literature (e.g. Banting et al. 2005). This paper is concerned with the potential energy savings that green roofs could offer in buildings located at the climate of Ningbo in China, which is a climate that has hot rainy summers and cold dry winters. The

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paper provides a method where experimental and simulation techniques are combined to overcome their limitations with regard to quantifying the energy savings from the application of green roofs in buildings.

A classic method in the literature for assessing the energy benefits from green roofs is by using on-site experimental set-ups. Measurements are taken of the heat flux and the temperatures across the green roof layers and in some cases there is an analysis of the different heat and moisture exchanges in the canopy and soil layers (e.g. convection in the canopy, evaporation of leaves, etc). For example, Jim and Tsang (2011) used temperature sensors on an intensive green roof with trees on top of a building in Hong Kong in order to verify that green roofs offer energy savings and investigate what effect the physical and biological processes of the green roof layers may have on the overall energy performance of the green roof construction. Wong et al. (2003) took also measurements on a rooftop of a low-rise commercial building in Singapore and they confirmed that green roofs offer thermal benefits to the indoor spaces of the building while they also analysed the contribution of the vegetation and the soil layers to these thermal benefits. Onmura et al. (2001) did also measure experimentally the surface temperature reduction that was offered by a roof lawn garden on a building in Osaka, Japan during the summer and they found that the green roof could reduce external surface roof temperatures during the summer by about 30^{o}C.

The main disadvantages of the experimental green roof assessments is that they are expensive, time consuming and the conclusions are only accurate for the specific building under testing while attempts to generalise these conclusions for other buildings would not account for the uncertainties and the dynamics in the indoor spaces below the roof. Dynamic building energy modelling does offer an alternative method for assessing the energy benefits of building technologies across a variety of building types and climates. The use of building simulation programs could address some of the drawbacks of the experimental methods and significant work has been done over the last decades on validating these programs, e.g. a summary of previous validation studies for the ESP-r program is given by Strachan et al. (2008). However, the development of green roof models that are accurate and integrated with whole building energy simulation models is currently limited and the inputs needed for such assessments are often difficult to obtain or may involve uncertainty. The most significant work in the area was done with the development of a green roof model in the EnergyPlus whole building simulation program (Sailor 2008). The specific model has some limitations, for example it cannot model time variable plant thermal and physical properties (e.g. time variable plant height and leaf growth) and there are uncertainties on obtaining some of the inputs that is using but it is currently the most detailed model within a whole building simulation program.

In this paper there is an attempt to overcome the limitations of both experimental and simulation methods and assess the energy performance of green roofs in Ningbo’s climate with an approach that could be generalised in several buildings types. The next section will describe the method used in this paper for assessing a specific green roof type in a generalised way and by combining both experimental and simulation techniques.

METHODOLOGY

The reductions on the heating and cooling energy requirements that could be offered by a green roof in Ningbo will be quantified by measuring weather data and temperatures in the green roof layers and by importing these measurements within the ESP-r simulation program. The measurements will be used by ESP-r as boundary conditions for modelling a different building than the one where the green roof is installed. The purpose of this procedure is to establish a way to use one set of measurements and simulate different building cases that are located in the same climate of the measurements.

The experimental part of this study took place at the CSET building which is located at the campus of University of Nottingham in Ningbo. The CSET building integrates a number of building technologies including an intensive green roof on top of its lab spaces (Figure 1).

***Figure 1**. A view of the green roof on top of the lab spaces at CSET building in Ningbo*

Weather data were collected on-site and a temperature sensor was placed on top of the roof's soil layer at a place where vegetation was removed. Another temperature sensor was placed at the bottom of the soil in the green roof (400 mm thick). There was only light vegetation (grass, LAI=0.1) on the roof during the period of the measurements. Figure 2 shows a diagram with the positions of the sensors. In this way the difference between the temperature of the roof without the green roof and the temperature below the soil could be measured and compared. Two sets of data could be then imported in ESP-r for further comparison between a building that is using these two different sets of boundary conditions (i.e. with roof surface temperature that varies in a same way as the two sets of measurements). It is worth mentioning that a thick for the levels of local building standards insulation layer (120 mm) is installed just below the green roof construction and any heat flows from the inner building lab spaces were minimised during the two periods of the measurements. The first set of measurements was taken during the heating season (from 3rd of January to 31st of January) and the second set was taken during the cooling season (from 1st of July to 31st of July). The measured ambient temperature during the two periods of the study is shown in Figures 3 and 4 where it can be seen that Ningbo has relatively cold periods in the winter and hot periods in the summer.

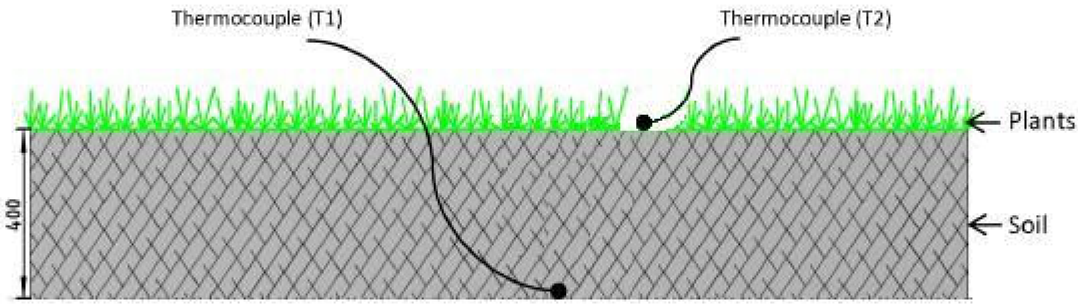

Figure 2*. A view of the green roof on top of the lab spaces at CSET building in Ningbo*

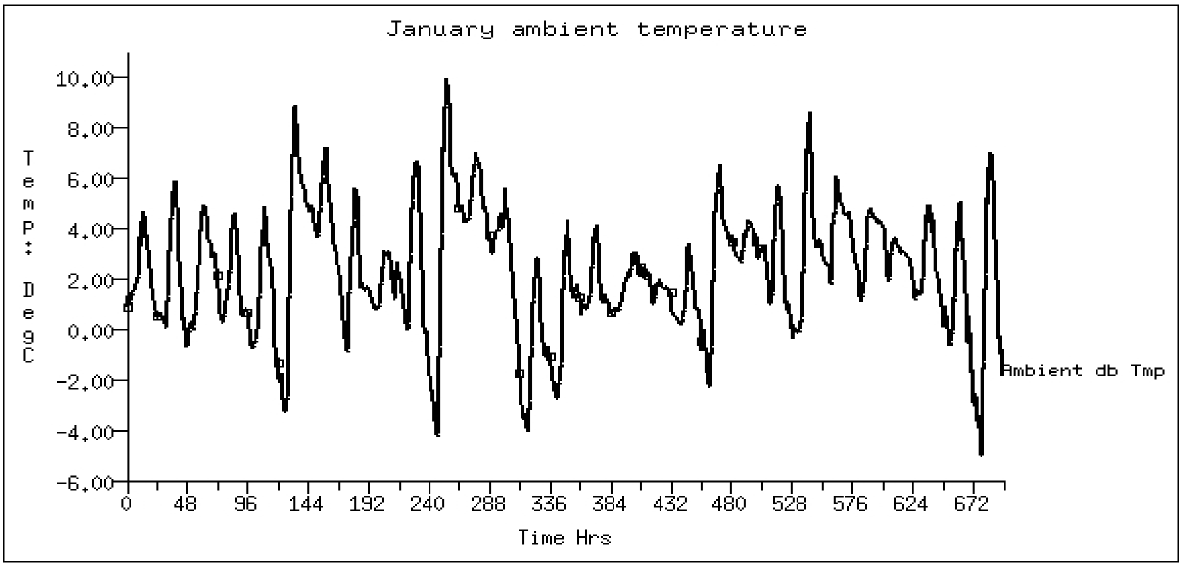

Figure 3*. Measured ambient temperature in Ningbo (3rd Jan – 31st Jan)*

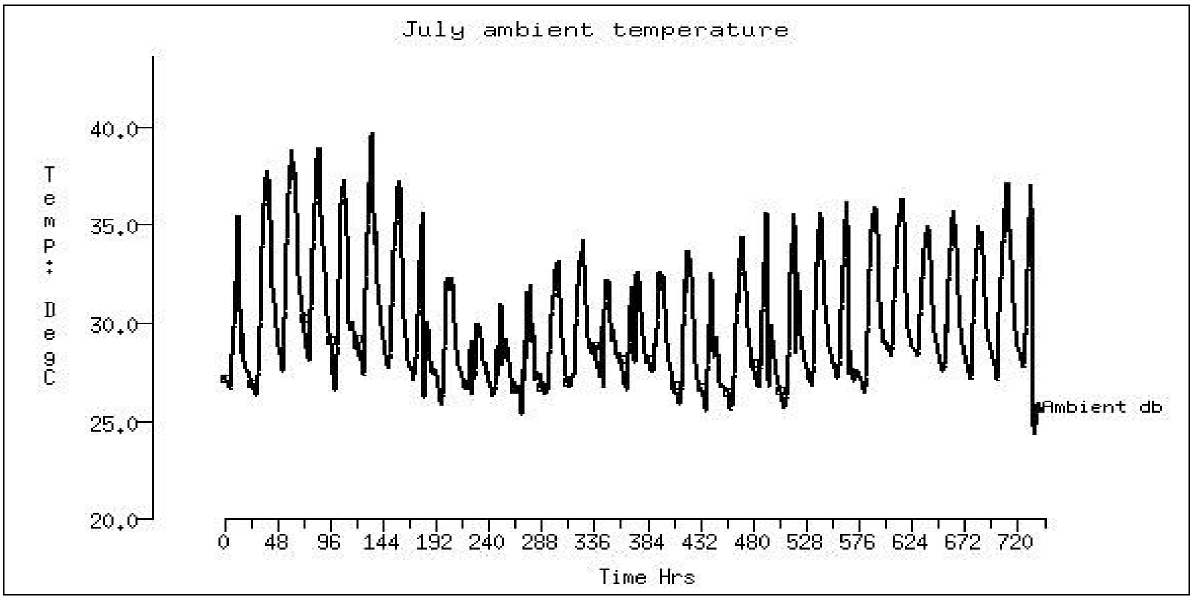

Figure 4*. Measured ambient temperature in Ningbo (1st July – 31st July)*

The data were then imported in the ESP-r simulation program, which currently does not have a detailed green roof model and the top floor of a potential design of another teaching building at the University's campus in Ningbo was simulated (Figure 5). ESP-r has a facility for importing measured climate data but there is no facility for importing measured surface temperatures. It was therefore necessary to expand the capabilities of importing measurements in ESP-r and use ESP-r's flexible open source structure to develop an option that replaces the calculated temperatures for a surface's external node with measured surface temperatures.

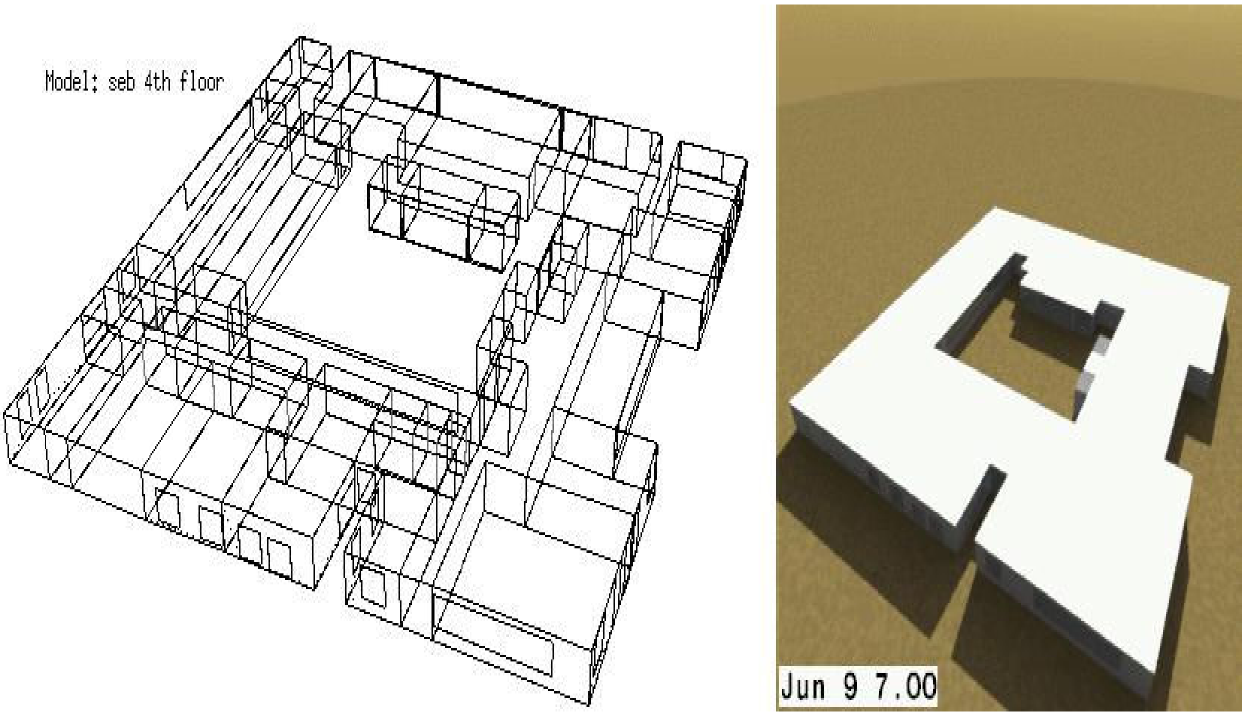

***Figure 5**. The building model of the study*

Importing the measured data in the ESP-r simulation program will allow for taking advantage of the program's existing capabilities. It will be possible to quantify the energy requirements of the building and assess the energy savings offered by the specific type of green roof in Ningbo's climate. The following building cases were simulated for this study for both the January and the July periods (eight simulation cases in total):

1. Uninsulated roof, without green roof
2. Uninsulated roof, with a green roof (400 mm thick soil and light grass vegetation)
3. 50 mm roof insulation, without green roof
4. 50 mm roof insulation, with a green roof (400 mm thick soil and light grass vegetation)

RESULTS

The simulation results revealed significant energy savings when the green roof boundary conditions were applied on the uninsulated roof but the green roof did not offer large savings when applied on the insulated roofs. The results have been summarised in Figure 6.

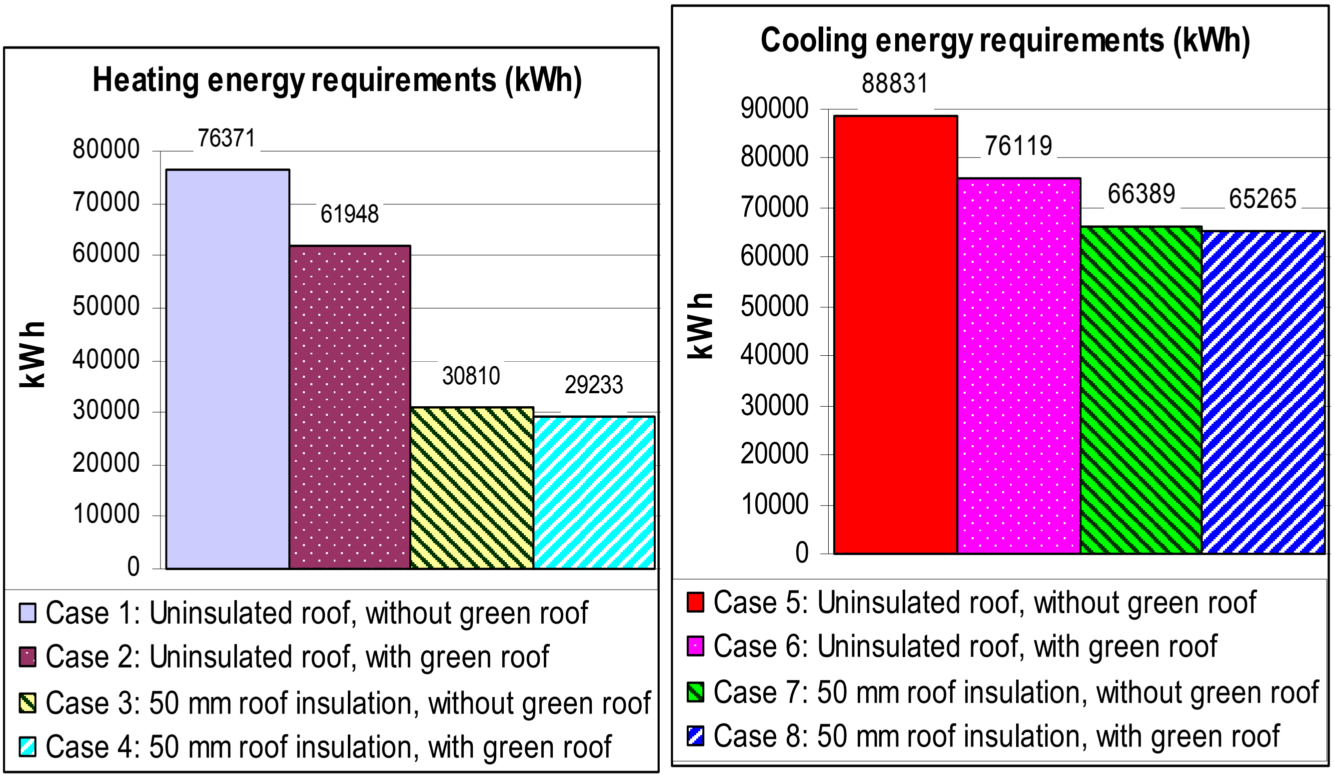

Figure 6. *Heating (January) and cooling (July) energy requirements for the simulated cases*

It can be seen from the above graphs that a building with an intensive lightly vegetated green roof and without any other type of insulation could have less energy requirements for heating and cooling than the respective uninsulated roof building case that does not have a green roof on top (i.e. compare Case 1 versus Case 2 & Case 5 vs Case 6 in Figure 6) but the savings are not as much as when a building incorporates a 50mm of roof insulation (i.e. compare Case 2 vs Case 3 & Case 6 vs Case 7 in Figure 6). In terms of heating energy requirements the results show that the green roof reduces the heating load of the building by about 19% for the uninsulated roof cases and by approximately 5% for the insulated roof cases. Significant savings could also be offered by the green roof in July. The green roof reduced the cooling energy requirements by almost 14.5% for the uninsulated roof cases but only by 1.7% for the insulated roof cases. It should be mentioned at this stage that the building of the study has adopted an intermittent heating and cooling strategy. The energy savings from the application of green roofs could be higher for buildings that have long operation hours (e.g. hotels, hospitals, etc.).

In addition, the use of the ESP-r program allows having access to a large number of performance results, including indoor air temperatures and peak thermal loads. Additional 1-day simulations were run with free float conditions (i.e. by turning off the heating and cooling supply) to identify the benefits from the green roof on reducing peak thermal loads and improving indoor temperatures. The 1-day period for the simulations was identified by investigating the periods with peak loads in the existing January and July results. The resulted indoor air temperatures for the eight model cases are presented in Figures 7 and 8 below.

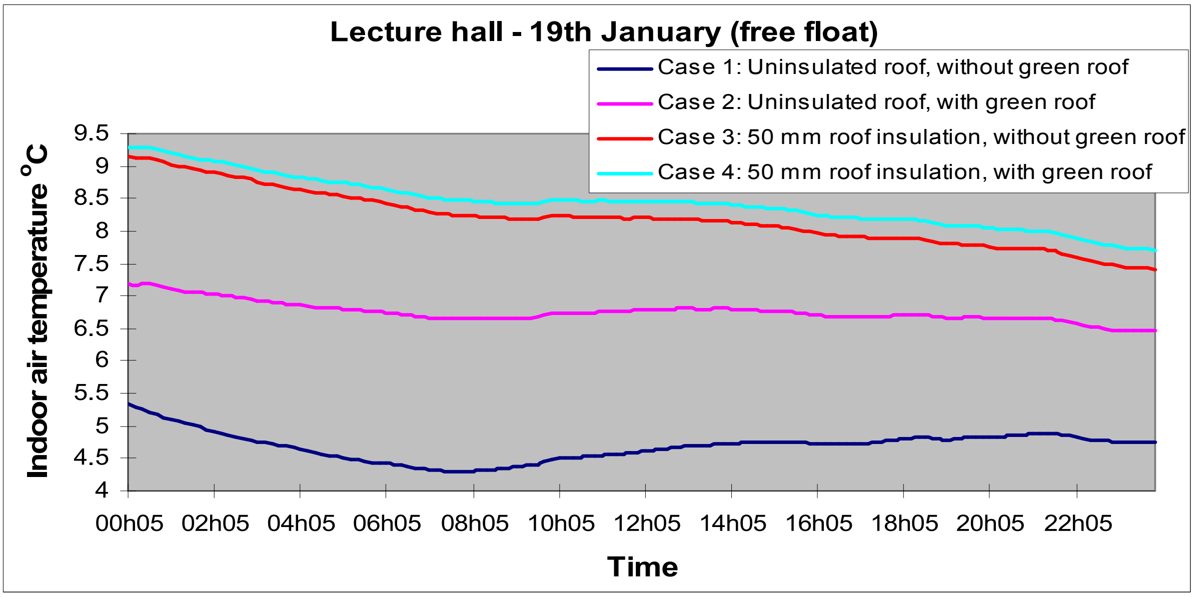

Figure 7. *Sample of indoor air temperature improvements during the peak heating season*

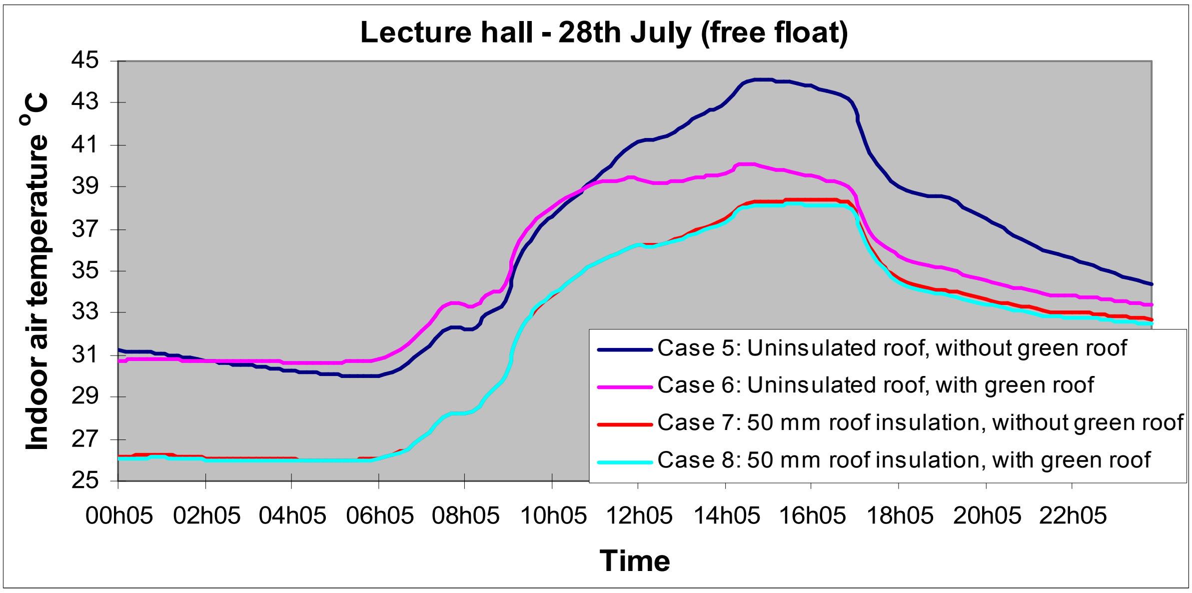

Figure 8. *Sample of indoor air temperature improvements during the peak cooling season*

It can be seen that indoor temperatures in the lecture hall could be increased during the peak heating period by more than 3^{o}C after applying the specific green roof on an uninsulated roof (Figure 7, Cases 1 and 2). On the other hand, only minor indoor air temperature improvements were noticed when the green roof was applied on top of an insulated roof (Figure 7, Cases 3 and 4). A similar trend was noticed during the peak cooling season (see Figure 8, Case 5 vs Case 6 and Case 7 vs Case 8)

CONCLUSION

This study combined experimental and simulation techniques to overcome the limitations of the two methods in assessing the energy savings from the application of green roofs in buildings located in Ningbo. The study focuses on the climate of Ningbo where an intensive green roof application was experimentally assessed and the measurements were then imported in the ESP-r program to assess the potential energy savings from the application of green roof on a different building design. The results revealed that green roofs could offer significant savings on the heating and cooling load of buildings with uninsulated roofs but the heating and cooling energy requirements did not reduce a lot in buildings where a 50mm insulation layer is also applied on the roof. The same conclusion was obtained when results of indoor air temperatures at free float conditions were extracted for days of peak thermal loads.

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REFERENCES

Alexandri E, Jones P. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment, Vol 43, pp. 480-493.

Banting D, Doshi H, Li J, Missios P, Au A, Currie BA, Verrati M. 2005. Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto. Report prepared for City of Toronto and Ontario Centres of Excellence – Earth and Environmental Technologies (OCE-ETech) by Ryerson University. Available at: http://www.toronto.ca/greenroofs/pdf/fullreport103105.pdf (Last accessed on: 24 Aug 2012).

Brenneisen S, 2003. The benefits of biodiversity from green roofs - key design consequences. Proceedings of 1st North American Greenroof Conference: Greening Rooftops for Sustainable Communities, pp. 323 – 329, Chicago, USA.

Jim CY, Tsang SW. 2011. Biophysical properties and thermal performance of an intensive green roof. Building and Environment, Vol 46, pp. 1263-1274.

Mentens J, Raes D, Hermy M. 2006. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning, Vol 77, pp. 217–226.

Onmura S, Matsumoto M and Hokoi S. 2001. Study on evaporative cooling effect of roof lawn gardens. Energy and Buildings, Vol 33, pp. 653-666.

Sailor DJ. 2008. A green roof model for building energy simulation programs. Energy and Buildings Vol 40, pp. 1466-1478.

Strachan P, Kokogiannakis G, Macdonald I. 2008. History and development of validation with the ESP-r simulation program, Building and Environment. Vol 43, pp. 601-609.

Susca T, Gaffin SR, Dell'Osso GR. 2011. Positive effects of vegetation: Urban heat island and green roofs. Environmental Pollution, Vol 159, pp. 2119-2126.

Teemusk A, Mander U, 2007. Rainwater runoff quantity and quality performance from a green roof: the effects of short-term events. Ecological Engineering Vol 30, pp. 271 – 277.

Wong NH, Chen Y, Ong CL and Sia A. 2003. Investigation of thermal benefits of rooftop garden in the tropical environment. Building and Environment, Vol 38, pp. 261-270.

Yang J, Yu Q, Gong P. 2008. Quantifying air pollution removal by green roofs in Chicago. Atmospheric Environment, Vol 42, pp. 7266–7273.