A simulation-based framework for a mapping tool that assesses the energy performance of green roofs

Georgios Kokogiannakis[a]*, Jo Darkwa[a]

[a]*Centre for Sustainable Energy Technologies (CSET), The University of Nottingham, 199 Taikang East Rd, Ningbo, 315100 China*

Abstract

This paper presents a framework for the development of a GIS open source mapping tool that aims to disseminate a database with results of detailed simulations in order to assess in a quick and easy way the energy performance of green roof designs across a range of Chinese climates. Detailed simulation results for heating and cooling loads are obtained from the EnergyPlus simulation tool. The study covers 12264 configurations by varying model parameters such as climate, glazing type, roof insulation, soil and plant characteristics, etc. It was found that green roofs can offer significant energy savings if they are applied on roofs without insulation but only limited energy savings where heavy insulation on the roof is also applied. Quick comparisons across a large range of roof characteristics could be easily made with the implementation of the GIS map tool and the design of green roof that fits the specific climate could be optimised without the knowledge of a detailed building energy simulation tool. The critical parameters that affect the green roof's performance are also highlighted.

Keywords: green roofs; detailed modelling; mapping database

1. Introduction

The role of green roofs on limiting the Urban Heat Island effect has been discussed by several researchers in the past, e.g. [1-2]. Green roofs have also been considered as a type of construction that could act as a thermal buffer for buildings. Research in the past (e.g. [3-4]) has shown that green roofs can reduce the heating and cooling loads of buildings but a consensus has not been reached on the specific characteristics of green roofs (e.g. types of soil, plant, etc.) that best fit the specific building's climate. The issue becomes more important in China, where the climate and the construction standards are significantly diverge across the country and large dense cities consume high amounts of energy and are experiencing the Urban Heat Island in summer.

A way for communicating detailed green roof simulation results should be available to the practitioners and policy makers in order to develop a consensus on the energy and comfort benefits associated with the different types of green roofs across the various Chinese climates. The modelling of green roofs for the build environment involves complex coupling of heat and moisture balances and it is

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* Corresponding author's *E-mail address*: georgios.kokogiannakis@nottingham.edu.cn

not a simple task for practitioners and policy makers. A current advanced implementation of a green roof model is available in the EnergyPlus program ([5] and [6]) and this model is used as the base for the detailed simulations of this study. This paper will describe the framework for the initial development of a tool in which a large number of detailed green roof simulation results are embedded into a database and are communicated interactively via open source web GIS maps. The purpose of the tool is to facilitate practitioners and policy makers in deciding the optimum green roof configuration that offers the highest reduction of heating and cooling loads for the specific climate and the specific construction type.

2. Methodology

2.1. The basic structure of the green roof GIS web tool

The simulation green roof results can be delivered via interactive maps by using the open source MapServer platform [7], which is often used to publish spatial data and interactive mapping applications on the web. MapServer requires a web server such as Apache to be installed. MapServer uses Mapscript as an interface to allow access to MapServer's functionality from a variety of scripting languages (e.g. Python, Perl, Ruby, PHP etc.). PHP is used for this green roof tool in order to access the detailed simulation data from a MySQL database. Vector and raster map layers for China and Chinese cities are available free of charge from the web and they could be incorporated in the MapServer files of the tool. However, work needs to be done in the development inside this framework of detailed map layers for buildings down at neighbourhood level. In this paper, only a representative building is simulated. The details of the green roof simulations will be given at the next section.

Policy makers, practitioners and building owners could be able to firstly access the map of China on the web and then click on large cities. The map layer of the specific city is then activated and displayed on which the users could focus on the available simulated buildings. In future developments of the tool the user will be able to zoom at a specific existing building of the city and assess the effect that different green roof configurations may have on the reduction of heating and cooling loads. This paper includes a residential building type for which several cases of green roof installations have been assessed.

Once the building is selected, the SQL database with the simulation results from EnergyPlus could be called and presented to the user who could make specific comparisons for the performance of the building with the different types of green roofs. The results are presented to the users without having to know how to use the simulation program or how to define queries for the sql database. Any whole building energy simulation program could be incorporated in this structure for expanding the MySQL database. EnergyPlus produces CSV files for each simulation of this study and post-processing with macros in MS-Excel will be necessary to bring the results in a format that could be used for creating the SQL database.

The steps involved in the development of the green roof GIS web map are summarised in Fig. 1. The dotted line with the step of using vector and raster layer data to automatically feed back the geometrical data needed in the energy simulation program is the most challenging part of the implementation.
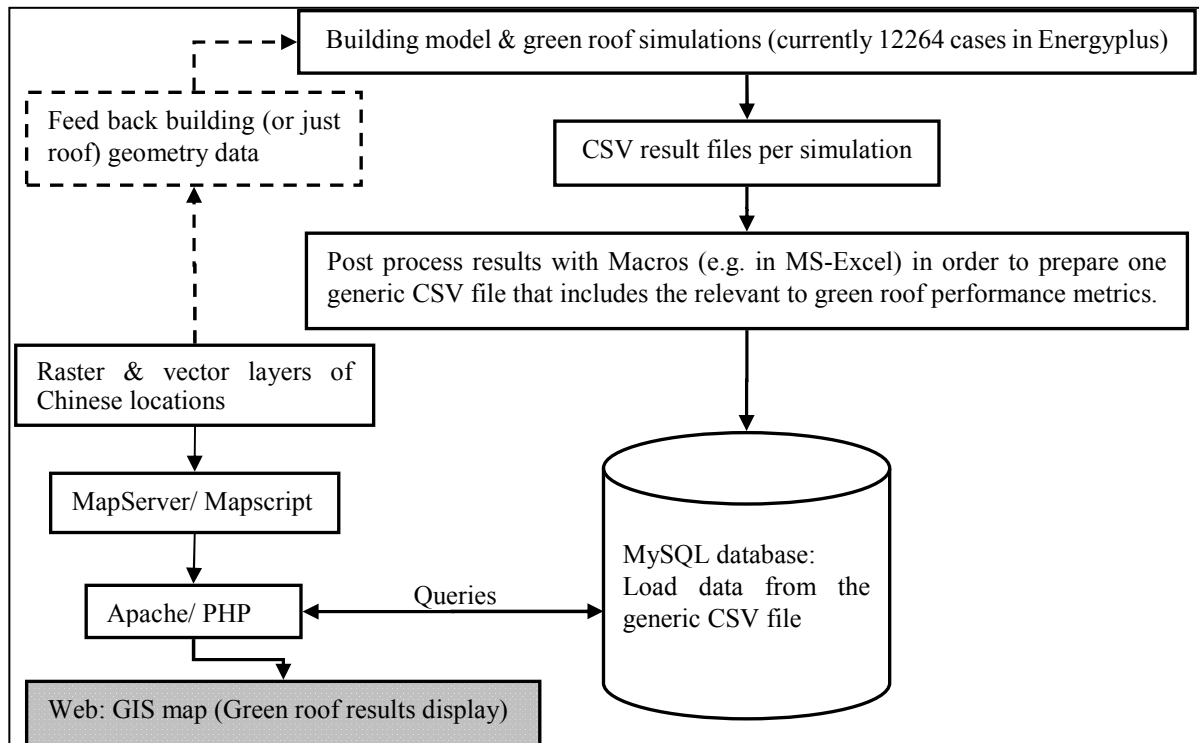

Fig. 1. Steps involved in the development of the green roof GIS map

2.2. Detailed simulations of green roofs

The green roof component in EnergyPlus is integrated with the rest of the building model and detailed complex heat and moisture exchanges are considered in the soil and foliage layers. A description of the mathematical model is given in the literature [5]. A typical building of a Chinese apartment was prepared in the software. A total of 12264 building configurations were modelled in order to cover all the cases described in Table 1 and develop the MySQL green roof application database. All cases were studied with and without the green roof. A drainage layer of 100 mm was also included below the soil of the green roof cases. The analysis was done at free float conditions, i.e. no heating or cooling system affected the internal conditions. The following temperature results were extracted and placed in the database as metrics for the reduction of heating and cooling loads:

- *Peak indoor air temperature* for the cooling cases and *minimum indoor temperature* for the heating cases in order to assess the potential reduction on peak cooling and heating loads respectively.

- *Peak inside face roof surface temperature* for the cooling cases and *minimum inside face roof surface temperature* for the heating cases. This metric is useful for assessing the roof structure itself.

- *Average indoor air temperature* and *average inside roof surface temperature* for the 3 days of the simulation period. Average temperatures could prove that a specific roof construction can be beneficial during a period of time and not only during extreme peak periods.

- For the cooling cases the sum of difference between the indoor air temperature results and the design temperature of 24°C (SUM(T_{air} - 24)) while for the heating cases the sum of difference between the design temperature of 20°C and the indoor air temperature results (SUM(20 − T_{air})). This will allow comparing the cases for the improvements they may offer across the whole simulation period.

Number of configurations and Parameter	Description
7 cases: Location/climate	Dense and important Chinese cities from all the five major climate zones of China are covered: *Ningbo, Beijing, Shanghai, Guangzhou, Xian, Harbin, Sanya.*
2 cases: Seasons	3 typical cold and hot days were used from each climate to assess the effect of green roofs during peak *heating* and *cooling* seasons respectively.
2 cases: External glazing types	Typical glazing was used, i.e. *a single clear 3mm and a double glazing for which two clear 3mm layers are separated by an air filled 13mm gap.*
3 cases: External wall insulation levels (where applicable, insulation was applied externally)	- *Uninsulated concrete call (thermal transmittance U-value of 2.83 W/m²K),* - *medium-insulated concrete wall (25mm insulation, U-value: 0.83 W/m²K),* - *heavily-insulated concrete wall (75mm insulation, U-value: 0.35 W/m²K).*
2 cases: Roof insulation levels (excluding green roof layers)	- *Uninsulated concrete roof (thermal transmittance U-value of 4.09 W/m²K),* - *heavily insulated concrete roof (100mm of insulation, U-value of 0.28 W/m²K).*
1+1 = 2 cases: Green roof application	*Yes, No*
3 cases: Soil thickness (green roof)	*10 cm, 35 cm* and *70 cm*
4 cases: Soil conditions (green roof)	Soil with the following thermal properties: - *thermal conductivity 0.5 W/mK, Density 500 kg/m³, Specific heat 1460 J/kgK.* For the purposes of this paper, this type of soil will be called "Dry", - *thermal conductivity 1.5 W/mK, Density 900 kg/m³, Specific heat 2040 J/kgK.* For the purposes of this paper, this type of soil will be called "Wet" following the recommendation in the EnergyPlus code with regard to the relationship of thermal properties of dry and wet soils. In addition the following irrigation schedule was applied to *both* of the above types of soil: *high levels of irrigation (0.1m/minute), daily: 07.00am to 17.00pm.*
3 cases: Vegetation density	Green roof plant layer: *Leaf Area Index (LAI)* of *0.1, 1* and *5*
2 cases: Minimum stomatal resistance	*180 s/m* and *300 s/m*
Number of models without green roof: 7*2*2*3*2*1 = 168 Number of models with green roofs: 7*2*2*3*2*1*3*4*3*2 = 12096	**Total number of models: 168 + 12096 = 12264**

Table 1. Building parameters and green roof configurations that are included in the database

3. Discussion of results

Large amount of results were extracted from the simulations and were placed in the database. Users can access the results by selecting a Chinese location in the map and by easily applying queries for all the parameters of Table 1. The following can be noticed from the overall range of results in the database:

- Green roofs could significantly reduce thermal loads for buildings that are not heavily insulated, e.g. peak indoor air temperatures were reduced by about 7^oC during the summer in Beijing's climate.

- For heavily insulated buildings green roofs can offer small energy benefits. It should be noted here that such heavily insulated buildings (see heavily insulated parameters in Table 1) are not currently common practice in most places of China and therefore green roofs are still a possible option for future building upgrades. Policy makers and building developers should consider the associated cost of upgrading to that degree of insulation against the advantages and the cost of adding a green roof on top of buildings. From the results obtained it can be seen that specific types of green roofs can have the same effect or even better as an 100 mm roof insulation layer.

- Irrigation is not a critical parameter for green roofs' energy performance. Only during the cooling season irrigation could be slightly beneficial for the uninsulated green roofs that have a thin soil layer and low vegetation density.

- Cooling loads were not affected by the two types of soils that were studied (in accordance with the details of Table 1). However, for the uninsulated roof cases the soil that had thermal properties of a typical "dry" soil resulted to minimum indoor air temperatures during the heating season that were by about 1 to 1.5^oC higher than the "wet" soil cases.

- The thickness of the soil is only an important parameter for the uninsulated roof cases. In such cases, soils of greater depths (i.e. 70cm) improved indoor air temperatures by about 1^oC when comparing with the same building configurations that use thin soil layers (i.e. 10cm).

- The density of the vegetation can determine the potential reductions of cooling loads for uninsulated roof cases. Peak indoor air temperatures can be reduced by about 0.5 to 1.0^oC during the cooling season if high LAI plants are used (LAI = 5) instead of the plants with a LAI of e.g. 0.1. The LAI is not an important factor during the heating season.

- The resistance of the plants to moisture transport and therefore the evapotranspiration rate is dependent in EnergyPlus by the value of the minimum stomatal resistance and the two options (see Table 1) that were simulated did not affect the resulted heating and cooling loads.

The users of the proposed for development GIS web map could easily notice all of the above points by browsing the map and selecting the green roof parameters of their choice. There is no requirement to run the large number of simulations presented here or to have knowledge of the simulation program.

4. Conclusions

A GIS web map tool is proposed to interactively disseminate detailed simulation results for the performance of green roofs across a range of Chinese climates. The tool aims to provide practitioners and policy makers with a quick way of determining the potential savings on heating and cooling loads in buildings that incorporate different types of green roofs. This paper described the framework for such a tool. Simulations were run and a results database was developed from which it was found that green roofs can offer maximum energy savings in China if the roof of the building is uninsulated and they could be a good alternative option to classic thick roof insulation layers. Future work will aim to include additional existing buildings in the map by translating vector layer data of existing roofs into building simulation models and to automate the energy simulation process of such buildings.

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