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Artificial neural network for predation of cooling load reduction using green roof over building in Sustainable City

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ABSTRACT

Over the summer's two test structures one with green roofs and other with RCC was built and tested at Sustainable City, Ujjain to determine their cooling potential. Results indicate that the test cell with the green roof consistently performs better than the test cells with the conventional cement RCC roof.

The objective of this work is to train an artificial neural network (ANN) to learn to predict the reduction in heat gain from the roof buildings with the different experimental data. A number of different training algorithms were used to create an ANN model. This study is helpful in finding the thermal comfort and energy saving of building by applying green roof over the roof. The data presented as input were daily Statistics for Dry Bulb temperatures temperature, relative humidity, average solar intensity and wind speed. The network output was reduction in heat gain from roof. The advantages of this approach compared to the conventional algorithmic methods are (i) the speed of calculation, (ii) the simplicity, (iii) adaptive learning from examples and thus gradually improve its performance, (iv) self-organization, (v) real time operation. ANN gives satisfactory results with deviation of 4.7% and successful prediction rate of 93.8–98.5%.

1. Introduction

Green roofs, also known as living roofs or eco roofs, are roofs include a layer of soil on the roof area to support plant growth. Most green roofs have vegetation growing in the substrate, but that is not a necessity. Green roofs or roof gardens have been in use for thousands of years, primarily as insulation and to control runoff from entering buildings. The hanging gardens of Babylon, of the ancient world, are the first historical models of green roofs were one of the original Seven Wonders of the World. Dunnett and Kingsbury (2008) classify modern green roofs as intensive, extensive, or semi-extensive. They characterize each of these types of green roofs as described below:

1. *Extensive green roofs*: Roofs that have a thin application of growth media, between 2 and 15 cm [0.79–5.91 in]. Typically these roofs require little maintenance or protection.
2. *Intensive green roofs*: Roofs that have a thicker application of growth media, deeper than 15 cm [5.91 in]. These roofs are designed for bearing heavy loads and can contain human activity. These roofs typically require the same maintenance as gardens on the ground.
3. *Semi-extensive green roofs*: Roofs that have elements of both the intensive and extensive green roofs. The green roof on UNM Pearl Hall could be considered a semi-extensive green roof. The Pearl Hall green roof has 20–23 cm of growth media, limited human activity, and has limited irrigation of native grasses.

A green roof is a layered system comprising of a waterproofing membrane, growing medium and the vegetation layer itself. Green roofs often also include a root barrier layer, drainage layer and, where the climate necessitates, an irrigation system. In the last decades, the space left to the greenery in the urban landscape has decreased, allowing the uncontrolled growing of roads and buildings. Roof gardens or green roofs have been used by many preindustrial societies. The Scandinavians used sod or turf as the final layer over a decking of sawn timber boards covered with a layer of water resistant birch bark between the timber decking and the turf. These turf roofs provided insulation and aided in the prevention of heat loss during the extreme northern winters. The turf roof was brought to the U.S. and used extensively during the colonization of the grass prairies. A "Soddy" was an entire home constructed of sod (Dunnett & Kingsbury, 2008). Flat roofs with a

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Nomenclature

Net	neural network
TR	initial training record created by train
train*V*	training data created by train
val*V*	validation data created by train
test*V*	test data created by train
$Q\,r$	heat transferred through roof [W]
R	resistance of layer [$m^2\,kW^{-1}$]
L	thickness of the concrete slab [m]
A	surface area of the roof [m^2]
T_0	temperature at outer surface [°C]
T_i	temperature at inner surface [°C]

dirt covering were also used in the Middle East where mud bricks were the common building material. These mud-brick houses and turf structures were made from materials readily available from the area around the home site (Dunnett & Kingsbury, 2008).

In the southwestern United States and northern Mexico, soil roofs were constructed by the indigenous people using locally available materials. The pueblo style architecture still in use was traditionally constructed using adobe bricks made from dirt excavated for the building foundation and the sunken floor within the home. The roof was constructed using vigas (small diameter trees with the bark removed), a perpendicular overlay of latillas (smaller and usually split sticks), and then another perpendicular overlay of grasses with dirt on top of the grasses (Cornerstones Community Partnerships, 2006; Young, 2009). Sometimes a toweled layer of mud plaster was applied over the grasses to block dust from the soil layer from falling into the building (Cornerstones Community Partnerships, 2006). Some of these flat roofs had native dry land grasses growing on them, either purposely planted or colonized from wind-blown seeds (Dunnett & Kingsbury, 2008).

Ondimu and Murase (2007) to determine thermal conductivity of biological materials for roof greening living composite material using inverse finite-element modeling and neural network optimization. The research hypothesis was that this property can be modeled as a weighted average of thermal conductivities of its constituents. Temperature regimes on either side of a Sunagoke moss mat (dimension 110 mm × 100 mm × 18.1 mm) in a thermally insulated transmission system were measured at different dry basis (db) water contents. Temperature regimes at 0%, 50% and 100% water contents (db) were input into a finite-element model and used to calculate nodal temperatures at six nodes across the thickness of the material. A weighted average model was used to compute effective conductivity for each element from the thermal conductivities of its constituents. Four multi-layer perceptron (MLP) neural network models were developed and used to optimize effective thermal conductivity of the material at 0%, 50% and 100% water contents (db). Hongming and Jim (2010) made simulation model based on the traditional Bowen ratio energy balance model (BREBM) and a proposed solar radiation shield effectiveness model (SEM). The BREBM investigates energy absorption of different components of radiation, and the SEM evaluates the radiation shield effects. The proposed model is tested and validated to be efficient to simulate solar energy transmission in green roofs, with some major findings. Daily net average is positive around 155–210 W/m^2. Ayata, Tabares-Velasco, and Srebric (2011) proposed a "basic model" for calculations of the convective heat transfer at green roof assemblies, which is a modified version of the Newton's cooling law, calibrated and then validated with different sets of data. For forced convection flow regimes, the proposed "basic model" resulted in RMSE (Root Mean Square Error) of 11 W/m^2. Similarly, the model provided RMSE of 6.6 W/m^2 for sensible heat fluxes with free convection conditions, this model will be used in on-site experimental studies to understand its performance under wind conditions that exhibit a much wider range than the studied velocity range near the leaf canopy.

A green roof offers a building and its surrounding environment many benefits

Ecosystem services: Oberndorfer et al. (2007) describe three categories of ecosystem benefits provided by green roofs: "storm water management, energy conservation, and urban habitat provision." In arid and semi-arid environments urban habitat provision would only be relevant if the roof was vegetated. Between 1990 and 2008 Albuquerque lost approximately 15,000 acres of desert to impervious surface growth (American Forests, 2009). Green roofs and green infrastructure could mitigate the effects of impervious surface growth.

Storm water Management: Green roofs (vegetated and non-vegetated) have been shown to reduce and delay the first flush of storm surge water and improve the quality storm water discharge (Mentens, Raes, & Hermy, 2006; Stovin, Dunnett, & Hallam, 2007). Reducing the volume of storm water will reduce the size of storm water management facilities.

Roofing membrane longevity: Roofing materials for green roofs tend to last much longer than materials used on traditional roofs because the roofing materials are protected by the soil from the deteriorating effects of ultra violet radiation (Teemusk & Mander, 2009).

Summer cooling: Summer cooling from green roofs is the result of the soil mass absorbing solar radiation that is released slowly overnight; rather than immediately radiating the solar heat back into the atmosphere. Green roof evaporation and transpiration provide a natural cooling mechanism to the building (Pandey, Hindoliya, & Pandey, 2011; Teemusk & Mander, 2009).

Winter heat retention: Green roofs can act as insulation during cold weather, though properly applied modern insulation under a green roof will increase the insulating value. The soil insulating value is soil specific and determined by the soil characteristics and moisture content (Dunnett & Kingsbury, 2008; Oberndorfer et al., 2007).

Reduction of the "Urban Heat Island" effect: Green roofs can mitigate some of the high temperatures that arise in intensely developed urban areas (Hunt & Szpir, 2006). Most of the impervious surfaces in the urban environment are dark and heat absorbing/radiating surfaces, such as black top and traditional petroleum based roofing materials (Oberndorfer et al., 2007; VanWoert et al., 2005).

Improved runoff water quality: Yang, Yu, and Gong (2008) stated that green infrastructure and low impact design are land development designs that the EPA is promoting to improve water quality. Slowing storm water and encouraging storm water to infiltrate have been shown to improve downstream and groundwater quality.

Improved air quality: Vegetation on green roofs is likely to act like other urban vegetation, which has been shown to "trap airborne particles and to take up contaminants such as nitrogen oxides (Yang et al., 2008)." However, studies of low growing plants typically used on green roofs, such as sedums, are lacking and the air quality benefits used for green roofs are projections from research of urban woody vegetation such as trees and bushes (Dunnett & Kingsbury, 2008).

1.1. Broad objectives

This article presents a more realistic model based on transfer of heat into the building. Moreover, the analysis of inter-related phenomenon of temperature variations was useful in accounting for sensible heat transfer, and thus in predicting cooling load reduction