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Effect of irrigation on the experimental thermal performance of a green roof in a semi-warm climate in Mexico

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ABSTRACT

A study of the experimental thermal performance of a green roof in a semi-warm climate of Mexico, which considers the irrigation effect, is presented. The experiment was performed in two stages. The first stage consisted of selecting from among five types of plants, commonly used in green roofs, the one that tolerates the greatest number of days without irrigation. This stage was carried out in the warm season and we selected the Aeonium subplanum plant for the thermal experimental evaluation. In the second stage, we constructed two test cells in which the temperature and the heat flux of a green roof and a concrete roof were measured for a period of 8 days. During the experimental test the green roof was watered in one day of the evaluation period. From the results, it was found that after the irrigation event the maximum temperature of the green roof components is reduced by 6.4, 4.8 and 1.3° C for vegetation, substrate and slab, respectively. The experimental results show that the use of a green roof decreased the temperature by 20.5 °C compared to a concrete roof. The test cell with green roof had an accumulated electricity consumption 1.3 kWh lower than the test cell with the conventional roof, representing 10.3% less electricity consumption.

1. Introduction

Buildings sector is one of the largest energy consumers in the world and it generates large amounts of waste and pollution. Buildings account for over one-third of the energy consumption and produce the same amount of carbon dioxide [1]. Air conditioning is one of the more important causes of energy use in buildings [2]. In urban areas, the increase of the ambient temperature due to the urban heat island (UHI) effect can increase the energy consumption in buildings and in others public Facilities, as lighting systems [3,4]. The effects of UHI also affect the environment, air pollution concentrations increase in warming cities, high pollution concentrations combined with high temperatures can have a negative impact on people health conditions [5].

Several building envelope techniques have been developed to improve the thermal comfort, to reduce the energy consumption from air conditioners and to mitigate the UHI effect [6]. The roof is the component of the building envelope with the highest temperature fluctuations and significantly contributes to the building energy load. In this sense, several passive technologies such as evaporative cooling, reflective materials, shading with photovoltaic panels, insulation and vegetation can be used to minimize the energy gain from a roof [7].

Green roofs have been increasingly investigated to determine how they can reduce the energy consumption from buildings and improve the quality of the urban environment. Green roofs are totally or partially covered with a layer of vegetation. The main components of a green roof are: waterproofing, root barrier, substrate and vegetation. Green roofs often include drainage, thermal insulation and irrigation system. There are two types of green roofs: intensive and extensive. The intensive green roof has a thick substrate layer (more than 20 cm) and allows to grow deep root plants such as shrubs and trees. The maintenance is high because required fertilizing, weeding and watering. The extensive green roof has a thinner substrate layer (less than 20 cm) and allows to grow small plants, such as grass or sedum. The installation cost is lower, and

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Nomenclature

CR	Concrete roof
G	Solar radiation (W/m^2)
GR	Green roof
q	Heat flux (W/m^2)
q_{sen}^{CR}	Concrete roof heat flux sensor (W/m^2)
q_{sen}^{GR}	Green roof heat flux sensor (W/m^2)
RH	Relative humidity (%)
T	Temperature (°C)
T_{CR}	Concrete roof temperature (°C)
T_{GR}	Green roof temperature (°C)
T_{veg}	Air temperature at the vegetation (°C)
$T_{slab,ext}^{CR}$	Concrete roof slab external surface temperature (°C)
$T_{slab,int}^{CR}$	Concrete roof slab internal surface temperature (°C)
$T_{slab,ext}^{GR}$	Green roof slab external surface temperature (°C)
$T_{slab,int}^{GR}$	Green roof slab internal surface temperature (°C)
$T_{Sust,ext}$	Substrate external surface temperature (°C)
$T_{Sust,int}$	Substrate internal temperature (°C)
ΔT	Temperature difference (°C)
ΔT_{CR-GR}	Temperature difference between concrete roof and green roof (°C)
ΔT_{amb-CR}	Temperature difference between ambient and concrete roof (°C)
ΔT_{amb-GR}	Temperature difference between ambient and green roof (°C)
t	Time (h)
V	Wind velocity (m/s)
VWC	Volumetric water content (m^3/m^3)
VWC_{sen}	Volumetric water content sensor (m^3/m^3)

Subscript

amb	Ambient
sen	Sensor
subst	Substrate
veg	Vegetation

Superscript

CR	Concrete roof
GR	Green roof

it has low weight and required minimal maintenance. The main factors that affect the heat transfer in green roofs are: cooling due to evapotranspiration, increased thermal insulation by adding layers of material and vegetation as a barrier to transmission of solar radiation.

The aim of a green roof is to provide aesthetical environmental and economic benefits. Green roofs can reduce polluting air particles and increase the oxygen production which contributes to the improvement of the environment. Green roofs can also reduce the urban storm water runoff problems, absorbing part of the rainfall and distributing the runoff over a long-time; provide food and habitat for native plants and animals; reduce noise pollution; create space where people can interact each other and rest; increases the internal roof layers' durability. Several of the benefits of green roofs are achievable, but due to lack of research green roofs are generally not designed to meet all those benefits. The benefits of green roofs depend of multiple factors as climate, geometry or materials composition [8]. However, the environment can determine its functionality in terms of the thermal performance. Some experimental studies have been made to understand the green roof thermal performance in different climates, a few of them are presented next. Most of the experimental work found in this research report the temperature in different layers of the green roof and some report the heat flow either measured or calculated, the results are often compared with a reference roof in different seasons. In temperate climate, green roofs are an effective solution to achieve thermal comfort and reduce cooling demand in summer. In winter a green roof functions as a thermal insulation, even in conditions of saturation it can reduce the heating energy demand compared with plywood and concrete roofs [9–11]. In tropical climate green roofs can reduce the outer and inner roof temperature in free floating conditions [12–14], saving the 22% of electric power in air conditioning conditions [15]. The previous benefits have been achieved in the summer season. In Mediterranean claimed Bevilacqua et al. [16] reported that during summer a green roof had an exterior surface temperature 12 °C lower than a lightweight concrete roof and it maintained the surface temperature 4 °C higher than the concrete roof in winter. Gagliano et al. [17] reported that during the summer a green roof lowered the maximum outdoor surface temperature by 27.7 °C compared to a concrete roof, the green roof also reduced the temperature range throughout the day. Coma et al. [18] reported for the same climate the electrical energy consumption of a heat pump system in two rooms, one with concrete roof and other with green roof; the results concluded that the green roof can reduce the energy consumption (even 16.6%) during warm season, but present a higher energy consumption (even 11.1%) during cold season. In semi-arid climate, Reyes et al. [19] recommended well irrigated green roofs with substrate depth (more than 10 cm), it can reduce the exterior surface temperature 13 °C below ambient temperature and helps to maintain a stable and suitable substrate water content. In hot climate, Dvorak and Volder [20] reported that even unirrigated green roofs can reduce the exterior roof temperature 37.7 °C in comparison with a concrete roof. In hot climate, La Roche and Berardi [21] reported that highly insulated green roofs can overheat the indoor temperature during summer in comparison with reflective and thermal insulated metal sheet roof. In cold climate, there are net benefit of the use of green roofs compared with concrete roofs, but the benefits are lower in extreme winter conditions when the substrate is frozen, when the roof has a snow layer and also during sunny conditions [22–24]. Zhao et al. [25] reported that a green roof in a cold winter claimed can reduce the building's heating energy consumption by 23% compared to a reference building with plywood roof. However, this energy saving was reduced to 5% with a snow layer accumulated on the roofs. Due to the importance of climate in green roof thermal performance most of the studies are agree on the need to report green roofs information in as many climates as possible in order to have more knowledge about its benefits.

In Mexico, there are few norms [26–29] oriented to the efficient use of energy in buildings and studies related to the application of passive techniques are scarce. Some passive techniques studied in Mexico are natural ventilation [30], earth-to-air heat exchanger [31], room-Trombe wall [32], insulation and reflective materials [33], window shading [34], cool roof [35], among others [36,37]. Below are presented some works that reports the thermal performance of green roofs in Mexico, these studies showed that green roofs reduced roof temperature compared to conventional concrete roofs in the warm season. Ovando-Chacón et al. [38] performed simulations to determine the air temperature distribution inside test cells with a concrete roof and a green roof. The simulation was performed using the climate data of the city of Veracruz, Mexico. The green roof reduced the temperature of the indoor air near the roof by 10 °C with respect to the concrete roof. Castañeda-Nolasco and Vecchia [39] conducted an experimental study that measured the temperature of a concrete roof and a green roof in a tropical climate in Mexico. The green roof reduced the maximum temperature of the interior surface by 13.7 °C with respect to the concrete roof. Ordoñez-López and Pérez-Sánchez [40] carried out an experimen-