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Seasonal variability of temperature profiles of vegetative and traditional gravel-ballasted roofs: A case study for Lebanon

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ABSTRACT

Vegetative roofs (VRs) are well recognized for their contribution towards better environmental performance and energy savings. This paper investigates the seasonal variability of temperature profiles of two Extensive Green Roofs (EGR8 and EGR16, with a substrate depth of 8 and 16 cm, respectively) and a Traditional Gravel Ballasted Roof (TGBR) for Lebanon, a country in the Middle East. Temperature measurements were recorded every minute from the 14th of January until the 21st of December 2016 using thermocouples placed at TGBR surface, air height of 110 cm above the surface of the mockups, and different layers of each EGR. Results indicated that temperature fluctuations were reduced throughout the 4 seasons considered, especially during hot summer days. In particular, results demonstrated the following: through the winter season, air temperature was decreased by 4.7 °C (EGR8) and 5.7 °C (EGR16), over the fall season, air temperature was mitigated by 5.7 °C (EGR8) and 5.8 °C (EGR16), through the spring season, air temperature was mitigated by 5.9 °C (EGR8) and 6.4 °C (EGR16), and in the summer season, air temperature was mitigated by 7.4 °C (EGR8) and 7.2 °C (EGR16). Therefore, VRs are more efficient for countries characterized by a Mediterranean climate such as Lebanon.

1. Introduction

Roofs are designed to shed water; in addition some can enhance aesthetic view, shield temperature fluctuations, and delay runoff of water [1,2]. Anciently, vegetative roofs (VRs) were promoted by modern architects, i.e. Le Corbusier and Frank Lloyd Wright, as an additional location for green space without previous knowledge of their direct positive impacts to the building and the surrounding atmosphere [3,4]. Nowadays, VRs have become more common since they offer numerous environmental, thermal, and economic benefits compared to Traditional Gravel Ballasted Roofs (TGBRs). As well, in some cities such as Paris, legislations concerning VRs are imposed on all new commercial buildings [5]. VRs have excellent insulation potential due to their additional layers compared to TGBRs [3,4,6]. In addition TGBRs are characterized by their low insulating properties due to the absorption of solar radiation which may lead to the cracking of the roof membrane [7–9]. For example, in the cold climates of Iceland and Scandinavia, VRs retain heat in the buildings, while in warm countries such as Tanzania, they cool the buildings which allows for energy savings [3]. Vegetative roofs improve air quality by reducing the concentration of NO_2 and particulate matter in street canyons by 40% and 60%, respectively [10]. Tong et al. concluded that vegetation on elevated buildings had a positive impact on air quality compared to ground levels by reducing the pollution load [11]. Besides, these landscaped roofs offer many other advantages such as retaining storm water [12–14], mitigating Urban Heat Island effect (UHI) [15,16] attenuating noise pollution [17,18], conserving energy [19–24], improving runoff water quality [25–29], creating a safe habitat for wildlife [30–33], enhancing membrane stability, and extending the life time of roof [3,12,34,35].

VRs vary in size, scope, and vegetation type. Almost all VRs include, from top to bottom: vegetative cover, soil system, filter sheet, drainage layer, root resistant barrier, thermal insulation layer, and waterproofing layer [3,36]. Based on the weight load capacity, the thickness of the soil layer, and the type of veg-

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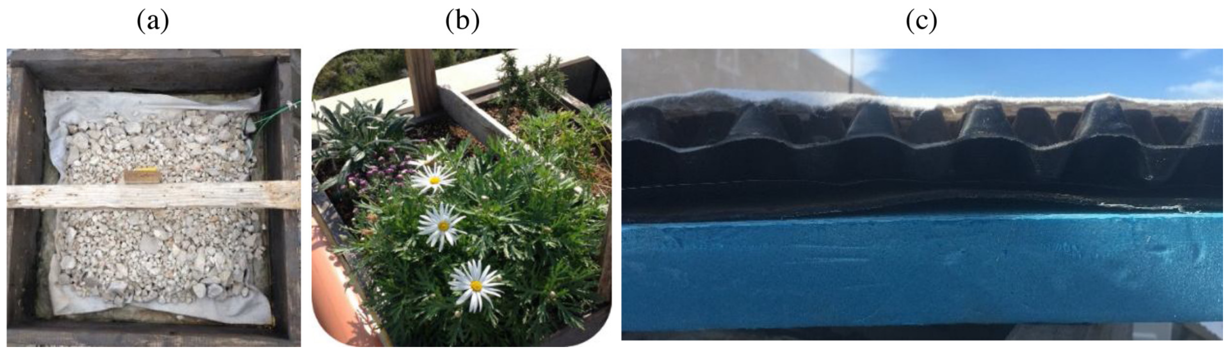

Fig. 1. (a) TGBR (b) EGR mockups and (c) different intermediate layers installed on the chemical engineering building.

etation, green roof industries have classified rooftop vegetation systems as "Extensive" or "Intensive". Extensive Green Roofs (EGRs) are characterized by a thin and light soil layer (<20 cm and 72.6–169.4 kg/m^2) and Intensive Green Roofs (IGRs) by a thicker and heavier soil layer (>20 cm and 290–967.7 kg/m^2) [3,22]. Moreover, IGRs are costly, need further roof support [37,38], and require a higher maintenance level than EGRs [3,39]. Therefore, EGRs could retrofit existing buildings and be installed approximately at the same cost of TGBRs. Germany has made vast use of VRs, of which 80% are of extensive type, ever since they found EGRs to be the most cost effective solution compared to IGRs [6,40].

In literature, several studies have been conducted on the environmental benefits of VRs for buildings [22,41–43]. In particular, Alexandri and Jones demonstrated that the thermal effect modeling in nine cities of both VRs and green walls had the greatest effect in hot and dry climates [44]. Moreover, Kosareo and Ries performed a comparative environmental Life Cycle Assessment (LCA) of VRs and TGBRs. They concluded that even though the initial costs of VRs were higher, the energy and cost savings made over the building lifetime revealed that the VRs roof option was better [45]. Another cradle-to-gate LCA study was conducted in the Middle East, specifically for Lebanon. El Bachawati et al. determined the environmental performance of a real EGR of 834 m^2 and three fictitious roofs of the same area: TGBRs, White Reflective Roofs (WRRs), and IGRs. They found that VRs were truly superior to TGBRs from a life cycle perspective, and EGR had the least environmental impacts for all impact categories [46].

Bevilacqua et al. investigated the thermal performance of EGRs compared to TGBRs in Italy. Their study showed that in summer VRs decreased the temperature by approximately 12 °C, whereas in winter a temperature of around 4 °C was maintained compared to TGBRs [39]. More to the point, a study was dedicated to the thermal performance of VRs over TGBRs for Lebanon and for the winter season. It confirmed that VRs protect the membrane from peak temperature variations and showed that VRs decrease air temperature by a factor of one and a half during sunny winter days (T_{airmax} = 32 °C) [47]. Another Lebanese study investigated the cooling effect of green roofs in summer [48]. Therefore, determining the seasonal temperature profiles of VRs could provide further insights and possible solutions to the Lebanese environmental and energy crisis. Indeed, the Lebanese electricity and water sectors have experienced high commercial and technical losses for many years [49–51]. Despite the major rehabilitation plan, the Lebanese government failed to restructure the electricity sector causing severe blackouts that can reach 13 h per day in some cities all around the year [51–55], an annual deficit of 1.5 billion dollars on the public purse, and a loss of at least $2.5 billion dollars per year on the national economy [47,56].

At the present time, greening technologies are almost absent in Lebanon because of the absence of any law imposing the installation of VRs in the commercial zones such as shops, offices, and restaurants. In particular, a total of only five VRs have been installed in the country so far. The biggest EGR (834 m^2) was installed at the Central Bank of Lebanon, Beirut branch.

The aim of this paper is therefore to study the seasonal variability of the temperature profile of two EGRs with different substrate depths and composition, and one TGBR for the Lebanese Mediterranean climate.

2. Material and methods

A TGBR and two EGR roof mockups (EGR8 with a substrate depth of 8 cm and EGR16 with a substrate depth of 16 cm) of square shape (70 cm × 70 cm) were installed on the rooftop of the Chemical Engineering Department at the University of Balamand, in the region of El Koura, North Lebanon. TGBR and EGRs mockups as well as their different layers are shown in Fig. 1. The roofs constituents and their respective amount are the same as the ones used by El Bachawati et al. [47], as shown in Table 1.

The different mockups were not covered and were installed about 10 m above the ground level [47]. The measurement period extended from January 14th until December 21st, 2016, covering the 4 Mediterranean seasons.

A total of 12 cross-calibrated thermocouples distributed as shown in Fig. 2 were used to measure the temperature throughout the mockups layers [57–59]. Air temperature at 110 cm above the mockup surface was monitored using a temperature sensor ordered from Gemini Data Loggers (United Kingdom) [60]. All temperature measurements were recorded every minute using a data logger [47].

3. Results and discussion

3.1. Temperature profiles

Temperature profiles from the 14th of January until the 21st of December 2016 are represented in Figs. 3 and 4. Fig. 3 represents the amplitudes of daily temperatures, i.e. the difference between the maximum and minimum daily temperatures versus the time on a daily basis. Results showed that during the winter season (from December until March), EGR8 and EGR16 slightly mitigate the temperature fluctuation at 110 cm height and on TGBR surface, whereas the mitigation was more noticeable for the summer season (June–September). On the other hand, during cold winter days (all February 2016), the average attenuation of temperature fluctuations was 28.26% at 110 cm height and 66.50% on TGBR surface for EGR8, compared to 17.39% and 40.92% for EGR16. During warmer spring days (all May 2016), the average attenuation of temperature fluctuations at 110 cm height and on TGBR surface was 32.62% and 70.91% for EGR8 compared to 28.02% and 60.91% for EGR16. During