Applied Energy 187 (2017) 424–437

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Green facade for energy savings in buildings: The influence of leaf area index and facade orientation on the shadow effect

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HIGHLIGHTS

- Leaf area index to measure the shadow potential of a green façade.
- Indirect method to measure LAI is suitable for green facades.
- GF provide comparable shadow factor for all orientations than artificial barriers.
- For a LAI of 3.5–4, 34% of energy savings was measured.
- Energy savings provided by GF are wall orientation dependent.

ARTICLE INFO

Article history:
Received 23 June 2016
Received in revised form 11 November 2016
Accepted 13 November 2016

Keywords:
Vertical greenery systems (VGS)
Green facades
Energy savings
Buildings
Leaf area index (LAI)
Shadow effect

ABSTRACT

To "green" building envelopes is currently one of the most promising ways to provide energy savings in buildings and to contribute to the urban heat island effect mitigation. The shadow effect supplied by plants is the most significant parameter for this purpose. One way to characterize the potential shadow effect of greenery is to calculate the facade foliar density by means of the leaf area index (LAI). As LAI is commonly used in horizontal crops, their use in vertical greenery systems (VGS) has generated dispersion and uncertainty in previous studies both in terms of methodologies and results obtained. In addition, a lack of data relating to the influence of the facade orientation in the final contribution of vertical greenery to the energy savings has been observed in previous studies.

This study aims at establishing a common and easy way to measure LAI and to lick it to the energy savings provided by VGS. Moreover, the energy savings achieved as well as the influence of facade orientation on the final thermal behaviour of two different VGS, a double-skin green facade and a green wall, was studied.

From the results, it can be stated that the most simple and quick procedure to measure LAI in order to characterize the foliar density of VGS is the indirect method based on the amount of light transmitted through the green screen. From the experimental tests interesting energy savings were obtained (up to 34% for Boston Ivy pant specie with a LAI of 3.5–4, during summer period under Mediterranean continental climate). Moreover, the dependence on facade orientation was confirmed with representative contribution over the whole energy savings from East and West orientation.

1. Introduction

Nowadays, buildings represent the largest energy-consuming sector in the economy, with over one-third of all energy and half of global electricity consumed there. As a result, they are also responsible for approximately one-third of global carbon emissions. With improvements in economic development and living standards expected to increase as the planet's population grows by 2.5 billion by 2050, energy use in the building sector is also set to rise sharply by 50%, placing additional pressure on the energy system [1].

In most regions of the world, heating and cooling loads represent the largest building-sector energy end-use. The building envelope - the boundary between the conditioned interior of the building and the outdoors - can be significantly improved to reduce the energy needed to heat and cool buildings. Therefore, there is an urgent need to make building envelopes more energy-efficient, as 20–60% of all energy used in buildings is affected by the design and construction of the building envelope [1].

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http://dx.doi.org/10.1016/j.apenergy.2016.11.055
0306-2619/

Among other innovative technologies to improve the thermal performance of building envelopes urban green infrastructure, that is green roofs and all vertical greenery systems (VGS), is standing out as one of the most promising [2]. These innovative and environmental friendly envelope systems not only contribute with thermal improvements to the building [3], but they provide also multiple ecosystem services at city scale, such as urban heat island mitigation [4,5].

This research relates specifically to the thermal performance of vertical greenery systems in buildings. In this regard, it must be taken into account the several strategies to vertically "green" a building because clear differences have been previously described, not only related to the design but also to their thermal performance [6]. A first great differentiation takes place between *green walls* (*living walls*) and *green facades*, requiring the former higher levels of maintenance (intensive) than the second (extensive) [6]. Among green facades, in which climber species are mainly used, the so-called *traditional green facades*, when the building facade material is used by plants as support, can be distinguished from *double-skin green facades*, when a real double skin is created by means of lightweight support structures that allows the vertical development of a plant to happen at some distance from the building facade (Fig. 1). This contemporary adaptation of traditional green facades, based on easy designs, is very promising as far as it is basically extensive, and it implies low investments and interacts only superficially with architecture [7,8]. In the present research, a double-skin green facade has been studied as passive tool for energy savings in buildings.

Referring to the contribution of these VGS to energy savings in buildings, this ecosystem service takes place essentially due to the shadow provided by the plants. Other effects that can contribute, although with minor magnitude, are cooling (evapotranspiration from plants and substrates), insulation (insulation capacity of the different construction system layers: plants, air, substrates, felts, panels, etc.), and the wind barrier effect (modification of the wind influence on the building surfaces due to the presence of plants and support structures) [3,6].

From the previous research about the potential of double-skin facades as passive tool for energy savings in buildings it can be observed that the most interesting parameters to consider in their analysis are the period of study (cooling, heating or both), the species used, the facade orientation, the foliage thickness (or the coverage percentage), and the air gap thickness between the plant layer and the building facade wall. Referring to the contribution to energy savings, generally the reduction on the exterior surface temperature of the building facade wall ranged from 1 °C to 15.18 °C [3].

In particular, in Hoyano [9] the effectiveness of a vine sunscreen for sun shading was found, reaching reductions up to 60% on solar radiation and 1–3 °C air temperature reductions in the studied veranda. Stec [10] conducted a lab experiment in order to evaluate theoretically (simulation) the shading effect by an Ivy layer (*Hereda helix*) instead of the common blinds layer used in a double-skin green facade. The temperature of the cavity air behind the plants layer was significantly lower (20–35%) than behind the blinds layer. Wong et al. [11] concluded from a large experiment under tropical climate that the average wall surface temperature reduction under the double-skin green facade was 4.36 °C, finding maximum reductions during the afternoon. In Ip et al. [12] indoor air temperature reductions of 5.6 °C during the day and 3.5 °C during the Summer nights were obtained by comparing two identical rooms in an office building due to a sun screen placed in a window of an office building. Pérez et al. [13] measured reductions of 5.5 °C under a building wall shadowed areas of a double-skin facade in reference to sunny areas in August, reaching maximum values of 15.2 °C on the South-West facade in September under Mediterranean continental climate. In similar studies, Perini at al. [14] obtained average reductions of 2.7 °C, and Koyama et al. [15] reductions of 3.7–11.3 °C, with coverage between 15% and 54%. Recently Jim [16] obtained reductions of 5 °C on sunny days and 1–2 °C on cloudy days, standing out the importance of facade orientation on the thermal behaviour.

It can be observed that these previous studies highlight, on one hand, the big potential of these systems to intercept solar radiation and to reduce the building wall surface temperatures, and on the other hand, the relation between this shadow effect and the foliage thickness. However, available data are too sparse and no conclusion referring to the influence of foliage thickness on the thermal behaviour can be withdrawn from these studies. In addition, a lack of experimental data referring to total final energy savings provided by these systems can be noted [3].

A simple way to characterize the thermal benefit that a green facade provides at any time during its development can be to measure the relation between the leaf density of the green layer and the shadow effect and, consequently, the energy savings provided.

In this regard, the most used methodology to characterize the leaf mass of a plant or set of plants is the leaf area index (LAI). Traditionally, the concept of LAI has been used in agriculture and ecology to measure the development and yield of crops, to compare among them and to schedule irrigation and amendments during the crop development [17].

Although some previous authors have used the concept of LAI in order characterize the potential of green facades as a passive tool for energy savings, after a literature review, a lack of knowledge

Fig. 1. Traditional green facade (left) versus double-skin green facade.