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Energy saving performance of green vegetation on LEED certified buildings

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A R T I C L E I N F O

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A B S T R A C T

Sustainable building practices can considerably reduce building's environmental impact in energy consumption. Covering a building envelope with green vegetation, such as green roof and green wall, is considered a sustainable construction practice, as green vegetation has a positive performance in energy savings. It reduces heat flux and solar reflectivity, generates evaporative cooling, increases thermal performance of the building envelope, and blocks the wind effect on the building. This paper analyses the energy performance of green vegetation in a high occupancy LEED Gold standard building in Canada. DesignBuilder software was used to model the energy consumption for heating and cooling, and EnergyPlus software was used to perform the detailed energy simulations. The developed simulation model was validated with the actual energy consumptions of the selected building. Three different scenarios of green vegetation were simulated and the results show that green vegetation could considerably reduce the negative heat transfer through the building façade in summer and winter months. However, the analysis demonstrated that the green vegetation is not cost-effective in winter months or cold climatic regions due to the low energy savings performance. The paper concludes with recommendations to improve the overall energy performance in green buildings.

1. Introduction

Building and construction industry is vital to provide human development needs. This professional sector provides multiple products to enhance the quality of life [1]. However, it is recognized that the construction practices are one of the major contributors of environmental problems. In 2012, U.S. Department of Energy estimated that buildings in the United States accounted for 73.6% of total electricity expenditures, and 40% of the total carbon emissions [2]. In order to address the said environmental concerns, the concept of sustainability has been introduced to the building construction sector. The aim of green buildings is to develop environmentally friendly construction practices that contribute in energy savings, reductions of emissions, and reuse and recycle of materials [3]. Research shows that green building practices can considerably reduce the building's environmental impact in terms of energy consumption. For example, a survey of 99 green buildings in the United States showed that an average of 30% less energy was used in green buildings compared to the conventional buildings [4]. Other studies also show that energy-efficient designs can reduce a building's energy consumption by as much as 50% [4].

However, in the last 30 years, U.S. buildings' primary energy consumption increased up to 48% [2]. As shown in Fig. 1, the energy use for space heating and cooling accounted for 47% of the building site energy consumption.

The green vegetation systems, such as green walls and green roofs, are developed to make the buildings more sustainable. Green walls can be divided into two main types: green facades and living walls. Green facades are systems in which climbing plants or hanging shrubs are grown with the use of special support structures to cover a desired area. The plants can be placed directly on the ground, at the base of the structure, or in pots at different heights of the facade. Green facades are simply based on the use of climbing plants without the complexity and technification of the living wall systems [5]. Living walls are made out of pre-vegetated panels, vertical modules, or planted blankets that are fixed vertically to a structural wall or frame. The panels and geotextile felts provide support to the plants. These panels are generally made out of plastic, expanded polystyrene, synthetic fabric, clay, metal, or concrete [6]. The living walls have three typical systems: i.e. trellis, modular panel, and felt layer system [7]. These systems usually have a vegetation layer, growing medium, irrigation system, container, waterproofing layer, and structural support [6–8].

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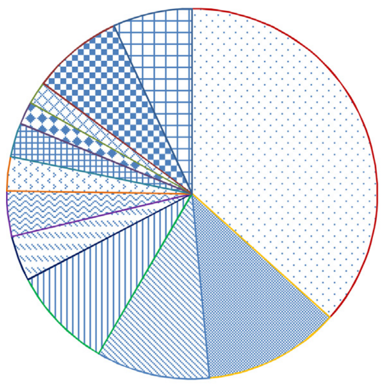

Fig. 1. Building site energy consumption by end use in 2010 (derived from USDOE [2]).

Compared with the complexity of green walls, green roofs are quite normalized in building systems. Green roof can be classified as intensive and extensive according to the purpose and characteristics [9]. Intensive green roofs are usually associated with roof gardens, which need a reasonable depth of soil and require skilled labor, irrigation, and constant maintenance [10]. Extensive green roofs have a relatively thin layer of soil, and are designed to be virtually self-sustaining, therefore require low maintenance [10]. There is a third type of green roofs called semi-intensive, which comprise extensive and intensive. However, the percentage of the extensive type should not exceed 25% of the total green roof's area [11].

Manufacturers offer different green vegetation systems in the market to match different customer requirements and weather conditions. Green roofs and living walls have totally different layers mainly because of the supporting structure differences. Green roof systems usually have a root barrier, drainage layer, filter layer, water retention layer, growing medium layer, and vegetation layer [9,12,13]. The growing popularity of green roofs and living walls in sustainable buildings is mainly because of their multiple environmental and social benefits that can be listed as: improvement of air quality, mitigation of urban heat island effect, reduction of energy costs for heating and cooling, reduction and delay of storm water runoff, reduction of noise pollution, improvement of human health and well-being, and increment of urban biodiversity and urban food production [14–20].

Energy savings is the main benefit that could balance the initial capital cost of green vegetation in buildings. A few previous research studies focused on calculating the energy savings of green roofs and living walls. Liu and Minor [21] demonstrated that the heat flow through a roof could be reduced by 70–90% in summer and 10–30% in winter, with the use of green roofs. Another research conducted by Liu and Baskaran [15] reported a 95% heat gain reduction and 26% heat loss reduction in 22 months observation period of a green roof. Castleton et al. [22] mentioned the energy saving potentials of green roof with different insulation levels. The same researchers concluded that the annual energy savings are not significant in the well insulated roofs. Di and Wang [23] also agreed that green vegetation reduces 28% of the cooling load transferred through a green wall. However, the reference building in the research was an old library built in 1919, and the wall insulation was not efficient compared to the current standards.

There is rarely a published analysis available on the energy performance of the green vegetation in Leadership in Energy and Environmental Design (LEED) standard green buildings, with a well-insulated building façade. This study aims to fill the said gap in the body of knowledge. The objective of this study is to assess the energy performance of a LEED Gold standard high occupancy building with exterior green vegetation. This paper is divided into four parts. First, background information of green vegetation in terms of the energy performance is introduced. Second, the simulation process of the studied green building is described. Technical drawings, specifications, daily operation record, and official governmental data are discussed under in this step. Third, the selected green building is simulated using the DesignBuilder software, and the energy consumption data is calculated using the EnergyPlus software [24]. The simulated model was then validated with the actual operational energy consumption in the building. Fourth, the energy saving performance of green vegetation, with different other scenarios was simulated and discussed. Then the annual and hourly energy consumption for heating and cooling were evaluated for the selected scenarios.

2. Energy savings and green vegetation: governing factors

There are many governing factors related to the energy performance of buildings with exterior green vegetation.

2.1. Reduction of heat flux and solar reflectivity

The surface temperature of a building is considered to be a primary indicator of the urban heat island; and the contribution to this temperature could be estimated from the incoming solar radiation and surface reflectance of the roof and the wall [25]. Green vegetation can cool down the temperature through latent heat loss and improve the reflectivity of incident solar radiation.

It is demonstrated that the exposed area of a black roof can reach up to 80 °C in summer, while the equivalent area beneath a green roof is only 27 °C [26]. Liu and Minor [21] conducted an experiment with a green roof, and a reference bare roof, with heat flux transducers. The results showed that the heat loss through the green roof was about 10–30% in the summer and 70–90% in the winter.

Castleton et al. [22] presented that the internal temperature peak under a green roof is slightly delayed and the overall temperature is slightly lower than a standard roof. The temperature peak delay is mainly due to the thermal mass effect of green roofs.

In green walls, the magnitude of heat flux reduction effect depends on the density of the foliage. "Ivy" is the species that provide the maximum cooling effect in the traditional green façade, and the difference in indoor temperature can reach up to 3 °C [27,28]. The interior temperature in a double-skin façade is generally lower, if plants are used instead of blinds. Installation of plants inside a double skin facade reduces energy consumption of the air conditioning system up to 20% [28].

2.2. Evaporative cooling performance

The evapotranspiration process of plants requires energy. This physical process generates the so-called "evaporative cooling". The evaporative cooling of the leaves depends on the type of plant and exposure. Also climatic conditions have an influence. Dry environments or the effect of the wind can also increase evapotranspiration of plants [6].

Feng et al. [29] used a mathematical model to analyze the evaporative cooling effect of a green roof in typical summer in China. The results demonstrated that 58% of the heat of green roof was lost by evapotranspiration. It is also proved by Castleton et al. [22] that wet green roofs have more than twice heat losses, through evapotranspiration, than of the dry green roofs. The additional evapotranspiration of the wet roofs not only prevents the heat