Energy and Buildings 82 (2014) 668–674

Contents lists available at ScienceDirect

Energy and Buildings

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

Experimental study on reduced heat gain through green façades in a high heat load climate

Mahmoud Haggag*, Ahmed Hassan, Sarah Elmasry

Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551 AL Ain, Emirates of Abu Dhabi, United Arab Emirates

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 16 April 2014
Accepted 29 July 2014
Available online 7 August 2014

Keywords:
Energy efficiency
Green wall
Hot climate
Thermal performance
Sustainability

ABSTRACT

The hot and arid climate in the United Arab Emirates (UAE) yields indoor temperatures much higher than the comfort zone, which poses unique challenges in improving energy performance through building construction systems. The study examines the introduction of green façades to reduce heat gain in indoor spaces as a strategy to lower cooling demand. A vegetative living wall was installed on a school building façades and experimentally studied. The experimental results showed that during day time in the peak summer month of July, the green facade can maintain on average a temperature that is 5 °C lower than a bare wall, consequently impacting building cooling load and improving energy performance.

1. Introduction

1.1. Passive means to reduce heat gain into buildings

Sustainability refers to an ecological process characterized by the fulfilment of human needs while maintaining natural resources. A sustainable building approach could be achieved by architects, engineers and manufacturers of building products working cooperatively to produce green building skins in an ecological and resource efficient manner. Use of a sustainable building skin increases energy efficiency, while reducing building impact on the environment [1].

The building skin is an important contributor to energy efficiency; responding to heating, cooling, ventilation, and natural lighting needs. It plays a dominant role on the overall energy performance by controlling heat transfer and solar radiation. It has to balance the need for ventilation and daylight and provide thermal protection appropriate to climatic conditions. Building skin design should be integrated with other aspects including material selection, daylight, ventilation, and air-conditioning. The building function is an important factor in skin design. Construction details and façade systems also play an important role in designing a building skin. Appropriate detailing systems are essential to guarantee the required level of thermal performance, reducing heat transmission, through conduction, convection and radiation. Conduction through the building skin is achieved through lowering the amount of heat transmitted through the unit area of skin layers in the unit time, which consequently lowers the thermal transmission coefficient (*U*-value). Similarly, convection and radiation through the building skin are also controlled through selective design of the building skin layers to reduce energy transfer by electromagnetic waves and reduction of thermal bridging [2]. The use of green wall strategies has gained popularity to minimize heat gain through building façades, leading to increased comfort levels, reduced operation costs and reduction of overall energy consumption and environmental impacts. Green walls can also reduce heat gain and their surface temperature is lower than an exposed wall. Based on the analysis carried out by the firm Green Over Grey, studies have shown that the external surface of a green wall is up to 10 °C cooler than an exposed wall; therefore the *U*-value for the green wall is usually lower and helps to reduce cooling loads [3,4].

1.2. Energy efficiency in school buildings

According to estimates of the US Department of Energy, 25% of expenditure on energy in schools could be saved through better building design and using energy-efficient technologies combined with improvements in operations and maintenance [5]. Literature concerned with energy performance of school buildings is devoted to savings via specific features such as utilization of solar energy,

* Corresponding author. Tel.: +971 505638461.
E-mail address: mhaggag@uaeu.ac.ae (M. Haggag).

http://dx.doi.org/10.1016/j.enbuild.2014.07.087
0378-7788/

construction features, such as thermal insulation, thermal mass, and shading, HVAC performance, and geothermals [6–8]. However, basic assumptions regarding thermal comfort, indoor air quality, occupancy and acclimatization schedules, internal loads, and architectural features of the school building are not identical in the various publications, and are usually based on local preferences [6].

Green schools benchmarks have been developing worldwide in attempts to meet such concerns, for example Leadership in Energy and Environmental Design (LEED) for school buildings by the U.S. Green Building Council (USGBC) [8]. Energy Smart School Program by the U.S. Environmental Protection Agency (EPA) [6], The Benchmarking Guide for School Facility Managers as part of the pilot benchmarking and best practices programme undertaken by Natural Resources Canada's (NRCan's) Office of Energy Efficiency (OEE) [9]. Also, the UK has been producing energy benchmarks and performance guides for almost 30 years, as Good Practice Guide 343, which includes typical and best practice values for primary schools [10]. In 2009, Estidama Pearl Rating System for school buildings emerged as a local effort in the UAE following the Estidama sustainability initiative [11] as part of the Abu Dhabi plan 2030.

1.3. Thermal performance of green wall systems

The term "green wall" is for both living walls and green façades. Living walls, also known as bio-walls, are composed of pre-vegetated panels or integrated fabric systems that are fixed vertically to a structural wall or frame. Green façades are made up of climbing plants that growing directly on a wall or supporting structure. The plant grows up the wall while being rooted to the ground, in intermediate planters or on the rooftops. Rigid panels and cable systems can be used to hold vines off the wall surface. Green wall systems are increasing in popularity due to their proven success in lowering the heat-island effect in the urban context, and their contribution towards achieving higher thermal comfort levels in spaces [12–16].

A number of studies have explored the thermal effect of vertical green surfaces on building skins. There is proven evidence that vertical greenery systems can reduce air conditioning load by shading walls and windows from incoming solar energy resulting in a 5.5 °C reduction in the outdoor ambient temperature wherein the shading effect was found to reduce the cooling load by about 23% and the usage of fans by 20%, resulting in an 8% reduction in annual energy consumption [6]. Through simulation, a 100% greenery coverage with plants of a higher shading coefficient, proved to achieve about an 18% drop in cooling load [6,15]. Also the study highlights that a lower shading coefficient results in better greenery effectiveness on glass façades. The thermal transfer value of the building skin and the leaf coverage of a plant are useful design variables when it comes to achieving the intended amount of thermal load reduction [17]. Studies also concludes that the materials needed to build up the green façades have an significant environmental impact when the energy demand of a building can be reduced or when the multi-functionality of the construction due to the integration of vegetation can be increased [18,19].

Alexandri and Jones [20] highlight the importance of the green walls in reducing the heat island effect in microclimates. They conclude that in hotter and drier climates, the greater is the effect of vegetation on urban temperatures. The study highlights that temperature decrease is primarily affected by the vegetation itself, as well as orientation. The study suggests that if applied to the whole city scale, green roofs and walls could mitigate raised urban temperatures, and, in hot climates, could achieve energy savings for cooling buildings ranging from 32% to 100%. Energy and environmental performance of a green roof system was experimentally investigated on a nursery school building in Athens. A cooling load reduction was observed due to green wall system which varied between 6% and 49% for the whole building while from 12% to 87% for the last floor [21]. A number of mathematical studies have been conducted to evaluate the thermal performance of green wall systems [22–25]. A daily net heat storage capacity of 155–210 W m^{-2} was observed for green wall system through simulation based on the traditional Bowen ratio energy balance model (BREBM) and a proposed solar radiation shield effectiveness model (SEM) [22]. In a separate study, the use of green roof system in an office building located in the greater Athens are reported to reduce cooling load of buildings up to approximately 40% at peak summer time. Green was found insignificant to influence the building's heating load [23]. Thermal performance of green walls and roofs were mathematical predicted to calculate heat transfer coefficient across green wall and roof system. The heat transfer coefficient reduction of 6–16 W/m^2-K was reported resulting in cooling load reduction of 37% due to incorporation of green wall compared to bare wall system [24]. A physically model was developed in Energy Plus building energy simulation and was validated through observations from a monitored green roof in Florida. The effect of thermal properties of growing media, plant type, plant depth, plant height and leaf area were investigated on the energy performance of the green wall system. These parameters are reported to influence the energy performance of building in different ways [25].

In addition to their significant thermal benefits, plantations have been used as barriers against urban noise pollution. Effect of the green roof on acoustics of building was studied experimentally. It was observed that green roofs contribute to significant sound reduction due to diffraction compared to non-vegetated roofs reaching up to 10 dB [26].

Green walls have an acoustical insulation that is far better (up to 30 dB) than that of an exposed wall. The degree of sound insulation provided by the green wall depends mainly on factors that influence noise reductions including depth of the growing media, type of plants, materials used for the structural components of the living wall system, and the layer of air between the plants and the wall [27,14,28].

Green wall technology can protect building surfaces and extend the lifespan of the building skin by reducing surface temperature of a building skin, and using appropriate techniques such as waterproof living wall panels. This protection comes mainly from keeping rain off the building while allow moisture to escape, reducing the expansion and contraction of building materials, and protecting walls against wind and solar radiation which might affect the building materials. Green wall technology has a visual impact on buildings, and it can help to address the lack of green space in urban environments. Plants improve human health, capture airborne pollutions, and filter harmful gases.

2. Experimental methodology and set up

2.1. Methodology

A green wall to reduce heat gain, a photovoltaic array to provide power for lighting and irrigation systems, and a grey water recycling system are applied in Liwa International School (LIS) located in Al-Ain City at latitude 24°16′ and longitude 55°36′ E. The city is characterized by a very hot and dry climate with summer daytime temperatures range from 35 °C to 50 °C and winter daytime temperatures ranging from 25 °C to 35 °C. As part of the on-going experimental work, the green façade of LIS is examined in situ to investigate the performance of the green wall system in the hot arid climate of Al Ain city. The vegetated wall installed on the building façades shown in Fig. 1, comprising of plastic planter boxes (30 cm × 30 cm × 25 cm) installed connectively on the façades; drip