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# Lifecycle assessment of living walls: air purification and energy performance

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ABSTRACT

Covering a building envelope with green walls is considered a sustainable construction practice. Green walls can be classified as green facades or living walls based on their purpose and characteristics. Living walls are built with different layers and variable planting styles depending on the geographic location, function, and weather conditions. This paper discusses a comparative lifecycle assessment (LCA) of three living wall systems: trellis system, planter box system, and felt layer system. Chemical emissions and energy consumption of the living wall materials are evaluated in the whole lifecycle, and compared with the chemical absorption and energy savings of operational living walls. The results demonstrated that the felt layer system is not environmentally sustainable in air cleaning and energy saving compared to the trellis system and modular panel system. The environmental performance of living walls is influenced by the types of materials and plants chosen for the systems, as well as the external factors, such as climate and building type. The LCA indicates the need of environmental friendly materials for sustainable living walls.



## 1. Introduction

It is recognized that construction practices are one of the major contributors of environmental problems. United State Energy Information Administration estimated that buildings account for 72% of total electricity consumption, and 38.9% of total carbon dioxide emissions (Buildings Energy Data book, 2008). In order to address the environmental concerns, such as global warming, deforestation, waste generation, the concept of sustainability has been introduced to the building construction sector. Research shows that sustainable building practices can considerably reduce the building's environmental impact in 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 (The Economist, 2004). Other case studies show that energy-efficient designs can reduce a building's energy consumption by as much as 50% (The Economist, 2004). Increasingly, vegetation is being used as an important new construction material to make the buildings more sustainable (Eumorfopoulou and Kontoleon, 2009; Fioretti et al., 2010). Integration of vegetation in buildings, through green roofs or green walls, increases the building's ecological and environmental benefits (Castleton et al., 2010; Eumorfopoulou and Kontoleon, 2009).

### 1.1. Types of living walls

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 using special support structures to cover a desired area (Pérez et al., 2011). 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 (Pérez et al., 2011). Ecological benefits of green facades, such as energy savings, thermal insulation, and building protection, are not as pronounced as they are with living walls (Weinmaster, 2009).

Living walls are made 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 (Pérez et al., 2011). There are many commercially available living wall systems, and they can be categorized in terms of different parameters. Loh (2008) classified the living walls into three systems: trellis, modular panel, and felt layer systems. This classification is based on

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the characteristics of the plant box. Perini et al. (2012) classified living walls with different features of growing medium. The potting soil is used as substrate in the planter box living wall system, the form is used as the growing medium in the form substrate living wall system, and the felt layers are used as substrate and water-proofing in the felt layer living wall system.

### 1.2. Benefits of living walls in air cleaning and energy savings

In the recent literature, many claims were made about the positive influences of living walls. The environmental benefits of living walls are; increasing the thermal performance of buildings (lowering energy costs), improving air quality, mitigating the Urban Heat Island effect (UHI), reducing noise pollution, improving water sensitive urban design (WSUD), increasing urban biodiversity and urban food production, and improving human health and well-being (Cheng et al., 2010; Wolverton and Wolverton, 1993; McCarthy et al., 2001; Getter and Rowe, 2006).

#### 1.2.1. Thermal performance

Living walls contribute to the cooling and insulating benefits of a building. The air layer between the façade and the living wall has an insulating effect, which makes the living wall as an extra insulator for the building envelope (Perini et al., 2011a). The phototropism effect created by the living walls can ensure a cooling effect in warmer climates. Of the sunlight falling on the leaves, 5%–30% is reflected, 5%–20% is used for photosynthesis, 10%–50% is transformed into heat, 20%–40% is used for evapotranspiration, and only 5%–30% passes through the leaves (Krusche et al., 1982; Ottelé et al., 2011). The green vertical cladding can also mitigate potential solar heat impact, which affects the indoor spaces even after the sunset. Computer simulation models showed that the shading provided by living walls in colder climates can decrease indoor temperatures significantly in summer, and may save 23% of energy costs (Bass and Baskaran, 2011). Eumorfopoulou and Kontoleon (2009) made an investigation in Greece, during the winter, to compare the thermal performance of a bare concrete wall and a plant-covered building façade. The results demonstrated that the surface temperatures of plant-covered wall sections were considerably lower than those of the bare wall sections. The effect was about 10.8 °C. Another recent study by Wong et al. (2010a), on a free standing wall in Hortpark (Singapore), with vertical greening, showed a maximum temperature reduction of 11.6 °C. Alexandri and Jones (2008) indicated that covering the building envelope with vegetation is an important method to save cooling and heating energy consumption. Depending on the climate type and the amount and position of vegetation on a building, the energy savings can vary from 35% to 90% (Alexandri and Jones, 2008).

#### 1.2.2. Air quality

It is well known that the outdoor plants can absorb toxic compounds from the air. Wolverton and Wolverton (1993) explained that potted-plants can significantly improve indoor air quality, not only because plants can absorb carbon dioxide and release oxygen through photosynthesis, but also plants can reduce air-borne contaminants such as nitrogen oxides, volatile organic compound (VOCs), and dust. Another experiment conducted by Ottelé et al. (2010) in the Delft University of Technology, demonstrated that green vegetation can reduce number of particulates ($<10$ μm) in the air, which have a long-term threat to human health. In addition, living walls can help in absorbing toxic gas emitted by vehicles, and improve the air quality. In a UK based study of air quality, with an indoor gas heater, Coward et al. (1996) found that houses with six or more potted-plants showed reductions of over one third in $NO_2$ levels. In a study of Korean native indoor species, Lee and Sim (1999) showed that indoor plants absorb and metabolise $SO_2$. Some additional studies showed that plants effectively reduced levels of benzene, ammonia, formaldehyde, nitrogen oxides, and particulate matter (Lohr and Pearson-Mims, 1996). Plants have also been shown to increase indoor relative humidity, by releasing moisture into the air, thus increasing the comfort level in sealed environments (Aydogan and Montoya, 2011).

### 1.3. Objectives

Living walls have environmental, social, and economical benefits such as reducing greenhouse gas emission, adaptation to climate change, air quality improvement, habitat provision, aesthetics perfection, and energy savings by insulation (Weinmaster, 2009; Ottelé et al., 2010; Perini et al., 2012). However, from the lifecycle point of view, the sustainability of living walls has rarely been analyzed. One notable attempt was made by Ottelé et al. (2011), where the environmental burden analysis of living walls from the entire lifecycle was conducted. Global warming potential, human toxicity, and fresh water aquatic eco-toxicity were considered by Ottelé et al. (2011), as the environmental burden profile, to conduct a comparative analysis on energy savings. However, the sustainability of the living wall was not demonstrated clearly due to the limitations and variations.

This paper attempts to investigate the sustainability of living walls from a new perspective. Since the two major quantitative benefits of living walls are energy savings and air cleaning (Bass and Baskaran, 2001; Eumorfopoulou and Kontoleon, 2009; Coward et al., 1996; Lee and Sim, 1999), this study not only consider the energy savings benefit, but also the air cleaning benefit of living walls, which makes the investigation more comprehensive. Furthermore, the environmental burden in this study, energy consumption and chemical emission, is based on the burden created by all the components of the living wall, in its entire lifecycle.

The objective of this paper is to compare chemical emissions and energy consumptions, with air purification and energy savings of living walls, over the product lifecycle. The paper discusses the sustainability of living walls in terms of energy savings and air purifications.

By performing the LCA technique, the environmental impacts of the living walls could be assessed. The major stages of an LCA study are raw material acquisition, materials manufacture, production, use/reuse/maintenance, and waste management (USEPA, 2012). The goal of this LCA is to evaluate the environmental performance of living walls in manufacturing, constructing, maintaining and disposing of 1 $m^2$ living walls. Furthermore, the air cleaning and energy saving performance of living walls, in the product lifecycle, are quantified with comprehensive statistical analysis.

Since there are many commercially available living wall systems, product costs could vary for different designs and functions. In this LCA research, three living walls systems are adopted from the greening systems presented by Ottelé et al. (2011). The first one is a trellis system, where the climber is planted on the ground, and grown on the stainless steel mesh. The second one is a planter box living wall system, and the third one is a felt layer living wall system. The materials data of the living walls required for the inventory analyses were cited from Ottelé et al. (2011).

## 2. Methodology

This paper evaluates the lifecycle sustainability of living walls, by comparing air pollution and energy consumption in the material production, construction, maintenance, and disposal stages, with