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Energy performance of living walls in commercial buildings

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Abstract: Building and construction industry is a major cause of environmental pollutions as it accounts for 30-40% of energy and natural resource consumptions on earth. It also contributes to 30% of greenhouse gas emissions. 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 at energy savings. This paper discusses a comparative lifecycle analysis (LCA) of living walls. Energy consumption of the modular panel living wall materials in manufacturing process are evaluated with SimaPro, and compared with the energy savings of operational living walls. The results demonstrated that the modular panel system requires 3 years to balance the energy consumed in the manufacture process. However, 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.

1 Introduction

Building and construction activity is important in providing human development needs, as the professional development dramatically enhance the quality of human life by creating multiple products (Tam et al., 2004). However, the construction practices are counted as one of the major contributors to environmental issues. In 2012, U.S. Department of Energy estimated that Buildings in United States accounted for 73.6% of total electricity expenditures, and 40% of the total carbon emissions (USDOE 2012). In order to address the environmental concerns, the new conception of sustainability has been brought in to the building construction industry. Research data demonstrates that the practices of sustainable building 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). It is also concluded from other data that as much as 50% of a building's energy consumption could be reduced by energy-efficient designs (The Economist 2004). The concept of green building is to establish environmentally friendly construction practices that can create energy saving, emissions reduction, materials recycle or reuse (Spence and Mulligan 1995). The green vegetation systems, such as green wall and green roof, are developed as a new technology to make the buildings more sustainable.

Green walls can be categorized into two main types: green facades and living walls. Green facades are systems in which hanging shrubs or climbing plants are grown on special support structures to cover a desired area. The plants can be placed directly at the base of the structure, on the ground, 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 (Franco et al. 2012), while living walls, which are widely used in commercial buildings nowadays, have big differences between systems. Living walls are made of planted blankets, pre-vegetated panels, or vertical modules that are fixed vertically to a structural wall or frame. The panels or 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). The living walls have three typical systems: i.e. trellis, modular panel, and felt layer system (Loh 2008).

The growing popularity of green roofs and living walls in sustainable buildings is mainly because of their multiple environmental and social benefits which can be listed as: mitigation of urban heat island effect, improvement of air quality, 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, increment of urban biodiversity and urban food production (Currie and Bass 2008; Liu and Baskaran 2003; Oberndorfer et al. 2007; Santamouris et al. 2007; Cheng et al. 2010; Wolverton and Wolverton 1993; McCarty et al. 2001).

From the lifecycle analysis (LCA) point of view, there are no reported evidence available to evaluate the overall sustainability of living walls in their lifecycle. The objective of this paper is to evaluate the lifecycle performance of living walls, in terms of energy savings. This study is divided into four parts. First of all, it has a brief background explanation of the structures of living walls and the theory of energy saving benefits in living walls. Next, a LCA for a modular panel living wall is presented with the SimaPro software. The energy savings abilities of the living walls are cited from (Ottelé et al. 2011); EnergyPlus V7.1 software was applied to evaluate energy consumption of the selected building structures. Finally, the LCA results are evaluated and discussed. Then the limitations of the results are noted and future work is suggested.

2 Background

In order to further understand the structure of the living walls, the layers of living wall systems are introduced in this section. The theory that makes the living walls as environmentally friendly products in energy savings is explained as well.

2.1 Layers of green walls

Different living wall systems are provided to the market by the manufacturers to catch the different customer requirements and weather conditions. There are three main living wall systems in the market: trellis system, modular panel system, and felt layer system. These systems usually have a vegetation layer, growing medium, irrigation system, container, waterproofing layer, and structural support(Perini et al. 2011a, Pérez et al. 2011, Loh, 2008).

The vegetation layer in the living wall has the same importance as the one in the green roof, almost all the environmental benefits of living walls are related to the vegetation layer. A large array of plants can be used for living walls. Proper vegetation is typically selected based upon resilience, site-specific environmental situations, rooting system, color, breeding rate, and texture. Living wall panels can also harvest small shrubs, perennials, edible plants, ferns, and ground covers (Cacciatore et al. 2010). The plants should not be the same in different systems of living walls. For example, the height of the trellis system should be considered when choosing the climbers, because some climbers can grow 5 to 6 meters high, others around 10 meters, and some species to 25 meters (Dunnett and Kingsbury 2004). Eco-regions should also be considered in choosing the appropriate plant as well (Dvorak and Volder 2010).

The character of growing medium layer in the living wall is almost the same as the one on in the green roof. With the consideration of weigh limit, the hydroponic systems are developed and applied to the living wall system. This system could grow plants without any soil, and the nutrients are added with water in the irrigation system (Weinmaster 2009). In the hydroponic system, air-filled porosity and water-holding capacity are the most important hydroponic growing medium factors needed for root formation (Schwab et al. 1998). Aydogan and Montoya (2011) used three porous materials: growstone, expanded clay, and activated carbon for hydroponic growing medium. Since biochar had positive effects on improving the nutrient retention, as well as decreasing the greenhouse gas emissions from soil (Lehmann et al. 2011), it has been used as a hydroponic growing medium by Nichols et al. (2010) in the research.

The irrigation system is critical as water and nutrients are fed to the vegetation via specific mechanical or natural irrigation system. There are many irrigation systems available in the market for different living wall systems. It is important to establish control and timing of the irrigation system to ensure a secure and regular water supply (Loh 2008). Moisture sensors installed into the growing medium are necessary to ensure best life conditions for plants. Moisture distribution is mainly shaped by the factor of gravity in the growing medium. There are many examples of proprietary irrigation systems of living walls in the commercial market. The common systems are water retaining irrigation systems, individual water drip irrigation systems, and computerized vertical drip irrigation systems (FLORAFELT 2013, Gsky 2010).

Generally, the waterproofing layer should be installed between the structure wall and the container of the living wall, especially on indoor systems (Cacciatore et al. 2010). The layer is designed to provide a water proof membrane on the building façade. The waterproofing layer is usually fastened to the structural support, so that no moisture is able to go behind the waterproof membrane and affect the building façade (Weinmaster 2009). Leak prevention is a priority of the whole system, which will ensure the normal operation of the irrigation system. In case of a leak in an operational living wall, the system may need to be removed completely to fix the leak. Usually, low-density polyethylene (LDPE), polyethylene (PP), or fleece is used as the waterproof layer (Ottelé et al. 2011). Not all the living walls have the waterproofing layer, as some advanced commercial systems make the modular panels waterproofed, and no extra waterproofing layer is required (Green over grey 2011).

The container in the living wall system is used to support the growing medium and the vegetation. In the trellis system, the plants usually start to grow in containers and then climb onto the trellis. The container is basically similar to a flower pot, located on the ground beside the building façade or at different heights of the facade (Loh 2008). In the modular panel system, container styles are varied in size and type, and they are usually fastened to the wall structure or an extra vertical support. The container should not touch the structural wall in order to allow adequate air flow that prevents condensation on the back of the panels (Cacciatore et al. 2010). In the felt layer system, several plastic layers are used as the support and water proofing for plants or mosses. Some textiles, such as nylon and polyester, provide similar properties like plastic layers, because they are capable of giving structural support, holding moisture, and allowing the roots to move freely throughout. These textiles may last indefinitely, even under constant moisture (Perini et al. 2011a). In summary, the commonly used materials for containers are wood, steel, aluminum, felt bag, plastics, and fibres. The different materials chosen for the system can have positive or negative influence on the environmental burden, and each of the materials might change the aesthetic and functional properties due to different weights, profile thicknesses, durability and cost (Ottelé et al. 2011).

The structural support comprises the frame of the living wall system. Usually, the components are not the same in different systems, and not the same from indoor to outdoor environment. The structural support has to hold loads from all the other layers. If the living wall is installed outside, the structural support has to handle additional wind, rain, or snow loads. The trellis systems usually use modular trellises, wired structures, or mesh structures to support the climber plants (Pérez et al. 2011). However, this system does not need to support the weight of any other layers except plants, therefore it is simple, and does not have too many components. The modular system and felt layer system have similar structural support, as both modular panels and felt layers are directly attached to the structural frame. The commonly used materials in the structural support are galvanized steel, stainless steel, aluminum, plastic, and wood (Ottelé et al. 2011, Weinmaster 2009).

2.2 The theory of energy saving benefits in living walls

In the last 30 years, the energy consumed by the U.S. building increased by 48% (USDOE 2012). It is shown in Fig 1 that the energy uses for space heating and cooling accounted for 47% of the site energy consumption. Therefore, this section will address the theory of the potential building energy reduction benefits of living walls.

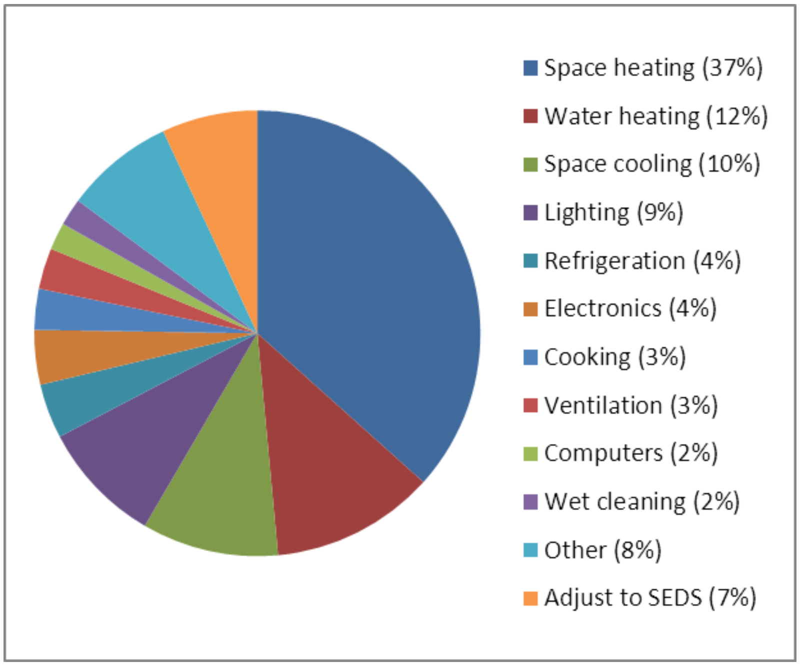

Fig 1: Building site energy consumption by end use in 2010 (derived from USDOE (2012)).

First of all, the living walls can reduce the heat flux and solar reflectivity of the building facades. Surface temperature of the 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 on the wall (Brown and Gillespie 1995). Green vegetation can help cool down the temperature through latent heat loss and improves the reflectivity of incident solar radiation.

Secondly, the living walls can generate evaporative cooling, and the heat gain through the building facades could be reduced. The physical process of plant evapotranspiration requires energy, which can generate the so-called ‘‘evaporative cooling’’. The climatic conditions, the type of the plants, and the exposure rate all have influence on the evaporative cooling of the leaves. The effect of wind or dry environments or can also increase evapotranspiration of plants (Pérez et al. 2011).

Thirdly, the living walls will increase the thermal performance of the building envelope. The addition of green vegetation can improve the insulation properties of a building, hence reduce annual energy consumption. The green vegetation can not only reduce the heat loss from the building in winter and heat gain into the building in summer, it also adds thermal mass to help stabilize the internal temperature in the whole year (Castleton et al. 2010).

Last but not the least, the living walls can mitigate the negative wind effect on the building which will create energy savings. In winter, blocking the effect of wind on the building façade will increase the building energy efficiency, as the cold wind is crucial in reducing the indoor temperature of the buildings. Green vegetation systems of buildings play a role as wind barrier and consequently block the effect of wind on the building facades. The foliage density and penetrability, the façade orientation, and the velocity of the wind are all impact factors to the effect of wind barrier created by green vegetation (Pérez et al. 2011).

3 Objective and methodology

This paper evaluates the lifecycle sustainability of a modular living wall, by comparing energy consumption in the material production phase, with the energy savings in the operation phase. The “balance years” refer to the time needed for achieving equality in energy consumptions.

The following section summarizes the adopted methodology to achieve the above objective.

3.1 Literature review

A comprehensive literature review was presented to explain the current background related to the structure of living walls. The theory of energy saving benefits created by living walls is explained as well.

3.2 Lifecycle analysis

Lifecycle analysis (LCA) was conducted to calculate environmental impacts of the production, use, maintenance, and decommissioning for three typical living walls. Simapro modeling (7.3.3) was then used to evaluate energy consumptions of the materials in the manufacturing process.

3.3 EnergyPlus modeling

EnergyPlus is a energy simulation tool which can be used to model hourly energy consumption of a building, subject to internal loads, schedules, user-specified construction, and weather (Kneifel 2010). The building energy simulations were run in EnergyPlus V7.1 (EnergyPlus 2012) to obtain the annual energy use in electricity and natural gas for heating and cooling. The results of energy savings, which were calculated by the multiplication between the data from EnergyPlus and the energy saving percentage cited from (Ottelé et al. 2011), were compared with the energy consumption results of Simapro to attain the balance years.

4 Lifecycle analysis of living walls

This study is trying to analyze raw material depletion, and energy consumption of living walls in their lifecycle stages, starting from the material manufacturing process to disposal options.

4.1 LCA inputs

This study analyzed a modular panel living wall. The components, density, and service life of the systems were quoted from (Ottelé et al. 2011) and listed in Table 1.

Table 1: Components, Material weight (Kg/m2), and service life (years) of living wall (Cited from Ottelé et al. (2011)).

System Name	Components	Material	Weight (Kg/m^2)	Service Life (years)
Modular Panel System	Bolts	Steel S235	0.27	50
	Spacer brackets	Steel S235	0.315	50
	Supporting U section	Steel S235	4.62	50
	Planter boxes	HDPE	13.2	50
	Watering system	PE	0.26	7.5

The maintenance, type of living wall, and weather conditions are relevant to the lifespan of the living walls. In this study, the service life of the modular panel living wall is based on the components of the system. The steel materials are estimated to have a lifespan of 50 years(Ottelé et al., 2011), the service life for the plastic (HDPE) planter box is assumed 50 years based on the study conducted by Riedmiller and Schneider (1992), and watering system have to be replace every 7.5 years because of crystallizing of salts ((Ottelé et al., 2011).

The data listed in Table 1 was used in Simapro to analyse the energy consumption of the modular living wall system. The energy savings of the modular panel living wall were calculated in three steps:

(1) The percentage of energy saving with the use of living walls was calculated based on Ottelé et al. (2011). (2) The energy consumption of a standard building was evaluated by the EnergyPlus simulation. (3) The total energy savings of a building, due to living walls, were obtained by multiplying the results of step one and step two. The results of step three were used to calculate the required time period to balance the initial energy usage in the material production with the energy savings in the operational phase.

4.2 Study results

Comparative analysis of energy consumption of living walls in the material manufacturing process and energy savings in the operations phase, are presented below. According to SimaPro inventory result, Table 2 lists all the energy requirements, from different energy sources, to make 1 Kg of each component of living walls.

Table 2: Amount of substances released due to the production of 1Kg material (Derived from SimaPro results).

Substance	Unit	Steel S235	PE	HDPE
Energy, from biomass	kJ	x	x	x
Energy, from coal	kJ	x	2793.17	x
Energy, from coal, brown	kJ	x	0.04	x
Energy, from gas, natural	kJ	x	27400.57	x
Energy, from hydro power	kJ	x	x	x
Energy, from hydrogen	kJ	x	x	x
Energy, from oil	kJ	x	38149.82	x
Energy, from peat	kJ	x	14.97	x
Energy, from uranium	kJ	x	3126.72	x
Energy, from wood	kJ	x	0.02	x
Energy, geothermal	kJ	x	x	x
Energy, geothermal, converted	kJ	x	27.30	x
Energy, gross calorific value, in biomass	kJ	198.97	x	313.28
Energy, kinetic (in wind), converted	kJ	53.36	15.87	0.19
Energy, potential	kJ	1200.30	583.21	585.33
Energy, solar, converted	kJ	0.78	0.10	0.00
Energy, unspecified	kJ	x	x	x
Total	MJ	1.45	72.11	0.90

By the combination of Table 1&2, the energy consumed in the material manufacture process could be calculated. In order to evaluate the time required for a living wall to balance the initial energy consumption in the manufacturing process, the energy savings of living walls was calculated according to the results of EnergyPlus Program and the saving percentage from (Ottelé et al. 2011). The balanced year is calculated according to the results above and listed in Table 3.

Table 3: Years needed to balance the energy consumption in manufacture process

Modular panel system		
Total energy required (GJ)		30.13
Energy saving percentages	Heating	6.30%

(Cited from (Ottelé et al., 2011))	Cooling	43%
Building energy consumption (GJ) (Derived from EnergyPlus results (EnergyPlus, 2012))	Heating Cooling	6.7 23.9
Balance year		3

5 Discussion of results

As it is shown in Table 3, the modular panel system only needs 3 years to balance the energy consumed in the manufacture process. Obviously, climatic conditions have a strong impact on the performance of living walls. Alexandri and Jones (2008) also concluded that energy savings by living walls in a tropical climate (Brasilia) could be as much as 68% and only 37% in a cold climate (Beijing). Thus, the living wall is a potential application to use broadly in warmer climates, to save cooling energy. In a cooler climate, modular panel systems is a better option than trellis systems as more heating energy can be saved.

The building facade, location, maintenance, and durability are all factors which can impact the final construction cost. Perini et al. (2011b) stated a range of costs for living walls in Europe: i.e. a trellis system 40-75€/m^2, a modular panel (HDPE) system 400-600€/m^2, and felt layer system 350-750€/m^2. In BC Canada, an architect from Sharp & Diamond Landscape Architects, who installed two of Metro Vancouver's most significant living walls, estimated that living wall systems cost $70-$150 per square foot (SORENSEN 2009). The application of living walls is affected by the high price, although the long term benefits of living wall can easily cover the initial cost (Wong et al. 2003). In order to green a urban city with green roofs, city of Toronto passed a by-law, starting on 31st January 2011, which requires industrial buildings render 10% or 2000 m^2 of their roofs green (Lewington 2009). In Vienna, Austria, the subsidies and grants are offered for green roof installations to guarantee proper maintenance and use. In 1989, the municipal by-law was passed in Stuttgart, Germany to enforce the installation of a grass roofs on all flat-roofed industrial buildings (Peck et al. 1999). If a similar government policy or program support is available for green wall installations, the popularity and market price of living walls would be changed gradually.

Some limitations existed in this study that need further research work. In the LCA, only the manufacturing process was considered. However, the transportation process might have larger energy consumption than the manufacturing process, if the materials need to be delivered from a distant location. On the other hand, the end of life disposal process might offset the energy consumption in the upstream process, as some components of the living walls can be reused or recycled, thus avoiding the production of new materials.

This study analyzed the Living walls' performance only in one type of weather condition, and a single building type was considered. In reality, there are a wide variety of building types. The Commercial Buildings Energy Consumption Survey (CBECS) separated the commercial sector into 29 categories and 51 subcategories, and the energy consumption for cooling and heating are totally different among these categories (Deru et al. 2011). Furthermore, the orientations of buildings, the locations of living walls, and the eco-regions are other identified parameters that will influence the energy saving of buildings (Gratia and De Herde 2007). All these parameters should be expanded for more representative results.

6 Conclusion

The results of this lifecycle analysis create vivid description of the environmental impact of living wall materials. The materials needed to build up living walls are important because they can directly change the environmental impact of living wall systems. The LCA results show that the modular panel system only needs 3 years to balance the energy consumed in the material manufacturing process. The LCA indicated the need for environment-friendly materials for sustainable living walls. The comparative analysis also showed that the climatic conditions, building types, and plant categories might impact the energy saving and air cleaning performance. Finally, the government policy and program support should be implemented to overcome the cost barrier for constructing living walls.

Reference

Alexandri, E., Jones, P., 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building Performance Simulation 43, 480–493.

Aydogan, A., Montoya, L.D., 2011. Formaldehyde removal by common indoor plant species and various growing media. Atmospheric Environment 45, 2675–2682.

Brown, R.D., Gillespie, T.J., 1995. Microclimatic landscape design: creating thermal comfort and energy efficiency. Wiley.

Cacciatore, P., Hogan, J., Mattern, R., Munoz, A., 2010. Best Practices Manual : Landscape Architecture.

Castleton, H.F., Stovin, V., Beck, S.B.M., Davison, J.B., 2010. Green roofs; building energy savings and the potential for retrofit. Energy and Buildings 42, 1582–1591.

Cheng, C.Y., Cheung, K.K.S., Chu, L.M., 2010. Thermal performance of a vegetated cladding system on facade walls. Building and Environment 45, 1779–1787.

Currie, B.A., Bass, B., 2008. Estimates of air pollution mitigation with green plants and green roofs using the UFORE model. Urban Ecosystems 11, 409–422.

Deru, M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., Liu, B., Halverson, M., Winiarski, D., Rosenberg, M., 2011. U.S. Department of Energy Commercial Reference Building Models of the National Building Stock.

Dunnett, N., Kingsbury, N., 2004. Planting green roofs and living walls. Timber Press Portland, OR, U, S, A.

Dvorak, B., Volder, A., 2010. Green roof vegetation for North American ecoregions: A literature review. Landscape and Urban Planning 96, 197–213.

EnergyPlus, 2012. EnergyPlus Example File Generator [WWW Document]. URL http://apps1.eere.energy.gov/buildings/energyplus/cfm/inputs/

FLORAFELT, 2013. VERTICAL GARDEN IRRIGATION GUIDE [WWW Document]. URL http://www.plantsonwalls.com/v/vspfiles/img/docs/Florafelt_Vertical_Garden_Irrigation_Guide.pdf

Franco, A., Fernandez-Canero, R., Perez-Urrestarazu, L., Valera, D.L., 2012. Wind tunnel analysis of artificial substrates used in active living walls for indoor environment conditioning in Mediterranean buildings. Building and Environment 51, 370–378.

Gratia, E., De Herde, A., 2007. Greenhouse effect in double-skin facade. Energy and Buildings 39, 199–211.

Greenovergrey, 2011. what are living walls [WWW Document]. URL http://greenovergrey.com/living-walls/what-are-living-walls.php

Gsky, 2010. Pro Wall System [WWW Document]. URL http://gsky.com/green-walls/pro/

Kneifel, J., 2010. Life-cycle carbon and cost analysis of energy efficiency measures in new commercial buildings. Energy and Buildings 42, 333–340.

Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C., Crowley, D., 2011. Biochar effects on soil biota - A review. Soil Biology and Biochemistry 43, 1812–1836.

Lewington, J., 2009. Council approves stringent green-roof rules [WWW Document]. Global and Mail Canada. URL http://www.theglobeandmail.com/news/national/council-approves-stringent-green-roof-rules/article4211599/

Liu, K., Baskaran, B., 2003. evaluation THERMAL PERFORMANCE OF GREEN ROOFS 1–10.

Loh, S., 2008. Living walls - A way to green the built environment. BEDP Environment Design Guide ACT 1–7.

McCarty, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S., 2001. Climate Change 2001. Impacts, Adaptation, and vulnerability.

Nichols, M., Savidov, N., Aschim, K., 2010. Biochar as a Hydroponic Growing Medium. Practical Hydroponics and Greenhouses 39.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R.R., Doshi, H., Dunnett, N., Gaffin, S., Köhler, M., Liu, K.K.Y., Rowe, B., 2007. Green Roofs as Urban Ecosystems: Ecological Structures, Functions, and Services. BioScience 57, 823.

Ottelé, M., Perini, K., Fraaij, A.L. a., Haas, E.M., Raiteri, R., 2011. Comparative life cycle analysis for green façades and living wall systems. Energy and Buildings 43, 3419–3429.

Peck, S., Callaghan, C., Kuhn, M., Bass, B., 1999. Greenbacks from green roofs: forging a new industry in Canada.

Perez, G., Rincon, L., Vila, A., Gonzalez, J.M., Cabeza, L.F., 2011. Behaviour of green facades in Mediterranean Continental climate. Energy Conversion and Management 52, 1861–1867.

Perini, K., Ottele, M., Fraaij, A.L.A., Haas, E.M., Raiteri, R., 2011. Vertical greening systems and the effect on air flow and temperature on the building envelope. Building and Environment 46, 2287–2294.

Perini, K., Ottelé, M., Haas, E.M., Raiteri, R., 2011. Greening the building envelope, façade greening and living wall systems. Open Journal of Ecology 01, 1–8.

Pérez, G., Rincón, L., Vila, A., González, J.M., Cabeza, L.F., 2011. Green vertical systems for buildings as passive systems for energy savings. Applied Energy 88, 4854–4859.

Riedmiller, J., Schneider, P., 1992. Maintenance-free roof gardens: new urban habitats. Naturwissenschaften 79, 560–1.

Santamouris, M., Pavlou, C., Doukas, P., Mihalakakou, G., Synnefa, a., Hatzibiros, a., Patargias, P., 2007. Investigating and analysing the energy and environmental performance of an experimental green roof system installed in a nursery school building in Athens, Greece. Energy 32, 1781–1788.

Schwab, A.P., Al-Assi, A., Banks, M.K., 1998. Adsorption of naphthalene onto plant roots. Journal of environmental quality 27, 220–224.

SORENSEN, J., 2009. Cost concerns for increasingly popular green walls [WWW Document]. Daily Commercial News. URL http://dcnonl.com/article/id35275

Spence, R., Mulligan, H., 1995. Sustainable development and the construction industry. Habitat international 19, 279–292.

Tam, C.., Tam, V.W.., Tsui, W.., 2004. Green construction assessment for environmental management in the construction industry of Hong Kong. International Journal of Project Management 22, 563–571.

The Economist, 2004. The Rise of the Green Building. Economist.

USDOE, 2012. 2011 Buildings Energy Data Book [WWW Document]. URL http://buildingsdatabook.eren.doe.gov/docs%5CDataBooks%5C2011_BEDB.pdf

Weinmaster, M., 2009. Are Green Walls as green as They Look? An Introduction to the Various Technologies and Ecological Benefits of Green Walls. Journal of Green Building 4, 3–18.

Wolverton, B., Wolverton, J., 1993. Plants and soil microorganisms: removal of formaldehyde, xylene, and ammonia from the indoor environment. Journal of the Mississippi Academy of Sciences 38, 11–15.

Wong, N.H., Tay, S.F., Wong, R., Ong, C.L., Sia, A., 2003. Life cycle cost analysis of rooftop gardens in Singapore. Building and Environment 38, 499–509.