UBC Social Ecological Economic Development Studies (SEEDS) Student Report

An Investigation into the Application of Vertical Garden

at the New SUB Atrium

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ABSTRACT

"A triple-bottom-line assessment on installing a vertical garden on the new Student Union Building and its inspirational impact"

By Kevin Shiah, JeongWoo Kim

In 21 Century, one of the biggest challenges is to bring the nature into urban areas and perhaps, the most effective and spectacular resolution is the vertical garden. In response to AMS Design Committee's goal of inspiring students and visitors, this report investigates the potential feasibility and inspirational factors of installing vertical gardens on the new Student Union Building (SUB) at the University of British Columbia. A vertical garden, also known as a green wall, is basically an interior or exterior wall that is completely or partially planted with vegetations.

A triple bottom line assessment is performed to examine the environmental, social, and economic influences of installing the vertical garden. After collaborative research and analysis, it is concluded that installing the vertical garden will not only improve the new Student Union Building aesthetically but also provide a good role model to the city of Vancouver on how future buildings can be constructed with vertical gardens installed. Most importantly, it will raise the public awareness in green features of the vertical garden to the building users and visitors.

Nowadays, the concepts of environmentally friendliness and sustainability earn more attention from the world. Being one of the leading institutions that advocate this sustainability concept, it is recommended to install the vertical garden on the new Student Union Building.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

GLOSSARY

Absenteeism:	Frequent absence from work or study without a reason.
Biofiltration:	The process of removing and oxidizing organic from polluted air using biofilter medium such as soil.
Cardiovascular Disease:	Heart disease.
Chlorofluorocarbons:	A chemical compound that contains that carbon, chlorine, and fluorine, which damages the ozone layer when released into the atmosphere.
Noise Reduction Coefficient	Also known as noise reduction coefficient. It is a scalar presentation of the amount of sound energy absorbed after reflecting from a certain surface.

LIST OF ABBREVIATIONS

AMS	Alma Matter Society
HVAC	Heating, Ventilation, and Air Condition
IAQ	Indoor Air Quality
NRC	Noise Reduction Coefficient
SBS	Sick Building Syndrome
SUB	the Student Union Building
UHI	Urban Heat Island
UBC	the University of British Columbia
VOC	Volatile Organic Compounds

1.0 INTRODUCTION

A vertical garden is planted vegetations spread over a surface of a terrain bordered vertically (Figure 1). The concept of the vertical garden was first used in 600 BC with the Hanging Gardens of Babylon. The first vertical garden in Canada was introduced at the Canada Life Centre - Environmental Room in downtown Toronto in 1994. Today, with the rapid growth of industrial cities, where fifty percent of the world`s population dwell, plants can provide better air quality, in the mean time sustaining the well being of the environments, human health and the psychological aspect. As urban areas become more crowded than ever, many city centres today are finding areas for plants in order to transform the CO_2 produced by cars and building heating into oxygen and carbon hydrates (Lambertini, A., & Ciampi, M., 2007). However, in an urban context, the solutions often require a large area of unoccupied land. The concept of vertical garden provides the best solution.

Figure 1. Examples of Vertical Garden 1

Source: www.yourkloset.com/lifestyle/green-berets/the-wall-of-the-living/

This report investigates the feasibility and the impacts of the installation of the vertical garden on an exterior wall of the new Student Union Building at the University of British Columbia, which is expected to be completed by September 2014. This report includes a triple-bottom-line assessment which researches and analyzes the social impacts, environmental impacts, and economic impacts. Moreover, this report also analyzes the further concerns and barriers that the AMS Design Committee can use as a reference.

2.0 SOCIAL ASSESSMENTS

Social assessment involves everything from psychological impact to aesthetic impact to health impact. Basically, any human behaviors and activities associated with the vertical garden is discussed and evaluated in this section. By and large, vertical garden seems to provide much more positive impacts than negative impacts.

2.1 Psychological Impact

Psychological impact is often very hard to quantify and based on subjective responses. However, when a number of studies show certain benefits to be present in its participants, it is safe to say that those benefits are true and objective. Biophilia, meaning affection to nature, is natural to humans as humans have lived with nature dating back to stone ages. (Butkovich et al, 2008) It is not uncommon to see people pack their bags and leave for outdoors, where nature is predominant with green plants. They do not leave because they are bored with city life. Rather, living in urban environment limits interaction with nature and increases depression and anxiety. (Darlington et al, 2001) In fact, there is a field of horticulture therapy that promotes plant-human relationships to induce relaxation and to reduce stress, fear, anger, and blood pressure and muscle tension. (Brown et al, 2004) In addition, vertical gardens have demonstrated that restorative effect of natural scenery holds the viewer’s attention, diverts their awareness from themselves and from worrisome thoughts and elicits a meditation-like state. (Peck et al, 1999) The retired elders who are in their 60s and 70s are easily the most affectionate and emotional to their garden. The benefits of garden can be discovered in workplace settings. Professor Fjeld’s study shows that an inclusion of green plants in offices and work environment has resulted in 5-15% reduction in absenteeism. Another study by Professor Lohr has demonstrated that plants inside classrooms reduce the stress level and 12% increase in productivity of students. (Butkovich et al, 2008) Given above benefits, it comes as no surprise that people in general prefer natural scene dominated by vegetation more than urban scene lacking vegetation. Also, having plants in buildings can increase social skills by contributing to more supportive patterns of interrelations among its residents. (Almusaed, 2011)

2.2 Aesthetic Impact

A vast number of buildings in urban setting is covered with cements and bricks, scoring little to zero artistic appeal. Often times, the sculptures are carved and patterns are embedded to give little more life to a building. Having vertical garden at the wall eliminates those gray, dull decorations and provides a fresh and vigorous life to the buildings. Vertical garden offers plants and smaller animals suitable habitats, improving biodiversity in the built environment. (Ottele, 2010) Increased green amenity space means that the bad designs can be disguised and become unnoticed. (Peck et al, 1999) Aesthetic impact of vertical garden is evident inside the building as well. Buildings with interior planting are view as more expensive-looking, more welcoming to its residents. (Smith et al, 2010)

2.3 Health Impact

Arguably, health impact of vertical garden is what most of people can experience and be relevant to their time spending around it. (Butkovich et al, 2008) Each year Sick Building Syndrome (SBS) is costing American economy 15 to 40 billion dollars. SBS is a collection of non-specific symptoms such as eye, nose, skin and throat irritations, headache, fatigue, and skin rashes. The nature of disease makes it impossible to find a perfect cure for its patients. Having vertical garden can reduce indoor volatile organic compounds (VOCs) and other compounds linked to SBS. (Butkovich et al, 2008) VOCs and other particulate matters are also found to decrease lung functions, increase respiratory problems as well as cardiovascular diseases. (Ottele, 2010) From physiological point, vertical gardens can elicit a wakeful and relaxed state characterized by a decreased heart rate and a quicker stress recovery time. (Peck et al, 1999) The symptoms such headache are reduced by at least 20% or more, depending on the nature of symptoms. (Bringslimark et al, 2009) Humidity Level is also an important factor in a working environment. The humidity between, 45-65% is range for the comfortable environment. (Cooney et al, 2004) Noise is another indoor environmental factor that affects occupants’ comfort. It has been well established that noisy environments are stressful, frustrating, and prevent people from working at their best capacity. (Huang, 2011) Installation of vertical garden can act as another layer to absorb noise from outside as well as inside the building. Moreover, the white noise produced by wind moving through the branches and leaves of vertical garden can play a positive role in occupants’ well-being. (Peck et al, 1999)

2.4 Job Opportunities

Vertical garden for some reason is not as popular in Vancouver as it should be. Given the biodiversity and its abundance of resources, there are only a handful of vertical gardens including the one in Vancouver Aquarium. If this vertical garden technology presents a new business opportunity, the market will grow exponentially. Aside from a plenty of resources, buildings in Vancouver seriously lack any aesthetic appeal. On top of aesthetic appeal, economic benefit will entice residents to implement to their homes and buildings. Given its versatility of the technology, rehabilitation of old buildings, with more colours and textures for designer to use, is readily easy to do. (Ibanez, 2010) As it is the case in Europe, especially Germany, green market is growing rapidly 20-30% a year. (Peck et al, 1999) Therefore it is not hard to imagine that vertical garden will create a new job opportunities for Vancouver, spreading out to rest of Canada.

3.0 ENVIRONMENTAL ASSESSMENT

To fully comprehend the feasibility of installing the vertical garden to the New SUB Atrium, some environmental factors have to be considered. In this section, the environmental aspects of the vertical garden are discussed. Such assessments include the locations of installation, plant choice, and the impacts on the environment. In addition, the impacts can be divided up into the direct and the indirect categories. The following is a detailed explanation of the listed assessments, and how these environmental factors are beneficial and inspirational to the users of the New SUB.

3.1 Locations

The location of installation of the vertical garden is as important as the functions of it. Figure 3 is the front design layout of the New SUB Atrium. Label 1, 2, and 3 are the potential locations for installing the vertical garden. Location 1 is glass windows, and it cannot be covered entirely with plants. Thus, the vertical garden can be constructed between the floors, where the glass will not be covered while blocking direct sunlight at noon. Location 2 is a wall with windows located partially. Therefore, a thin layer of vertical garden can be installed as long as they do not affect the windows. Location 3 is at the top of the building. There seem to be a large available space for the vertical garden.

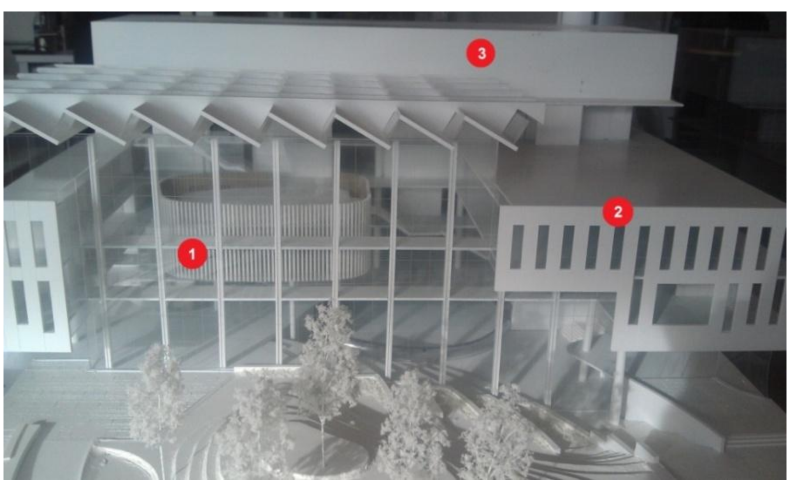

Figure 2: Locations of the Vertical Garden

3.2 System Choice and Plant Choice

There are two major types of vertical garden: Living Wall and Green Facade. The living wall is a kind of vertical garden in which vegetations are pre-planted onto panels or planters. These panels and planters are then installed vertically to a frame on a structure (Lambertini, A., & Ciampi, M., 2007). This type of vertical garden allows a wilder diversity of vegetations. Due to this reason, it has less resistance against Vancouver's windy and rainy weather, and requires constant maintenance. Thus, the living wall will not be considered in this case. Figure 3 is an example of a living wall.

Figure 3: Living Wall Example

Source: tournesolsiteworks.com

Green Façade is another kind of vertical garden in which climbing vegetations are designed and trained to grow and cover a designated supporting structure. Metal frames, square panels, and cable systems are the options for the supporting structure.

Figure 4 is an example of green façade. The purpose of these supporting frames is to keep the vegetation off the wall surface so that they will not damage the exterior and will provide easy access during building maintenance. These self-clinging vegetations can be rooted in the ground or in hanging planters. In this case, each supporting frame (each block), will be 1 m in width, 1 m in height, and 30 cm in depth, and the entire vertical garden will be constructed with combination of blocks. English Ivy is suitable for living in a temperature between 5~25 Celsius and temporarily surviving extreme condition of -10 ~ 40 Celsius (Lambertini, A., & Ciampi, M., 2007). In conclusion, the combination of English Ivy and Green Façade system can be considered in constructing the vertical garden.

Figure 4: Green Façade Vertical Garden of Ivy Growing on Supporting Frames

Source: www.nytimes.com

3.3 Direct Environmental Impacts

The vertical garden has a high possibility for positive environmental change in the New SUB area; especially it is very close to the UBC Bus Loop and the heavy traffic

Westbrook Mall. These beneficial influences are reduction of UHI effect, improvement of air quality, improvement of energy efficiency, and noise reduction.

3.3.1 Reduction of Urban Heat Island Effect

The UHI effect is the increment in temperature caused by the modification of the land by construction of new buildings. The materials used on the modern buildings, such as concrete and wood, trap heat and reduce the air flow in the city. This effect will occur once the New SUB is constructed as it will locate closely with the old SUB and the UBC Aquatic Centre. The vertical garden is capable of promoting natural cooling process. This is achieved by breaking the vertical air flow, which cools down the air as the vertical circulation slows down. (Green Roofs for Healthy cities, 2008) Moreover, the vertical garden simply provides shading to the surface of the building, thus it absorbs less heat.

3.3.2 Improvement of Air Quality

Chemical particles such as NO_2, SO_2, VOC, and CO are harmful to human body. The emission of such particles has increased around UBC in the past decade (Ibanez, 2010) The vertical garden can filter these hazardous gases by capturing airborne contaminants and depositing them on leaf surfaces. On the other hand, the overall CO_2 emission of the building can also be deducted as the vertical garden absorbs CO_2.

3.3.3 Improvement of Energy Efficiency

According to the assessment on renewable energy from previous year, lack of thermal insulation capacity of the SUB can be one of the biggest factors that decrease the energy efficiency. The vertical garden simply reduces the surface temperature of the building by limiting the heat flux going through the wall (Bass, 2007). On the other hand, air itself is a good insulator, by installing the vertical garden, a gap of air is formed between the garden and the wall. As describe above, the vertical garden slows down the vertical movement of heat. Therefore, the heat is trapped during cold weather, and is insulated during hot weather. Table 1 shows the average energy consumption of a five story building with and without the installation of the vertical garden (Binabid, J., 2010).

Energy Consumption	Average Energy Consumption (kWh)	Average Energy Consumption with Vertical Garden Installed (kWh)
Heating from Natural Gas	220,000	216,000
Cooling from Electricity	78,000	66,000
Lighting from Electricity	27,000	27,000
Hot Water from Natural Gas	70,000	70,000
Total	395,000	378,000

Table 1 Average Energy Consumption of a Five-Level Building with and without Vertical Garden

3.3.4 Noise Reduction

The vegetations and the soil in the vertical garden will also contribute to improving the sound insulation and reducing sound reflection. The soil itself is a superb noise absorber. The noise reduction coefficient, NRC, is a scalar indication of the total absorption of sound energy after reflecting from a certain surface. A 1 represents a perfect absorption; a 0 represents a perfect reflection. The traffic noise frequency ranges from 100Hz to 1300Hz. This range includes tire/road noise, exhaust noise, and horn sound. At 1000Hz, a painted concrete wall has NRC of 0.07; an ordinary window glass has NRC of 0.03; plywood has NRC of 0.1. Whereas soil has a high NRC of 0.64 and a dense-planted grasses surface has NRC of 0.23 (*Absorption Coefficient Chart*). Thus, the vertical garden significantly complements the low NRC of the building.

4.0 ECONOMIC ASSESSMENT

Every technology is bound to be decided on whether it can be profitable or not. Economic assessment evaluates the possible ways that a technology can retrieve its capital cost and stay profitable over its lifespan. The initial installation cost can vary from $100 per square foot to $1200 per square meter.(Curtis 2010; inhabitat,2007) However, vertical garden presents a number of ways to be financially beneficial and be a feasible option for new SUB building.

4.1 HVAC Systems

In the urban environment, a phenomenon known as Urban Heat Island effect is common in concrete buildings. At daylight, heat is absorbed by the building and stays captured in the building. As a result, the building temperature rises above its surrounding and becomes a heat island. (See Figure 5 below)

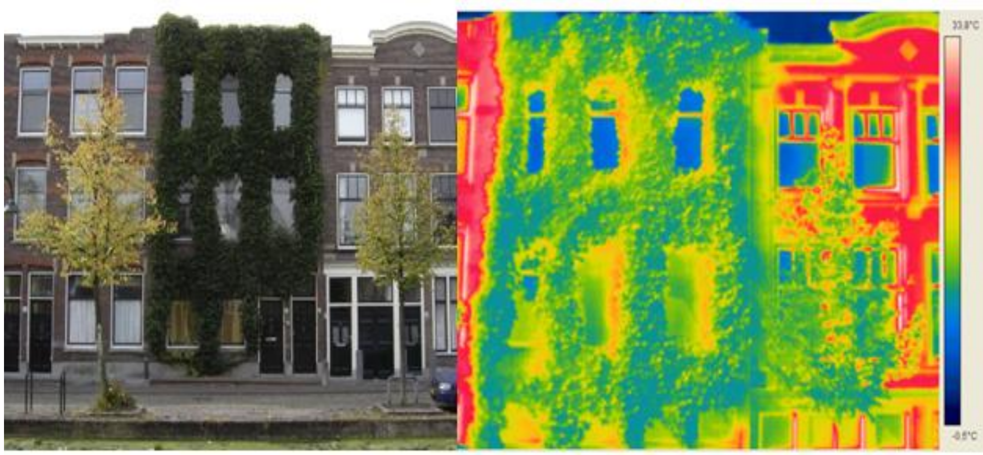

Figure 5: Urban Heat Island Effect, (Ottele, 2010)

It is no secret that the occupants will suffer from a high temperature and have to use air-conditioning emitting Chlorofluorocarbons and other GHGs. Also the electricity is produced by burning fossil fuels generating sulfur dioxide, nitrous dioxide harmful to respiratory system. For Vancouver, having vertical garden can reduce the energy for air-conditioning as much as 30%. (Bass, 2001) This is possible because vertical garden can act as a plant canopy and by the evapo-transpiration of plants. Evapo-transpiration simply means cooling effect by evaporation of water on the leaves. For instance, 2.5MJ energy is needed to evaporate 1kg of water. (Ottele, 2010) In summer, plants can store energy to lower the temperature of the shaded surface and regulate humidity at night by trapping air and in winter, plants can insulate and gives off heat to minimize temperature drop. (Bass, 2007) As a plant canopy, vertical garden can mitigate wind effect by decreasing wind chill factor by 75% and heating demand by 25%. (Peck et al, 1999) In numbers, potential savings during the peak energy requirements in the heat of summer and the cold of winter are estimated to be 0.24 and 0.4 KW per occupant respectively. (Darlington, 2004)

4.2 Stormwater Management

Vertical gardens are not as effective as green roofs when it comes to stormwater management. This is due to its design characteristics and location on the side walls of building. Under heavy rain and strong wind, vertical garden is able to interrupt and delay run-off to some extent. For grey water treatment, vertical garden can clean and filter the water through a system of planters filled with swam grasses and aquatic plants (Peck et al, 1999) Also, Hydroponic system in vertical garden can store rainwater and use it as a nutrient for plants to grow. Consequently, less water goes to the sewage. (Ottele, 2010)

4.3 Biofiltration of Indoor Air Quality

Canadians spend more time indoor as much as 80 %of their time on a daily basis. (Butkovich et al, 2008). It is imperative to have a good Indoor Air Quality (IAQ). Vertical garden inside the building can act as a bio-filter as well as oxygen-generator. For instance, 25 m^2 of leaf surface area can produce 27g of oxygen per hour during the day, equal to human consumption and 150 m^2 can balance human intake for one year. (Peck et al, 1999) This is just a huge amount of oxygen produced by a small leaf. If there are plants, not just the leaves, are present at a reasonable size, its impact is very powerful. In addition, 60m^2 of vertical garden can filter 40 tons of harmful gases and process 15kg of heavy metals. (Vertical Ecosystems, 2011) Inside the building, VOCs, benzene, toluene and other toxic fumes are degraded by plants. (Darlington et al, 2001) These benefits will greatly impact and help people suffering from asthma and other respiratory diseases. In terms of energy savings, 3.5kw per person can be saved at peak seasons. (Cooney et al, 2004)

4.4 Other Economic Impacts

Vertical garden is not only a money-saving, but also a money-making feature for a building. It is a widely spread misconception that vertical gardens will damage the wall. What really happens at the wall of buildings is that vertical garden can actually protect building material from UV radiation, driving rain, ice accretion, tear cause by moisture, and temperature difference. For maintenance, little is need once the plants have established. (Peck et al, 1999) If a section of vertical garden fails to thrive or dies, panels can be easily popped from their slot and replace without interfering rest of the structure. (Canwest 2008) However, the vertical garden becomes a financial burden, energy wasting, unappealing and destructive if it is not maintained properly. (Binabid, 2010) This is very unlikely to happen unless it is purposely left to be untouched. Lastly, American and British Studies show that having a green plant can increase the value of property by 6-15%. (Peck et al, 1999) Thus, the new SUB building’s property value will increase even more with the vertical garden.

5.0 Concerns and Barriers

Even with all positive and beneficial aspects of vertical garden, there are barrier and concerns making this technology very slow to spread. How these barriers and concern can be resolved is the key to a wide-adoption of vertical garden.

5.1 Barriers for wide-adoption

In his report, Peck et al (1999) has stated that even with all the benefits of vertical garden, there are barriers that prevent this new technology from being used. There are four barriers presented in the report are as following:

-Lack of knowledge and awareness

-Lack of incentives to implement

-Cost-based Barriers

-Technical Issues and Risks associated with Uncertainty

These four barriers are closely related to each other. For instance, Lack of knowledge and awareness leads to technical issues and ricks associated with uncertainty. This can be solved by conducting more researches on vertical gardens and its application in urban setting. Once these two barriers are overcome, inevitably the government will promote using the technology by giving out incentives in a similar fashion to hybrid cars.

Also, similar to hybrid cars, people are willing to pay for premiums upfront if they view the technology beneficial. (See Figure 6 below)

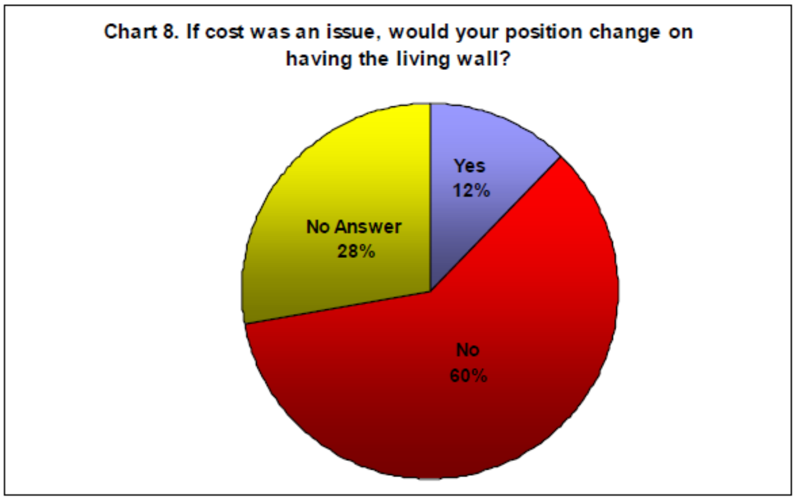

Figure 6: Perception on cost of vertical garden (Knowles et al, 2002)

Therefore, cost-based barriers will also be overcome over time as energy-saving becomes more and more intrinsic property of our homes and buildings without compromising the use of fossil fuels.

5.2 Concerns

The concerns for vertical garden are mostly associated with the plants themselves. It is possible to have unpleasant odour and airborne diseases spread by pollen, dusts and other contaminants from having plants indoor. This can be solved by carefully choosing the right plants for indoor and make sure nothing allergic is present. Also, insects can be another factor to not have plants indoor but most of the insects will have a hard time finding foods indoor. (Peck et al, 1999)

6.0 CONCLUSION

After the triple-bottom-line assessment on the social, environmental, and economical impacts of the vertical garden on the New SUB at the University of British Columbia, it can be concluded that the vertical garden is beneficial in social, environmental, and economical aspects. Therefore, the installation of the vertical garden is recommended

The vertical garden implemented at the New SUB will inspire UBC students and visitors by the green features of the vertical garden. While all the benefits of installing a vertical garden is shown, public will then be motivated to extensively apply the concept of the vertical garden. Consequently, more vertical gardens will be constructed and, thus, the goal of improving the environment is achieved.

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Appendix

Table 1
Overview of the reviewed studies with regard to research design, subjects and setting, experimental manipulations, exposure duration, outcome measures and results as reported.

Study	Research design	Subjects and setting	Experimental manipulations	Duration of plant exposure	Outcome measures	Effects of plants as reported
Talbott et al., 1976	Single-group quasi-experiment with multiple observations before and after intervention	15 people with severe psycho-pathology, able to eat in a hospital dining room	(1) 4-week control period with normal dining room setting, then (2) 4-week test period with 1 vase yellow chrysanthemums on each dining room table	Lunch periods during 4-week test period	Vocalization, social gazing, seating location, time in the room, amount of food consumed	Significant but transient increase in vocalization; significant increase in mean time spent in dining room and food consumed
Shoemaker et al., 1992	Non-equivalent groups quasi-experiment with 3 measurement points	Workers in private and open offices (number not clear, but 157 or more); only 14 completed all 3 surveys	Removal of personal plants, followed after 3 months by (1) plantscaping (1–3 desk- or floor-sized plants for private offices; planters and desk- or floor-sized plants for open areas), or (2) installation of artwork and then plantscaping 6.5 months later	Workdays over (1) 6.5 + 3 months or (2) 3 months	Job satisfaction, assessment of workspace, attitudes toward plants and artwork	No significant effects of plants between conditions, across measurement points or at any one measurement point, but a positive attitude toward plants
Coleman & Mattson, 1995	Within-subjects design with 3 repetitions of a set of 4 sessions (baseline and then 3 treatment sessions); random assignment to the treatments in each set; repeated measures in each session	26 (of 30) students completed all 12 sessions, run in 3 compartments in a classroom	(1) One 25 cm foliage plant in front of the subject on a stool, (2) a life-sized photo of the same plant in front of the subject on the stool, (3) the stool alone, without plant or photo, (4) no-plant or stool baseline	20-min sessions twice a week for 6 weeks	ST	No significant effects
Lohr et al., 1996	Between-subjects design with treatment and control groups; not clear if subjects randomly assigned	81 students and 15 non-students in a large, windowless university computer lab	(1) 17 plants 25–225 cm high/long placed around the periphery of the computer lab, (2) no-plant control	ca. 10–15 min; estimate based on steps in procedure	Reaction time and errors in a shape-recognition task, BP, HR, ZIPERS	Treatment group had 12% faster reaction time; systolic BP change consistent with lower stress reactivity and faster stress recovery, higher reported attentiveness
Fjeld et al., 1998	Randomized crossover design with repeated measures in each condition	51 persons working in identical private offices, each with a large window	(1) 13 small foliage plants placed on window sill, 1 large (175 cm) plant in pot on floor in back corner with 4 smaller plants at its base, (2) no-plant control	Workdays spread over 3 months	Health and discomfort symptoms on the given day	Less fatigue, dry throat and cough, dry facial skin with plants; 21% lower total symptom score
Larsen et al., 1998	Between-subjects design with measures during plant exposure	71 students and 10 non-students; a university office	(1) 10 plants, filling 7.16% of cubic space in the room, (2) 22 plants, filling 17.88% of cubic space, (3) no-plant control	ca. 15 min for instructions and tasks, plus some minutes for a questionnaire at the end of the session	Timed letter identification task (a productivity measure), mood pictogram, room assessment	Office rated as most attractive with the highest number of plants; productivity lowest with the highest number of plants; no significant effect on mood
Adachi et al., 2000	Between-subjects design with pre- and post-test measures	53 students and 5 community members; a room at a university	(1) 3 vases with flowers, some fragrant, (2) 5 potted foliage plants, (3) no-plant control	ca. 20 min, during which subjects watched a video	Items derived from the Profile of Mood States (POMS), room assessment	Few significant mood effects; room with flowers rated more attractive than the no-plant condition and less 'off-putting' than the foliage condition

Fjeld, 2000 (Study 2)[a]	Single-group quasi-experiment with repeated measures both pre- and post-intervention	48 employees of a hospital radiology department; a large windowless room	Introduction of 23 containers with 1 or more foliage plants (up to 175 cm) and change to full-spectrum fluorescent lighting	Workdays spread over ca. 3 months	Health and discomfort symptoms on the given day	25.6% reduction in mean symptom score for group; amount of symptom reduction a function of exposure time, 34% for those who spent most and 17% for those who spent least time in room on a workday
Fjeld, 2000 (Study 3)[a]	Quasi-experiment with treatment and control groups, single measurement post-intervention	120 junior high school students; 3 intervention and 3 ordinary classrooms	(1) Large and smaller plants in a bioprocess system, full-spectrum fluorescent lighting with higher lux; (2) no-intervention control	Not clear; at most 1 year	Health and discomfort symptoms during the past week, room assessment	21% lower mean score for health symptoms in classrooms with plants; more positive evaluation of the classrooms with plants (more beautiful, brighter and more comfortable)
Lohr & Pearson-Mims, 2000	Randomized experiment with repeated measures	176 students, 22 university employees or community members; typical office space	(1) 5 plants in containers from 10 to 20 cm in size, (2) other decorative or colorful items, (3) no-plant control	ca. 17–20 min, with about 12 min before test of pain tolerance (CPT) and time for self-reports after the CPT	Pain tolerance, ST, BP, ZIPERS, room assessment	Higher pain tolerance; no significant effects on skin temperature or BP; higher scores on individual ZIPERS positive affect items before and after CPT; room assessed more positively (e.g., more pleasant)
Shibata & Suzuki, 2001	Randomized experiment with repeated measures	70 students; simulated office setting without windows	(1) Three plants from 15 to 30 cm, not in sight when working on task, (2) no-plant control	5 min during task, 3 min break, 5 min during task + time for a questionnaire	Key-response task, mood, fatigue, room assessment	Higher rate of correct response in 2nd task period with plants; no significant effects on mood or fatigue; room with plants rated more silent and smaller
Shibata & Suzuki, 2002	Randomized experiment with repeated measures of mood	146 students; laboratory setting with a curtained window	(1) One 100 cm high foliage plant 145 cm in front of the subject, (2) the same plant 145 cm to the side of the subject, (3) no-plant control	15 min + time for instructions and self-reports	Either word association or card sorting task; mood; assessments of task-performance, room effects, and plant	Among men, slightly fewer word associations in the no-plant versus plant-in-front condition; no significant effect on sorting task or change in mood from pre- to post-task
Kim & Mattson, 2002	Randomized experiment with repeated measures	150 students; windowless bio-monitoring laboratory	(1) Nine 15 cm pots of flowering geraniums with minimal scent, (2) nine 15 cm pots of same type of geranium but with flowers removed, (3) no-plant control	5 min following a 10 min stress induction procedure	EEG, EDA, ST, ZIPERS	Among highly stressed women, flowering geraniums promoted faster and more complete stress recovery, as seen in declines in beta activity and EDA; flowering geraniums also evoked greater increase in positive affect, less decline in attentiveness in women generally; no significant effects found for men

(*continued on next page*)

Table 1 (*continued*)

Study	Research design	Subjects and setting	Experimental manipulations	Duration of plant exposure	Outcome measures	Effects of plants as reported
Liu et al., 2003	Four period crossover design: randomization of treatments to time slots (weekday and hour) for each of 4 weeks and random assignment of subjects to a time slot, which remained the same across the weeks; repeated measures in each session	66 students; windowless bio-monitoring laboratory	(1) One 45 cm wide and high flower arrangement, (2) lavender fragrance diffused in room, (3) both flower arrangement and fragrance, (4) no-plant or fragrance control	30-min in each condition; one session per week	EEG (alpha and beta), EDA, ST, ZIPERS	Among women, comparisons of the control to the visual and olfactory exposures alone and in combination suggest lower levels of activation and negative affect with treatments, for particular minutes or subperiods of the exposure both before and after a mental task, but not consistently over the different physiological indices. Among men, the cut flower arrangement reduced fear, and the lavendar fragrance alone increased EDA for some minutes of exposure
Park et al., 2004	Randomized experiment with repeated measures	90 female students; simulated hospital patient room set up in windowless bio-monitoring laboratory	(1) 10 foliage plants, (2) 3 foliage plants and 7 flowering plants, (3) no-plant control	Approx. 10 min	Pain tolerance, self-ratings of pain intensity and pain distress, EEG, EDA, ST	With foliage plants alone, longer pain tolerance, lower self-ratings of pain intensity, lower EDA compared to no-plant control; with both foliage and flowering plants, longer pain tolerance, lower self-ratings of pain intensity and pain distress than both foliage plants alone and no-plant control
Shibata & Suzuki, 2004	Randomized experiment with repeated measures (mood only)	90 students; laboratory setting with a curtained window	(1) One 150 cm high potted plant ca. 200 cm in front of subject, (2) similarly sized rack with magazines ca. 200 cm in front of subject, (3) no-plant/ magazine rack control	Approx. 15 min	Association task, mood, assessment of feelings about the task, their own performance, the room, and effects of the room on their performance	Women had better task-performance with plant present than with magazine rack (though not better than controls), independent of mood; control subjects generally less confident and energized, across measures; plants rated more calm and tranquil, less distracting, than the rack with magazines
Khan, Younis, Riaz, & Abbas, 2005	Quasi-experiment with single post-test measure	222 masters and graduate students and 28 teachers at a college	Potted plants introduced into classrooms of the college	Class and other working time on up to and perhaps more than 30 work days	Self-reported change in indoor air quality, aesthetics, performance	Large majorities reported that the plants improved air quality, increased pleasantness, and helped improve performance
Chang & Chen, 2005	Within-subject experiment with three random orders of visual stimulus presentation	38 students; laboratory looking at photo simulations of office setting	3 window view conditions (nature view, city view, no window) crossed with 2 plant conditions (6 plants versus no plants)	Unspecified time for rating the office on a set of adjectives, then a 15 s period for simply viewing each slide, then time for filling in an anxiety inventory	EEG, facial EMG, BVP, state-anxiety	The combination of nature view and a plant engendered the lowest mean level of alpha activity as measured on the right side of the head; lower anxiety with plants present, especially if combined with nature view
Dijkstra, Pieterse, & Pruyn, 2008	Randomized experiment with single post-test measure, use of a scenario method to frame a rating task	77 students in an unspecified setting looking at a single photograph of a hospital room	(1) Hospital room with window onto urban environment, several small to large plants in view from the bed, (2) same room without plants	Not specified but presumably brief	Perceived stress and attractiveness of the given room	Perceived stress was lower and room attractiveness higher with the room with plants; the attractiveness of the room mediated perceived stress
Park & Mattson, 2008	Randomized experiment with repeated measures	90 appendectomy patients; 10 identical single-patient hospital rooms	(1) 12 potted foliage and flowering plants in view from the bed, (2) no-plant control	Multiple days of postoperative recovery	Length of stay in hospital from day of surgery; use of pain medication; BP, HR, respiratory rate, body temperature; self-reports of pain intensity, pain distress, fatigue, and state anxiety; room assessments	With plants, lower systolic BP and HR day of surgery and 1st day after surgery; less anxiety days 1–3 of recovery; less frequent analgesic intake, less pain intensity, distress, and fatigue 3 days after surgery; rooms rated more positively. No effects of plants for length of hospitalization, diastolic BP, body temperature, or respiratory rate during recovery
Park & Mattson, 2009	Randomized experiment with repeated measures	80 female thyroidectomy patients; identical single- and 6-patient rooms	(1) 12 potted foliage and flowering plants in view from the bed, (2) no-plant control	Multiple days of postoperative recovery	Length of stay in hospital from day of surgery, use of pain medication, BP, HR, respiratory rate, body temperature, self-reports of pain intensity, pain distress, fatigue, anxiety, room assessment	With plants, slightly shorter stay in hospital after surgery; less frequent analgesic intake 4–5 days after surgery; less pain intensity 3 and 5 days after surgery; less pain distress and fatigue 5 days after surgery; less anxiety over recovery days; rooms rated more positively. No effects of plants on BP, HR, body temperature, or respiratory rate during recovery

Abbreviations: BP – blood pressure; BVP – blood volume pulse; CPT – cold pressure test; EDA – electrodermal activity; EEG – electroencephalogram; EMG – electromyography; HR – heart rate/pulse; ST – skin temperature; ZIPERS – Zuckerman Inventory of Personal Reactions, which includes scales for positive affects, anger/aggression, fear, sadness, and attentiveness.

[a] The cited paper recapitulates the results of Fjeld et al. (1998) as Study 1.

Table 16.1 Different categories of green walls and roof

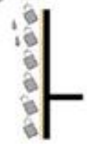
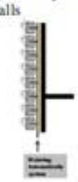
Criterions	Extensive green walls		Intensive green walls		Green roof
	Spots green suspended walls 	Compact green suspended walls 	Living walls 	Energetic biophilic walls 	
Effectively in architectural creation process	High, to create architectural elements composition	Middle, need a large conceptual process	Middle, need large conceptual process	High, efficiency in architectural integrality	Middle, limits in creation arts work
Potential	Low potential	Middle potential	Middle	High, in selection plants	High in selection plants
Visibility from the outside	High	High	High	High	Low
Fruit production	Low, or non	Low, just climbing plants	Low	Middle	High
Clean atmosphere	Low, limited green area	Middle, a large superficial 2 dimension green area	High, plants and vegetation, 3 dimension plants	High, very effective system	High, is recommendable for combat urban heat island phenomenon
Thermal insulation	Low, very diminutive	Low, diminutive	Middle, can be efficient	High, more efficient	High, excellent
Costs	Low cost	Middle, need a financial plan	Middle, need a financial plan	High, come into sight of building cost	High, come into sight of building cost
Plants utilized	Low, limited	Low, limited	Middle, numerous kinds of plants	Middle, numerous kinds of plants	High, a variety of kinds of plants

Table 16.1 (Continued)

Criterions	Extensive green walls		Intensive green walls		Green roof
	Spots green suspended walls 	Compact green suspended walls 	Living walls 	Energetic biophilic walls 	
Environment friendly	Low, is more decorative	Middle, need relationship between building and green areas	Middle, need relationship between building and green areas	High, green is a part of buildings model	High, green is a part of buildings model
Acoustical benefit	Low, or non	Low, diminutive	Middle, more efficient	High, is very effective	High, is very effective
Urban heat effects reduction	Low, employment	Middle, employment	Middle, employment	High, effective in combating the phenomenon act	High, effective in combating the phenomenon act
Recreation	Low, or non	Low, just visual	Low, just visual	Low, Just visual	High, can walk through the green areas