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Assessment of the Cooling Potential of an Indoor Living Wall using Different Substrates in a Warm Climate

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Key Words
Green walls · indoor environment · vertical greenery systems · vertical garden · substrate · temperature · humidity

Abstract
The use of vertical greenery systems in buildings is becoming very popular as they provide several benefits. In this work, the influence of an indoor living wall on the temperature and humidity in a hall inside the School of Agricultural Engineering (University of Seville) was studied. Four different substrates, Geotextile, Epiweb, Xaxim and coconut fibre, were used to grow the plants in order to assess their performance. Several parameters such as temperature, humidity, plant growth or water consumption were monitored and analyzed during a 4-month period. The cooling effect of the living wall was proven, with an average reduction of 4°C over the room temperature though maximum decrements of 6°C have been observed in warmer conditions. Higher air humidity levels were experienced near the living wall, increasing the overall humidity in the room. All the substrates tested were suitable for plant growing and their behaviour was similar. Geotextile showed the best cooling capacity but higher water consumption, coconut fibre presented degradation problems and Epiweb performance was the poorest. Therefore, these systems have been proven to be very useful and interesting for warm indoor environments due to the cooling effect observed in addition to their bio-filtration capacity and the aesthetic component.

Introduction

Vegetation plays an important role in our cities where the rampant urban development is causing many problems such as pollution, increased air temperature, lack of green

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space and excessive energy consumption. Following the concepts of sustainability, urban greening practices are becoming a popular way of reducing the undesired effects of increasing construction and achieving ecological goals. Nowadays, greenery systems offer the potential to incorporate advanced materials and new technologies to promote sustainable building functions [1].

Vertical greening systems also known as green wall technologies, vertical gardens or bio walls are vertical vegetated structures that may or may not be fixed to a building facade or to an interior wall. Based on the different plants and support structures used, these systems can be divided into two major groups: green facades and living walls. In green facades systems, the vegetation covering is formed by climbing plants or cascading groundcover mainly rooted at the base in the ground or in plant boxes. Living walls are generally more complex and involve a supporting structure with different attachment methods and a waterproof backing to isolate the living wall from the building in order to avoid moisture problems. In this case, the plants fix their roots to a substrate attached to the vertical structure.

Some studies have been conducted involving these kinds of systems which proved to have many benefits. For instance, the appropriate use of vegetation on the built environment can adequately adjust the urban microclimate and improve the thermal behaviour of building envelopes [2]. Plant-covering of building surfaces can provide a beneficial cooling effect within the building zone as plants absorb a considerable quantity of solar radiation for their growth and biological functions [3]. Therefore, the opportunity to reduce the cooling load in the summer and the potential to decrease the use of air-conditioning is giving a great impetus to the increasing use of plants within the built environment. For example, Hoyano [4] and Ip et al. [5] employed deciduous climbers to offer seasonal regulation of shading. This potential reduction of temperature inside the buildings has another remarkable consequence: energy savings. With appropriate placement of vegetation, an important reduction of cooling energy demands can be achieved [6] as the temperature reduction needed to match the comfort temperature is lower. Then, the shading and cooling effect of vertical greenery systems can be translated into a reduction of the energy used for cooling by approximately 20% [7], though potential cooling energy savings of up to 60% during warm summer days have been described [8]. There are also acoustics benefits of vertical greenery systems in facades due to the sound-absorbing effect of substrates and they may be useful in enhancing speech privacy if they are installed internally [9] or be used as noise barriers [10]. Nevertheless, most of these studies refer to systems attached to the exterior facades of buildings. Therefore, indoor living walls and their influence on interior environments have not been analyzed to a great degree.

People in urbanized societies spend over 80% of their time indoors [11]. For that reason, indoor environmental quality is of critical importance to our health and well-being [12]. The indoor environment is a dynamic interrelationship between thermal comfort needs, physical factors and chemical and biological factors [13,14]. Some studies assess the effect of vegetation on air quality improvement [15–17]. It is not only restricted to particle adherence, it is also efficient in absorbing air polluting substances [18] due to a process known as bio-filtration [19,20].

According to the Spanish regulations in buildings, for good indoor air quality in an indoor environment, temperature and humidity levels should be maintained within the range of 20–24°C and 30%–70%, respectively [21]. In warm climates, it is difficult to maintain these levels without using air conditioning systems, which are high-energy consumers.

As living walls must be constantly irrigated, indoor air humidity increases providing a cooling effect that reduces the room temperature when needed. Also the plants' evapotranspiration process helps to regulate the temperature. Given that indoor air is usually too dry, particularly in situations with internal heating or cooling systems, this humidity increment is also beneficial [22]. Lohr [23] conducted a study demonstrating that plant transpiration may increase the indoor air humidity by 3%–5% creating a humidity level that matches the recommended human comfort range.

The main objective of this work was to analyze the effect of an indoor living wall on the environment inside buildings, in particular, involving temperature and humidity as the main variables. The effect of using different substrates was also evaluated.

Methods

The living wall was constructed for this study in 2008 inside a small hall (4.40 m × 11.10 m, 4 m height) at the School of Agricultural Engineering in Seville (southern Spain). This area is characterized by long warm periods with temperatures over 30°C, so the use of air conditioning is frequently necessary. The data acquisition started in 2009, in order to ensure the proper settlement and

Fig. 1. Living wall and substrate disposition.

development of the vegetation prior to the beginning of the study. The hall is located in the ground floor with South-east orientation and it is connected to the rest of the building by a long corridor. The access to the hall is provided by a double door in order to enhance insulation from the exterior conditions. The hall is not equipped with an air conditioning system. During the study period, the average outdoors temperature was 16.4°C and the average maximum outdoors temperature was 23.6°C.

The living wall covered nearly 8 m^2 of wall (Figure 1) and consisted of a vertical galvanized iron structure attached to the wall. A tank, built of the same material and with a capacity of 500 L of water, was placed at the bottom of the structure. A substrate layer with pockets for the introduction of plants was attached to the vertical structure. The back of the structure was covered by a waterproof layer to prevent moisture problems in the room wall.

Four different substrates were used and tested in this study, two of organic origin, coconut fibre and Xaxim (a material composed by fern roots, mainly *Dicksonia sp.*) [24]) and two synthetic, Epiweb (based on Polyetylentereftalat) [25] and Geotextile (acrylic textile made of different fibres with a polypropylene base) [26]. A preliminary analysis of organic substrates was performed to determine their pH and salinity levels. Two pulverized samples of each organic substrate (5 g dissolved in 25 mL of distilled water) were tested to determine salinity levels (using measures of electrical conductivity for the saturated extract) and pH (several measures obtained from the saturated paste using a pH meter). When the system was already operating, a conductivity and pH analysis was conducted on the draining water as the water used for irrigation was recovered in the tanks and reused until

Table 1. Selected species for the living wall

Selected species
Adiantum capillus-veneris
Anthurium scherzerianum
Asparagus densiflorus
Asparagus setaceus
Asplenium nidus
Chamaedorea elegans
Chlorophytum comosum
Cissus rhombifolia
Codiaeum variegatum
Dieffenbachia tropic
Epipremnum aureum
Ficus pumila
Hypoestes sanguinolenta
Kalanchoe blossfeldiana
Nephrolepis exaltata
Peperomia variegata
Pilea cadierei
Plectranthus australis
Saxifraga stolonifera
Soleirolia soleirolii
Solenostemon scutellarioides
Spathiphyllum wallisii
Tradescantia spathacea
Tradescantia zebrina

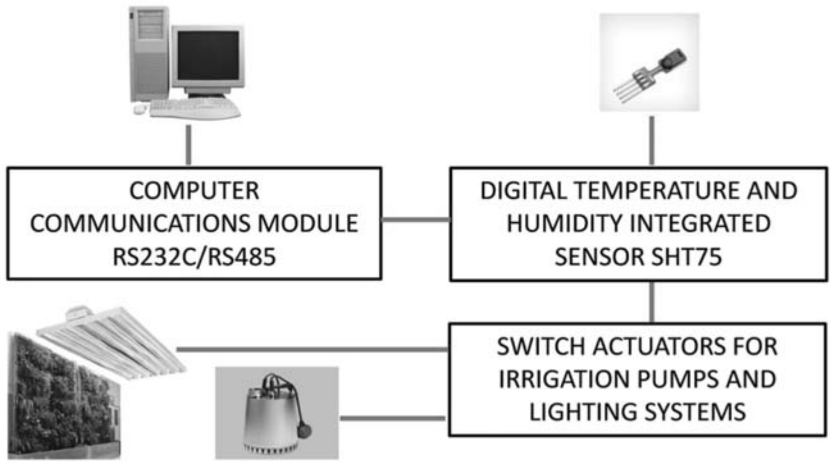

Fig. 2. Monitoring system's schematic.

certain undesirable conductivity or pH levels were reached. The initial objective was not to exceed an electric conductivity of 3,500 μS/cm, a high level for most horticulture crops [27], but ultimately, the limiting factor was the pH level. The pH recommended value of 7.5 was often surpassed due to the characteristics of the water used to refill the tank. Therefore, in order to optimize the maintenance operations and as the ornamental quality was not affected, the maximum pH level was established at 8.

Twenty-four different species were used in the living wall (Table 1). These were ornamental species commonly used in indoor environments. The main criterion used for their selection was their potential to adapt to a vertical structure [26,28]. As the plants were chosen for an indoor living wall, it was desirable that they not emit pollen producing allergies. The different species have been arranged following practical criteria (shading between plants, adaptability to substrates and humidity conditions) though the aesthetic component should also present (grouping of plants, playing with colours). In addition, to detect the influence of planting height, same species were planted at different heights. When it was possible, most species were planted on the four substrates to be able to compare their performance in all of them.

Three systems were also required for the correct operation of the living walls: irrigation, monitoring and lightening systems. Irrigation was provided by a network of PVC pipes. Horizontal pipes were placed at regular vertical spacing and small holes along their length allowed water flow. The monitoring system integrated a data logger attached to five digital temperature and humidity sensors SHT75 Sensirion (one for each substrate and one for the room temperature used as control) placed at the same height (1.80 m) and separated by 0.3 m from the living wall to avoid interactions with the conditions under the canopy. The control values (ambient temperature and humidity values slightly influenced by the living wall) were collected by a sensor located at the opposite side of the hall. The data logger was connected to a computer (Figure 2) to ease the analysis of the information. Temperature and humidity data was recorded every 15 min. A software program was also developed in Visual Basic 6.0 to operate the data and to control pumps and lights according to a programmed scheme. Lightening system was composed by six fluorescents Grolux Silvania (58 W).

In order to carry out the study of the different substrates properly, the living wall was organized in four independent sections, each one with its own autonomous systems (irrigation, pump and tank). Therefore, different sections could be managed individually. The structures supporting the organic and inorganic substrates were also separated.

Once the living wall was planted, a maintenance program was necessary to promote plant survival and growth and to prevent problems such as pump and/or irrigation system malfunctioning.

The test started once the system was operating correctly and the plants were fully settled. The data collection occurred from March to mid-June period, when the temperature would be increasing progressively. From mid-June, academic activities in the school would be finished so the occupancy pattern of the School changed. Hence, the test was not prorogued to the warmer months due to this change of conditions.

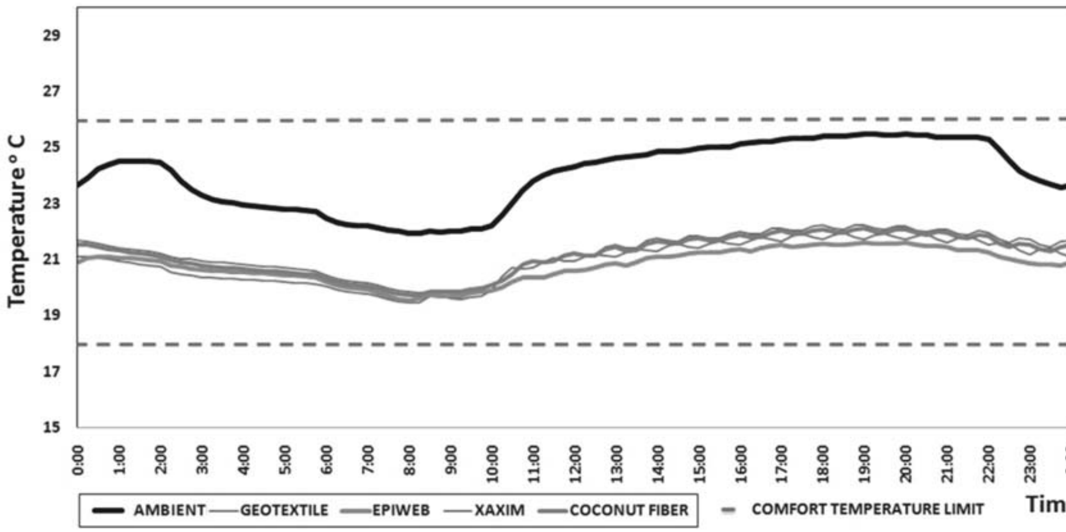

Fig. 3. Temperatures during an average day in the study period.

Results and Discussion

Substrates Analysis

The pH values obtained in the preliminary analysis were 5.81 for coconut fibre and 5.38 for Xaxim. These measures revealed that both substrates were in the medium acid interval, characterized for being the most suitable for plant growth, though Xaxim was in the limit of high acid.

The salinity level tests showed 4.23 dS/m for coconut fibre and 2.26 dS/m for Xaxim. The second value can be considered within an acceptable salinity interval for most plants [29], though 4.23 dS/m would be slightly high. Those levels are common for coconut fibre substrates and the excess soluble salts could be easily and effectively leached from the material under customary irrigation regimes [30].

The drainage water was tested periodically for each substrate to obtain the pH and conductivity levels required. Average conductivity values were always below the minimum threshold for hydroponic cropping (below 1500 μS/cm is considered very low) [27]: 435, 457, 635 and 793 μS/cm for Geotextile, Epiweb, Xaxim and Coconut fibre, respectively. This was precisely the objective as an adequate growth was compatible with an acceptable ornamental quality and would reduce water consumption. With this method, the water nutritive solution could be reused for a longer-than-usual period (up to 8 weeks in this case). Similar values of low nutritive supply were suggested in Blanc [26].

Slightly basic average levels of pH were observed (Geotextile: 7.95, Epiweb: 7.5, Xaxim: 7.21 and coconut fibre: 7.25). Most vegetal species would prefer a more acid pH though in this case, apparently, this situation did not have much effect on the appearance or development of the vegetation.

Water consumption during June (which had the most extreme temperatures during the study period) was 5.01, 3.94, 3.3 and 3.94 (in $l\,m^{-2}\,day^{-1}$) for Geotextile, Epiweb, Xaxim and coconut fibre, respectively. In this case, the substrate had a high impact on the values as a significantly higher consumption was observed for the synthetic ones. The reason might be the higher retention capacity of the organic substrates, which minimized water evaporation from their surfaces.

Influence on the Indoor Environment: Temperature and Humidity

In order to study the influence of the living wall on indoor temperature and humidity using the different substrates, those variables were measured and recorded during a 15-week period (from March to mid-June) for each substrate.

Figure 3 shows the temperature variations during an average day. The performance of the different substrates was quite similar, but there was a divergence with the ambient temperature of close to 4°C during the last hours of the day. This difference of performance was less when the temperature dropped between 7 and 10 am. Epiweb presented the greatest difference with the ambient temperature (nearly 1°C more than the other substrates in some cases) though Geotextile produced similar values. The average ambient temperature during the studied

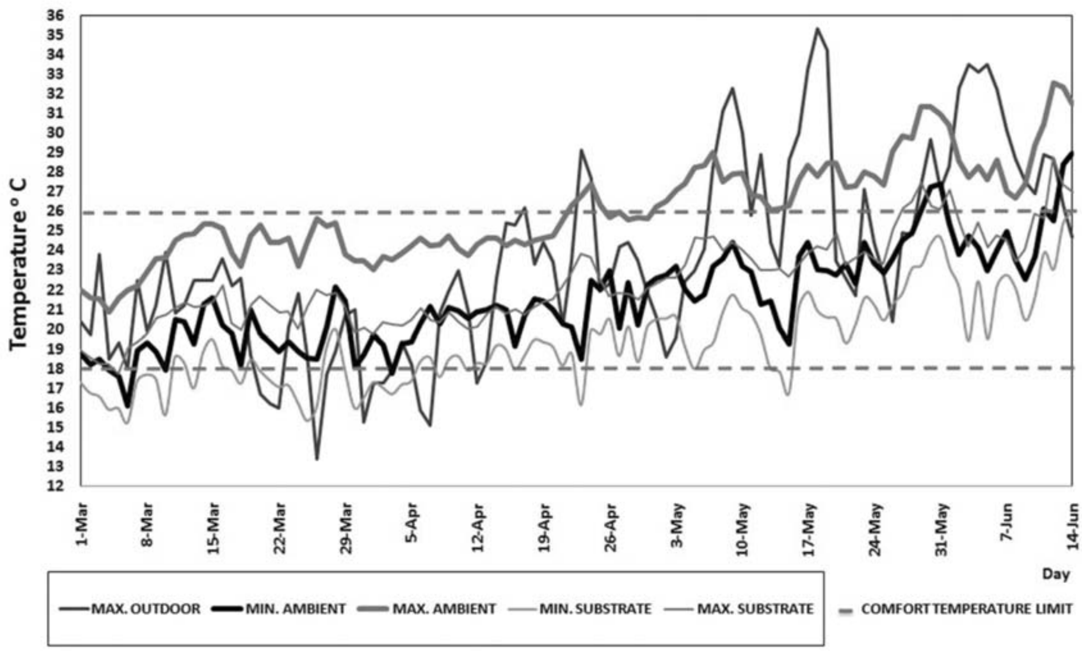

Fig. 4. Daily maximum and minimum temperatures (°C) for the control and living wall in the study period.

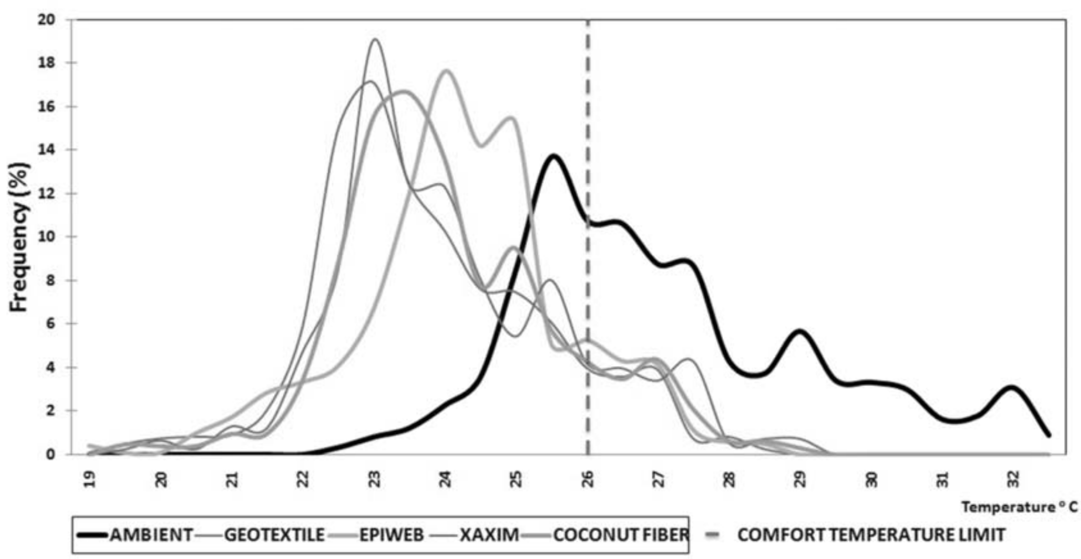

Fig. 5. Frequency of occurrence of temperatures in June.

period was 24°C, being 20.8°C when synthetic substrates were used and 21.2°C when the substrates were organic ones. Maximum and minimum temperatures were 32.5°C and 16.1°C for ambient values, 28.6°C and 13.8°C when using synthetic substrate and 29.2°C and 15.4°C when using organic substrates. Therefore, the difference in the temperature effect between organic and synthetic substrates was small, less than 1°C on average, but the minimum temperature was lower when synthetic substrates were used.

Maximum and minimum daily temperatures for the control (ambient temperatures) and near the living wall (average values for all the substrates) are shown in Figure 4. An average of 3°C difference between the control and the living wall maximum temperatures was observed along the studied period. The temperature

Table 2. Correlation between temperature differences and ambient temperature

Values for June	Ambient	Geotextil	Epiweb	Xaxim	Coconut fibre
Average temperature (°C)[a]	27.1 ± 0.06c	23.8 ± 0. 04a	24.2 ± 0.04b	24.1 ± 0.04b	24.1 ± 0.04b
Máximun (°C)	32.5	28.4	28.6	29.2	28.9
Mínimum (°C)	22.5	19.0	18.8	19.3	19.4
Average difference to control temperature (°C)[a,b]		3.29 ± 0.02c	2.82 ± 0.03a	2.95 ± 0.02b	2.98 ± 0.02b
Correlation between temperature difference and ambient temperature[c]		0.492	0.291	0.426	0.477
Size effect		Medium (almost large)	Small (almost medium)	Medium	Medium

[a]When compared with correlated measures ANOVA, values with same letter were not significantly different at level $p = 0.05$ (*Dunnett's C test*) (2-tailed).
[b]Positive number indicates a higher control air temperature.
[c]All correlations have significance at level $p < 0.01$ (Tau_b de Kendall).

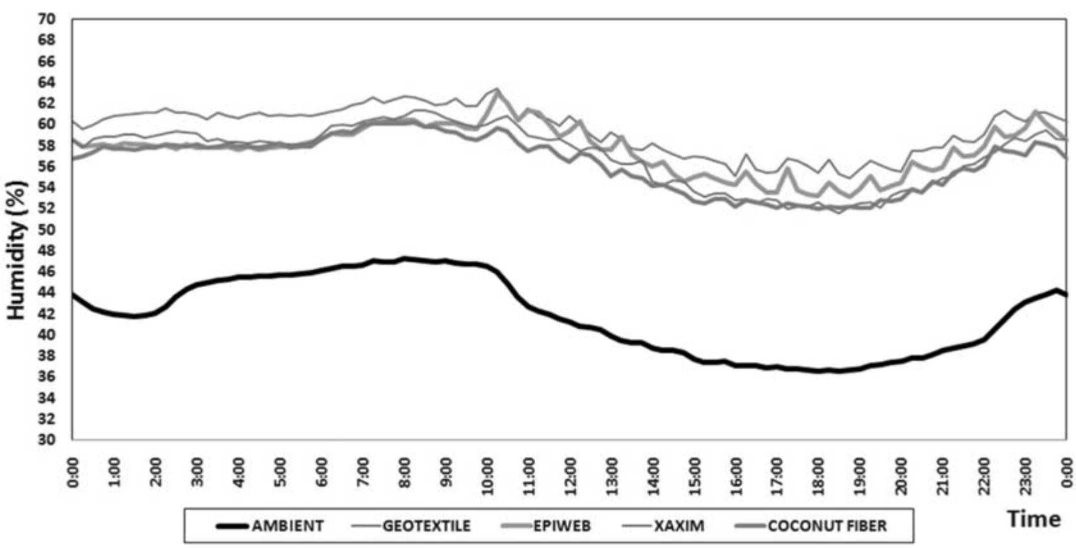

Fig. 6. Humidity average values for the different substrates.

difference between maximum and minimum values was less when influenced by the living wall due to a buffering effect on the temperature near the plants.

As temperatures during June were higher, the cooling effect of the living wall was more obvious. Figure 5 shows the frequency of occurrence of temperatures in June. The most usual temperatures for the control case were in a range from 25°C to 28°C and those below 24°C were hardly observed. Taking into account the influence of the living wall, the most frequent temperatures registered were between 22°C and 25°C and exceeded the comfort limit only a few times.

Within the different substrates, Epiweb showed the higher temperatures. Geotextile had the best performance though it was quite similar to the organic substrates.

Looking into the distribution of temperatures in the second week of June, the results above mentioned were confirmed. During only the last 2 days of the week temperatures near the living wall exceeded the comfort limit, while the ambient temperature went over this limit on several occasions. Once again, the different substrates had a similar behaviour with the exception of Epiweb, which showed a slight divergence for low temperatures. It was also observed that the difference between the ambient and living wall temperatures (thermal gap) would further increase in warmer situations, exceeding 5°C in some cases. This increment of the thermal gap would occur at higher temperatures as the evapotranspiration rate would rise with increasing temperature, thus producing a cooling effect near the living wall.

Table 2 shows average, maximum and minimum temperatures in June for all the substrates and the correlation between the thermal gap and the ambient temperature. Geotextile provided a higher thermal gap with the maximum correlation being the values lower than the case when using Epiweb. Xaxim and coconut fibre had a similar behaviour. This means that Geotextile had the best cooling effect at higher ambient temperatures. On the other hand, Epiweb produced the worst performance though the differences were small.

The drop in temperature observed due to the living wall is consistent with other studies. For example, Wong et al. [2] observed reductions in the ambient temperature of up to 3.3°C close to the living wall. Cheng et al. [31] and Kontoleon and Eumorfopoulou [3] obtained a temperature difference of 3.6°C and 3.5°C, respectively, using a green coverage on the façade. Anyway, these studies involved outdoor systems that introduced other variables such as wind or direct solar radiation, though the thermal gap measured was quite similar in all the cases.

The cooling effect observed would be very useful in warm climates as this would reduce the air conditioning requirements with the associated energy savings. A 5% reduction in power consumption can be obtained for each °C dropped [7], so for the average 4°C reduction observed, 20% of energy savings could be obtained.

Humidity values during the day are very much influenced by irrigation events, therefore, only average daily values have been considered (Figure 6). An average increase in air humidity of 15% was observed near the living wall with higher values obtained when using Geotextil. Those elevated levels contributed to an increase in humidity in the room though a decreasing humidity gradient was experienced associated with the distance from the living wall. An excess of indoor humidity can cause problems [32], so monitoring this value is advisable to moderate the condition by ventilation when required.

Plant Growth, Durability and Irrigation

Some differences have been observed in the behaviour of vegetal species growing in the different substrates. Certain species presented a quick expansion on the substrates' surface, showing an epiphyte development from their initial position inside the planting pocket. The organic substrates provided higher epiphyte colonization on their surface so the aesthetic aspect of the living wall was enhanced. When Xaxim was used, an elevated germination of fern spores (mainly *Adiantum capillus-veneris*) occurred so this section of the living wall was highly colonized. The four substrates provided an important stolon proliferation, mainly for *Saxifraga stolonifera* and *Nephrolepis exaltata*, though this development was more obvious in the case when organic substrates were used.

Taking into account the substrate durability, the synthetic ones and Xaxim maintained their structure without any change. However, certain degradation was observed in coconut fibre even when it was reinforced with a latex reticular structure. Therefore, this substrate may need to be replaced sooner than the others.

The living wall sections with inorganic substrates showed more evapotranspiration, so water consumption was higher. Also, for the same irrigation frequency and dosage, it was observed that synthetic substrates dried faster than organic ones possibly due to their higher retention capacity [24]. Therefore, more irrigation events were required for the synthetic substrates and in case of an irrigation system failure; the consequences would be more dramatic for the plants growing in these substrates.

Conclusions

All the substrates tested were suitable for plant growing though coconut fibre required irrigation leaching to lower its higher salinity. Low water conductivity was maintained in order to obtain an adequate growth compatible with an acceptable ornamental quality. Water consumption was considerably higher for the synthetic substrates.

Though the behaviour of the substrates was quite similar, Geotextile showed the best performance. Organic substrates also demonstrated good qualities, but some problems were identified. The use of coconut fibre for living walls is not advisable except for ephemeral purposes due to its degradation. In the case of Xaxim, the fern species utilized for the elaboration of this material are in danger of extinction so its use is not recommended.

Promising results have been obtained as the cooling effect of the living wall has been proven. Temperature decreases of 4°C on average can be achieved close to the living wall though maximum decrements of 6°C have been observed. This cooling effect would be enhanced if the temperature is warmer in the room. High humidity levels were observed near the living wall due to irrigation and plant evapotranspiration, which is beneficial in case of dry indoor environments. If necessary, proper ventilation is advised to avoid problems associated with excessive moisture.

Energy savings can be achieved due to the cooling effect observed. Also, thanks to the bio-filtration capacity of the living wall, ventilation requirements may be lower (depending on the humidity levels), leading again to less energy consumption. These outcomes could be enhanced if an air flow was forced through the living wall (active living wall system).

References

1 Köhler M: Green facades - a view back and some visions: Urban Ecosys 2008;11:423–436.

2 Wong NH, Tan AYK, Chen Y, Sekar K, Tan PY, Chan D, Chiang K, Wong NC: Thermal evaluation of vertical greenery systems for building walls: Build Environ 2010;45:663–672.

3 Kontoleon KJ, Eumorfopoulou EA: The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone: Build Environ 2010;45:1287–1303.

4 Hoyano A: Climatological uses of plants for solar control and the effects on the thermal environment of a building: Energy Build 1988;11:181–199.

5 Ip K, Lam M, Miller A: Shading performance of a vertical deciduous climbing plant canopy: Build Environ 2010;45(1):81–88.

6 Meier AK: Strategic landscaping and air-conditioning savings: a literature review: Energy Build 1990;15:479–486.

7 Bass B, Baskaran B: Evaluating rooftop and vertical gardens as an adaptation strategy for urban areas. Institute for Research and Construction NRCC-46737, Project number A020; 2001. Available at: http://www.roofmeadow.com/technical/publications/BBass_GreenRoofs_2001.pdf (accessed Jan 12, 2010).

8 Parker JH: The use of shrubs in energy conservation in plantings. Landsc J 1987;6:132–139.

9 Wong NH, Kwang Tan AY, Tan PY, Chiang K, Wong NC: Acoustics evaluation of vertical greenery systems for building walls: Build Environ 2010;45:411–420.

10 Ottelé M, van Bohemen HH, Fraaij AL: Quantifying the deposition of particulate matter on climber vegetation on living walls: Ecol Eng 2010;36(2):154–162.

11 Hodgson MJ, Oleson B, Fountain M: Environmental acceptability in an environmental field study: in Proceedings, Healthy Buildings/IAQ 1997, Washington DC, USA, pp. 195–200.

12 Yu CWF, Kim JT: Building environmental assessment schemes for rating of IAQ in sustainable buildings: Indoor Built Environ 2011;20(1):5–15.

13 Wood R: Improving the indoor environment for health, well-being and productivity. Greening cities: a new urban ecology conference. April 2003. Sydney: Australian Technology Park. Avialable at: www.aila.org.au/nsw/ greeningcities/papers/proc_wood.pdf (accessed Feb 03, 2010).

14 Fang L, Clausen G, Fanger PO: Impact of temperature and humidity on the perception of indoor air quality: Indoor Air 1998;8:80–90.

15 Wolverton BC, Wolverton JD: Plants and soil microorganisms: removal of formaldehyde, xylene and ammonia from the indoor environment: J Mississippi Acad Sci 1993;38(2):11–15.

16 Raza SH, Shylaja G: Different abilities of certain succulent plants in removing carbon dioxide from the indoor environment of a hospital: Environ Int 1995;21(4):465–469.

17 Todd JJ: Urban air quality. Environmental Design Guide: RAIA 2005;1(34):1–8.

18 Miyawaki A: Restoration of urban green environments based on the theories of vegetation ecology: Ecol Eng 1998;11:157–165.

19 Darlington A, Dixon M, Pilger C: The use of biofilters to improve indoor air quality: the removal of toluene, TCE and formaldehyde: Life Support Biosp Sci 1998;5:63–69.

20 Darlington A, Chan M, Malloch D, Pilger C, Dixon M: The biofiltration of indoor air: Implications for air quality: Indoor Air 2000;10(1):39–46.

21 Reglamento de Instalaciones Térmicas de los Edificios. RITE 2009 (In Spanish).

22 Fjeld T, Veiersted B, Sandvik L: The effect of indoor foliage plants on health and discomfort symptoms among office workers: Indoor Build Environ 1998;7(4):204–209.

23 Lohr VI, Bummer LH: Assessing and influencing attitudes toward water-conserving landscapes: HortTechnology 1992;2:253–256.

24 Faria RT, Valle Rego L, Bernardi A, Molinari H: Performance of different genotypes of Brazilian orchid cultivation in alternatives substrates: Brazilian Arch Biol Tech 2001;44(4):337–342.

25 Hallander H: EpiWebben deliver what it promised. EpiWebben håller vad den lovade. Swedish Orchid Society: Orkidèer 2009;January:22-28.

26 Blanc P: The Vertical Garden: From nature to the city. New York, USA, W. N. Norton and Company, 2008.

27 Alexander T, Knutson A, Harrington M: The best of growing edge. Vol. 2. Corvallis, USA, New Moon Publishing, Inc., 1999.

28 Leenhardt J, Lambertini A, Ciampi M: Vertical Gardens. London, UK, Verba Volant, 2009.

29 Bunt AC: Media and mixes for container-grown plants. A Manual on the Preparation and Use of Growing Media for Pot Plants. London, UK, Unwin Hyman Ed., 1988.

30 Abad M, Noguera P, Puchades R, Maquieira A, Noguera V: Physico-chemical and chemical properties of some coconut coir dusts for use as a peat substitute for containerised ornamental plants: Biores Tech 2002;82:241–245.

31 Cheng CY, Cheung KKS, Chu LM: Thermal performance of a vegetated cladding system on facade walls: Build Environ 2010;45:1779–1787.

32 Wolkoff P, Kjaergaard SK: The dichotomy of relative humidity on indoor air quality: Environ Int 2009;33(6):850–857.