AA E+E Environment & Energy Studies Programme / Architectural Association School of Architecture

Graduate School / MSc & MArch Sustainable Environmental Design 2011-12

Term I / Research paper I

The "vertical green" facades in office buildings in Continental Mediterranean climates.

Analysis of "indirect climber" system versus "hydroponic wall" system

Which is the better system to achieve comfort spaces?

Tomas Swett, January 2012.

Authorship Declaration Form

ENVIRONMENT & ENERGY STUDIES PROGRAMME ARCHITECTURAL ASSOCIATION GRADUATE SCHOOL

PROGRAMME: MSc / MArch SUSTAINABLE ENVIRONMENTAL DESIGN 2011-12

SUBMISSION: RESEARCH PAPER 1

TITLE: THE “VERTICAL GREEN” FACADES IN OFFICE BUILDINGS IN CONTINENTAL MEDITERRANEAN CLIMATES.

Analysis of “indirect climber” system versus “hydroponic wall” system

Which is the better system to achieve comfort spaces?

NUMBER OF WORDS: 4184 words
(Excluding footnotes and references)

STUDENT NAME: TOMAS SWETT

DECLARATION:

“I certify that the contents of this document are entirely my own work and that any quotation or paraphrase from the published or unpublished work of others is duly acknowledged.”

Signature:

Date: 09/01/2012

Abstract

The current energy consumption of office building is worrying. One of the main factors is the cooling system demanded to achieve comfortable spaces. In Continental Mediterranean climates, this demand is increasing by the climatic factors. The high heat gains in offices building aggravate even more this problem. Thus, the efficient and adaptability of facades are highly relevant to decrease the solar gains and reduce the inside temperature. The “vertical green” systems help to improve the thermal performance and quality of indoor spaces. This research aims to study the continental Mediterranean climate and office buildings´ requirements and analyse which is the best “vertical green” system to improve the performance of office building facades in this climate.

Table of contents

1. Introduction
2. Description of Continental Mediterranean climates.
3. Office building requirements.
4. “Vertical green” facades.
    - 4.1 “Indirect climber” system.
    - 4.2 “Hydroponic wall” system
    - 4.3 Comparison between both systems.
5. Conclusion
6. References

Acknowledgement

I would like to acknowledge CONICYT Bicentennial Becas Chile Scholarship for the bursary I was awarded to attend the AA SED MArch course 2011 - 2013. Also, I want to thank the entire AA SED staff for their assistance along this term, especially Paula Cadima who guided this research paper.

1. Introduction.

Despite new technologies and sustainable software, the energy consumption in office buildings is not decreasing. Only a few new office buildings achieve the last international agreements of energy consumption. Due to the high internal heat gains; the need of cooling systems is elevated if there are not strategies to reduce them. Thus, the use of air conditioning has become vital to achieve comfortable spaces. But, it increases the “urban heat island” effect and the energy consumption, being one of the main factors of the current environmental problems.

There are new systems and innovations which could replace the air conditioning, reducing the environmental effects. They allow adaptive robotic solution in building facades and inside spaces. A good implementation of these solutions could achieve the comfort with low energy consumption. Unfortunately, the high cost and the expertise required to use them have avoided the diffusion of these system around the world. On the other hand, the “vertical green” systems could be effective and cheaper ways to reduce the energy consumption. They are divided in two main groups, having both diverse sub-systems. This study will be focus on the “Indirect climber” sub-system and “Hydroponic wall” sub-system which use plants as the main material but in different ways.

Thus, the purpose of this research paper is to analyse the “indirect climber” system and the “hydroponic wall” system in facades, defining which system helps to achieve a better performance for office buildings. Due to the importance of climatic factor, the analysis will focus on office building in Continental Mediterranean climate. The objective will be to understand the main requirements of office buildings in this climate and to analyse the effect of both systems on the envelope´s performance. To achieve the aim, the research paper will base the analysis on some literature and case studies, dividing the investigation in 3 main topics: Description of Continental Mediterranean climate, office building requirements and “vertical green” systems.

2. Description of Continental Mediterranean climates.

Continental Mediterranean climates are located in some parts of Spain, Sicilia, Turkey and Chile (Fig.1). It is a mix between the rainfall features of Mediterranean climate and the extreme temperatures of Continental climate. The summers are very warm and winters highly cold. The temperature fluctuates from 16°C to 18.5°C approximately. Commonly, summers can reach temperatures from 30 to 35 °C, while winter´s temperatures can decrease up to 0°C. Rains are concentrated between autumns and springs with rainfalls between 300 and 800 mm per year. In some case, the summers can be totally dry.

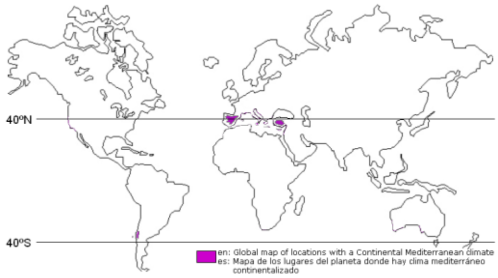

Figure 1. Continental Mediterranean climate map. Image without copywrigt from www.wikipedia.org

Due to this diverse climatic condition along the year, there are many design´s requirements to achieve the thermal comfort in inside spaces. Building elements have to be able to reduce solar gains during summer and the heat loss in winter. Thus, solar radiation is desired on facades in some part of the year, but it is totally undesired during hot seasons.

Base on www.inm.es, Madrid´s averages of high temperatures fluctuate from 17°C to 32°C, between April and October. During these months, the averages of low temperatures vary from 6°C to 13°C. On the other hand, the averages of high and low temperature between November and March fluctuate from 11°C to 16°C and from 0°C to 4°C respectively. In other words, Madrid presents higher the percentages of high temperatures and sunny days than low temperatures and cloudy days (Fig. 2).

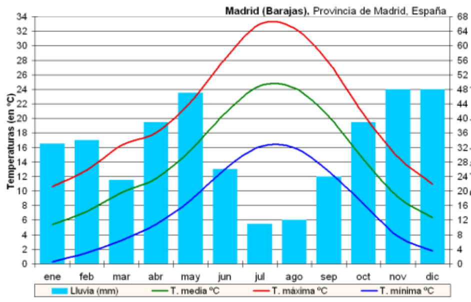

Figure 2. Annual temperatures and rainfalls in Madrid. From Instituto Nacional de Meteorología ©, Spain.

The average temperatures plus internal heat gains could achieve the comfort zone during some months of the year. It will depend on the program and the building´s features. Nevertheless, during the coldest and the warmest season is needed the use of mechanical or natural systems. Moreover, the façade´s orientation and the obstruction produced by close buildings are also important factor. Therefore, it is highly important for this climate to consider the occupancy patterns, surroundings and the variation of annual climatic factors for the building´s design.

3. Office building requirement.

In this climate office buildings demand cooling system the main part of the year. The high internal heat gains decrease the need of heating during cold seasons. Unfortunately, nowadays office building facades are commonly glazed (Fig. 3). Thus, offices are based on heat or air conditioning systems to achieve the thermal comfort. On the other hand, in work areas is relevant the illuminance and the air quality to obtain comfortable spaces. To introduce the office buildings requirements in Continental Mediterranean climates, the study will present the main technical requirements of office´s programs. Among several factors, this brief analysis will be focus in 4 topics: Activities and occupancy patterns, density and heat gains, air quality, and daylight.

Figure 3. Madrid, Spain Photograph © Tomas Swett

First, the main activities in office buildings are work, meet and walk. Based on Nick Baker AA´s lecture, the metabolic rates vary from 105 W to 210 W per person in this kind of activities. The common insulation value of clothing is between 1.0-.08 clo. On the other hand, the occupancy pattern is almost the same along the year. It estimates that the range of work hours goes from 09:00 am to 19:00 pm during the whole year, being the 42% of the day.

Second, people´s density is an important factor to achieve the comfort and to determinate the rates of internal heat gains. Metabolism, appliances and lights produce heat, increasing the inside temperatures. These items are, in some cases, the cause of overheating and in other, the solution to get the thermal comfort during cold seasons. South and west facing could have overheating because of the high solar incidence if there are not elements to reduce or control the solar gains.

Third, the air quality is a fundamental issue to have a good performance in work spaces. The need of fresh air per person required fluctuates between 8 and 10 litres/second (Yannas 2011)[i]. It allows replacing oxygen, removing odours and pollutant from inside spaces Thus the quantity of occupants, the need of fresh air and the volume of the space will determinate the range of air change per hour required. This air change must be controllable to avoid uncomfortable situation. Furthermore, the ventilation required to achieve fresh air also helps to decrease the inside temperatures in this kind of climate, being essential the apertures and night ventilation.

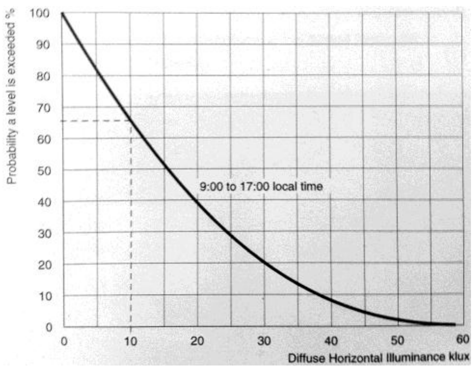

Figure 4. Annual daylight availability (diffuse only) for London showing the threshold illuminance of 10 Klux (to give 200 lux in the office with 2% of daylight factor) is exceeded for 66% of office working hours. .From Baker and Steemers. 2002. Daylight design Building.

Finally, a good daylight design reduces the use of lights and as a consequence, the energy consumption. The occupancy pattern coincides with daylight and sunshine hours. The range of lux required for office building in 300 to 500 lux, but it can vary from 100 lux (corridors) to 750 lux (drawing office). The percentage of daylight factor will depend on the space depth, the glazing ratio and the external obstruction. In general work areas, the average of daylight factor must be between 2% and 5% to achieve the illuminance standards (Baker and Steemers 2002)[ii].

In resume, office buildings must control the solar incidence and/or the ventilation. Ventilation is essential to get fresh air and to reduce indoor temperatures. On the other hand, solar incidence is important for illuminance and to increase the temperature during cold seasons. Thus, the duality to reduce solar gains but to increase daylight factors complicates the design of office building facades. In other words, the design of building envelopes is a key issue to achieve comfortable spaces.

"… allow solar gain but keep out excessive solar heat, provide sufficient daylight without causing glare, allow controllable ventilation into the building but keep out excessive noise, allow visual contact with the surroundings but ensure sufficient privacy and ensure safety". (UCD Energy Research Group & University College Dublin & (ACE) & Softech & (SAFA), 2001)[iii]

4. "Vertical green" Facades.

"In sustainable architecture the link between building performance and the design of the envelope is critical". (UCD Energy Research Group & University College Dublin & (ACE) & Softech & (SAFA), 2001)[iv]

The role of facades is essential to achieve the light, fresh air and heat requirements. These three topics are relevant for the thermal performance of office building in any climate. As it was analysed, the Continental Mediterranean climates demand adaptive facades to manage the different climatic factors and program requirements along the year. There are many façade systems to improve the building performance around the world. This document will be focused in one of them: The use of vegetation in office building facades.

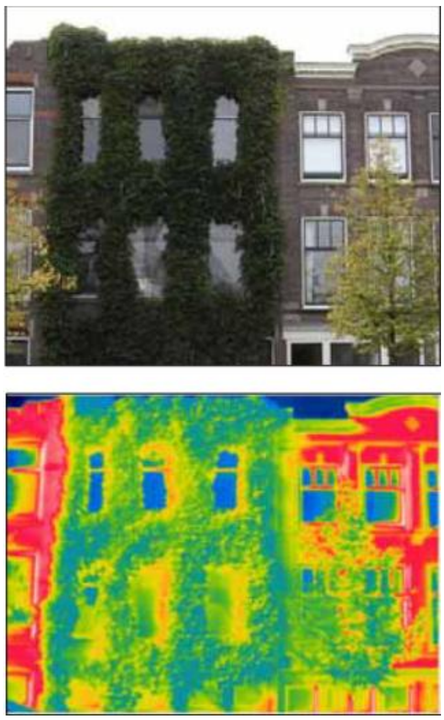

Figure 5. "Direct climber" system, Delft summer 2009. Photograph © Ottelé 2011. From the green building envelope: vertical greening.

The use of vegetation in facades produces many benefits in the urban, building and inside scale. The vegetation helps to decrease the "urban heat island" effect. Besides, it reduces the external noise, removes organic pollutant, holds water during rainstorm, absorbs Co^2 emissions and improves the urban biodiversity, among others. In the building scale, the vegetation decreases the solar heat gains by shading or covering facades. "*From 100% of sun light energy that falls on a leaf … 5-30% is reflected, 5-20% is used for photosynthesis, 10-50% is transformed into heat, 20-40% is used for evapotranspiration and 5-30% is passed through the leaf" (Fig. 6) (Krusche et al.,1982 in Otellé 2011)*[v]. On the contrary during winters, plants work as a protection and insulation layer, decreasing the wind chill and the heat loss. The evapotranspiration of vegetation also goes down the façade surface temperature. Moreover, it shields the envelopes from ultra-violet light, heavy rainfall and hail, enlarging the life of surface. In the inside scale, besides the heat transfer improvements, the use of vegetation on glazed facades helps to control the glare, daylight and privacy.

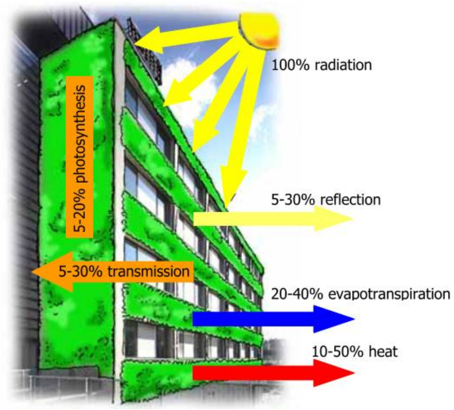

Figure 6. Energy balance of vegetation. Ottelé´s adaptation from Krusche et al., 1982. From the green building envelope: vertical greening.

Focusing in building and inside scale, there are different views of how the vegetation contributes to reduce solar heat gains and internal heat loss. Ottelé in his research indicates that *"the insulation value of vertical greened surfaces… is mainly related to trapping a stagnant air layer inside the foliage, filtering of the suns radiation by the foliage and preventing of moving wind along the façade due to the foliage"* (Ottelé,M. 2011)[vi]. Dunnett and Kingsbury explain that *"the effectiveness of this cooling is related primarily to the total area shaded than the thickness of the climber" (*Dunnett and Kingsbury, 2008) [vii]. Both authors share the idea that, filtering the suns radiation or shading the envelopes, helps to decrease the solar gains. Besides, Ottelé presents the relevance of the foliage, the air cavity and the effect on wind in vegetation system. In the same way, the performance of vegetation systems also depends on the supporting structures features. Thus, the diverse dimensions of air cavities and supporting structures have dissimilar results of sun and wind shield.

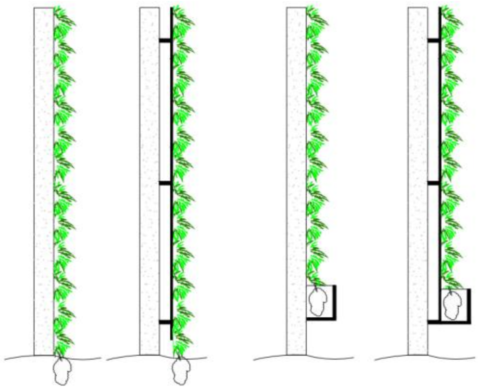

Figure 7. "façade greening" systems. Scheme © Ottelé 2011. From the green building envelope: vertical greening.

Authors use different terms to name the use of vegetation in facades. In this research paper will be used the definition: *"Vertical green is the result of greening vertical surfaces with plants, either rooted into the ground, in the wall material itself or in planter boxes attached to the wall in order to cover buildings with vegetation."*(Ottelé, M. 2011)[viii]

Based on *Dunnett and Kingsbury (2008)*, the "vertical green" systems can be separate in two groups. The first group is *"façade greening"* (Fig. 7) which are based on the use of creepers planting in the ground or potting soil. These climbers are holding directly on walls or indirectly in external supporting structures, which separated the vegetal skin from the opaque or glazed facade. The second group is *"living wall"* (Fig. 8) which is based on herbaceous plants planting directly in walls or indirectly in external attached modules only on opaque facades. At the same time, these two groups can be classified in sub-system by:

a) Type of rooted.
   i. Potting soil.
   ii. Ground.
   iii. Artificial Substrates.

b) Kind of vegetation.
   i. Climbers (evergreen or deciduous)
   ii. Herbaceous.

c) Type of fixation against the facades.
   i. Direct.
   ii. Indirect.

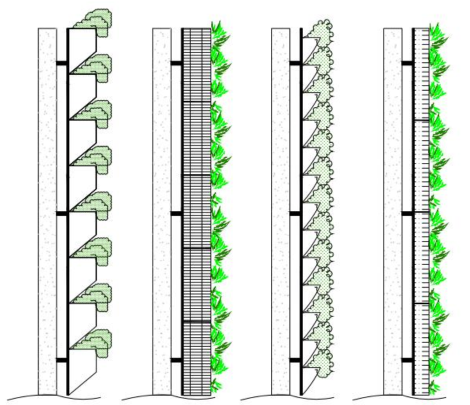

Figure 8. "Living wall" systems. Scheme © Ottelé 2011. From the green building envelope: vertical greening.

This classification divides in several sub-systems both group, creating a wide range of options. One objective of this research is to analyse both groups and identify which system helps to achieve better thermal performance in this climate. To achieve this aim, this study will be focused on one sub-system of each group: The “indirect climber” system of “façade greening” group and “hydroponic wall” system of “living wall” group.

4.1 The “indirect climber” system.

This system is based on the use of creepers which can be evergreen or deciduous, depending on the aims of the project (Fig. 9). The selection of the species has to be done according to the climate, orientation, objectives, speed of growth, native species and ecological balance. Other selection factors are the height required and foliage density. The Creeper´s requirements are fertile soil, constant supply of moisture and irrigation during dry seasons, avoiding waterlogging. Thus, these plants can be rooted into the ground or potting soil (window boxes) along the facades. In continental Mediterranean climates, this system uses *Bougainvillea, Plumbago, Ficus repens, Wisteria sinensis*, among others.

Figure 9. Consorcio Building, Santiago, Chile. “Indirect Climber” system. Photograph © Enrique Browne.

“Indirect” is because this system is separate from the façade, creating an air cavity (buffer) between both skins (Fig. 10). The air cavity varies depending on the design, objectives and supporting structure. Therefore, creepers need a supporting structure to grow and cover the building façade. They can be made in wood, metal, cables and wires, plastic or ropes. It is relevant to analyse the climate and the climbers used to avoid possible problems like decay, corrosion, strength and life. To define a safe support system it must be consider the weight of plants, water, snow, wind and maintenances. The direction (horizontal or vertical) and distances between supporting is related to the kind of plant selected.

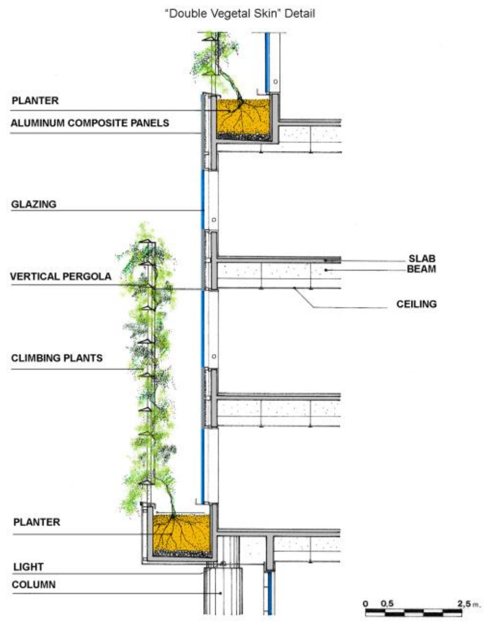

Figure 10. Detail of Consorcio Building, Santiago, Chile. “Indirect Climber” system. From www.ebrowne.cl © Enrique Browne Architects.

The main advantage of this system is the adaptability. It can be installed on opaque and glazed facades because it allows the pass of light through the foliage. Depending on the objectives, during cold seasons creepers allow to absorb solar radiation (deciduous) or reduce the heat loss (evergreen). On the other hand, a wide air cavity permits to open windows and ventilation. The creeper´s species and the pruning allow creating diverse foliage densities, colours and views. Thus, it is possible to regulate the solar incidence according to the user´s requirement. Another advantage of this system is the fifty years of service life, installing on stainless steel supporting. Finally, comparing with other green systems, it has a low cost of installation (40-75 €/m2). (Otellé 2011).

On the contrary, there are some disadvantages in the use of “indirect climber” system as the growth time required to cover a whole façade. Relying on the area and the specie used, the thermal performance of the building will be affected during the period without this skin.

4.2 The “hydroponic walls” system.

The “hydroponic walls” systems (fig. 11) *“grow without soil using balanced nutrient solutions to provide all the plant´s food and water requirements”* (Dunnett and Kingsbury 2008)[ix]. It is a modular system attached to the wall by a structure which lefts an air cavity between both surfaces. “Hydroponic wall” systems can be only installed on opaque facades because it does not permit the pass of light. The type of vegetation must be selected according to the climate, orientation and sun light.

Figure 11. Caixa Forum. Madrid, Spain Photograph © Tomas Swett

“On a load-bearing wall or structure is placed a metal frame that supports a PVC plate 10 millimetres (0.39 in) thick, on which are

stapled two layers of polyamide felt each 3 millimetres (0.12 in) thick. These layers mimic cliff-growingmosses and are support the roots of many plants. A network of pipes controlled by valves provides a nutrient solution containing dissolved minerals needed for plant growth. The felt is soaked by capillary action with this nutrient solution, which flows down the wall by gravity. The roots of the plants take up the nutrients they need, and excess water is collected at the bottom of the wall by a gutter before being re-injected into the network of pipes: the system works in a closed circuit. Plants are chosen for their ability to grow on this type of environment and depending on available light". (Blanc 2011)[x]

The main advantage of this system is to reduce the heat transfer by convection and increase the thermal resistance of facades. The air cavity and the different layer of the system (PVC plate, polyamide, polypropylene and vegetation) increase the insulation properties of the façade, reducing the solar gains and heat loss on walls. On the other hand, the fast installation and the herbaceous plants used have an immediate visual and thermal effect on building facades.

On the contrary, the cost of installation and life expectancy are some disadvantages. Based on Otellé (2011), the cost of installation is 750-1200 €/m2 and the service life are only 10 years. Furthermore, because of the calcium in the nutrient solution, the pipe system can be blocked. Finally, this system left glazed facades without sun and thermal protection, being these areas the most common in office building façade.

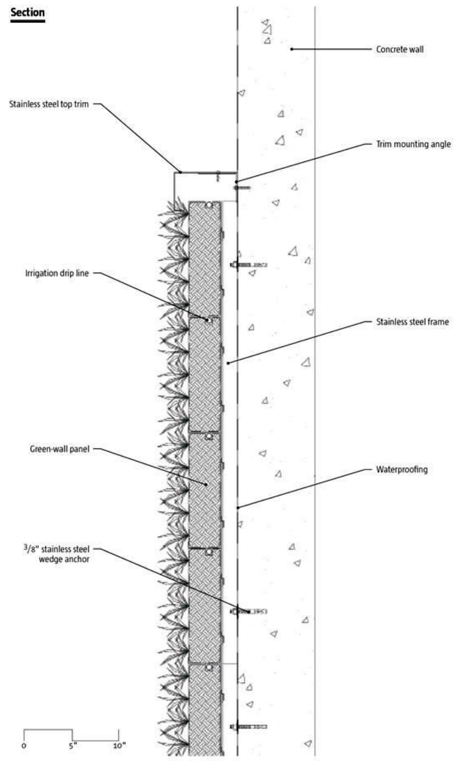

Figure 13. Detail of "Hydroponic wall" system.
From http://www.architectmagazine.com

4.3 Comparison between both systems.

The thermal resistance performance of envelopes in vertical green facades is a result from the heat transfer by convection, the insulation properties of the green system, the incidence of solar radiation and the evapotranspiration.

Table 1. Improvement of thermal resistance by adding green layer. From Ottelé 2011. The green building envelope: vertical greening**.** © Ottelé

construction	influence of greening type on the *R-value*	
	climbing plant	*Living wall system (LWS)*
double brick wall	24.3%	123%
cavity wall	15.7%	45%
insulated cavity wall	2.9%	14%

The heat transfer for convection has a direct relation with the wind velocity on façades (Fig. 13). The higher is wind velocity, the higher is the heat transfer from envelopes to the outside. The properties of layers, the percentage of transparency and the dimension of air cavity have an essential role in the reduction of wind velocity on facades.

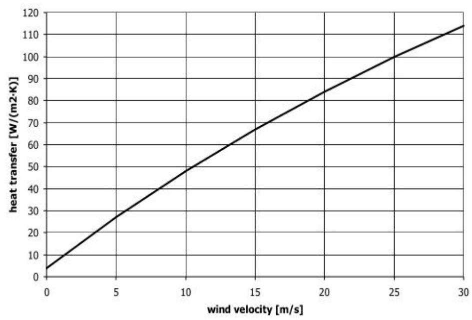

Figure 13. The heat transfer coefficient for convection as function of the wind velocity. From Tammes and Vos. 1984 in Otellé 2011

Based this analysis on Ottelé´s measurements, the "Indirect climber" system reduces the wind speed on surface in 40%, from 0.65 m/s to 0.39 m/s (Table 1). The reason why the wind velocity increased in 290% from the foliage to the envelope is because the 20 cm thickness of air cavity. According to Otellé "*The higher wind velocity found inside the air cavity of 20 cm thickness of the indirect greening system demonstrates that it is also possible to speak about an optimal air cavity thickness for greening systems (around 40-60 mm)"* (Otellé, 2011)[xi]. On the other hand, the "hydroponic wall" system reduces the wind speed on surface in 79%, from 0.47 m/s to 0.10 m/s (Table 2.). In this case, the wind velocity decreased in 75% from inner leafs to the envelope is because the layers and the narrow air cavity (4 cm) on the system.

In resume, the main factors in the reduction of wind speed are the thickness air cavity and the thermal properties of the layers. Thus, it can be said that the “hydroponic wall” system achieves better results in the reduction of heat transfer for convection in facades. Nevertheless, the “indirect climber” system could present better opportunities for cooling in Continental Mediterranean climates. There, during warm seasons (60% of the year), is highly important to reduce the outside surface temperature. Thus, an air cavity thickness of 140 cm (Consorcio building example) between the dense foliage skin and the façade could create a chimney wind effect. It would increase the wind speed and the heat transfer by convection, keeping the sun filtration on facades (Fig. 15).

Table 2. The effect of “Indirect climber” system in wind speed in facades. From Ottelé 2011. The green building envelope: vertical greening**.** © Ottelé.

	highest W [m/s]		average W [m/s]		lowest W [m/s]	
Bare wall 1 m wind speed	0,76	*100%*	0,27	*100%*	0,10	*100%*
Bare wall 0,1 m wind speed	0,69	90%	0,65	239%	0,65	665%
Greened wall 0,1 m wind speed	0,62	81%	0,62	230%	0,60	617%
Greened wall inner leaf wind speed	0,16	20%	0,10	38%	0,15	158%
Greened wall air cavity wind speed	0,36	47%	0,39	142%	0,27	274%

Table 3. The effect of “Hydroponic Wall” system in wind speed in facades. From Ottelé 2011. The green building envelope: vertical greening**.** © Ottelé

	highest W [m/s]		average W [m/s]		lowest W [m/s]	
Greened wall 1 m wind speed	2,33	*100%*	0,47	*100%*	0,12	*100%*
Greened wall 0,1 m wind speed	0,63	27%	0,56	119%	0,39	319%
Greened wall inner leaf wind speed	0,36	15%	0,41	87%	0,23	184%
Greened wall air cavity wind speed	0,13	6%	0,10	21%	0,06	45%

On the other hand, based on Ottelé (Table 4), the envelope surface temperatures are totally different in both cases. In the “indirect climber” system, wall surface temperature was 36.5% lower than the air temperature, going down from 16.55 °C to 10.5 °C. The air temperature was regular, decreasing in 1.26 °C. It can be said that the temperature drop is related to the sunscreen of leafs which reduces the incidence of solar radiation on facades.

Table 4. The effect of “Indirect climber” system in surface temperature. From Ottelé 2011. The green building envelope: vertical greening**.** © Ottelé.

Table 5.4.2 Indirect façade greenery, temperature and wind speed.

	highest T [°C]		average T [°C]		lowest T [°C]	
Bare-greened wall 1 m air temperature	22,29	*100%*	16,55	*100%*	13,73	*100%*
Bare wall 0,1 m air temperature	21,60	97%	15,63	95%	13,02	95%
Bare wall surface temperature	18,16	81%	13,23	80%	11,11	81%
Greened wall 0,1 m air temperature	21,80	98%	15,50	94%	12,63	92%
Greened wall outer leaf surface temperature	18,89	85%	13,04	79%	10,77	78%
Greened wall inner leaf surface temperature	17,56	79%	12,24	74%	9,72	71%
Greened wall inner leaf air temperature	21,36	0,96	15,46	94%	12,72	93%
Greened wall air cavity air temperature	20,90	94%	15,29	92%	12,59	92%
Greened wall surface temperature	14,52	65%	10,50	63%	8,17	59%

Finally, in the “hydroponic wall” system (Table 5), wall surface temperature was 53% lower than the air temperature, going down from 15.15 °C to 7.1 °C. Furthermore, the air temperature was also regular, but it increased in the air cavity in 1.18 °C. This fact is because the stagnancy of the air in the cavity. Both, the block of solar radiation and the insulation layer of the system were the causes of the high decrease on surface temperature.

Figure 15. Consorcio Building, Santiago, Chile. Inside view of “Indirect Climber” system. Photograph © Enrique Browne.

Table 4. The effect of "Hydroponic wall" system in surface temperature. From Ottelé 2011. The green building envelope: vertical greening**.** © Ottelé.

Table 5.4.3 Living wall system, temperature and wind speed.

	highest T [°C]		average T [°C]		lowest T [°C]	
Greened wall 1 m air temperature	20,68	*100%*	15,15	*100%*	12,28	*100%*
Greened wall 0,1 m air temperature	21,67	105%	15,42	102%	12,47	102%
Greened wall outer leaf surface temperature	17,18	83%	10,95	72%	7,55	62%
Greened wall material surface temperature	14,89	72%	9,18	61%	6,86	56%
Greened wall inner leaf air temperature	22,05	107%	16,27	107%	12,91	105%
Greened wall air cavity air temperature	20,91	101%	16,33	108%	13,23	108%
Greened wall surface temperature	10,83	52%	7,10	47%	6,58	54%

5. Conclusion

Continental Mediterranean climates demand different thermal requirements along the year, because of its temperature fluctuation. The cold seasons are short and warm seasons long. The high internal heat gains of office buildings reduce the need of heating systems during cold seasons but produce overheating during warm periods. Thus, cooling systems are mainly demanded almost all the year. The orientation and buildings surroundings affect the climatic factors and change the comfort requirements. Therefore, the role of facades in the control of solar gains, ventilation, daylight and heat transfer is essential to achieve comfortable spaces.

The market has defined that office building facades are commonly glazed, going up the solar gains and the air conditioning demand. Therefore, the need of new façade system is imperative in office building in Continental Mediterranean climates. More than a system which insulates and keeps the inside temperatures, it needs a system which increase the heat loss and reduce the solar gains.

The "vertical green" facades are excellent alternatives to solve this problem, benefiting the urban, building and office scale. Analysing the thermal performance of facades, the "hydroponic wall" system has better thermal insulation properties, reducing the temperature 16.5% more than the other system. Thus, this enclosed, thick and opaque system achieves lower surface temperature for summers. The sun incidence on walls is zero, maintaining cold the indoors. On winters, it presents lower heat transfer by convection, decreasing the heat loss. However, the demand of adaptabilities, views and daylight of building office become the "indirect climber" system in a better option. Installed on glazed facades, at the same time it reduces the solar gains but allows the daylight in inside spaces. Also, it allows natural ventilation but reduce the heat transfer. All of these adaptive solutions affect directly in the energy consumption of the building.

Finally, this research was an introductory investigation in this topic which did not pretend to establish this system as the unique solution. There are many strategies which must be combined with the "indirect climber" system. Better orientations, low percentage of glazed facades, narrow office´s layout and/or night ventilation can be other strategies.

6. References

[i] Yannas, S. (2011) Architectural Association School of Architecture. SED´s lecture. Form and Function, Nov 2011.

[ii] Baker, N and Steemers, K. (2002). *Daylight design Building*. Chapter 4.2: "The component of daylight". p. 61

[iii] UCD Energy Research Group & University College Dublin & (ACE) & Softech & (SAFA). (2001). A Green Vitruvius – *Principles and Practice of Sustainable Architectural Design.* Cycle (p. 65). Earthscan Publications Limited.

[iv] UCD Energy Research Group & University College Dublin & (ACE) & Softech & (SAFA). (2001). A Green Vitruvius – *Principles and Practice of Sustainable Architectural Design.* Cycle (p. 61). Earthscan Publications Limited.

[v] Ottelé, M. (2011*). The green building envelope: vertical greening*. p. 117. Retrieved from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid:1e38e393-ca5c-45af-a4fe-31496195b88d. (2011)

[vi] Ottelé, M. (2011*). The green building envelope: vertical greening*. p. 118. Retrieved from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid:1e38e393-ca5c-45af-a4fe-31496195b88d. (2011)

[vii] Dunnett, Nigel and Kingsbury, Noel. (2008). *Planting Green Roofs and Living Walls*. Chapter 5: "Façade Greening". p. 195.

[viii] Ottelé, M. (2011). *The green building envelope: vertical greening*. p.118. Retrieved from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid:1e38e393-ca5c-45af-a4fe-31496195b88d. (2011)

[ix] Dunnett, Nigel and Kingsbury, Noel. (2008). *Planting Green Roofs and Living Walls*. Chapter 5: "Façade Greening". p. 239.

[x] Blanc, P. Retrieved from http://en.wikipedia.org/wiki/Patrick_Blanc. (2012)

[xi] Ottelé, M. (2011). *The green building envelope: vertical greening*. p.150. Retrieved from http://www.narcis.nl/publication/RecordID/oai:tudelft.nl:uuid:1e38e393-ca5c-45af-a4fe-31496195b88d. (2011)

- Energy and Buildings, Volume 37, Issue 5, May 2005, Pages 419-427

- Tsoumarakis, C., Assimakopoulos, V. D., Tsiros, I., Hoffman, M., & Chronopoulou, A. (2008). 635 : Thermal Performance of a Vegetated Wall during Hot and Cold Weather Conditions. *Environmental Research*.

- Damas, D., Morelli, D. E. O., Lucila, D., & Labaki, C. (2009). Green Walls: Environmental Quality in Buildings. Energy, (June), 22-24.

- Browne, E. (2007). The "Consorcio-Santiago" Building 14 Years Later . www.ebrowne.cl (2011)

- Chanampa, M., Rivas, P. V., Ojembarrena, J. A., & Olivieri, F. (n.d.). Systems of Vegetal Façade and Green Roofs used as a Sustainable Option in Architecture. *International Journal*, *4*.

- Poirazis, H. (2004). *Double Skin Façades for Office Buildings Literature Review*. *Building Design*.