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ECOENVELOPES R&D. Passive architectural envelopes high thermal performance and low environmental impact for tropical geo-climatic zones

ECOENVOLVENTES I+D. Envolventes arquitectónicas con alto desempeño térmico y bajo impacto ambiental para zonas geoclimáticas tropicales

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SUMMARY

"Ecoenvelopes" is about the development of building envelope solutions for tropical humid climates involving passive control of thermal gains on their surfaces, allowing for better internal conditions and comfort without the use of thermal machines. Environmental principles, design, and technological aspects are specifically defined based on the peculiar conditions (geo-climatic, technological, of biodiversity, economic and anthropic) present in the Colombian low altitude regions, marked by constant high temperatures. Thermal and CFD simulations orient the process of experimental verification in a permanent laboratory counting on partnerships and available know-how.

RESUMEN

"Ecoenvolventes" plantea el desarrollo de soluciones de envolventes arquitectónicas para clima tropical húmedo, que permiten el control pasivo de las ganancias térmicas en sus superficies permitiendo el mejoramiento de las condiciones internas e generar condiciones de confort sin el uso de máquinas térmicas. Principios, diseño, tecnologías y aspectos medioambientales son expresamente definidos en función de las peculiares condiciones (e.i. geo-climáticas, tecnológicas, de biodiversidad, económicas y antrópicas) presentes en las regiones colombianas con baja altitud, caracterizadas por altas temperaturas a lo largo de todo el año. Simulaciones térmicas y CFD orientan el proceso de verificación experimental en un laboratorio permanente contando con convenios con empresas locales y know-how *disponible* in situ.

113-127

Keywords: Building envelopes; passive facades; living walls; passive thermal comfort; climate sensitive design; tropical sustainable architecture; green architecture.

Palabras clave: *Envolventes arquitectónicas; envoltorios arquitectónicos; sistemas pasivos de fachada; jardines verticales; confort térmico pasivo; diseño sensible al clima; arquitectura tropical sostenible; arquitectura verde.*

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1. INTRODUCTION

The generous availability of resources and biodiversity, and climatic conditions where great part of the average temperatures is between 24ºC and 28ºC (1), except for the Andean and inter-Andean areas, characterizes the Colombian territory. Its location between the tropics and the variety of edaphoclimatic conditions, reflected in a 10% -15% of the global biodiversity in an extension of 0.07% of the terrestrial surface, make available native natural resources that can be implemented *in situ* in the constructions favoring the quality of life, and allowing for the aggregation of value with modest and controlled environmental impacts.

The country is the third most populated within the subcontinent, with an economy mainly dedicated to commerce and services, and a low industrialization. The construction industry is characterized by the passive assimilation of foreign technologies and by a substantial do-nothing policy derived from rents of position due to a market little selective favored by a strong population increase. The residential sector constitutes the second one by energy consumption with 27.1% and the construction with 4%. Although the CO_2 emissions of the country correspond to 0.25% of the global ones, in the projections for the year 2050 there is an increase in the annual average air temperature between 1°C and 2°C, and a variation in precipitation levels between ± 15%. According to Ortega *et al.* (2), even though Colombia contributes with 0.37% of contamination GHG effect, is highly vulnerable in terms of climatic change.

As for governmental policies, the measures to reduce energy consumption and the environmental impact generated by the exploitation of renewable energy sources are little significant in the construction sector, even if recognizing that the Capital District, which accounts for 17% of the country's population, is developing a Sustainable Construction Code. Contrary to what has been happening in high latitude countries, where climatic adversities have forced the development of functional and technological solutions for the thermal control of living spaces, the reduction of consumption and the increase of more efficient energies, in Colombia research on this field is still at its very first stages.

Not unknown technological development that refers to active and hybrid functions (3), materiality (4) and typologies (5), especially referred to facades. Vacuum insulation panels, insulation surfaces with aerogel, stratified facades with isolated fi bers and vegetal materials, different solutions of ventilated facades and double skins, as well as the integration of micronal or phase change materials (pcm) in surfaces, particularly internals, reflect research in a context highly demanding in term of energy consumption, with a purchasing power, an industrial development that has no comparison with the Colombian. The absence, in addition, of specific rules and, in general, of a consolidated environmental consciousness, make envelope rationalist solutions of solar protection have disappeared with the advent of air conditioning. The domestic construction industry, with a strong market, nor does it present real development or patents.

In this potentially rich context, though strongly unequal, lacking in binding norms and with little vocation for research and innovation, "Ecoenvelopes" is situated.

For this reason, it has seen fit to investigate on the basis of the technology in place locally, with an "adaptive" approach, facing in addition resistors, which raise the use of foreign technologies, with an "advanced" approach, very distant from the interests and the possibilities of the local construction industry.

2. PROJECT AIMS

This project is oriented to the development of building envelopes able to improve the conditions of thermal comfort in the spaces confined with a low environmental impact based on geo-climatic, technological, economic and anthropic conditions particular of Colombia. The search for highly effective passive thermal control of buildings in tropical climatic conditions has implied the identification of technologies and designs that better allow for the passive control of internal conditions, and which can be developed with the know-how of local companies. In this context, the project has analyzed the extent to which it is possible to take advantage of natural resources available in Colombia for the building envelope of low environmental impact.

The aforementioned aims to allow the access to improved habitat conditions to a wider range of the population in terms of environmental respect, technology and controlled exploitation of native resources.

With this purpose, the central activities of Ecoenvelopes are the simulation of the thermal and fluid dynamic behavior of envelopes in a defined place, where experi-

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mental testing can be accomplished, using design components, materials, species and technologies locally available (within a 200 km radius from the site).

Therefore the project associates companies that, without experience in R+D+I, contribute with their practical knowledge, instrumental and material resources: a software vendor company (Voxel), a brick maker company (Helios), a gardening plant nursery (Jardineros S.A.) and a bamboo processing industry (Induguadua) are supporting in the issue of technological transfer and product development.

To be able experimentally to verify the values resulting from the simulations allows to define with greater certainty performance data that take part in life cycle assessment and thus to define the impacts generated by the eco-envelopes. Also, depending on the forcefulness and the reliability of these results, the development of an oriented architectural culture to sustainability and a low environmental impact materiality could grow as an alternative to dominant models that are substantially indifferent to the environment and to geo-climatic conditions.

3. EXTERNAL ENVIRONMENTAL CONDITIONS

The experimental testing of the envelopes performance is taking place in Girardot, where the climate is common to great part of the Colombian territory. Located to 292 m asl, Latitude 4.16 N and Longitude 074.49 W, has an average temperature of 27.4ºC (minimum: 24.0ºC, maximum: 32.3ºC), a relative average humidity of 80%, 821 mm of precipitations with raining 76 days and 213 hours/month of solar brightness. The peaks of maximum temperatures reach to 40.0ºC, whereas the minimum fall to 21.0ºC. Generally, in 273 days/year (74.8%) temperature rises above 32ºC.

Even without considering the urban heat island effect and the heat generated by the anthropic activities, the thermal-hygrometric values surpass, except rare occasions - when more intense is the regime of rains- the comfort range. The wind speed, with a tropical breeze character, is substantially constant throughout the year varying from the 1.92 m/s to the 2.57 m/s.

The general thermal conditions vary in average from 24ºC (at 6 to 7 in the morning) up to 32ºC (at 3-5 P.M.); in order to verify the effectiveness of the proposed solutions the most unfavorable thermal values are considered, which show more evidently the differences between external and internal temperatures, and the most significant statistically average values.

With an annual average 4.575kWh/m^2/day solar radiation, is evident that the sun is an agent who takes part strongly in the thermal economy of the envelopes contributing in 4ºC (in average) up to 11ºC to the air temperature.

4. GENERAL PRINCIPIES

To passively achieve thermal comfort, two principles are applied: the reduction of the interior/exterior exchange in the day, specially in the afternoon when the temperatures are excessive, and the maximum exchange in the hours of the night to refresh by means of dissipating the heat accumulated by the internal surfaces; consequently the envelopes must be slightly permeable to air flow in the warmest hours and very permeable in the freshest hours.

The solar thermal gains are limited reducing the exposed surfaces and using materials with high specific heat. A primary envelope is complemented with a ventilated envelope of thin joints to generate the stack effect. In order to optimize the air flow, the windows have a frame with the same depth of the envelope system with operable louvers in the top and inferior bounds to manage the ventilation of surfaces and the quality of indoor air; the transparent surfaces are protected of the solar radiation by means of movable external louvers that allow interior daylight illumination and the air exchange in any configuration.

The use of ventilated envelopes creates a chimney effect that generates ascending air flows that dissipate during the day the heat of the exposed surfaces to solar radiation. During night time and first hours of the day the temperature of inside building spaces is decreased by means of natural ventilation reaching the same temperatures of the outer air, lower than 26ºC in the absence of wind and up to 29ºC with winds of 1 m/s (3).

The proposed envelope solutions are composed and defined by one inner surface (primary envelope), built with conventional technologies using hollow clay block, with a 2.5cm thick external continuous vegetable insulation and 1.5cm thick internal plaster.

The primary envelope has a dual behavior: during the day it takes advantage of his reduced thermal transmission coefficient and its inertia to maintain an internal temperature inferior to the external one; nevertheless the efficiency of the system is reduced

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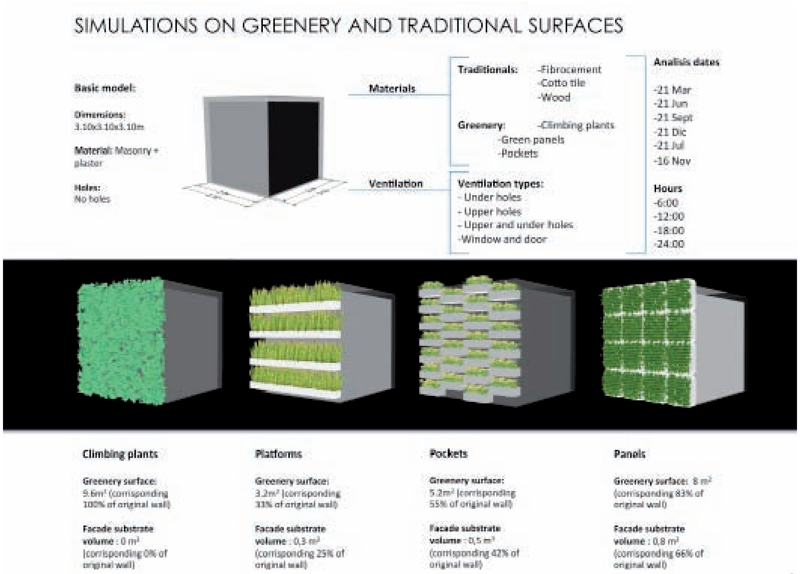

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1. UPC Classroom Building Rendering with bamboo guadua ventilated envelope.

2. Simulations on Greenery and traditional surfaces.

by the ventilation needed to maintain the indoor air quality and by the user's heat released. In order to allow the interior/exterior air exchange to achieve the nocturnal thermal dissipation, the designed openings are operated in order to control the ventilation for people and/or to refresh the surfaces of floor and ceiling (Figure 1).

5. NATIVE RESOURCES

In warm climate, otherwise than roofs built with common construction materials, a vegetal roof usually does not reach temperatures of more than 25ºC (4); natural green plants, besides working as an additional layer of isolation increases the envelope's thermal mass, protecting it from the temperature variations and the atmospheric agents. The reduction of the thermal gains by means of the envelope performance is essential in the economy of the project: the green plants envelope contribute to the buildings' protection, avoiding overheating of interior spaces and taking advantage of the breeze to refresh and the increasing the environmental humidity due to the evapotranspiration of the plants.

Its use also contributes in noise dissipating and capturing of particulate matter. Nevertheless, working with live plant species implies a high level of uncertainty that can be substantially reduced after a long term testing and experimentation. In spite of the ample diversity of plants found in Colombia, many exogenous plants that are easy to reproduce propagate and maintain, are used in gardening. The use of native species, in which its propagation is not well documented, researched or studied, implies a greater delay in the investigation, but generates dynamics that will increase the scientific knowledge providing local aggregated value. The types of greenery facades considered are schematized in Figure 2.

From the green envelope systems, the green roof intensive and extensive solutions have been analyzed; whereas for the facades or green walls, the following solutions are considered due to design and disposition of the vegetal material: surfaces, vertical boxes, pockets and platforms.

For vertical boxes, species grasses, ferns and vines that allow a great vegetal covering in just a short time and require little maintenance, are being used in the propagation studies (5). Specifically the bamboo *Guadua Angustifolia Kunth*, is used among the species which can be worked and are susceptible of physical and chemical processes, and other vegetal species (*Phylodendrum spp.*, *Hipomoea spp*, *Epipremun aureus*, *fulgida Epicia*, *Piliea sp*, *Lantyana sp.*, *Caldium sp.*, *Vincas sp.*, *goodsefiana Dracaena*, *Potulacas sp.*) have been analyzed aiming to use them in envelopes.

The reasons for the use of the first one are its extraordinary performances, the endemic character, its diffused presence and the historical background in architecture and permanence in the constructive culture. The second species grows spontaneously on the walls and roofs finding its only survival needs on the support surface and the weather; its rusticity and capacity to absorb CO_2 are associated to the photosynthesis and not to the increase of the temperature of the surface exposed to the solar radiation.

Therefore they reduce the temperature and the heat island effect, controlling the thermal oscillation by means of isolation and thermal inertia. Depending of the orienta-

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tion, species with greater tolerance to the luminosity are preferred limiting the use of heliophytes in conditions of incident radiation ≥30%, and shade tolerance plants with radiation <30%.

Wild or not extensively domesticated species sub utilized and not well known are considered as promissory because of their environmental friendly and economical potentials. The knowledge or this selection is provided by farmers, indigenous communities and results of scientific researches.

As local or native resources, the installed capacity for production of construction materials is also considered. Specifically clay tiles and brick making industries. Clay tiles and bricks, although artificial and with higher embodied energy, are long-lasting, with good hydrothermal behavior and the diffused knowledge among the local community in its use as a construction material, represents a viable alternative and of easy acceptance by the market.

For example, in the case shown in Figure 1, it is thought a ventilated facade with shutters similar to those in use in the Mediterranean and with the profiles of the fins that favors the indirect illumination.

6. AREAS OF STUDY

6.1. Thermal performance

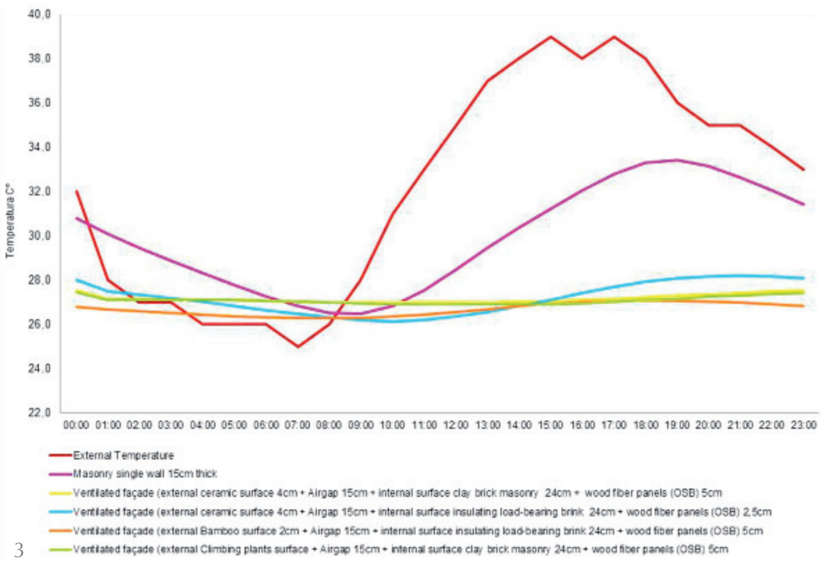
The quality of the permanence or living experience in confined spaces depends on two main aspects: user's comfort, especially in its thermal connotation, and indoor air quality. Only passive solutions are implemented to control both aspects. The opaque surfaces of the external envelope reduce the thermal charge on the building, protecting the interior from the direct solar irradiation effects setting a resistance to the heat trespassing; at the same time eliminating the thermal bridges and, over all, lagging and alleviating the heat waves.

The importance in the contribution of ventilated envelopes to the achievement of thermal comfort in warm climate is clearly recognized by analyzing their specific thermal behavior. When exposed to direct sun radiation, the surfaces of facades and roofs, built with construction materials, reach temperatures above the ones of the external air; different it is the condition of the envelopes with green plants that transform photons into the energy needed for the photosynthesis.

Although the use of clay, *bamboo guadua* or green plants on envelopes generate different thermal curves, the ventilation air space compensates the possible thermal gains maintaining the temperature within values that, at night can be lower than the external air temperature and that at day time is above in up to 5ºC, in line with other experimental results; in similar thermal conditions, T_{ext} = 29°C, surface temperature measurements done on a hollow clay block ventilated facade surface show T_{se} = 39°C (6).

This condition allows to obtain internal space temperatures significantly below the ones reached in internal spaces with a conventional The bearing structure for the ventilated envelopes is manufactured with laminated bamboo (guadua) and it can be applied to new and existing constructions. The simulations have been realized on a cubical volume of 30m^3 with the same dimensions of the permanent laboratory to be built in the current year; taking as a referent the most common constructive system used in Girardot (brick facades, plaster on the interior surface of facade walls, concrete slabs for fl oor and roof) and the internal thermal gains determined by the presence of 1 person with moderate activity.

Thermal curves with different types of coating on the hottest day (July21) are shown in (Figure 3).



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3. CFD – thermal simulation on July 21 12:00 h in the classroom UPC Building , Girardot.

After a comparative analysis of 48 different cases, three models were identified revealing a promissory performance, all with ventilated facades and roofs, of which the first components have been carried out toward the end of 2010. With envelopes in clay hollow block of 12cm and 24cm thick, the heat balance is very similar with variations in the thermal range: of 3.4ºC to 1.9ºC during the warmest day and 0.5ºC to 0.2ºC during the day with average temperature.

The three types to experiment with are:

- Ventilated envelopes with added kaolin hollow flat brick tile, with light coloration (e.g. #29). With respect to the conventional reference model, the simulations have demonstrated a thermal improvement of up to 11.5ºC in T_{max} with 9 hours of thermal gap and an average of -5.1ºC during the hottest day.

- Green plants walls and roofs with native species of easy propagation and locally cultivated, supported by bio-plastic panels reinforced with mineralized vegetal fibers, (e.g. #19) the registred thermal improvement is similar to the one of the brick: up to 11.5ºC in T_{max}, 9 hours of thermal gap and an average -5ºC during the hottest day.

- Bamboo panels laminated, immunized and preserved against the humidity and UV radiations. There are in production two configurations: a flat surface and one with inclined blinds; with the first solution (e.g. #48 with a clay cellular structure primary envelope) with thermal improvement of up to 11.9ºC in T_{max}, 4÷6 hours of thermal gap and an average -5.5ºC during the hottest day.

The three selected model solutions, even with different thermal curves, show an improvement of the thermal comfort from the interior of 10ºC in the warmest day and ≥5.8ºC in 75% of the days.

In relation to the type of construction actually used, with only the facade and roof coating, the internal temperature average-day is reduced 1.8-3.1ºC in the warmest day (0.9÷1ºC in the average day) in static regime (without ventilation) is of 6.4÷6,8ºC in the average day, in the most unfavorable conditions. The differences in the maximum values are significant: 38ºC v/s 27,1÷28,8ºC in the warmest day and 32ºC v/s 25,1÷25,7ºC in the average day.

Additionally, simulations have been realized on a real case revealing a considerable internal thermal contribution: the classroom building in UPC Girardot, with 20 students in each classroom during the day and a 30% of crossed ventilation. It has been observed a drop of temperature in up to 6.58°C when implementing the ventilated facades and roofing, on the third floor, under ceiling, therefore in the most unfavorable thermal conditions, with respect to the temperature in the classroom with the single existing envelope surfaces (brick facades with plaster in both faces and fibrocement corrugated roof sheet on steel truss structure) 31.08ºC v/s 37,62ºC, values that decrease in the lower floors, being in first floor of 29,62ºC and 33,98ºC. In the average day these values fall of 5-6ºC with resulting well comfort conditions in internal spaces without air conditioning.

In Figure 4 can be observed the temperatures of the UPC building with brick ventilated envelope (left part) and those that are generated with the current casing on the hottest day of the year.

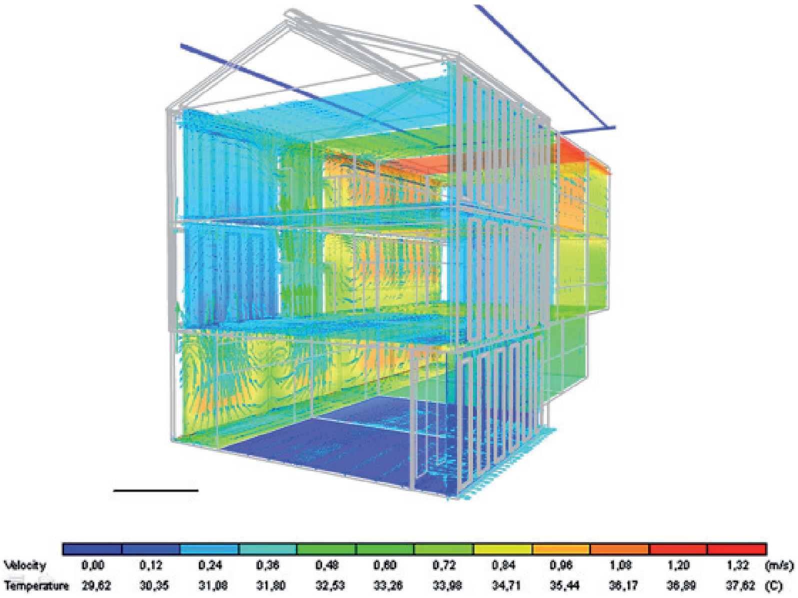
6.2. Design

Concerning the design aspects and applications of the research carried on, three different stages of development can be defined, two of which have already been finalised.

The first stage implied a study of the state of the art and further definition of the design problem. It involved a wide literature review and the analysis of various facade configurations, placing emphasis on those solutions of a local nature, and responding to the climatic conditions of our particular interest at this stage, i.e., hot and humid. A number of designs were compiled and sometimes 3D modelled, allowing for the production of summarised case studies.

In Figure 5 shows, as an example, the façade cladding of the UPC Girardot headquarters with greenery panels.

Based on the information previously compiled, the second stage had to do with the development of generic design model following our own particular assumptions, i.e., those given as results of the present research. A general structure was proposed guided by three main determining factors: functional, technological, and environmental.



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4. Thermal curves depending on surface type (July 21).

Each group had specific factors and was translated into design possibilities by the changing parameters and their relative values, producing a conceptual parametric structure.

Having defined and developed the conceptual structure, the third stage looks for the functional implementation of such structure, whose expected outcome (still in development) is a parametric definition (interactive model) that contemplate their particular performance in terms of the previously defined determining factors.

6.3. Impact

The life cycle assessment (LCA) of the product is defined according to the ISO 14.040 and ISO 14,044 standards. The impact evaluations have been realized on the reference model, usually implemented in almost all of the constructions in Girardot: plastered or face brick facade and flat roof in concrete or fibrocement.

The highest performance models have been compared with the referent construction and the Girardot climate in order to choose the best environmental and of thermal comfort option. Secondary sources are used due to the lack of local information and indicators in the field of life cycle assessment. These data is opportunely interpolated to have relatively reliable referential values.

The evaluation of the impact has considered the damages to the resources, ecosystems and human health, the carbon footprint, atmospheric acidification, the eutrophication of waters and bodies and the consumed energy. The exposition of the product life cycle assessment for the project of eco-envelope is oriented towards the identification of the combination of more advisable materials for the construction of a module, within the framework of balance between thermal comfort and environmental impact.

Solutions that use fibrocement have been discarded, which report the highest values in the impact, after the equivalent ones in concrete, whereas the use of the wood in structure represents 3.7 times less impact than the one of steel structure. The impact aimed to achieve by Ecoenvelopes is still smaller with respect to the common construction materials as a result of the advantages of using native species.

The values have been calculated using like physical referent a cube of 30m^3, with the same dimensions and specifications of the experimental station in phase of accomplishment.

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5. UPC Classroom Building Rendering with biodiverse native plants on bio-plastic trays.

6.4. Envelope-ecosystem connection

The vegetable envelope becomes a living element in the city, generating spaces for the ecological connections and allowing the flows of birds in the city. With this purpose the list of possible species is narrowed privileging those that constitute a favorable habitat for birds that feed themselves with insects that live in the green envelope (e.g.: *Carduelis sp*, *Spinus sp*, *Thraupis episcopus*, *Pitangus sulphuratus*).

The climatic conditions of high temperatures throughout the year force to implant species without leafs and shapes that can serve as water puddles in order to prevent the establishment, proliferation and or the permanence of insects potentially harmful for humans. The undertaken ways are referred to rustic species of good foliar development, low irrigation demanding and that repel insects like mosquitoes.

6.5. Night cooling

The natural air flow contribution is essential for the achievement of the energetic balance of buildings where the external temperatures surpass the comfort threshold. The heat dispersion caused by air flows, is directly proportional to the relative moisture content of the air: the advantages in the use of natural ventilation are appraised mainly at night and at dawn, being also useful to evacuate the overheated air in the afternoons. In the morning hours the nocturnal heat dissipation helps to slow down the overheating of the confined spaces increasing the comfort.

7. CONCLUSIONS

"Ecoenvelopes" has defined building envelope models for humid warm tropical climate under a framework of great respect for the nature and ecosystems balance.

The implementation of ventilated facades and roofs has been simulated in both, a structure-laboratory, with primary envelope and of ad hoc coating, and in an existing construction with high internal thermal contribution, superposing an additional ventilated envelope with hollow flat brick tiles to the existing one. In both cases internal registered temperatures has been significantly below than in the conventional constructive typology, inside or very next to the range of thermal comfort.

These results allow passing to the experimental phase with system and attainable materials of low environmental impact with technologies and resources available on site. Three solutions, all with mechanicals fixings, and with laminated bamboo structure are at the moment under development: one with traditional materials (Clay tile), a second one with surfaces and louvers of bamboo guadua with low waste technology and a third one with biodiverse native plants on bio-plastic.

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