The sustainability of construction: techniques and technologies for energy efficiency and the reduction of greenhouse gases – methodological aspects

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Abstract

In order to adapt densely packed cities to climate change, there is a pressing need for the adoption of techniques that contribute to the sustainability of constructions and, therefore, of the cities themselves, so that they become more appropriate places to enable their citizens to live and work. Indeed, adopting techniques for greening built-up environments and making use of non-energy-intensive construction technologies has proven to be an environmentally friendly and energetically efficient alternative, enhancing the micro-climate of adapted buildings and the meso-climate of the built up environment, creating ecologically appropriate alternatives for renewal of areas vulnerable to degradation and the expansion of sustainable newly constructed areas. In this context, with the support of the Rio de Janeiro State Research Funding Agency (FAPERJ), a practical experiment is currently underway at the Federal University of Rio de Janeiro (UFRJ) involving the application of naturation. This is a practical experiment that consists of applying vegetation to constructed surfaces using the COMPEC brick, which is comprised of organic and inorganic matter derived from solid urban waste. The aim is to evaluate energy and thermal comfort aspects by measuring the potential for energy conservation and efficiency gains when compared with conventional building materials. At present, 3 prototypes

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measuring 25m^2 each are being built with conventional and ecological materials: Prototype 1 (slab covering made of concrete and walls made of ceramic brick), Prototype 2 (slab covering made of concrete and walls made of COMPEC bricks) and Prototype 3 (slab covering naturated and walls made of ceramic bricks), into which heat-sensing equipment will be installed internally. The methodology of this experiment calls for monitoring the thermal behavior of the materials employed, analyzing and comparing each prototype, as well as calculating the greenhouse gas emissions of the materials employed. The purpose of all this is to see whether the resulting data corroborates the hypothesis that it is possible to improve the thermal comfort of buildings via the application of naturation, as well as to reduce greenhouse gas emissions by using and recycling solid urban waste.

Keywords: sustainability of constructions, naturation, non-energy-intensive materials, reduction of greenhouse gas emissions ("GGEs").

1 Introduction

In the energy context, we are currently witnessing expansion of the supply of energy to the point where it is becoming a major challenge all over the planet. Huge nations with high economic growth rates in the order of 10% per year, such as China and India, have encountered difficulties in meeting the rising demand for energy. Even nations with abundant availability of sources of energy and more modest annual economic growth rates, such as Brazil, have found it difficult to keep pace with the domestic demand for energy. Indeed, the tender (bidding) process for new electric power generation projects has become increasingly complex and subject to a series of obstacles: legal and environmental issues, technical-economic feasibility and even political differences or conflicts of interest involving social minorities (Stilpen [8]).

Against this backdrop, energy conservation stands out as an option that is increasingly significant from an economic standpoint. The amount of energy "saved" (measured in Brazil in terms of reais (BRL) per megawatt hours – R$/MWh) due to reduction in consumption through enhanced energy efficiency of equipment and/or change in habits of the population, is less than the cost of any type of "new" energy resulting from new projects (Stilpen [8]).

After the 1st Oil Crisis in 1973, several countries established governmental programs and specific legislation intended to foster energy efficiency. In Brazil, the National Electric Energy Conservation Program – PROCEL – was introduced in 1985 and has produced good results since then. Between 1986 and 2004 total investment in the order of R$760 million was made. The combination of energy saved and additional power generated totaled almost 19.6 TWh/year. In other words, there was a saving in terms of overall generation of just under R$ 39.00/MWh, that is, approximately 28% of the average cost of electricity sold in the 1st Auction for Purchase of Energy from Alternative Sources held by the Energy Research Company – EPE – on June 18, 2007 (R$ 137.32/MWh). This reduction in the demand for energy is equivalent to avoiding the need to build a hydroelectric power plant with rated capacity of 4,600 MW. By comparison, the controversial Jirau and Santo Antônio plants on the Madeira River have respective rated capacities of 3,300 MW and 3,150 MW (Stilpen [8]).

The National Energy Plan for the year 2030 (EPE [3]) forecasts that the demand for electricity in that year will be a total of 1,101.3 TWh. There is also the forecast of 109.0 TWh (around 10% of the total demand) being obtained from energy conservation strategies. It is worth pointing out that this amount of saved energy is equivalent to approximately double the electricity generated annually by a project on the scale of the Itaipú plant on the border of Brazil and Paraguay (which has a rated capacity of 14,000 MW) (Stilpen [8]).

Specifically as regards the structure of electricity consumption in the residential sector, the EPE [3] has adopted a criterion to the effect that the thermal conditioning of environments accounts for 3% of residential demand for electricity. According to this document, this percentage will remain constant through 2030. Considering the rise in purchasing power on the part of a significant portion of the Brazilian population as from the Real Economic Stabilization Plan in 1994, it is projected that by the year 2030 there will be a substantial rise in purchases of air conditioning equipment (chiefly by the population that previously did not have a single unit of such devices in their homes). Allied with this trend, as an adverse effect of global climate changes, the rise in the average atmospheric temperature will cause greater use of devices to mitigate residential heat (ventilator fans and air conditioners). In this sense, it is highly recommendable that the EPE revise its estimate as soon as possible to take into account the increased share of air-conditioning in residential electricity consumption (Stilpen [8]).

Based on data taken from the National Energy Balance Sheet (EPE [3]), it can be concluded that at present residential thermal air-conditioning consumes 2,510 GWh (the annual amount of power from a hydroelectric power plant equivalent to rated capacity of 602 MW). In the year 2030, the same final use of electricity will consume 8,580 GWh (the annual amount of power from a plant equivalent to 2,057 MW rated capacity, or a nuclear power plant of the same size as Angra 2 in the State of Rio de Janeiro) (Stilpen [8]).

In the environmental context, the global problem of climate change can currently be observed locally in major human agglomerations. The crowding of cities results in steep rises in the number of built-up areas and the resulting increased impermeability of the urban soil, frequently to the detriment of the existing green areas, and alterations to the local climate, amongst other aspects. In turn, owing to this climactic alteration, events such as unusually intense rainfall or the complete absence thereof occur, a situation that is aggravated by the rising phenomenon of islands of heat and atmospheric pollution (IPCC [4]).

To adapt our cities, or at least the most vulnerable parts of them, so as to be able to cope with climate change (IPCC [4]), there is a pressing need for the adoption of techniques and measures that contribute to improving the meso-climate of urban areas, making them more suitable as places in which citizens can live and carry out their day to day functions. Adopting techniques for the greening of built-up environments and making use of non-energy-intensive construction technologies are environmentally friendly and energy efficient alternatives, as they enhance the usable green space without altering the already built-up areas, thereby enhancing both the micro-climate of the buildings adapted and the built-up meso-climate environment, creating ecologically adequate alternatives for the renewal of areas vulnerable to degradation and enabling the expansion of sustainable newly built-up areas (Rola [7]).

1.1 The innovative construction technologies adopted in this research project

1.1.1 The brick known as COMPEC (Comp-Ec or Ecological Compost)

One of the aims of this research project is the investigation of the technical and financial viability of a method for partial use of solid wastes in making materials for Civil Construction. The method in question is directed towards the implementation of new cycles for residues, the focus being on recycling activities employing exclusively Brazilian techniques. The development of processes for re-using materials classified as class II type residue, according to the Brazilian Technical Standard ABNT NBR 10.004 [1], enables more adequate control over anthropic disposal in the environment, with direct and interlinked improvement in collective health, as well as the mitigation, through technical innovation in the production of alternative materials of the effects of agents that are toxic and engender climate change.

The current need for changes is global, in terms of climate, considering the contribution to climate change of the sub-products of human consumption, including such gases as methane (CH_4) and carbon oxide and dioxide (CO and CO_2). Gas emissions, as the final phase of bacterial activity in the anaerobic environment of the final deposits of waste are estimated even with the variation of the local climate to reach an average (in tropical countries) of between 30 and 50m^3 of gas/year from just 1m^3 of city garbage collected and stored. Out of these volumes, 98% are the cited gases, termed Greenhouse Gases – GEEs (Augenstein 1990 and Bingemer and Crutzen 1987 apud Peer *et al.*, 1993).

One of the activities for the mitigation of these gases is the transformation of the collected residue into compost. This material is an organic fertilizer that, according to the Industrial Department of the Rio de Janeiro Municipal Sanitation Company (COMLURB – Municipal Waste Company), makes use of an aerobic production system that by itself eliminates the emission of atmospheric pollutants and, moreover, for each ton of solid urban waste (RSU) processed turns out a final total of 500 kg of compost.

Observing a city such as Rio de Janeiro, where an average of 8,000 tons of urban waste is collected every single day, requires monitoring of the portion of waste that is not collected and stored.

To illustrate one of the chief characteristics of the construction activity proposed in this paper, and based on the data presented, it is estimated that each m^2 of masonry, or each m^2 of enclosed walls, built with bricks employing compost is capable of setting off the emission of between 3.0 and 5.0 m^3 GGs/year. That is, a simple wall measuring 3 meters long and 2.4 meters high (7.2 m^2) can offer to the environment can tie up, through straightforward civil construction, waste material that could otherwise emit between 21.7 and 35.9m^3 GGs per year (Carvalho [2]).

1.1.2 Technique for greening the built-up environment

Urban naturation involves transforming buildings into biotypes and urban spaces into a new economically and ecologically optimized form, so that, joined by green corridors, they facilitate atmospheric circulation and enhance a city's micro-climate by reducing acoustic, thermal and optic emissions and immissions as well as the reduction in use of undesirable materials (Rola [7]).

The "Naturation System" is a technology for applying vegetation to built-up surfaces which, in accordance with the principle of greening of built-up areas and following the directives of Agenda 21, seeks to ease the impact of urban development. The idea is to apply scientifically responses to environmental demands and redirect cities towards sustainable development, with a view to enhanced integration between urban spaces – citizens – nature (Rola [7]).

The Naturation System can be applied in any built-up areas, that is, roofs (surface covers), façades and paved surfaces. It basically involves transforming an old system of cultivated terraces into a system for the installation of vegetation onto built up surfaces with indexes of control and benefits for the environment. This system is comprised of four layers which are at the study phase for adaptation to Brazilian bio-climactic and technological conditions: (i) Vegetal; (ii) Sub-stratum for supporting vegetation; (iii) Drainage; and (iv) Waterproofing (Rola [7]).

The advantages of applying the naturation system are: (i) Positive impact on city and regional climate by retention of dust and contaminating substances air particles; (ii) Increase in usable green areas; (iii) Influence on the interior environment of buildings; (iv) Cooling of spaces under the roof in summer, caused by the evaporation-transpiration of plants; (v) Diminished heat loss in winter, which presumes energy savings; (vi) Increase in thermal insulation; (vii) Absorption of noise; (viii) Prolongation duration of coverage in relation to artificially waterproofed surfaces; (ix) Improved degree of humidity; (x) Reduction in the quantity of water supported by urban drainage systems; (xi) Reduction in the heat island effect (Rola [7]).

2 Objective

The objective of this article is to describe the practical experiment that was carried out at IVIG/COPPE/UFRJ with the construction of prototypes that adopted different building practices and in which a monitoring system was installed. The purpose of such monitoring was to generate input for future evaluation of the potential for energy conservation and energy efficiency gains obtained through naturation and the COMPEC brick, when compared with conventional building materials.

3 Proposed methodology for analyzing the thermal performance of naturation

3.1 Prototypes and comparison strategy

The first stage of the research project involved building three (03) prototypes (three rooms measuring 25m^2 each), according to the following specifications:

- Prototype 1: Slab Covering made of concrete and walls made of Ceramic Bricks.
- Prototype 2: Slab Covering made of concrete and walls made of COMPEC Bricks (soil-cement).
- Prototype 3: Slab Covering made of concrete employing the naturation system and walls made of Ceramic Bricks

The comparison of the thermal performance and greenhouse gas sequestration will be the result of comparison between the three prototypes and an equivalent, so as to focus on one different factor in each comparative pair study, as follows:

- COMPEC Brick vs. Conventional Brick
- Naturated Covering vs. Conventional Covering
- Naturated Walls vs. Conventional Walls

3.2 Preparation of the master plan and construction of the prototypes

Development of this activity was supported by the LABCECA, the Comfort Lab of the Fluminense Federal University's School of Urban Architecture (EAU/UFF), in analysis of the bio-climactic aspects that contributed both to implementation of the prototypes in the plot of land, as well as detailing of the buildings as such. The buildings were set up in the plots of land in such a way that they had the same areas of exposure to the sun.

Each model built measures 5.00 x 5.00 meters, with a reinforced concrete slab covering of 6.20 x 6.20 m and height of 2.90 m, placed on a radier with the same dimensions as the slab covering. The frames are all made of wood, consisting of a door, six windows arranged to favor cross ventilation, a bio-climactic strategy recommended for the type of climate in which the experiment is located (Latitude South: 22° 51' 51.22" and Longitude West: 43° 13' 44.54" in the Atlantic Tropical Rainforest region of Southeast Brazil).

Prototype 1 is the reference model for comparisons with the measures adopted in the other two modules. For this reason, the roof was made of concrete slab on which a coat of paint in a color featuring low light absorption was spread and vertical opaque closings were placed in embossed ceramic brick masonry and likewise painted in a color with low light absorption (high albedo). Prototype 2 differs from the others in the type of brick used: soil-cement bricks without embossment and remaining visible. Prototype 3 is equal to the first module, though a natured roof was added to it.

To position the modules in an adequate manner, a survey was conducted of the bio-climactic conditions in the area of the experiment, and a study made of the prevailing local winds as well as a further study of the sun chart for Rio de Janeiro, which determined the incidence of solar radiation on the façades.

Inasmuch as direct solar radiation is the main factor influencing the heat gains and source of light in a building, the modules were implemented so as to accompany the direct solar trajectory in the four façades oriented to the cardinal points. This orientation permitted the maximum amount of solar radiation to be received directly onto the façades and may provide differentiated data regarding the heating of the interior of the building. The larger windows face South and East, the smaller ones West and North, thus avoiding direct sunlight inside the building, which would result in increased thermal load. The solar diagram of the city of Rio de Janeiro and the velocity, direction and frequency of occurrence of winds for the location will likewise be considered in future analyses.

3.3 Manufacture of the COMPEC – Ecological Compost brick

The main raw materials for the manufacture of the COMPEC brick are urban waste, as follows: compost, organic fertilizer manufactured by COMLURB, and the dust of building residue from civil construction work in general. In other words, materials resulting from the end of the life cycle of various materials consumed by society. The recycling of this material requires extra time, compared to the earth used to produce ceramic bricks, in order for them to become fully adequate.

Certain difficulties arise in this innovative manufacturing process, in that the raw materials used are not available in the ideal format for the task, principally owing to the fact that their source is urban waste.

One significant negative factor in this process is related to obtaining the appropriate grain size for the compost. Various stages of sifting and pulverizing have to occur, not just owing to the size of the grain (vegetable tissue) being inappropriate, but also the high number of pieces of glass contained in the midst of the volume received.

As for the dust from civil construction residue (debris), since it is not yet a routine activity to pulverize and recycle such residue, it was necessary, in order to obtain the quantity required for total brick production to overcome the breakage of pulverizing equipment, breakage of tractors feeding the crusher, excessive rainfall, etc., all of which combined to impede the natural passage of the dust gathered, due to excess dampness.

At the same time, during preparation of these inputs, which took an average of 120 days for each step, the equipment needed to adjust the grain size proved less than ideal, requiring innovative use of equipment originally designed for other purposes. Even the hand press for casting the bricks, obtained on loan due to its structural modification, was subject to breakdown. Such breakage was due to the fact that this equipment was modified without the relevant structural reinforcements being implemented.

The construction of module 2, using the COMPEC bricks, was extremely difficult due to the lack of an adequate press, which resulted in blocks which lacked the required resistance to compression, and which, given the advanced delay in assembling the experiment, had to be replaced by soil-cement blocks, also non-energy-intensive and with thermal performance already gauged by Mello [5].

3.4 Installation of naturation system

The third module built was covered with a natured roof, a construction technique already examined at length by Rola [7]. Anti-root waterproofing was applied to the slab, followed by mechanical (geo-textile) protection between the waterproofing and the expanded clay drainage. A new layer of geo-textile (filtering layer) was installed between the expanded clay drainage and the substratum of organic and inorganic matter.

Finally, 1,800 saplings of succulent plants belonging to the crassulaceous family were added – two species, in fact: *Kalanchoe blosfeldiana* and *Sedum dendroideum*, better known locally as flower of fortune ("*Flor-da-fortuna*") and Balsam, respectively.

4 Comparative evaluation of the thermal performance of the modules

To attain the objectives proposed for this research project, heat sensor equipment was installed by Professor Saulo Güths of the Laboratory of Porous Means and Thermo-Physical Properties (LMPT) of the Santa Catarina Federal University (UFSC). The monitoring system is the Acquisition and Control System – AQUIS – a device for monitoring thermal and mechanical magnitudes, comprised of a module connected by a serial port to a PC, which constantly takes readings of the data that will serve as parameters for analysis of the research project.

Equipment recording the temperature of globes, dry bulb, humidity and winds was installed internally in the center of each module and surface temperature sensors were installed on the walls facing the North (internally and externally) and in the covering slabs of Prototypes 1 and 2 (internally and externally in the middle of the slab). On the roof of Prototype 3, three (3) heat sensors were installed, permeating the naturation system (the 1st between the waterproofing and the drainage, the 2nd between the drainage and the substratum and the 3rd on the substratum at the level of the plants), in each of the three modules.

A weather station was installed on the external part and close to the three prototypes. This station made it possible to measure the direction and intensity of the wind, rainfall, relative humidity of the air, solar radiation and air temperature.

5 Preliminary results

We present here the results of the initial phase, being the fruit of conclusions drawn from the first sample. By and large, all the prototypes featured higher temperatures inside than outside, except the one built with a natural covering roof, which at times featured lower values, as per the sequence shown in the graphs. The minimum temperature of the internal environments was above the minimum values recorded in the external environment.

During the period monitored, all the internal temperatures were above the limit of the maximum comfort temperature suggested by Givoni – 290. Higher external air temperatures were recorded at around 3 p.m. and higher internal temperatures were noted in the soil-cement brick prototype, followed by the ceramic module and then by the natural covering roof module. Lower internal air temperatures were recorded in the soil-cement prototype, followed by the roof with natural covering compatible with the ceramic brick. The thermal delay was slight during the period monitored.

6 Results

Along general lines, the results based on this sampling point to the following:

- Higher heat amplitudes provided by walls made of soil-cement bricks;
- Greater heat mitigation obtained with the green covering;
- Greater heat stability provided by the naturated covering.

7 Conclusions

Once the difficulties were overcome, the modules built, the sensors installed and the weather station in operation, the prototypes were sealed against entry of natural ventilation and the monitoring began on April 21.

The next stage of the research project consists of the statistical treatment of the data gathered and the preparation of graphs with the records of the external and internal humidity and temperature, which will provide data relating to the technical performance of each one of the alternatives adopted in comparison with the reference module. Initially, the monitoring occurs without the presence of natural ventilation, for subsequent comparison with the presence of same. Data such as thermal delay, heat mitigation, thermal amplitude and degree – hours of discomfort will lead to conclusions regarding the thermal performance of each alternative adopted.

So far, several stages of the work have been completed, and we have set out the methods employed and the difficulties encountered. The resulting data may corroborate the hypothesis that it is possible to improve the thermal comfort of buildings with the application of naturation, as well as to reduce greenhouse gas emissions by using and recycling solid urban waste.

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