Greenhouse technologies for a painting studio

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ABSTRACT: In this paper we demonstrate that lightweight dry techniques for construction have a great potential for the development of low energy architecture in the Mediterranean area, when the complete Life Cycle Analysis is taken into account. This hypothesis is demonstrated in a real building used during the daytime as a painting studio. While the thermal analysis of the building shows a fairly good performance (less than 10 kWh/ m^2/year in heating and less than 50 kWh/ m^2/year in cooling demand), the most important feature is that its CO_2 emissions are estimated to be 1'2 % of a conventional building in the region. These results open a new path for research in combining the greenhouse structure with other building techniques which can improve the thermal performance, still keeping the ecological footprint far below the average. This path will be followed with new experimental buildings at the ETSAV.

Keywords: low-energy impact, self-construction, re-usable materials.

1. INTRODUCTION

The project is a studio for a painter in Valldoreix, nearby Barcelona. The space, about 55 m^2, required good natural lighting but no glares. The building should be easily dismantled, so the terrain could serve other purposes in the future.

The architects, Coque Claret and Daniel Calatayud, professors at the ETSAV, based their work on three keystones:

- the experiences in low-cost housing by Lacaton&Vassal,
- the greenhouse sector, with previous research experiences [1], and
- two basic materials: galvanised steel and polycarbonate.

The building was planned and built in 800 hours from June to November 2005 by the two architects themselves and a team of volunteers (fifteen students and four professors). It is an exercise of using self-construction to learn about the building process with dry materials.

In addition, this exercise has permitted the architects to evaluate the complete ecological footprint of the construction of the building, as well as to estimate the footprint required to dismantle it. A further exercise of simulating the building energy consumption during its life span will provide the entire Life Cycle Analysis of the building. These energy simulations also aim to foresee what the thermal behaviour of the building will be like.

Figure 1: Image of the greenhouse-studio during the building process.

2. BUILDING DESCRIPTION

The building consists of a set of concrete lintels, which fix the galvanised steel structure (greenhouse model from a catalogue) to the ground. It has been oriented following the cardinal directions, with the entrance door at the East wall and a high window at the North side.

The floor slab has a gravel bed for water drainage, a structure of recycled wooden pallets with open ventilation, a layer of glass wool insulation and an OSB floor on top. The total U-value of the resulting floor structure is 0'35 $W/m^2·K$. The polycarbonate walls and roof (U=2'7 $W/m^2·K$, solar factor G=58%) were mounted on the ground on an aluminium substructure, and later screwed to the main galvanised steel structure. Silicone laminates are used for air-tightness.

Half of the roof can be opened with a motorised system for ventilation, leaving an opening towards the South to catch the local winds (sea breeze coming from the South and South-East). In addition, a solar screen is mounted on top of the roof in the summer months, which provides 80% additional shading to the already reduced solar transmittance of the polycarbonate (47%). The surrounding vegetation reduces further the solar gains in certain seasons: pine trees in the West (perennial), an ivy wall in front of the Southern façade (deciduous), 30 cm apart, and an olive tree by the Northern wall (perennial).

The total material impact of the building is 15'8 Tm (metric tones), that is, about 0'3 Tm/m^2, which represents a 15% of the materials weight of buildings constructed using humid techniques. From the total, a 66% corresponds to the flooring. Moreover, 15'4 Tm might be reused.

3. EVALUATION OF ENERGY CONSUMED DURING USE

The thermal performance of the building is expected to be poor, given its high average U-value (over 2 $W/m^2·K$) and its low thermal inertia. TRNSYS simulations have been performed to test such expectations. The results of the analysis show that the interior temperatures of the building when neither heating nor cooling system is used are a few degrees above the outside temperature (see Figure 2 and Figure 3).

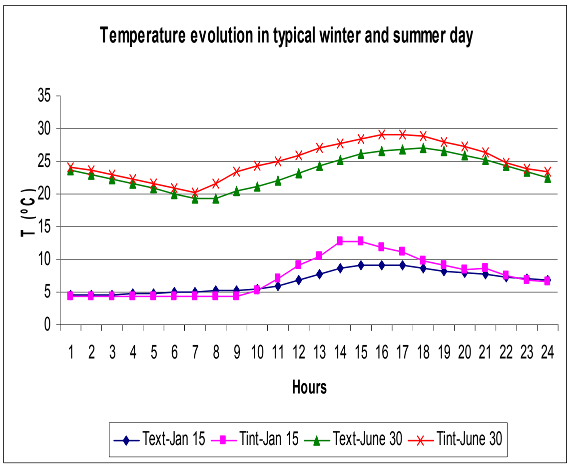

Figure 2: Temperature evolution in a typical winter and summer day, when neither active heating nor cooling is on. During the warm period (May through September), an additional screen on the roof and a deciduous vegetation wall in front of the Southern façade provide additional shading. During the colder months (October through April), an air renovation of 0'5 volumes/hour is assumed, while a renovation of 5 volumes/hour is taken when outside conditions are favourable in the warm season.

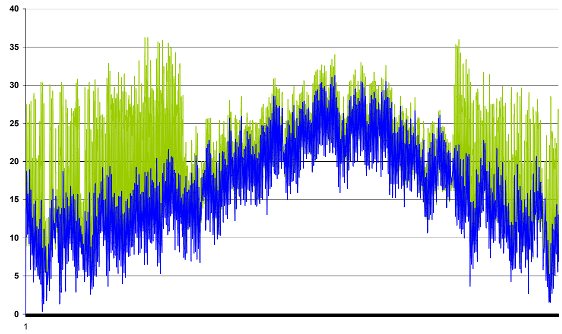

Figure 3: Temperature evolution during the year. With this simulation conditions, early on in the year, temperatures over 30 degrees could be reached inside if no additional ventilation is established.

From these simulations we can conclude the following:

– The semi transparency of the walls and roof does not compensate in winter the transmission losses through the walls.
– The solar protection of most of the envelope during the hot season, which screens around an 80% of the solar radiation on the South, West and North façades as well as the roof, prevents a large increase of the temperatures in summer.
– During intermediate seasons, the building would perform very well if the solar protections could be gradually added throughout the spring season and removed during autumn. This is the case for the deciduous ivy wall, but not that of the perennial vegetation nor that of the solar screen. If the solar screen had an automatic control, it would be easily extendable and foldable.

With regards to the energy performance, the results are very encouraging and point towards some more research on these dry building techniques for low energy buildings. The average heating is of 9'9 kWh/m^2/year, that of a *Passive House* [2]. Nonetheless, one has to be cautious with the use of the term *Passive House*, due to two main reasons:

a. The *Passive House* concept was developed in a mid and Northern Europe climate context, and thus the South European equivalent should or could probably be lower.
b. The demand has been calculated on the basis of a daytime use of the painting studio, from 9 h to 21 h. Were the studio to be used during the night, this value would be higher. We considered, though, that it was more interesting to calculate its real demand, linked to the real use of the building.

The demand for cooling, 46'7 kWh/m^2/year, is not as high as would be expected for a greenhouse-type building. This is mainly due to the presence of extra shades during the warm seasons (April through September), as well as a reasonably high set point temperature of the interior, at 26 ºC and a good ventilation (5 renovations/hour) when the exterior conditions are favourable.

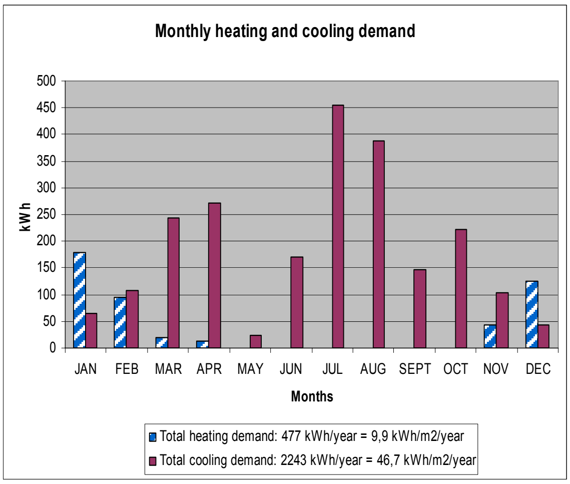

Figure 4: Monthly heating and cooling demand for a painting studio used during the day (9 h to 21 h) with set point temperatures equal to 18ºC in winter and 26 ºC in summer.

With this energy analysis, considering the life span of the building to be 25 years, and taking into account that no active cooling system will be installed, the total energy consumption for heating is 11'9 MWh = 42'6 GJ. If a biomass stove is used, then the greenhouse emissions are zero.

The electricity consumption for lighting is estimated to be, at most, 5W/m^2 x 48 m^2 x 6 hours x 300 days/year= 432 kWh/year, considering that the studio is used 300 days/year. During its 25 years lifetime, this produces an electricity consumption for lighting of 38'9 GJ. The other only relevant consumption is that of the motorised ceiling. Assuming a 500 W motor used during 10 minutes each day (5 minutes for opening and 5 minutes for closing), this produces a total consumption of 2'25 GJ. The total electricity consumption is 41'15 GJ.

Finally we add the energy required to manufacture the appliances (stove, motor and lamps), which is listed in Table 1.

Table 1: Energy embedded in the materials used to manufacture the electric appliances of the greenhouse painting studio. Source: TCQ 2000 program (www.itec.es).

Appliances	GJ
7 kW iron-cast biomass stove (115 kg iron cast)	3'77
Motor (500 W)	0'68
Lamp (250 W)	0'47
Total appliances	1'15

Adding all the contributions, the total energy consumption during the building use is 84'9 GJ. This value will be included in the Life Cycle Analysis of the building.

4. LIFE CYCLE ANALYSIS AND ECOLOGICAL FOOTPRINT

A complete Life Cycle Analysis has been undertaken, which takes into account, not only the energy used to manufacture the materials involved, but also the energy consumed during the building process. This energy is summed to the energy during the 25 years building use and the energy that can be recovered from recycling the materials is subtracted at the end. The fact that the whole building process was controlled by the architects has permitted a very precise counting of each concept. Table 2 and Figure 5 show the results of such analyses.

Table 2: Energy consumption throughout the complete life cycle of the greenhouse painting studio in Valldoreix.

Energy consumption		Energy (GJ)
Project		**13,45**
Implantation		**0,23**
Building elements	Foundation	12,6
	Structure	57,8
	Floor slab	6,7
	Skin	68,37
	Tightness	1,73
	Flooring	12,32
Total building elements		**159,52**
Transportation		**2,91**
Assembly		**99,89**
Use	Heating	42,60
	Electricity	41,15
	Appliances	5,00
Total use		**84,90**
Recycling	Foundation	0,00
	Structure	-40,40
	Floor slab	-5,06
	Skin	-57,30
	Tightness	0,00
	Flooring	-12,30
Total recycling		**-115,06**
RES for heating (biomass)		**-42,60**
NET ENERGY		**203,23**

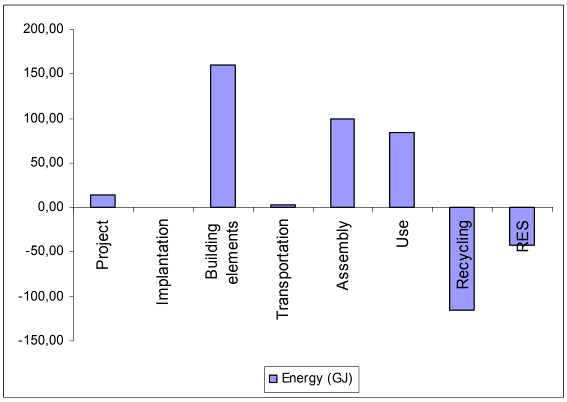

Figure 5: Energy consumption throughout the complete life cycle of the greenhouse painting studio in Valldoreix.

The most energy consuming parts of the whole process are: the energy embedded in the building elements (which can be compensated at the end of the lifetime of the building if techniques that allow for recycling are used), the energy consumed during the assembly, and that used during operation, part of which can be obtained from renewable sources.

Table 4: Ecological footprint of the greenhouse painting studio in Valldoreix. The emissions have been calculated using the Catalonian electricity mix of 1999 (67'1 % nuclear, 16'9 % gas, 11 % hydraulic, 3'2 % fuel-gas oil, 1'8%cool, giving a total emission of 0'107 kg CO_2 eq/kWh=0'30kg CO_2 eq/GJ [3].

Total footprint	Greenhouse studio	Reference(*)	Percentage to reference
Net Energy (GJ)	203,23		
Nºusers (hab.)	1		
Building Life (y)	25		
GJ/(hab*y)	8,13		
Tco2/(hab*y)	0,24	21,00	
Ecological footprint (Ha)	0,12	10,50	1,2%

(*) Average building energy in Catalonia: 30 GJ/m2/hab/year for a rate of 2'4 hab/building.

The data show that the CO_2 emissions of the greenhouse painting studio are 0'29 Tm CO_2/hab/year and the resulting ecological footprint is 0'12 Ha, which is 1'2 % that of a conventional building in Catalonia.

5. CONCLUSIONS AND FUTURE RESEARCH

The greenhouse painting studio demonstrates that lightweight dry building techniques open new prospects for low energy buildings in the Mediterranean area, taking into account the energy consumed throughout their complete life cycle.

The total demand for heating and cooling is 56'6 kWh/m^2/year when the building has a daytime use.

The ecological footprint of this building has established to be 0'12 Ha, which is about a 1'2% of an average construction in Catalonia (21 Tm CO_2/hab/year). There is room for increasing the thermal comfort, either by increasing the thermal inertia or the insulation, or both at the same time, as well as to extend its use for living purposes. Such adaptations could increase the ecological footprint of the resulting building, but the resulting building would still have a footprint far below the average.

An additional and very important aspect of this project is that the cost of building which such lightweight dry techniques, which allows for self-construction, is also about one tenth of a building with the same area constructed with traditional heavy wet techniques. Firstly, this low price opens the opportunity for users to invest in efficient technologies for HVAC systems and lighting. Secondly, this opens a new debate that has social implications, especially in a country where the continuous rise of housing prices has placed important barriers to the young population.

The most interesting feature of the greenhouse-studio project has been to re-establish contact between the university and reality. This building has become a prototype of a future experience at the ETSAV: in 2006, a similar structure — but larger and with several thermal spaces — will be built on-Campus by the students. The aim is to count energy consumption throughout the life-cycle of the building and to simulate and test different improvements to these dry, self-constructed, building techniques.

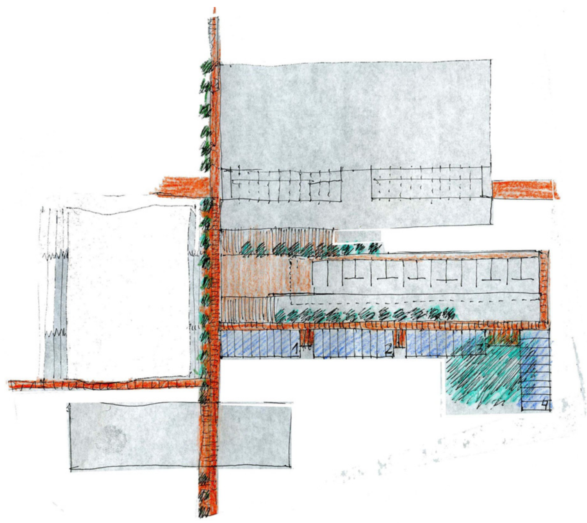

Figure 6: Sketch of the new greenhouse-type modules to be placed by the main university buildings at the ETSAV (4 in total). Each module will have an area of 200 m^2 and will be used by different departments for research and teaching activities. The first module will be built during the summer of 2006.

AKNOWLEDGEMENT

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[3] Source: Pla de Millora Energètica de Barcelona, Agència de l’Energia de Barcelona, 2000.

[4] Source: Solanas, Antoni *et al.* Casas ecológicas. Ed. Gustavo Gili. To be published.