Sustainable Test Cell – Performance Evaluation

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Summary: *Energy is one of the main causes of the environmental pollution. In the European Union, buildings are responsible for 40% of the final energy demand and 1/3 of the emissions of greenhouse gases. Therefore, in order to promote the energy consumption reduction, it is fundamental to employ sustainable development principles in the construction sector. In order to demonstrate and show the potentialities of Sustainable building technologies two Test Cells were built. Comparing the solutions obtained via "in-situ" measurements and energy simulation tools, it was verified that the new Sustainable solution has a better energetic and environmental performance.*

Keywords: *Sustainable, passive solar technologies, test cell, energy simulation*
Category: *Energy efficiency*

1 Introduction

The conflict between economic development and the environment have lead to a state of global environmental urgency. The building sector in the EU is responsible for 40% of the final energy demand and 1/3 of the emissions of greenhouse gases, then it is easy to realize that this sector has a large responsibility in the environmental pollution. Different measures are necessary for the construction of sustainable buildings: since energy regulation to the awareness of the intervening parts to the benefits of energy efficient solutions in buildings [1,2].

With this challenge in mind, a Sustainable Test Cell (Fig. 1 → 1) and a Conventional Test Cell (Fig. 1 → 2) were built in order to compare the performance of both solutions. The other Test Cell (Fig. 1 → 3) was built using the guidelines of the Passys European Project and its called Passys Test Cell (PTC), but it wasn't used in this Case Study [3].

Fig. 1. Test Cells.

2 Case Study

The current case study is based on the performance evaluation of the Test Cells. The Sustainable Test Cell (STC), as shown in Fig. 2, contains two compartments: the compartment 1 simulates a bedroom. It was constructed using compacted earth walls [4] and an opening in the south façade. The high thermal inertia combined with an opening equipped with exterior horizontal and vertical shading devices - in order to avoid overheating in the summer - is a passive solar technique. In order to improve the sustainability of the solution the exterior walls of this compartment where built with a locally available material - Earth; the compartment 2 simulates an office. It is a lightweight construction with insulation and a large opening in the north façade in order to promote the daylightning and thus reduce the energy spent in lightning.

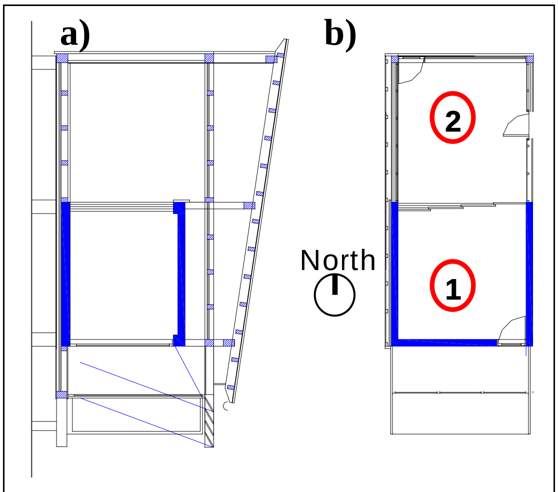


Fig. 2. Plants of the STC; a) lateral; b) top.

The Conventional Test Cell (CTC), as shown in Fig. 3, contains three compartments: the compartment 1 simulates a bedroom; compartment 2 simulates a bathroom; compartment 3 simulates a hall. The CTC was constructed with a double pane hollow brick envelope wall with insulation on the air gap. This Test Cell represents the conventional Portuguese Construction [5,6].

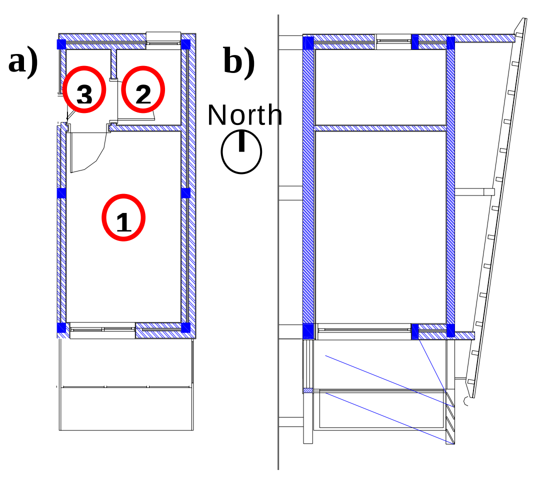


Fig. 3. Plants of the STC; a) top; b) lateral.

Both Test Cells were equipped with Sunspaces, in order to implement an indirect gain solar strategy (Fig. 1).

2.1 Measurement System

In order to evaluate the performance of the Test Cells, as well as proceeding to the comparison between the chosen solutions, it was necessary to install a measurement system in the Test Cells. The measurement system can be divided in three base components:

1 Weather station - this component contains all the sensors configured to measure climatic parameters. Thus, the weather station (Fig. 4) is composed by: 1 air temperature and relative humidity sensor; 1 wind speed and direction sensor; 1 solar radiation sensor; 1 precipitation sensor.

Fig. 4. Weather Station.

2 Test Cells measurement system - this component contains all the sensors configured to measure interior parameters. Thus, this system is composed by: 3 interior temperature sensors; 4 interior temperature and relative humidity sensors; 37 superficial temperature sensors (distributed by the interior and exterior walls and glazings of the three Test Cells); 4 heat flow sensors; 2 luminosity sensors; 2 air flow sensors (Fig. 5).

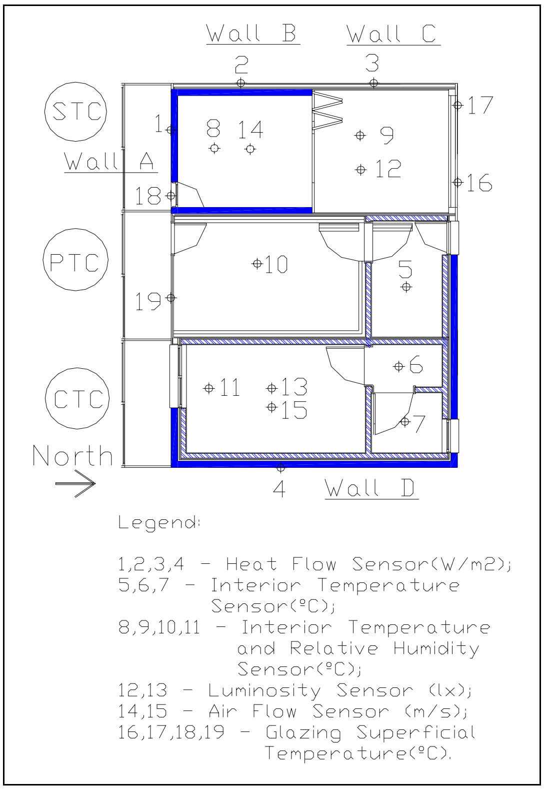


Fig. 5. Distribution of sensors inside the Test Cells.

3 Data acquisition system - this component contains a data-logger (Fig. 6) with two multiplexers (in order to achieve all the necessary inputs) and a support computer.

Fig. 6. Test Cells data-logger.

3 Performance Evaluation

The evaluation of the performance of the test Cells is based on “*in-situ*” measurements, data available from the materials used and simulation made on VisualDOE [7]. The model used to simulate the

Test Cells was calibrated based on experimental data. Additionally, the experimental data also allowed verifying the "goodness" of the proposed model.

Then, prior to the performance evaluation it was necessary to generate two models (one with sunspace and the other without sunspace) that represented the Test Cells, like the one in Fig. 7.

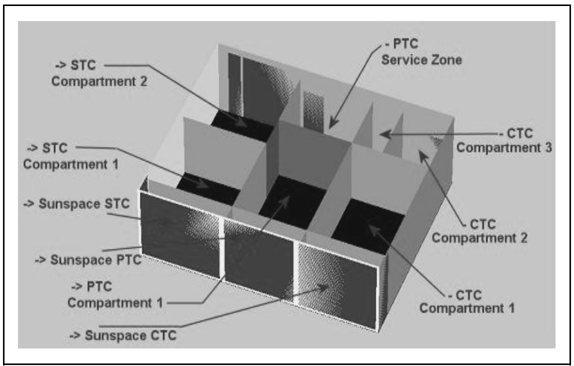


Fig. 7. Model of the Test Cells.

In order to guarantee a good precision of the model, it was necessary to calibrate it, adjusting the model to the reality. In this Case Study the calibration was made in three main steps:

1 Obtaining a climatic file that represent the climatic conditions that the Test Cells were exposed;

For this case study the climatic file was obtained using the data retrieved from the weather station installed in the Test Cells. But in order to obtain all the parameters required for the VisualDOE climatic file [8], in addition to the parameters directly obtained by the weather station, it was necessary to calculate the remaining parameters [9-11] using the ones obtained "*in-situ*" (Table 1).

Table 1. Parameters necessary to obtain the climatic file.

"In-Situ" Parameters	Required Parameters	Obtained from:
1) Temperature	Dry bulb Temperature	1)
2) Relative Humidity	Wet bulb Temperature	1); 2)
3) Precipitation	Humidity Ratio	1; 2)
4) Wind Direction	Enthalpy	1); 2)
5) Wind Speed	Precipitation	3)
6) Total Horizontal Solar Radiation	Wind Direction	4)
	Wind Speed	5)
	Total Horizontal Solar Radiation	6)
	Direct Solar Radiation	6)
	Clarity ratio	6)

2 Obtaining the "*in-situ*" thermal resistance of the exterior walls;

The method used for the calculation of the "*in-situ*" thermal resistance of exterior elements was the sum technique from the ASTM Standard C1155–95 [12]. With this method it was necessary to obtain the heat flux, interior an exterior superficial temperature. Thus, the elements which were in condition for applying this technique were (referenced in Fig. 5):

Wall A – Compacted earth, 15 cm;

Wall B – Agglomerated board (concrete / wood), 1.2 cm + Air layer, 4 cm + Expanded cork insulation, 5 cm + Compacted earth, 15 cm;

Wall C – Agglomerated board (concrete / wood), 1.2 cm + Air layer, 6 cm + Agglomerated board (concrete / wood), 1.9 cm + Expanded cork insulation, 8 cm + Coconut fiber insulation, 2 cm + Carton / plaster gypsum board, 1.3 cm;

Wall D – Stucco, 2cm + Hollow brick, 11 cm + Air layer, 4 cm + Extruded Polystyrene insulation, 4 cm + Hollow brick, 15 cm + Stucco, 2cm.

The results obtained are shown in Table 2.

Table 2. Test Cells exterior walls Thermal Resistance.

Element	Thermal Resistance	
Wall A	0.34	$m^2.°C/W$
Wall B	2.97	$m^2.°C/W$
Wall C	1.04	$m^2.°C/W$
Wall D	2.2	$m^2.°C/W$

3 Comparing the compartments interior temperature, measured "in situ" with the interior temperature calculated by VisualDOE.

This procedure is very useful for making the last adjustments of the model, like for detecting some inaccuracy of the model or adjusting the thermal inertia. In Fig. 8 and 9 it is possible to observe the results from the model adjustments.

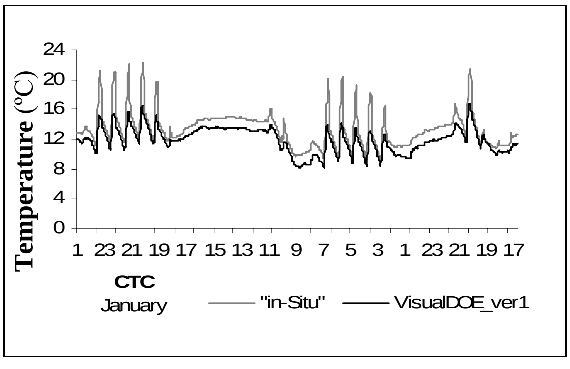


Fig. 8. Test Cells Interior Temperature – VisualDOE first version of the model.

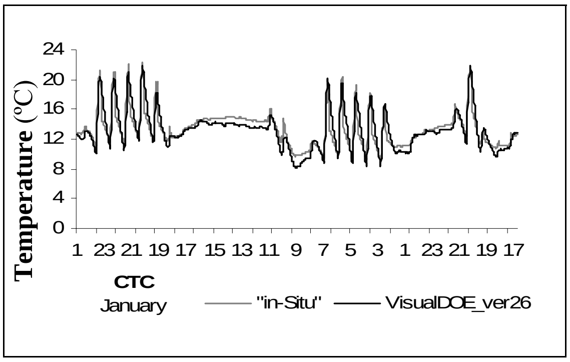


Fig. 9. Test Cells Interior Temperature – VisualDOE final version of the model.

With the model calibrated, it was tested the average error of the model, comparing the Test Cells interior temperature obtained "*in-situ*" and by VisualDOE for all the months of the simulation – October 2003 to October 2004. Between October 2003 and February 2004, the Test Cells weren't equipped with the Sunspace (constructed in March 2004), and thus the model of the Test Cells without sunspace was tested for average error between October 2003 and February 2004 and the model with sunspace was tested for the remaining months. The average error of the models is shown in Table 3 (without sunspace) and Table 4 (with sunspace).

Table 3. Average error of the model without sunspace.

	Months	**Average error** Temperature (ºC)	**Average error** Percentage (%)
STC – South	Oct, Nov, Dec - 2003; Jan, Feb – 2004	1.3	7.9
STC – North	Oct, Nov, Dec - 2003; Jan, Feb - 2004	1.1	7.2
CTC	Nov, Dec -2003; Jan, Feb – 2004	1.1	6.9
PTC	Oct, Nov, Dec - 2003; Jan, Feb - 2004	2.4	10

Table 4. Average error of the model with sunspace.

	Months	**Average error** Temperature (ºC)	**Average error** Percentage (%)
STC – South	Aug, Sep, Oct – 2004	1.1	4.3
STC – North	Aug, Sep– 2004	1.5	6.4
CTC	Apr, Mar, May, Jun, Jul, Aug, Sep – 2004	0.8	3.5
PTC	Jun, Jul, Aug, Sep – 2004	1.5	5

Taking in consideration that the average errors covers one year of measurements, the obtained average errors assure us that the results obtained with application of the VisualDOE are representative, and thus it was possible to test the energetic performance of the Test Cells.

3.1 Environmental performance

The environmental performance was evaluated by:

- Quantification of materials embodied energy (PEC) – it was obtained using the data available from the materials employed, presented in Table 5 [13-15];

Table 5. Weight and PEC of materials used in the Test Cells.

CTC		
MATERIALS	Weight (kg)	PEC (kWh)
Clay (hollow brick)	9778,1	12320,4
Aluminum	250,0	11120,0
Concrete	32411,6	10695,8
Steel	955,6	2656,5
Extruded Polystyrene	54,0	1504,4
Stainless Steel	75,0	729,7
Glass	127,2	649,9
Asphalt / carton shingle	112,5	455,6
Gypsum (projected plaster)	270,0	283,5
Polycarbonate	8,9	215,5
Agglomerated board (concrete / wood)	153,9	166,2
Wood (pine)	851,1	153,2
Floating floor in wood	94,5	131,4
Plastic ink (in wet base)	11,7	65,1
Particle board (wood)	40,3	43,6
Synthetic varnish	1,7	36,6
Polyethylene shingle (expanded)	1,4	32,7
Total	45197,5	41260,3
Total / m^2	3013,2	**2750,7**
STC		
MATERIALS	Weight (kg)	PEC (kWh)
Concrete	18344,8	6053,8
Agglomerated board (concrete / wood)	2161,4	2334,3
Steel	681,3	1894,1
Expanded cork insulation	884,4	981,7
Stainless Steel	75,0	729,8
Vulcanized rubber	34,0	661,0
Glass	106,8	545,8
Asphalt / carton shingle	112,5	455,6
Carton / plaster gypsum board	397,8	417,7
Polycarbonate Alveolar	16,4	396,5
Wood (pine)	1971,3	354,8
Gypsum (projected plaster)	306,0	321,3
Coconut fiber insulation	57,8	225,4
Synthetic varnish	9,5	204,7
Floating floor in wood	107,1	148,9
Compacted earth (Adobe)	4995,0	134,9
Particle board (wood)	83,5	90,2
Lime painting (slaked)	144,0	40,0
Polyethylene shingle (expanded)	1,5	37,0
Plastic ink (in wet base)	3,6	20,0
Wood	80,0	14,4
Total	30573,7	16061,7
Total / m^2	1798,5	**944,8**

- Quantification of energy consumption for material transportation (E_{MT}) [16] – it was obtained using the following equation:

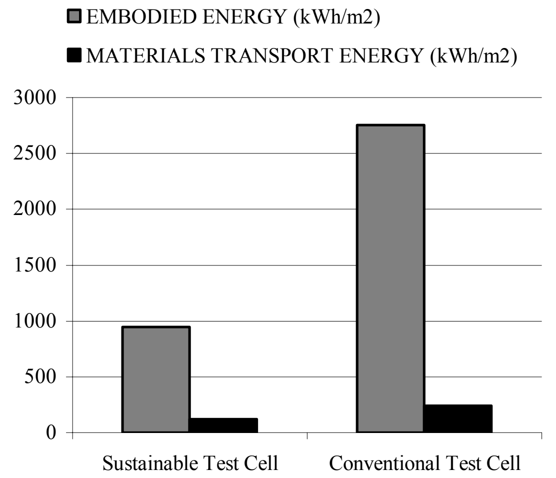
Equation 1

$$E_{MT} = 0.80278 \cdot D \cdot W \text{ (kWh/m}^2\text{)}$$ with:

D – Distance covered in the materials transportation (Km);

W – Weight of the materials (Kg).

In both cases there are lower consumptions for the STC, consequently the STC has a better environmental performance (Fig. 10).



	STC	CTC
Embodied Energy	944.8	2750.7
Transport Energy	121.4	241.9

Fig. 10. Environmental performance of Test Cells

3.2 Thermal performance

The thermal performance was evaluated by the application of a Simulation Tool – VisualDOE 3.1 - to the case study. With the models calibrated (with and without sunspace) it was introduced in VisualDOE a HVAC system and regulated the heating comfort temperature for 20 ºC and the cooling comfort temperature for 25 ºC. The results of the simulation are presented in Table 6 and 7.

Table 6. Energy consumption for the STC.

Energy consumption (kwh/m^2.year)		STC		
		Compartment 1	Compartment 2	Total
with sunspace	Heating	73.3	187.9	130.7
	cooling	15.7	81.9	48.8
	Total	89	269.8	**179.5**
without sunspace	Heating	103.6	186.9	141.7
	cooling	23.8	83.7	48.9
	Total	127.4	270.6	**199**

Table 7. Energy consumption for the CTC.

Energy consumption (kwh/m^2.year)		**CTC**
with sunspace	Heating	126.8
	cooling	15.1
	Total	**141.9**
without sunspace	Heating	158.2
	cooling	37.1
	Total	**195.4**

Analyzing the data of Tables 6 and 7 it is possible to conclude that the compartment 1 of the STC always presents the best energy performance. However, the STC has an inferior global performance. Nonetheless, for the case without sunspace the difference is insignificant and for the heating season the STC even presents a better performance. On the other hand one confirms that the application of a sunspace results in an improvement of the energy performance in both Test Cells.

The inferior global performance of the STC can be explained because of the large opening in the North façade in order to promote daylightning, but as the Test Cells are not occupied there is no lightning consumption and the effect of the daylighning is not included in the energy consumption.

In order to improve the performance of the compartment 2 of the STC the opening in the north façade was reduced (2.4 X 1.8m => 1.4 X 0.4m) and replaced the polycarbonate to double glass. With the changes in compartment 2 of the STC, it will be fit to simulate a bedroom instead of an office. The results of this modification are shown in Table 8.

Table 8. Energy consumption for the STC after the modifications.

Energy consumption (kwh/m^2.year)		**STC**		
		Compartment 1	Compartment 2	Total
with sunspace	Heating	74.5	129.7	102.1
	cooling	16.2	36.9	26.6
	Total	90.7	166.7	**128.7**
without sunspace	Heating	107.5	129.1	118.3
	cooling	24.8	37.7	31.3
	Total	132.3	166.8	**149.6**

With the reduction of the opening and substitution of the Polycarbonate sheet for double glass, in the compartment 2 of the STC, the global energy performance of the STC improved significantly, but reducing the degree of natural illumination. Therefore, considering that in the base case the CTC without sunspace was 2% more energy efficient than the STC, after the modification the STC is 23% more energy efficient than the CTC. Considering the case base of the CTC with sunspace it was 21% more energy efficient than the STC. After the modification the STC is 9% more energy efficient than the CTC. Thus, the STC acquires an energy performance more efficient than the CTC in any in case. Additionally, for the STC without greenhouse it haves inferior heating and cooling consumptions needs that the CTC.

4 Conclusions

From the study carried out it was concluded that the use Sustainable Construction Technologies and materials with less embodied energy and of local availability, can be solutions with similar or superior energy performances than the conventional solutions in Portugal. Thus, the use of innovative solutions can be beneficial to the environment, as well as in terms of energy consumption, resulting in solutions that stimulate the Sustainable Development.

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