652: Applying sustainable renovation policies to buildings: Are we missing a step?

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Abstract

In 1999 an architectural competition was held to select a building design for the new research and technology transfer centre of the School of Architecture of the Vallès in Barcelona. Because of its constructive and architectural characteristics, the winning proposal did not address interior comfort or environmental aspects.
A complete overhaul of the original plan is being made to correct the original design using passive techniques. However, because of time and economic constraints it was necessary to design and apply an action plan to provide adequate interior conditions in summer in a period of three weeks, so a practical approach was adopted. In the case of uncertainties regarding the simulation models or real energy consumption, previous steady-state calculations of the building's performance and past and current interior parameters were considered as the main inputs for decision making and for validating results. This approach is discussed in the paper.

Keywords: improved interior environment, energy restoration, renovation policies, passive strategies

1. Introduction

It is known that buildings are large consumers of energy and there is potentially big energy savings in the construction sector in the near future [1].
In the Technical University of Catalonia (UPC), the Plan UPC Sustainable 2015 has a branch, *Building, Energy and Climactic Change,* developed specifically to address this issue [2]. Since the year 2000, within this political frame, diverse situations have been developed to establish a methodology to define environmental objectives that would be implemented in the process of promotion and construction of a building.
The experiences [3, 4], which evidenced the lack of order and information about this process, intended to create a mechanism that would guarantee the achievement of these objectives throughout all of the phases. Generally, the processes had failed and had been interrupted. Once the strategic lines were developed, it was difficult to put them into practice due to the confluence of conflicting interests of the large number of institutions involved in the projects. However, valuable information has been obtained about the characteristics and mechanisms of the process of promotion and construction of the buildings, as well as their subsequent energetic running [5].
The School of Architecture of the Vallès (ETSAV) has persistently emphasized the link of research and transference of technology as teaching related tools. To provide a physical support for these works, in 1999 an architectural contest was held to choose a design for the new centre for research and technology transference building (CRiTT) [6]. Construction was completed in 2006. Despite the policies and competition objectives, the building turned out to have major indoor-comfort problems.
A year later, it was decided it was urgent to improve summer comfort with the minimum use of economic and energy resources.

Fig 1. Building seen from the south - west

In terms of methodology and expediency, a preliminary analysis was undertaken using information that was already available:

- monitored indoor and outdoor data from three previous weeks of June 2007
- existing steady-state analysis of the building

This will be shown in section 3.

Secondly, simulations were made with DesignBuilder software [7].This will be shown in section 4.
Taking into account the results from both exercises, actions were designed and executed to provide for the necessary improvements. Then, indoor and outdoor conditions were monitored to validate the efficiency of the improvements. The above process will be discussed further in the paper.

2. Description of the original building

The building is a rectangle 70 metres long and 15 wide; the area is approximately 730 m^2. The occupied ground floor has a height of 3 metres and has a completely ventilated semi-basement lower level. As can be seen in figures 2 and 3, the longer façades are made of glass; more precisely the north façade is double paned glass with an air chamber (covering 1) and 25% of the area with operable windows. The south façade is also double paned glass with an air chamber (covering 2) but 12% of the surface consists of windows with vertical louvers made of simple glass (covering 3). The east façade (covering 4) is made of light concrete and the west façade has a solid section made of insulated sheetrock (covering 5) and two operable single glass parts (covering 6). The roof is a unidirectional slab with 5cm insulation and 5cm of earth above (covering 7); the base is reinforced concrete (covering 8).

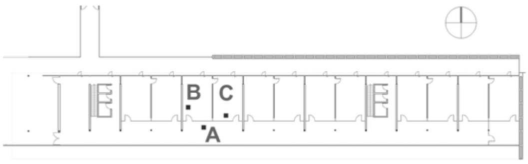


Fig 2. Building plan

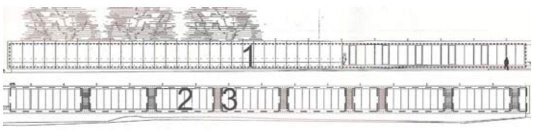


Fig 3. North (above) and south (below) elevations of the building with types of enclosures

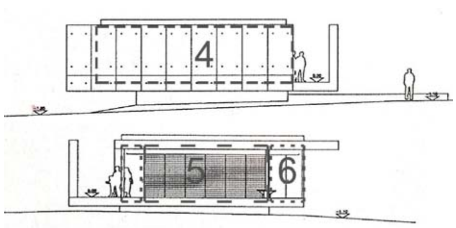


Fig 4. East (above) and west (below) elevations of the building with types of enclosures

Table 1: Summary of the characteristics of the enclosures.

Enclosure	U ($W/^oC.m^2$)	Surface(m^2)	Orientation
1	3.30	174.25	N
2	3.30	152.25	S
3	5.80	22.50	S
4	1.29	26.00	E
5	0.53	18.12	W
6	5.70	7.88	W
7	1.83	726.02	-
8	0.64	726.02	-

The explained constructive solutions imply some thermal transmission values, which are shown in table 1.

3. Previous studies already available

3.1 Thermal analysis in summer

First, in order to understand the building from the point of view of the user's experience [8, 9], a previous steady-state calculation of thermal expenditure was reviewed. This calculation was carried out [10, 11], according to the formula:

$Q = Q_{tra} + Q_{rad} + Q_{ven} + Q_{int}$

Where:

$Q_{transmission} = U*S*(T_{interior}-T_{exterior})$

$Q_{radiation} = S*radiation$ [8].

$Q_{ventilation} = 0.3*V*(T_{interior}-T_{exterior})$ [12].

$Q_{internal} = Q_{lighting} + Q_{occupancy} + Q_{aparatus}$

(S=surface, T=temperature, V=volume)

The results of the calculation are shown in the following table 2:

Table 2: Results for the calculation of the expenditure during summer by different types of enclosures.

Enclosure	Q_{tra}	Q_{rad}	Q_{ven}	Q_{int}	Q (kW)
1	1.0	9.6			10.6
2	0.9	12.2			13.1
3	0.2	1.8	0.9		2.9
4	0.06				0.06
5	0.02				0.02
6	0.08	1.2	2.4		3.7
7	0.8				0.8
8	0.2				0.2
Total (kW)	3.3	24.8	3.3	6.0	37.4

The analysis of the enclosures by types of expenditure allows us to quantify the problems that were previously observed about the building:

- Transmission: there are significant gains through the north and south glass façades and the roof (in this order).
- Radiation through the north façade is similar to the southern façade because the building in front is white. However, the north façade is unprotected while the south has an eave of two metres.
- Ventilation: the infiltrations are concentrated in the corridor (enclosures 2 and 6) and not in the offices, which is where there is more expenditure.
- Internal expenditure: can strongly vary from one office to another.

In general the design is clearly unfavourable in the summertime because of the significant gains. The thermal capacity, as well as the reflection of the concrete northern wall and the white façade from the building in front, worsens the problem. Furthermore, because the interior layout of the building has all the offices facing the north and the corridor facing south, the zones behave differently.
Winter steady-state analysis is not displayed here, but was also available and considered to give an overall understanding of the building's performance.

3.2 Temperature monitoring

Over a three week period in June 2007 the interior temperatures of the building in the corridor (probe A) as well as the offices (probes B and C) were monitored in order to compare them simultaneously with exterior temperatures [13]. Probes' location is shown in figure 2.

From the original 21 days, only 14 were complete and usable for the study. Table 3 shows registered temperatures during the aforementioned month. As an example, figure 5 shows the changes of temperatures throughout one week of June 2007.

Table 3: Registered interior and exterior temperatures (ºC) during June 2007. Amp= Temperatures' Amplitude (ºC), Mean= Mean temperature (ºC), Delay= Time delay from outdoor temperatures (h)

Day		Office			Corridor			Outdoor	
	Amp	Mean	Delay		Amp	Mean	Delay		Amp
12	4,3	28,3	-1	4,0	26,7	-1,75	12,1	22,0	0
13	4,8	28,2	-2	6,1	25,8	0	12,2	21,8	0
16	2,4	28,3	-1	4,7	25,3	-1,25	8,7	20,6	0
17	3,5	28,3	0	5,3	25,7	-0,25	10,0	21,9	0
18	5,2	28,0	1,5	6,6	26,4	0,75	9,6	22,3	0
19	4,7	28,9	-1,5	7,8	26,8	-1	10,5	22,9	0
22	4,8	27,8	2,5	4,9	25,5	2,25	8,0	20,8	0
23	3,4	27,8	2,25	5,6	24,1	2,75	11,6	19,7	0
24	4,3	28,0	1	7,9	25,4	1	14,1	21,7	0
26	5,1	26,9	0,5	4,3	23,9	-0,5	7,3	19,6	0
27	4,9	25,9	1,5	3,4	23,5	1	5,8	18,2	0
28	4,1	25,9	3	3,9	23,6	1	9,2	19,9	0
29	4,6	26,7	2,5	4,4	25,1	1	7,6	22,3	0
30	4,2	27,6	0,25	6,2	25,4	-0,25	11,2	22,4	0
Mean	4,3	27,6	0,7	5,4	25,2	0,3	9,9	21,2	0

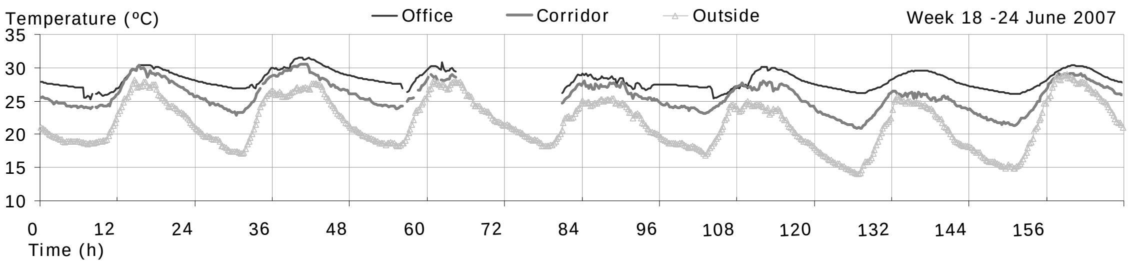


Fig 5. Variation of temperatures throughout three weeks in June 2007

Each day the behaviour of the building is the same: the interior temperatures are higher all day inside the building, and in the offices the temperature is much higher than in the corridor (even though they are situated on the north façade). We should remember that this is due to the fact the corridor has exterior solar protection during the day and can be easily ventilated, while in the offices there are reflections from the facing building (the protection is on the interior face of the windows) and they have more internal gains and cannot be ventilated.

The behavioural pattern is shown in figure 5.

4. Modelling

4.1 Original building

To complete the analysis, the building has been simulated with DesignBuilder software. To validate the model, a simulation of the original building was run for the sample summer week set as default by the software.

These DesignBuilder's simulation results don't stray much from the registered temperatures, as can be seen in table 5 and figure 6.

When comparing the results for each day in tables 5 and 6, it may appear that simulation results are not valid. First, established weather data in the software did not match exactly with actual measured data. Nevertheless, when looking at the amplitude and mean temperature for the entire week, a difference of one degree seemed acceptable taking into account that simulation weather data are statistical.

Thus amplitude, mean temperature and delay were considered as adequate indexes to describe building behaviour.

Table 4: Average day's interior comfort indicators of the original building for the summer week according to DesignBuilder.

Indicator	**Office**	**Corridor**
Discomfort hours	6.4	2.7
Fanger PMV	0.8	0.6

As can be seen in table 5, the simulation could also provide comfort indexes [14] for the northern area (offices) and the southern (corridor). The hours of discomfort are calculated for all types of clothing and for the occupied period, according to the ASHRAE 55-2004 [15]. The Discomfort hours data below is equivalent to ASHRAE 'unmet load hours'.

Table 5: Variation of temperatures for the original building throughout the default summer week by DesignBuilder. Amp= Temperatures' Amplitude (ºC), Mean= Mean temperature (ºC), Delay= Time delay from outdoor temperatures (h)

Day		Office			Corridor			Outdoor	
	Amp	Mean	Delay		Amp	Mean	Delay		Amp
1	5,3	26,8	2	5,7	25,6	0	11,1	21,9	0
2	5,6	27,2	1	6,1	26,0	0	11,1	22,8	0
3	4,3	26,9	0	3,6	25,5	1	7,8	22,8	0
4	4,6	27,0	2	4,7	25,5	1	8,3	21,9	0
5	5,2	27,0	2	5,7	28,6	1	12,2	21,4	0
6	3,7	27,1	3	5,0	25,6	1	10,0	21,5	0
7	3,5	27,5	3	4,8	26,0	0,5	8,9	22,7	0
Mean	4,6	27,1	1,9	5,1	26,1	0,7	9,9	22,1	0

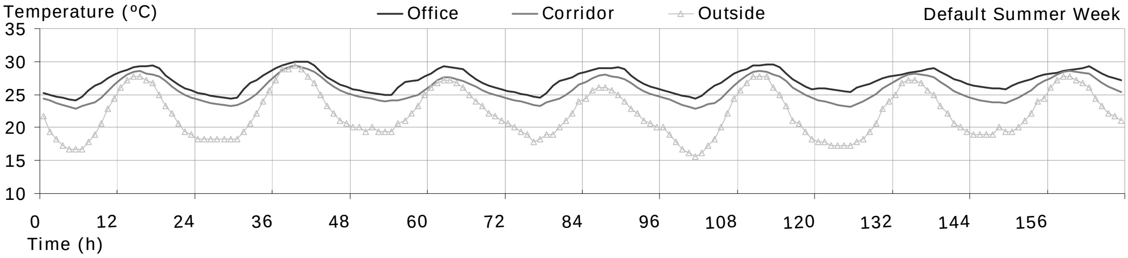


Fig 6. Variation of temperatures for the original building throughout the default summer week by DesignBuilder

4.2 Improved building

The model then was used as an assessment tool to decide the improvement actions, which will be explained in detail in section 5.

A new distribution of temperatures for a summer week can be seen in figure 7 compared with the original situation.

Indoor mean temperatures are lower and amplitude is greater. Delay is shorter due to ventilation. These results still don't match required comfort for the occupied period.

Table 6 shows that there were still 4,4 uncomfortable hours in the occupied period , but that the Predicted Mean Vote has passed from the "slightly hot" range to the "neutral" range for the office.

These results were the best obtained with passive measures according to time and economic constraints. Therefore they were considered worth executing.

Table 6: Average day's indicators of interior comfort for the improved building during the summer week according to DesignBuilder.

Indicator	Office	Corridor
Discomfort hours	4.4	1.7
Fanger PMV	0.2	0.3

Table 7: Variation of temperatures for the improved building throughout the default summer week by DesignBuilder. Amp= Temperatures' Amplitude (ºC), Mean= Mean temperature (ºC), Delay= Time delay from outdoor temperatures (h)

Day		Office			Corridor			Outdoor	
	Amp	Mean	Delay	Amp	Mean	Delay	Amp	Mean	Delay
1	5,9	25,2	2	6,3	24,4	1	11,1	21,9	0
2	6,5	25,5	1	7,1	24,8	0	11,1	22,8	0
3	5,4	25,2	0	4,8	24,5	0	7,8	22,8	0
4	5,1	25,2	1	5,4	24,3	1	8,3	21,9	0
5	6,1	25,2	1	6,4	24,3	0	12,2	21,4	0
6	4,1	24,4	2	5,6	24,0	1	10,0	21,5	0
7	4,4	24,7	3	5,5	24,6	1	8,9	22,7	0
Mean	5,3	25,0	1,4	5,9	24,4	0,6	9,9	22,1	0

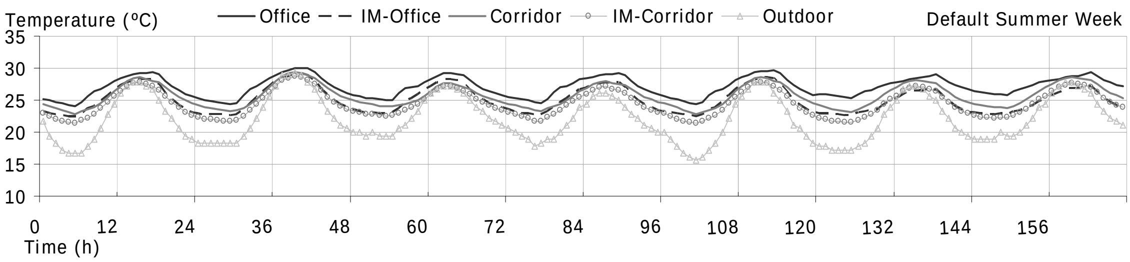


Fig 7. Variation of temperatures for the improved building throughout the default summer week by DesignBuilder

5. Improvement proposals for summer

After the displayed analysis, two solutions were proposed: firstly, to minimize the gain through the roof and the north façade and secondly, to cool the building at night.

5.1 Shade

To minimize the gains through the roof and north façade, agricultural mesh was chosen. It is a product easily installed and economically feasible.

Fig 8. White mesh installed on the roof

Fig 9. Black mesh installed over exterior corridor on the north façade

A white STR-250 white mesh has been placed on the roof to create 75% shade, as shown in figure 8. Also shown in the photo is the white façade of the nearby building and the exterior concrete wall that defines the exterior corridor in much of the north façade of the building.

Above the north exterior corridor a black STR-250 mesh has been placed to create 80% shade, as in figure 9.

The cost of the intervention was €4,500, which included the installation work and only the extra materials necessary, since the netting was donated by the manufacturer.

5.2 Vegetation

To resolve the problem of the north façade in the five interior modules that don't have outer corridors but a white building nearby, three rapid-growing deciduous trees have been planted (*quercus rubra* type) four meters apart. They are still found in a period of growth so the results cannot be verified with real measurements.

5.3 Nocturnal ventilation

To lower interior temperatures and take advantage of the thermal capacity of the building's concrete floor, one of the offices has been ventilated for an entire month, registering the changes of the interior conditions and comparing it with another unventilated office.

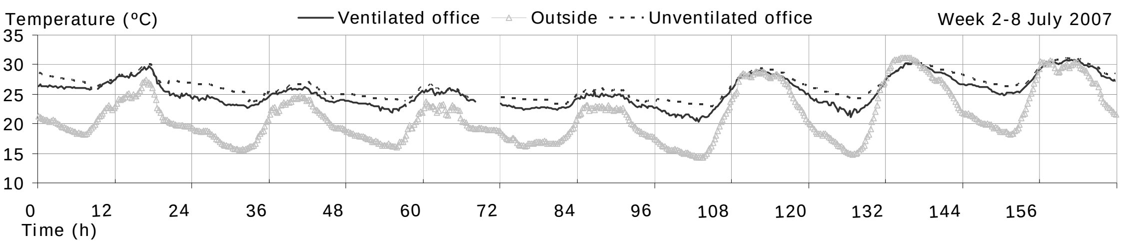
Just as can be seen in figure 10 and table 8, the temperatures in the ventilated office remain lower throughout the day than those of the unventilated office.

In actuality the ventilation wasn't only at night. For the entire day, it was necessary for the building to remain totally open in order to release the heat due to large glass surfaces. Because of all the glass, the interior temperatures during the hottest hours of the day are similar to the exterior ones, as figure 10 shows.

This intervention has not yet been applied to the entire building since it is a one-storey building and nocturnal ventilation proposes security risks such as intrusions, which haven't been resolved.

Table 8: Measured variation of temperatures throughout days of July 2007

Day	Ventilated Office			Unventilated Office			Outdoor		
	Amplitude(ºC)	Mean(ºC)	Delay (h)	Amplitude	Mean	Delay	Amplitude	Mean	Delay
2	5,4	26,7	0,5	4,1	27,7	0,5	9,2	21,5	0
3	3,4	24,3	1	3,4	25,7	1,25	9,0	19,8	0
5	3,1	23,5	1	3,0	24,6	3	6,9	19,3	0
6	8,8	24,8	0	6,4	26,0	0,5	14,5	21,6	0
7	9,3	26,2	0,5	5,9	27,3	0,5	16,4	23,3	0
8	6,0	27,9	2,5	4,9	28,6	2,5	12,5	24,4	0
9	5,4	26,7	-1	4,1	27,7	0,25	11,9	23,3	0
12	5,8	27,6	2	4,8	28,4	2,5	13,1	24,3	0
13	3,1	26,3	-1,5	-	-	-	7,2	21,8	0
14	3,3	25,5	-2	-	-	-	5,7	21,3	0
15	4,2	25,2	-0,5	-	-	-	7,2	21,5	0
Mean	5,3	25,9	0,2	4,6	27,0	1,4	10,3	22,0	0



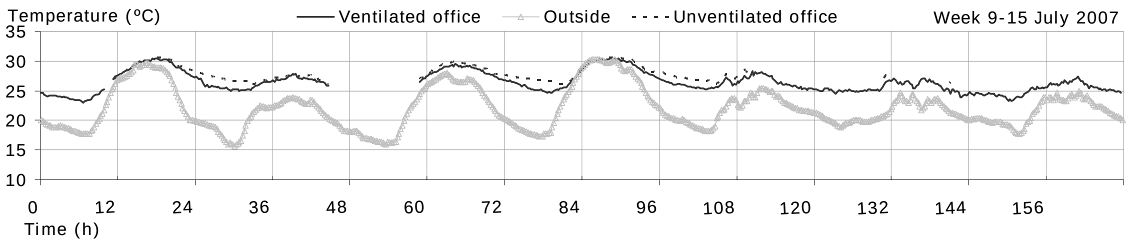


Fig 10. Measured evolution of temperatures throughout two weeks of July 2007

6. Discussion and conclusions

Due to the limitations mentioned before, the methodology presented in this paper is very limited in precision. The results of the comparisons are also limited in application due to the simplicity of the assumptions. On the other hand, the results of this specific case study could be discussed:

- Comparison of measured and simulated results for a ventilated office shows that for the actual building behaviour, mean temperature is higher and it is not delayed. This might be because in reality ventilation has not yet been applied to the entire building but only to the studied office. Simulation results suggest that it would be convenient to ventilate all the building.
- Simulated results for the corridor could not be contrasted with real measured temperatures of the corridor.
- Comparison of the measured temperatures for the ventilated and unventilated offices show the expected improvement: mean temperature is lower and amplitude is greater for the ventilated office. However, temperatures are still above comfort levels.

At this moment, renovation actions are not fully implemented. Furthermore, the process has been suspended due to a decision of the many agents involved in the management of the building.

7. Conclusions

This article has presented a general overview of the process of construction of a sustainable building, from the policies to the failures of the building. The attempts of retrofitting the building with passive strategies have also been explained.

As a summary, some general aspects can be mentioned:

(i) The improvement of energy efficiency in buildings is among the first priorities of the UPC policies. However, detailed measures to handle the problem in its real dimension had not been developed.

(ii) During the long process of promotion and management of the construction (and renovation) of the building, there have been incidents that have resulted in the executed solutions not being the ones that were originally planned. The necessity to control the management of these works is reaffirmed.

(iii) It is possible to fast obtain results using passive strategies.

(iv) The process of analysis and renovation of the original building has been carried out in the context of a School of Architecture. Teaching and apprenticeship have been further developed with research and with the application of the acquired knowledge in practical cases. The experience has been very positive.

8. References

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