Environmental design and performance of the ENERPOS building, Reunion island, France

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ABSTRACT: Located in the French tropical Island of La Reunion in the Indian Ocean, the 681 m^2_{NFA} ENERPOS Building was inaugurated in January 2009. The building is located on the Saint Pierre Campus of the University of Reunion Island and was designed from the outset to be a net zero energy project with mixed-mode air conditioning systems in some areas.

This paper reports the results of a recent user survey of the staff and students who use the building, and relates the users' perceptions to some of the environmental control systems installed. Indications are that the users have been able to achieve thermally comfortable conditions for much of the year without recourse to the air conditioning systems. However, there is still the need for more readily available information on how to get the best from the windows and the ceiling fan systems for the ever-changing cohorts of students, and staff who may only use the classrooms intermittently. For the more permanent staff group, preliminary indications are of improved health and productivity by comparison with their experience of other buildings.

Conference theme: Sustainability Issues

Keywords: Net zero energy building, tropical climate, post occupancy evaluation, thermal comfort.

INTRODUCTION

La Reunion is a French overseas territory located in the Indian Ocean 200 km West of Mauritius. The ENERPOS Building is located in the second biggest city of La Reunion, Saint-Pierre, in the South of the island at latitude 21 ^{O}S. The climatic conditions of Saint-Pierre are listed in Table 2. **[1]**

Table 1 : Climate conditions in Saint-Pierre, La Reunion

	Air Temp (°C)			RH	Mean air speed	Mean global solar radiation
	Mean	Min	Max	(%)	(m/s)	(kWh/m^2.day)
SUMMER	25.6	17.8	32.5	73	2.4	6.1
WINTER	21.3	14.3	29	73	3.2	4.7

The energy situation is complicated because La Reunion is very a small island. The production of electricity is limited, and the island aims to have energy independence by 2030. Renewable energy is considered an appropriate source and special effort is being focused on reducing consumption in the building stock. Currently, the vast majority of office buildings are cooled using air-conditioning rather than natural ventilation. Roof insulation and protection from solar radiation are poorly designed.
The average energy index for a university building is 140 kWh_{FE}/m^2.yr (final energy per square metre of net floor area) **[2]** in terms of annual electricity consumption. One objective of the ENERPOS Building is to show that the factor 4 objective can be easily met. Factor 4 means dividing the power consumption by 4 to get under a target of 50 kWh/m^2.yr. Given that air-conditioning is highly energy intensive and represents more than 50% of the power bill, followed by computers (25%) and artificial lighting (11%) for a standard office building **[3],** another major goal is to show that thermal comfort can be obtained, most of the time, without using air conditioning in public buildings.
ENERPOS is the first zero energy building constructed in the French Island of La Reunion and the third in the world in a tropical climate.

1. BUILDING DESIGN PROCESS AND MAIN FEATURES

Designed by the architect Thierry Faessel-Bohe and inaugurated in January 2009, ENERPOS is an academic building. It is a positive energy building: that means that through different active and passive systems, the building consumes very low energy and is able to produce independently more electricity than it consumes over the year thanks to BIPV roofs that are used as shading systems as well. ENERPOS is a two-storey building composed of two parallel blocks with a green patio in between (see Figures 1 and 2). There is a car park underneath the patio. The ground level is composed of offices for staff members and two classrooms. There are only classrooms at the first level.

Figure 1: General view of ENERPOS. ENERPOS is composed of two parallel wings separated by a green patio. A car park is located underneath the patio and the left wing.

The immediate surroundings of the building, the structural envelope elements, and the efficiency of the systems have been designed with respect to the PERENE specifications (Garde 2010). PERENE is the acronym for ENErgy PERformance of Buildings in French. The main objective was to produce a document based on experience and local skills gained during the last 15 years in the residential and non-residential sectors using previous experimental standards **[4].**

The building integrated photovoltaic roof covers an area of 350 square metres and enables the production of 70 000 kWh/y of electricity. These PV panels assist the roof insulation as they prevent the sun from shining directly onto the roof. Moreover, the roof was insulated with a 10cm layer of polystyrene (less than 0,5% of the solar radiation comes through the roof). A strip of vegetation at least 3 metres wide was arranged around the building. The vegetation creates a pleasant climate around the building by the shade it provides, and lowers the temperature by absorbing solar radiation. Further, the North-South orientation of the main facades limits the amount of sunlight falling on the easterly and westerly gables which are perpendicular to the breezes which blow during the hot season. The ventilation of the spaces is thus optimized. The porosity of the building (window-to-wall ratio) is 30% (10% more than a standard building). Interior louvres have been installed in the building to allow cross-ventilation. High performance ceiling fans were installed for better air circulation inside the rooms and therefore a better cooling effect. Solar shading made of wooden strips was installed on the north and south facades of the building to prevent direct glare inside the rooms and to reduce the temperature of these walls.

Figure 2: View of the green patio composed with a mixture of native and exotic species.

Particular attention has been given to the design for natural daylight. The use of artificial lights is minimized. In some classrooms, artificial lighting is even completely absent. The building is closely monitored with data collected every minute. This allows better control of electricity consumption, rapid identification of excessive consumption, and improved understand of the electrical consumption characteristics of the building.

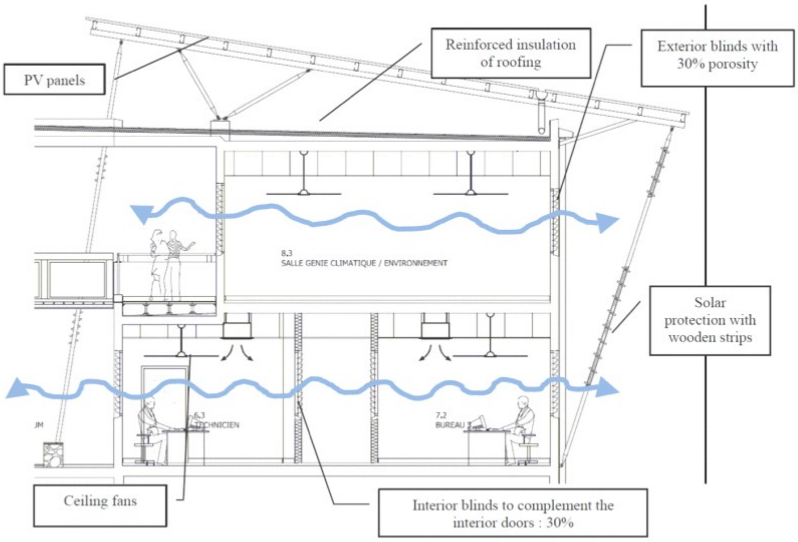

Figure 3: Passive principle of the ENERPOS building.

2. POST OCCUPANCY EVALUATION METHODOLOGY

The BUS methodology (Building Use Studies) was used for this survey [5] – a three-page questionnaire for staff and a shorter one-page version for students. Aspect investigated included building design, space, image of the building, cleanliness, availability of meeting rooms, storage capacity, size of the offices, furniture, noise, thermal comfort according to the seasons, productivity, health, control of heating, cooling, ventilation, lighting, and round trip journey from home to work. The vast majority of responses are on a seven points scale, typically ranging from unsatisfactory to satisfactory or comfortable to uncomfortable.

10 members of the staff and 127 students completed the questionnaires during two weeks in April 2011. Care was taken to include students from all classrooms of the building.

3. USERS' PERCEPTION OF THE ENERPOS BUILDING

3.1. Overall Response

The number of staff working permanently in the building is relatively low (12 persons). While most responded, given the relatively low number, the results should be interpreted with caution.

For all of the surveyed staff, the building is their usual place of work. They work an average of 4.5 days per week in the ENERPOS Building and average 8 hours per day. 6 persons were aged 30 and more, 5 had worked in the building for more than a year and 4 at the same desk or work area.

The average scores for each of the survey questions are listed in Table 2. The table also indicates those aspects of the building that the staff perceived as being significantly better, similar to, or worse than the benchmark and/or scale mid-point. Overall, some 20 aspects were significantly better, 13 significantly worse, while the remaining 11 aspects had much the same score as benchmark.

The students' perception scores are also indicated (in brackets). The student questionnaire includes only 14 variables. Of these fourteen variables, four aspects (temperature, air, health, and lighting overall) score are significantly better than the staff, seven significantly worse, while the remaining three aspects have approximately the same score.

3.2. Overall Performance Indexes

Three indexes of overall performance have been used. These use standardized scores (also called z-scores) which put the variables on a common scale with mean equal to 0 and standard deviation equal to 1.

The Satisfaction Index, which is the average of the standardize scores for design, needs, health and productivity is +0.65 for the staff and +0.57 for the students. Note that the scale mid-point in these cases is zero on a -3 to +3 scale. The Satisfaction Index is an indicator which shows if people are pleased to work in this building. Overall the staff and student indices indicate that both groups find the building to be satisfactory.

The Comfort Index is the average of the standardized scores for temperature in summer and winter, air in winter and summer, lighting, noise and comfort overall. This index is +0.57 for staff and +0.99 for students. This shows that both groups find the environmental conditions comfortable. The Summary Index is the average of the Comfort and Satisfaction Indexes - in this case, +0.61 for the staff and +0.78 for the students.

Table 2: The ENERPOS Building - Average staff scores for each factor and whether they were significantly better, similar to, or worse than the BUS Benchmarks (student scores in brackets).

OPERATIONAL FACTORS

	Score	Worse	Similar	Better
Image (5.74)	6.2			•
Space in building	5.6			•
Space at desk - too little/much[4]	4.9	•		
Furniture	5.8			•
Cleaning	4.8		•	
Availability of meeting rooms	6.33			•
Suitability storage arrangements	5.4			•
Facilities meet requirements	5.2		•	

ENVIRONMENTAL FACTORS

Temp and Air in Winter

	Score	Worse	Similar	Better
Temp Overall (5.73)	4.86			•
Temp - too hot/too cold[4]	4.83	•		
Temp - stable/variable	4.2		•	
Air - still/draughty[4]	5.0	•		
Air - dry/humid[4]	3.67		•	
Air - fresh/stuffy[1]	2.6			•
Air - odourless/smelly[1]	3.2		•	
Air Overall (5.79)	5.0			•

Temp and Air in Summer

	Score	Worse	Similar	Better
Temp Overall	4.63			•
Temp - too hot/too cold[4]	3.0	•		
Temp - stable/variable[4]	3.75	•		
Air - still/draughty[4]	3.88		•	
Air - dry/humid[4]	4.63	•		
Air - fresh/stuffy[1]	3.4			•
Air - odourless/smelly[1]	2.71			•
Air Overall	5.33			•

Lighting

	Score	Worse	Similar	Better
Lighting overall (5.39)	5.2		•	
Natural light – too little/much[4] (4.52)	4.2	•		
Sun &Sky Glare-none/too much[1] (3.41)	3.8		•	
Artificial light - too little/much[4] (3.8)	3.8	•		
Artificial light Glare - none/too much[1] (2.58)	1.8			•

Noise

	Score	Worse	Similar	Better
Noise overall (4.42)	4.5		•	
From colleagues – too little/much[4]	3.44	•		
From other people - too little/much[4]	3.89			•
From inside - too little/much[4]	3.56	•		
From outside - too little/much[4]	4.44	•		
Interruptions – none/frequent[1]	2.9			•

CONTROL FACTOR

		Score	Worse	Similar	Better
Heating	0%	1.5	•		
Cooling	25%	1.8	•		
Ventilation	50%	6.6			•
Lighting	25%	6.4			•
Noise	0%	3.7		•	

SATISFACTION FACTORS

	Score	Worse	Similar	Better
Design (5.74)	5.8			•
Needs (5.38)	5.78			•
Comfort Overall (5.58)	5.6			•
Productivity % (+11.25)	+17.5			•
Health (4.47)	4.22		•	

NOTES :
a – unless otherwise noted, a score of 7 is 'best'; superscript [4] implies a score of 4 is best, superscript [1] implies a score of 1 is best.
b – the percent values listed here are the percentages of respondents who thought personal control of that aspect was important.
c – student scores are in brackets – the temperature and air scores cover all seasons

An additional Forgiveness Index is a measure of tolerance, being the ratio of the score for comfort overall to the mean of the six other environmental variables. It is 1.14 (a factor of 1 being the mid-point on a scale that normally ranges from 0.5 to 1.5) for this building, which indicates that staff is relatively tolerant of minor shortcomings in individual aspects such as winter and summer temperatures **[6].**

Figure 4 indicates the mean scores for the main overall variables for both staff and students. The squares indicate scores that are better than the mid-point of the scale and the relevant benchmark (based on the scores for the previous 50 buildings surveyed), while a circle indicates a score that is not significantly different.

The following sections will focus on some specific aspects.

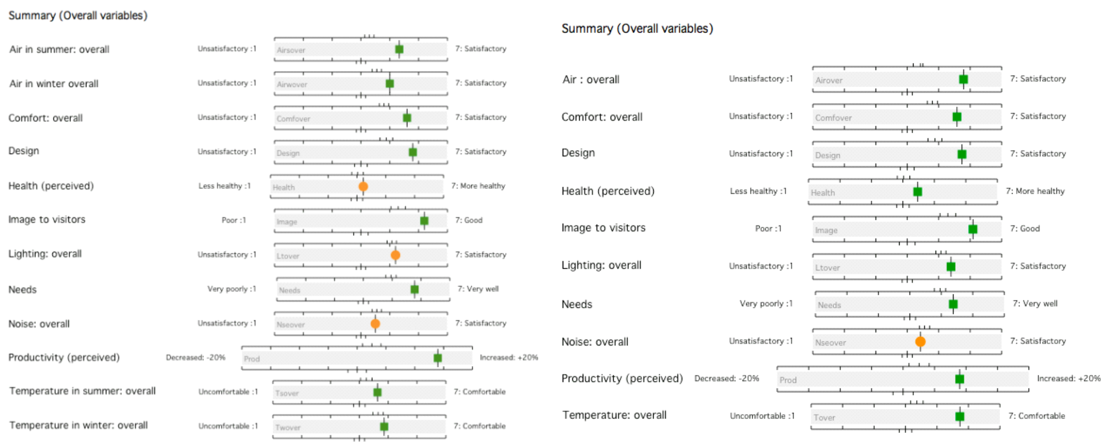

Figure 4: Overall variables for staff (left) and students (right).

3.3. Temperature

An average student score of 5.73 places the ENERPOS Building at the 94th percentile (see Fig 5) of the BUS benchmark.

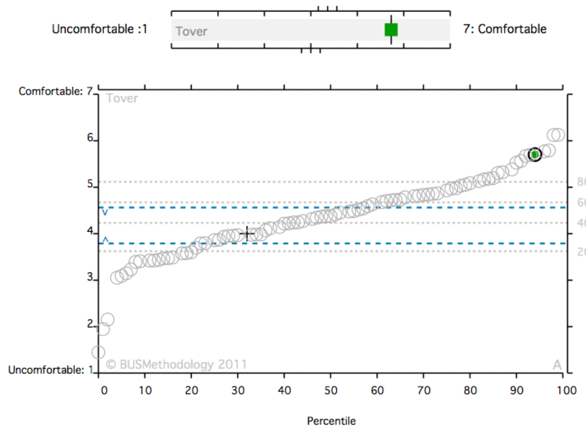

Figure 5: temperature perception by students.

For the staff there is very little difference in the scores for temperature overall between winter and summer (4.86 and 4.63 respectively). In both cases, the scores are significantly better than the average of other buildings surveyed so far.

This is particularly encouraging, given that the air conditioning is not used in the classrooms and used rarely in the staff area (only two days during the last hot season). The passive cooling techniques rely on the use by the occupants of cross natural ventilation thanks to the manual louvres and the ceiling fans (in case of the lack of wind). This building is therefore a good example of what can be done in practice.

3.4. Air

The staff scores for air overall were better than the benchmark in both winter and summer. The quality of the air was perceived to be odourless and fresh, relatively humid in summer and relatively dry in winter. However, one can note that during the winter, the building is particularly draughty. Nevertheless, all the staff, even those who were initially reluctant to work in a non-air-conditioned building, are very happy with their new environment and do not want to go back to work in an air-conditioned building.

3.5. Noise

ENERPOS is an academic building where noise should be avoided so that students and staff can study in peace. Particular attention should be given to this aspect. For staff and students, the perception scores for noise overall were similar (4.50 and 4.42 respectively). In both cases, the scores are at the lower limit of the average of the benchmark set of buildings.

This seems a reasonable result, given that the building is naturally ventilated with a high percentage of openings and the potential for noise transmission from one classroom to another.

3.6. Lighting

The perception of lighting in this building is highly dependent on the location of the room. In some rooms the light is too bright to use a video-projector while in other rooms it is slightly dark. Similarly, glare can be experienced at specific times (early in the morning or at sunset) in some rooms while in other rooms there is no problem of glare effect.

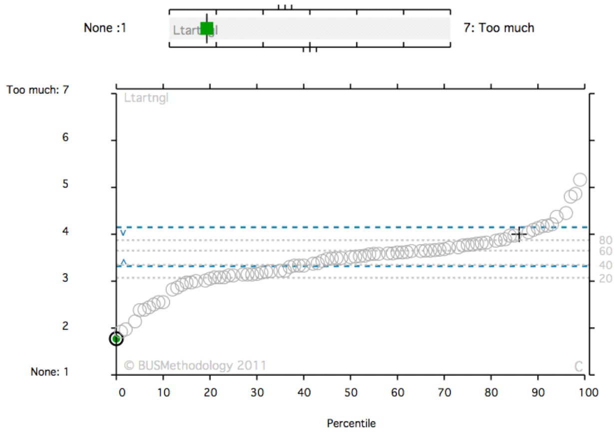

Figure 6: glare from artificial lights (staff score).

As for artificial lighting, users do not complain about glare effect. This is most likely because the artificial lighting is practically unused. During the construction of the building, special attention was given to maximizing the use of daylight. In addition, the building is equipped with type T-8 low energy luminaires that use indirect lighting (that dazzle less than conventional lighting). As a result, the ENERPOS building performs extremely well in relation to glare caused by artificial lights (see Figure 6). Glare from sun and sky scores around the average of the benchmark. This source of glare is mitigated by large exterior wooden solar shades installed on the North and South facades.

3.7. Control

Some studies have shown that peoples' perception of comfort can depend on their ability to change their environment. The width of the comfort 'zone' if measured purely in physical terms will therefore depend of the capacity to control the environment **[7].** The more people have the capacity to control their environment (light, ventilation, temperature, etc) the more comfortable they feel. Not surprisingly few of the staff feel they have any control of cooling of their workspace. This percentage is important because air-conditioning is not used in the offices except a few days during the hot season. The same comment applies to heating control as there is none in the offices. The climate of La Reunion is tropical, the temperature in winter is pleasant, and heating is not required.

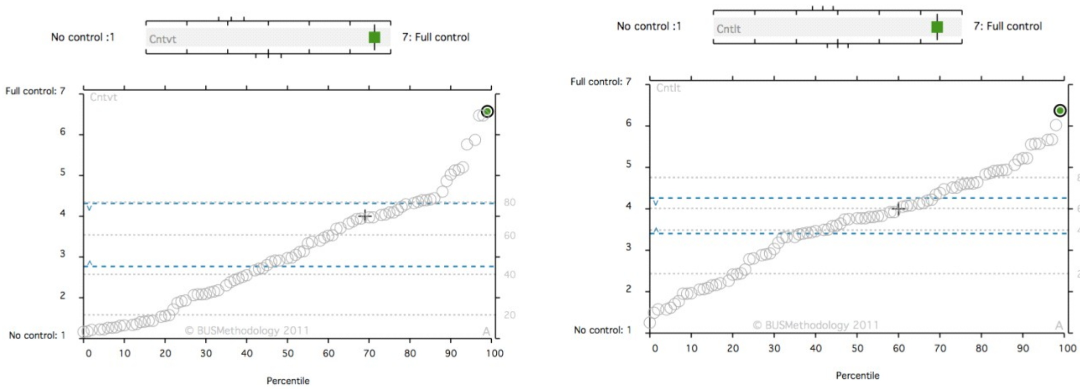

Figure 7: Control over ventilation (left) and over lighting (right).

Control of ventilation and lighting have good scores. These two parameters are the best of this set.

Users can improve ventilation by controlling manually the louvres and the ceiling fans.

Efficient ceiling fans were installed in each office and classroom. Each ceiling fan covers an area of 10 square metres. As a consequence, in the offices, the staff members have their own ceiling fan which thus ensures individual control. This explains the high scores given by users (see Figure 7).

As for solar shading, large fixed wooden blinds were installed on the outside facades of each block (see Figure 1). The users can't control the blinds but they can control the artificial lighting.

3.8., Image to visitors and Needs

For the staff, their perception of the image that the building gives the visitor scores 6.2 on average, with the student score 5.74.

For the needs category, the rating given by the staff is 5.78, which is well above the benchmark. Better than benchmark scores were also achieved for space in the building (5.6), furniture (5.8), meeting rooms (6.33) and storage (5.4).

3.9. Productivity (perceived) and Health

Productivity is generally better than the benchmark figure with averages of +11.25% for the students and +17.5% for the staff. This places the ENERPOS building within the top 10% of the benchmark set. All those surveyed felt an improvement in their productivity. In the case of Health, the results are quite good with scores of 4.22 for staff and 4.47 for students, at the upper limit of benchmark for staff and above the benchmark for students. The most recurrent comments for the health issue are dry eyes due to natural ventilation.

3.10. Journey to work

In determining the environmental performance of a building, a factor often overlooked is the method of transportation from home to workspace. In fact, a building can be ecologically efficient but if the only way to reach it is by plane or helicopter, its environmental performance is diminished. It is therefore interesting to study this parameter. On that score, this building is not particularly good. The average travel time between home and work is 39 minutes. The majority of people surveyed (71%) stated they are alone in their car to come to work – a discouraging result. This is also due to the lack of efficient public transportation facilities on the island.

3.11. Users' comments

The comments from users indicate they are generally satisfied with their workspace. Interesting requests have been submitted through this questionnaire (as for example the desire to have a bicycle storage or a shower in the building) and will soon be realized. As construction work was in progress near the building during the survey, comments on this point were registered and also about the noise generated by the maintenance of the garden (principally the discomfort due to noise of the lawnmower). Of the over 52 comments from the students, only 8 were concerned with health and ventilation. The most frequent comments concerned the noise generated by other students during breaks or when they move near their classroom.

3.12. Monitoring system

An energy monitoring system was installed to better understand the energy use profile of the building. Energy meters measure consumption of electricity by type of use (indoor lighting, outdoor lighting, ceiling fans, plug loads, lift, ...) to identify the most energy-consuming items and to correct them if necessary. Portable units measuring environmental conditions have been deployed to provide short-term assessment of temperature, humidity, illuminance, air velocity, radiant temperature... Over 1000 sets of measurements were conducted for the three last hot seasons with students to determine the optimal conditions of thermal comfort. These results have already been recently published [1].

3.13. Energy performance

The annual final energy use index for the year, from May 2010 to April 2011 is 14.4 kWh/m^2.yr, which is ten times less than a standard building. The main source of consumption corresponds to the electrical outlets (46% of consumption over a year), followed by the split system used to cool the two technical rooms (15%), interior lighting (14%), the ceiling fans (11%), the exterior lighting (7%) and the lift (7%). The air conditioning was switched on only two days during the last hot season. For the ENERPOS building between May 2010 and April 2011, the overall consumption was 10,323 kWh and the PV production was 72,040 kWh. The building thus produces about seven times more electricity than its own consumption.

CONCLUSION

This study shows that, with Summary Indices of +0.61 for staff and +0.78 for students, those surveyed were satisfied overall with their work environment. The initial goal of this building was to reduce its energy consumption by 4. This objective was met and largely exceeded. Today, ENERPOS consumes 10 times less energy than a standard building. ENERPOS showed that a building can significantly reduce its energy consumption and thus its environmental impact while maintaining a good level of comfort for its users. Indeed, the study showed that this building is generally rated higher than others in the BUS benchmark set. This building can be an good example for new projects in tropical climates. It demonstrates that even an academic building can achieve comfortable conditions for its occupants by enabling them to use passive methods (natural ventilation, daylight) rather than energy consuming systems such as air-conditioning.

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