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THE CONSTRUCTION OF A ZERO ENERGY BUILDING IN REUNION ISLAND. PRESENTATION OF A NEW APPROACH TO THE DESIGN STUDIES

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SUMMARY

This paper presents a zero energy project applied to a university building in Reunion Island. The aim is to create a building which uses half the energy of a standard building. The methodology was conceived to meet requirements defined during the thermal design and building systems planning stage. Innovations relating to architectural design, building systems performance and numerical simulation are presented. Solar panels integrated into the roofing provide sufficient electrical energy for the building to produce more energy than it uses.

INTRODUCTION

The energy situation in Reunion Island

Reunion Island, like other insular regions, has difficulty matching its energy supply to the demand, 87% of which comes from buildings. The growth in demand for power and energy is about 7% per year, and currently, the absence of any thermal regulations allows the construction of buildings such as the one shown in Figure 1.



Figure 1: A perfect counter-example in thermal design for tropical climate building. The unprotected glass frontage faces east.

Fortunately, the authorities such as the Regional Council (*Conseil Régional*) encourage the construction of 'green' buildings; indeed, the Council has funded an energy plan for the entire island named PRERURE, the objective of which is to make Reunion energy self-sufficient by 2025 (Lopez, 2000). Among other things, the study's conclusions relate to managing energy use and planning the use

of various renewable energy sources.

The University of Reunion and energy management

The University of Reunion has the same problem, on a different scale, as the rest of the island, in having growing energy needs, recurring energy management problems and buildings which devour energy. The energy consumption rate is 165 kWh per year per square metre of useful area (kWh/yr/m²UA). This rate includes the air conditioning, its auxiliaries and all other uses (principally computing and lighting). The electricity bill in 2004 was about 560 thousand euros, 40% of which was for air conditioning. Five years ago the university introduced an energy management policy, and in this paper we intend to present the methodology adopted for new buildings, using as illustration a zero energy building project.

METHODOLOGY AND OBJECTIVES

The energy use objectives which we have for 2020 are those fixed by the Kyoto protocol, and involve reducing greenhouse gas emissions fourfold. This will lead to less energy use in buildings. Figure 2 shows the current energy use, that intended for the new, optimised university buildings, and that of a zero energy building, the objective for 2002 being a rate of 40 kWh/yr/m² UA.

The basic aim of our methodology is to try and achieve a state of thermal and visual comfort with passive means. Air conditioning and artificial lighting must be used as a last resort. To do this, new university buildings must respect a number of building quality criteria, relating to :

- The surrounding environment ;
- The thermal and airflow design;
- The technical systems and facilities;
- The control and monitoring of energy use.

These quality criteria are laid out in a note about energy management which is part of the building construction programme. Buildings should also respect the guidelines given recently by the PERENE programme (Garde 2005). The PERENE programme (a French acronym for Energy PERFORMANCE in Buildings) prefigures a project relating to thermal regulations in the French overseas departments for businesses. In the face of the tardiness of the authorities in setting up even minimal regulations for the building sector, local professionals in the industry decided to put together a design aid which could be applied to both residential

and business buildings, allowing good design for a building in any of the island's climatic zones. Objectives for the power of installations and energy consumption are given. This design tool has been in use since 2004 and is currently being tested.

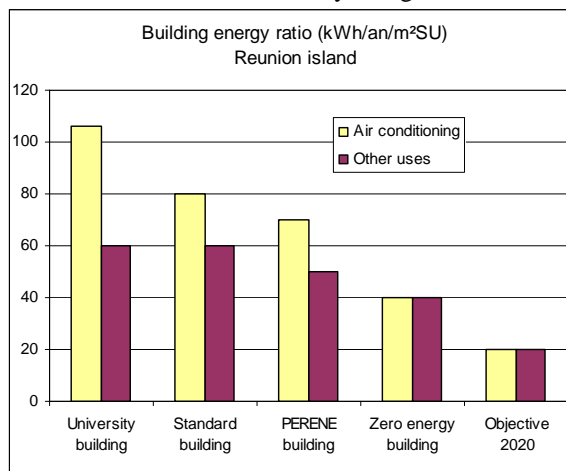


Figure 2 : Energy use objectives

The zero energy building project was among the buildings chosen during this test period. It is also the hope that the project will be awarded the 'Greenlight' label for lighting; this European label is a reward for buildings which are well-designed with regard to the use of artificial and natural lighting. The clearly stated objective is to make this building the reference in the French overseas departments for energy optimisation.

THE ZERO ENERGY BUILDING PROJECT

The project is composed of four small, parallel buildings. The main facades face north and south (see Figure 3). The two buildings to the north will house a degree level course in Communication Services and Networks, while the southerly buildings will be for an M.Sc. in Civil Engineering (to chartership level).

The room types are as follows:

- offices for the two departments on the ground floors of the lateral buildings;
- classrooms for teaching practical work;
- computing rooms.

Table 1 : Classification of useful area by room type

Rooms	Air conditioned areas	Areas without air conditioning
Department offices	401 m ²	
Computing rooms	423 m ²	
Classrooms		401 m ²
Others		512 m ²
Sub Total	824 m² (47%)	913 m²(53%)
Total useful area	1737 m²	

The classification of useful area by room type is given in Table 1. We note that 47% of the useful area is air conditioned. A requirement of the programme is that the classrooms should not be air conditioned, and so it is up to the designers to find passive ways

of ensuring an acceptable comfort level in these rooms.



Figure 3 : 3D view of the building. The azimuth of the northerly facades is -14° East/North

RESULTS AND DISCUSSION : THERMAL COMFORT

Objectives :

As mentioned above, the objective is to reduce, if possible completely the period with air conditioning. Standard buildings sometimes need air conditioning all year long, but the average use is seven months (from the start of October to mid May). To achieve the objective, the environment surrounding the building and the airflow and thermal designs are paramount.

The surrounding environment

Both the construction programme and PERENE require peripheral vegetation at least three metres wide around the building, in order to avoid letting the air heat up and penetrate the buildings when in natural ventilation mode. Figures 3 and 4 show that this point has been respected. Further, the orientations of the main facades north-south limit the amount of sunlight falling on easterly and westerly gables, and these are perpendicular to the thermal breezes which blow during the hot season. The ventilation of the rooms is thus optimised.



Figure 4 : View of the northerly facades (solar protection with wooden strips) and the westerly ones (sheet metal and wood cladding).

Thermal design of the building envelope

PERENE and the building programme give values of a solar factor for the opaque walls and windows, and the project has respected these solar factor values which must not be exceeded. The technical solutions to keep within the PERENE values are the following:

- Roofing : insulation using 9 cm of polystyrene on suspended slabs with a ventilated over-roof.
- Wall and windows north and south : overhanging roof, passageways and brise-soleils made of wooden strips fixed to oblique galvanised steel supports.

With regard to optimising the brise-soleils, it is impracticable to model them using the usual thermal simulation codes. For each façade, the number of strips, their spacing and their angle was therefore calculated using a 3D reconstitution of the building in Autocad. Figure 6 demonstrates the efficiency of the solar protection on a northerly façade during an April day. The ultimate objective is to have full protection during the teaching hours (from 8am to 5pm) for the northerly facades until the end of April and for the southerly facades during December.

Airflow design

The basic principle in a tropical climate is to have rooms allowing air to blow through, by having opposite exterior facades with a porosity higher than 20%. This principle is applied in the building

programme. Thus, all the classrooms exhibit this property, with a porosity level above 30% due to louvre blind-like constructions which have the advantage of allowing regulation of the airflow, while also providing protection against cyclones and break-ins. Because of this, the rooms are usable with natural ventilation at night, being cooled by night breezes. Thanks to this principle, it is possible to recycle the air at a rate of 40 to 100 vol/h with interior speeds of 1 m.s^{-1} for wind speeds of about 2 m.s^{-1} .

The design of the offices is more difficult because, as one can see in Figure 5, the configuration is a standard one of offices off a central corridor. The original feature of the project is to have interior louvre blinds made of frosted glass which ensure that the interior air flow is well spread, providing an interior porosity of 30%. Lastly, another innovation is to have planned for large fans in all the rooms, including those with air conditioning. These guarantee additional air speed on windless days and allow a transitional period before turning on the active cooling (see Figures 5, 11 and 12).

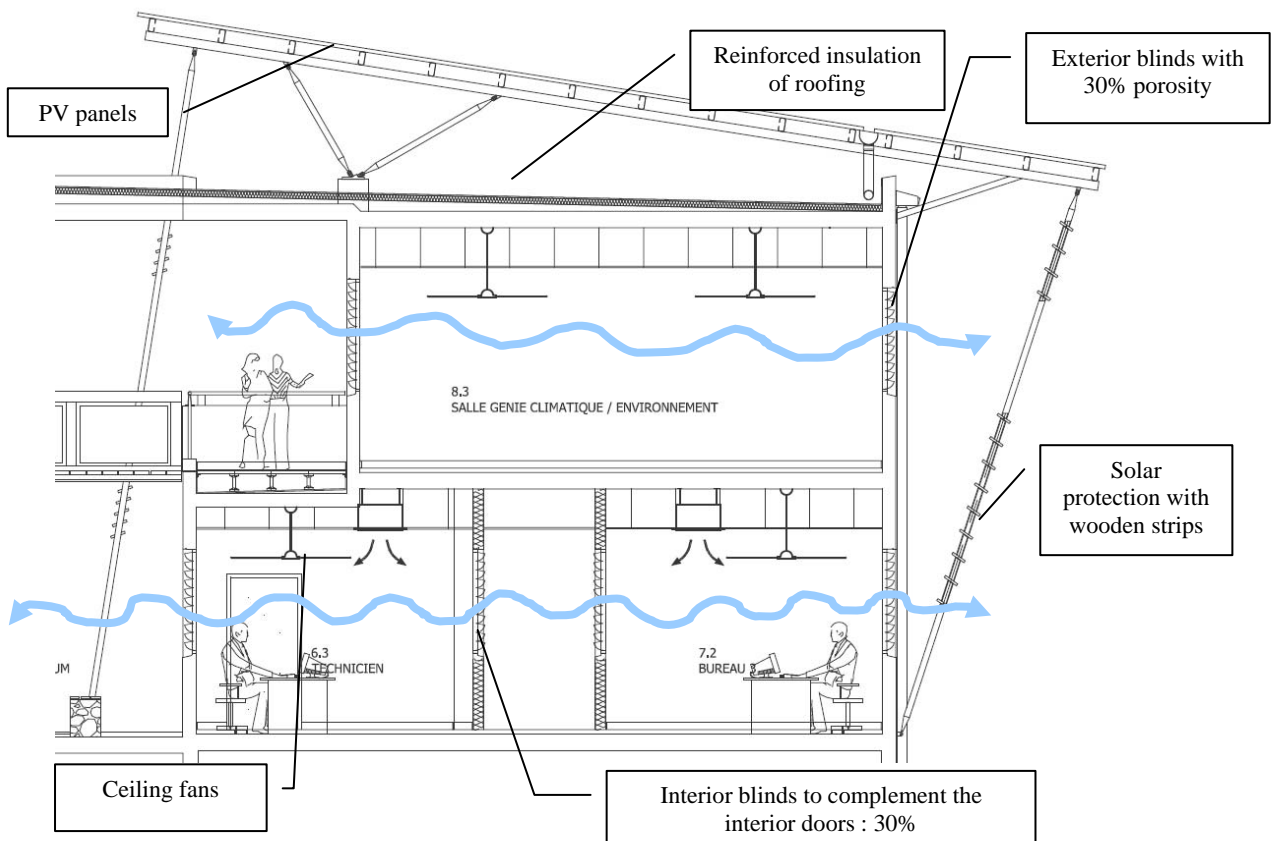


Figure 1 : The technical solutions chosen for the thermal and airflow design of the building.

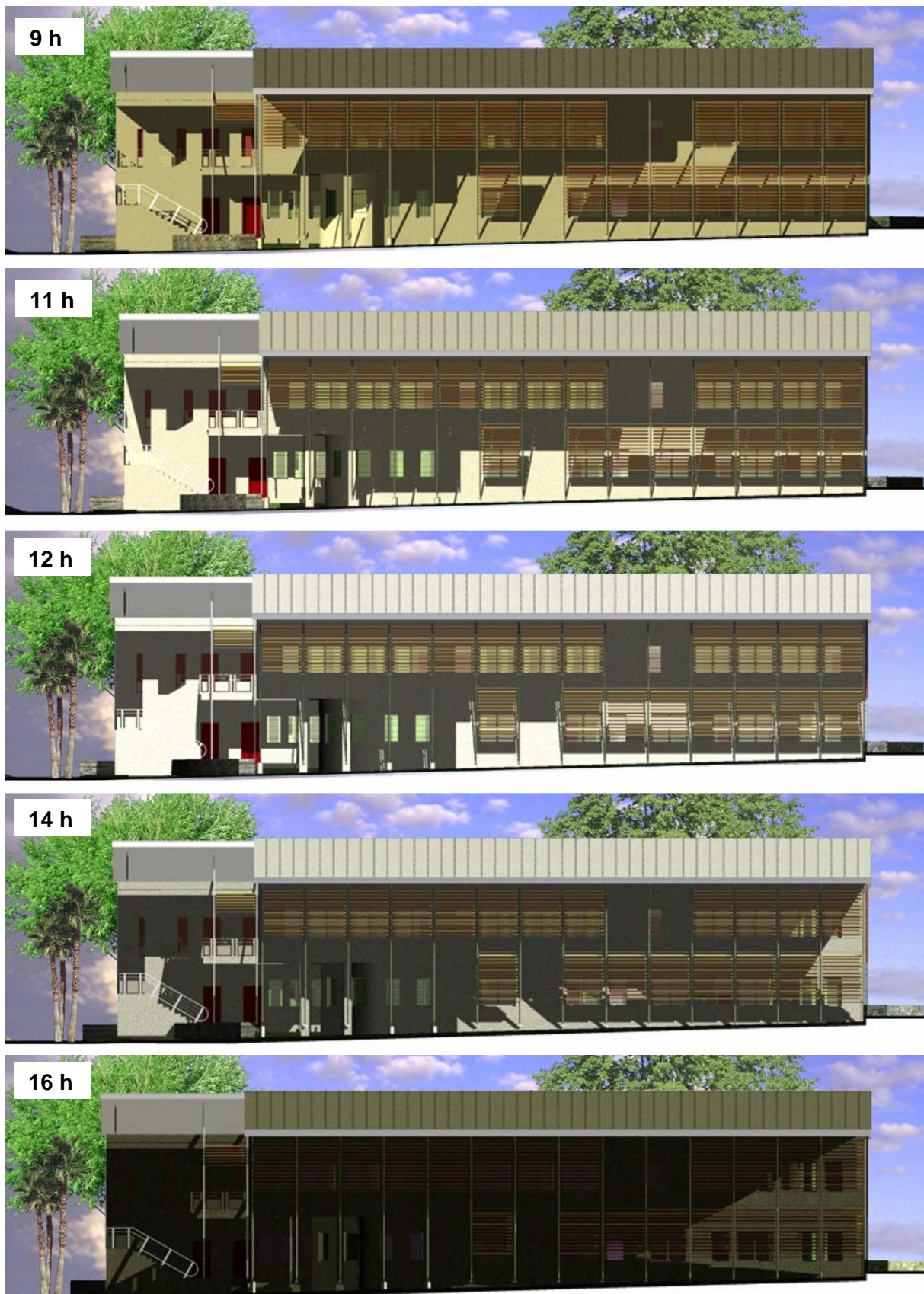


Figure 2 : Simulation of the efficiency of the solar protection on the northerly facade of the northerly building at different times of the day during an April day : The openings are always in the shade.

Dynamic simulations

The dynamic simulations were intended to predict the different operational periods : natural ventilation, air fans or air conditioning. These simulations were carried out by researchers at the university working with the thermal design office. A thermal and air flow simulation program was used, which, in conjunction with a model of large openings under pressure, modelled the impact of natural ventilation on the thermal comfort. Roldan's mass transfer model, detailed in (Boyer 1998), was used. The model takes into account one air pocket per room, and stratification is neglected. The comfort indices chosen were Givoni's comfort diagram and the resultant temperature T_{res} . The formula for T_{res} combines the air temperature T_a and the average wall temperature T_{m} for a naturally ventilated room ($T_{res} = 2/3.T_a + 1/3.T_{m}$). The comfort zones allow us to find the percentage of points within each comfort zone (0 m.s^{-1} , 0.5 m.s^{-1} and 1 m.s^{-1}) as well as the number of hours of discomfort. The resultant temperature gives us an idea of the different operational periods. The weather record used was for a year with hourly increments. This was extrapolated using an incomplete database of site measurements; the extrapolation method used is given in (David 2005). The average interior air speed was estimated using a correlation coefficient between the porosity and the exterior air speed given by (Allard 02). Thus, for a porosity of 30% and a wind speed of 1.5 m.s^{-1} , we find average speeds of 0.5 m.s^{-1} . As for the air speed with the large air fans, measurements on site have given speeds above 1 m.s^{-1} .

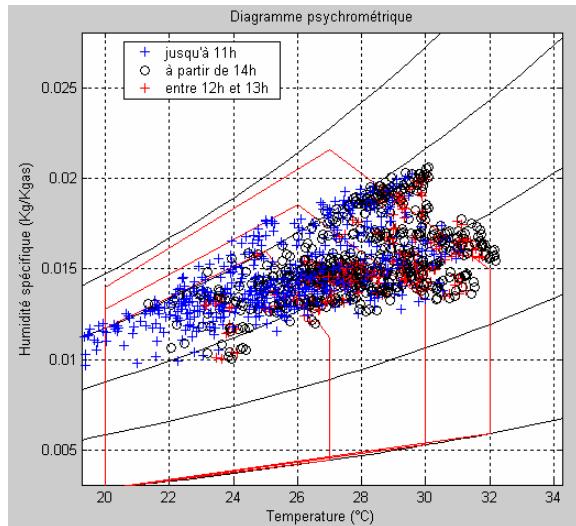


Figure 7 : Simulation results for an office during the hot season (1st October to 31st April)

Figures 7 and 8 show simulation results for a three person office. For the interior loads, we supposed that natural lighting would be sufficient, while the computers used 200W, a slight over-estimation compared with recent flat screen computers which use on average only 120W. Figure 7 and Table 2 show that 89% of the pairs of resultant temperature/humidity values are within the comfort zones for the period from 1st October to 31st April, the hot season. The occupants will thus experience discomfort 11% of the time, principally at the beginning of the afternoon, for a total of 160 hours. A possibility therefore would be to use natural ventilation in the morning and active cooling in the afternoon.

The same simulations were carried out for a classroom of 60 m² with 40 students and a computing room containing 20 students and 20 PCs. In each case, natural lighting is assumed sufficient; Table 2 gives the results. Naturally, the discomfort level is higher in the computing room, with twice as many discomfort hours (i.e. twice as many points outside the comfort zone) as in the office. This number of hours corresponds to the time of active cooling.

Table 2 : Percentage of points within the comfort zones and number of hours of discomfort

	Office	Classroom	Computing room
0 m.s ⁻¹	24%	26%	23%
0.5 m.s ⁻¹	38%	38%	36%
1 m.s ⁻¹	27%	22%	23%
Total %	89%	86%	82%
Hours of discomfort	160 h	270 h	335 h

Using Figure 8, it is possible to predict the different operational periods – natural ventilation, air fans or air conditioning – by using the change in resultant temperature through the year. The transition from natural ventilation to air fans to is made partly using our experience and knowledge of the site and climate, but also on the basis of a maximum average resultant temperature above 28°C, and using a study of the transition from Trade Winds to thermal breezes. The transition from air fans to air conditioning was made when the resultant temperature exceeded 30°C. This is because an office worker dressed in summer clothes begins to feel the heat above 30°C with an air speed of 1 m.s^{-1} . We recall that the temperature experienced at this speed is 4°C below the actual resultant temperature. We see therefore that an office only requires active cooling from January, and that air fans are sufficient until the end of the calendar year.

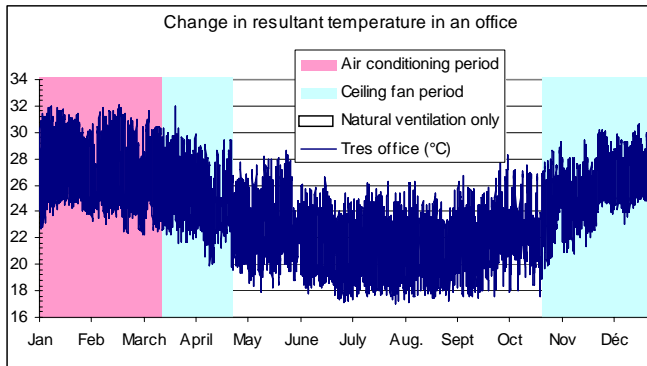


Figure 8 : Change in resultant temperature in an office during a typical year.

Figure 9 shows the different operational periods defined using dynamic simulations. We see that the office spaces are air conditioned for 1.5 months and the computing rooms for 3 months (15 days in December and from the start of February to mid April).

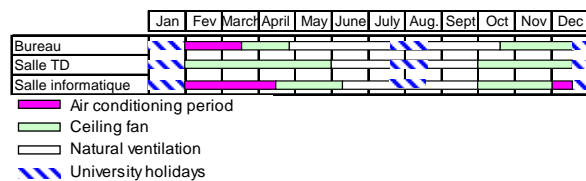


Figure 9 : Operational periods of the air conditioning and the air fans defined using dynamic simulations

It was thus possible to calculate the annual energy consumption of the air conditioning and the air fans. We found that the zero energy building consumed four times less electrical energy than a standard building with a rate of 17 kWh/yr/m²UA for the air conditioning. This includes the refrigeration, auxiliaries and the air fans.

RESULTS AND DISCUSSION : VISUAL COMFORT

Context and objectives

Just as for the thermal comfort, adequate lighting must be provided by passive means, in other words by natural lighting. In the case of artificial lighting, French standards relating to lighting at work tend to lead to unnecessarily large installations. As an example, a typical figure is 17W/m² giving 700 lux of illumination, whereas 300 lux would be more than enough; this results in buildings which consume twice as much energy as necessary. The building

programme and the energy management note require the electrical installations to use less than 7 W/m². We will see that this condition can easily be satisfied with no significant extra cost.

Natural lighting

All the rooms were classed by type and were modelled using software capable of simulating the level of natural lighting. This software is widely available in design offices (DIAL).

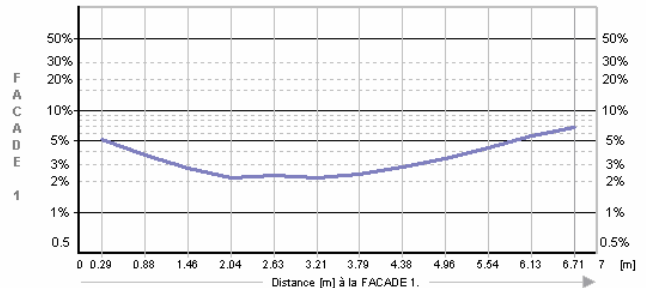


Figure 10 : Change in the daylight factor along a section through a first floor classroom

As an example, Figure 10 shows the change in the daylight factor on a cloudy day for a first floor classroom. This factor must be higher than 1.5% to provide acceptable lighting. This type of figure combined with the results in Table 3 reveal that throughout the first floor rooms, artificial lighting is never necessary at teaching times (8am to 5pm), throughout the year.

Table 3 : Percentage of daylight factor higher than 1.5% by room type

Room	% of room's area with factor \geq 1.5%	Daylight factor minimum (%)
Ground floor office beside inner court	60%	1.0%
Ground floor classroom beside inner court	Between 40 and 82%	1.2%
First floor classrooms	100%	1.6%

The only rooms which pose a problem are two ground floor classrooms in the central buildings. We are currently investigating ways of improving the natural lighting, in particular by reducing or piercing the terrace slabs (see Figure 3). A technical solution is provided by the interior blinds in the offices which are used for natural ventilation but also allow extra daylight into the corridor (see Figures 5 and 11). The simulations have therefore shown that the corridor does not need artificial lighting.

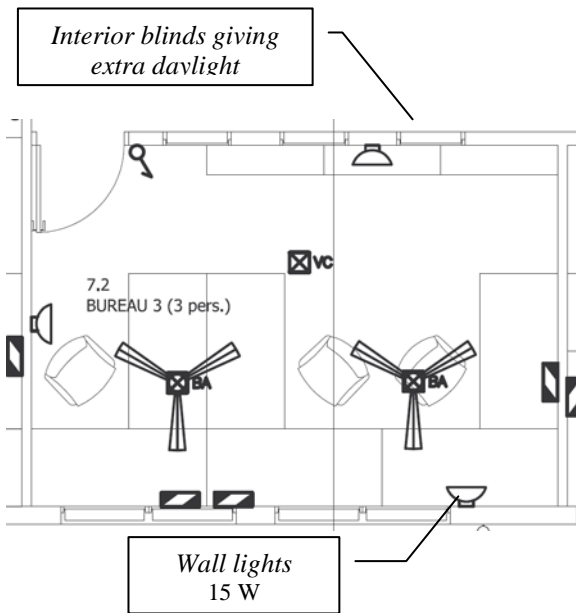


Figure 11 : Methods of natural lighting (interior blinds giving extra daylight) and artificial lighting (wall lights) in an office.

Artificial lighting

To attain the objective of 7 W/m^2 , the layouts of the office and the classrooms were rethought to take into account the presence of air fans and to avoid any stroboscopic effects interfering with work. French legislation requires an average of 425 lux in an office and 325 lux in a classroom. Our approach was to respect 400 lux over the desks, but we considered that 100 lux elsewhere would be quite sufficient. Therefore, as shown in Figure 11, the artificial lighting in the office is given by three low energy 15W wall lights made of frosted glass, and three low energy office lamps. The power of the installations is $90 \text{ W}/20 \text{ m}^2$, or a rate of 4.5 W/m^2 . A standard building would have had lighting from three $4 \times 18 \text{ W}$ installations, giving a total power of 216 W and a rate of 11 W/m^2 . Turning to the classrooms, the level of lighting required by the programme is 250 lux, i.e. 100 lux less than required by law. Natural lighting will make up the difference. As a result, in technical terms, the $4 \times 18 \text{ W}$ installations normally used have been replaced by $2 \times 24 \text{ W}$ installations with electronic components. The power of the installations in a room like the one shown in Figure 12 is thus 8.4 W/m^2 , whereas it would have been 14 W/m^2 in a standard building. The room in Figure 12, in common with the others, features double lighting so that the central part can be used alone, should the daylight factor be too low. Of course, the solutions put forward have been studied using simulations to check that the necessary levels of illumination with artificial lighting were

achieved. The average power of the installations throughout the building is 7 W/m^2 , and the energy use rate is 5.5 kWh/yr/m^2 , compared with 9.4 kWh/yr/m^2 for a standard building.

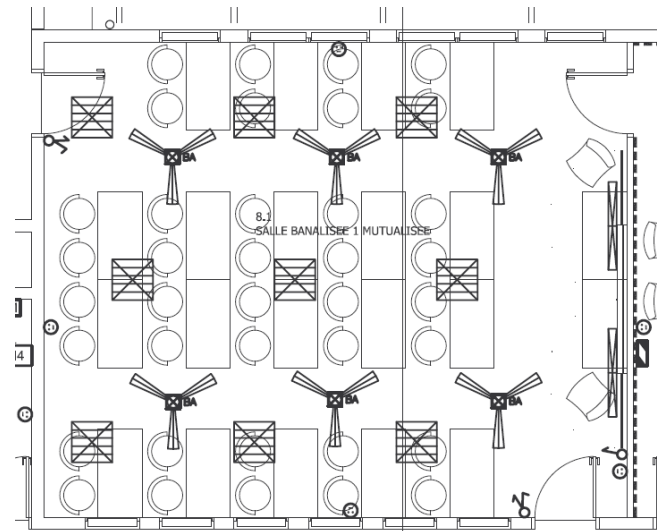


Figure 12 : Methods of artificial lighting and positioning of lights and air fans for a classroom of 60 m^2 .

RESULTS AND DISCUSSION : TECHNICAL EQUIPMENT

Overview of technical equipment

The construction programme imposes a minimum performance level on certain technical equipment. Thus, the refrigeration will be provided by two different types of single unit scroll compression devices placed on the terrace roofing. Having two types of device will allow their performances to be compared; the types are:

- a chiller for the SRC department;
- a VRV device – i.e. variable refrigerant volume, for the Civil Engineering department.

The VRV device uses a cooling fluid between the device and the end units. This technology is widely used in Reunion and exhibits very good refrigerating efficiency, of about 10, where the refrigerating efficiency is defined here as the refrigerating power delivered divided by the device's electrical power. The programme requires this efficiency to be higher than 3, for any load. The electrical power of these devices is 30 kW, but would have been 78 kW for a standard building. Turning now to the artificial lighting, all the lights used are fluorescent with low luminance. The exterior lighting will be provided by high pressure sodium lamps; halogen lights are forbidden. The offices are equipped with movement detectors which increase the thermostat to 27°C and turn off the lighting if the room remains unoccupied

for a while. A centralised management system (CMS) controls and monitors the energy use. The CMS gives the energy consumption for each type of usage and calculates the load on the building in real time. The high performance technical solutions combined with the high thermal quality of the building have allowed us to greatly reduce the power demands of the building. By taking into account profusion effects and simultaneity factors, we find a maximum electrical power demand of 51 kW. It would have been 94 kW for the same building without energy management. Figure 13 gives the overall consumption rates by type of usage. We see that the building will use a third of the energy used in a standard building, with a total rate of 50 kWh/yr/m². The annual consumption is about 87 MWh/yr.

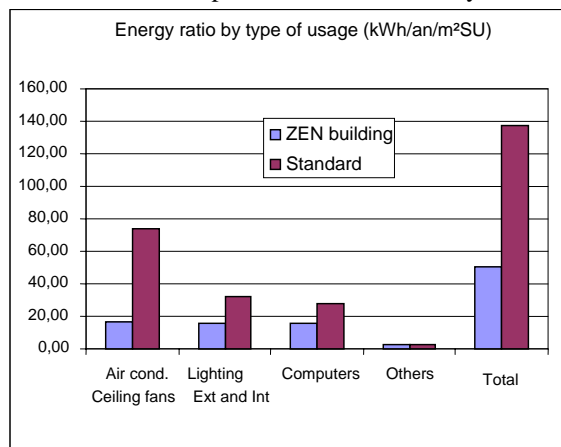


Figure 8 : Summary of energy use by type of usage for the zero energy building and the same building with standard design.

Renewable energy

The four mono-inclined over-roofs north and south are made of poly-crystalline PV panels fixed directly to the metal structure, in place of the normal sheet metal. Roofs 1 and 3 have a northerly slope of 9°, while roofs 2 and 4 have southerly slopes of 9° (see Figures 3 and 5). Simulations carried out using PVSYST (PVSYST 3.4) showed that the southerly roofing produced only 5% less energy over the year than the northerly ones. The productivity is about 1500 kWh/kWp/yr (see Table 4).

Table 4 : Nominal power, energy produced and productivity for the four roofs.

	Area	Nominal power kWc	Production MWh/yr	Productivity kWh/kWp/yr
Roof 1	360m ²	46	71.1	1553
Roof 2	252m ²	32	47.5	1484
Roof 3	242m ²	31	47.9	1558
Roof 4	317m ²	40	59.9	1485
Total	1171m²	149 kWp	226.4	

The nominal power is 149 kWp. The annual production is estimated as 226 MWh, which is 2.5 times the provisional consumption by the building. We can see that roofs 1 and 3 could meet the consumption and power needs of the building on their own. All the solar panels are connected to the grid, and the financial arrangement for their installation involves renting them and is tax-free. The university rents the roofs and as it does not own the solar panels, it is not responsible for their maintenance.

CONCLUSION

The energy use objectives have been met. This was thanks to excellent collaboration between the contractors and the university researchers, who pooled not only their dimensioning aids and expertise, but also their design approaches. Thus, by using a few architectural innovations such as interior blinds, wall lights, using air fans, improved management and intelligent dimensioning of the building systems, it is possible to create a building which uses a third of the energy of a standard building with an additional cost of 2%, due mainly to the optimised CMS. Further, the solar panels will produce the equivalent of 2.5 times the building's energy use.

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