TROPICAL NZEB

BY AURÉLIE LENOIR, STUDENT MEMBER ASHRAE; AND FRANÇOIS GARDE, PH.D., P.E., MEMBER ASHRAE
ENERPOS, a classroom and office building on the French island of La Reunion near Madagascar, demonstrates that sustainable design saves significant energy while providing a comfortable environment in an idyllic, yet challenging setting. More than 800,000 islanders rely on a limited supply of electricity, which is generated from fossil fuels. The growing energy demand from the increasing population sometimes exceeds what the island’s public utility can supply, leading to shortages during the austral summer.

Additionally, in the French tropical regions, nonresidential buildings are often badly designed with no respect to basic bioclimatic principles. Air conditioning and lighting are often oversized, wasting energy.

ENERPOS (French acronym for POSitive ENERgy), the first net zero energy building (NZEB) on La Reunion, is also one of only three NZEBs in a tropical climate, and is the only tropical educational NZEB. Because it is one of few NZEBs in a tropical climate, the building’s performance is monitored and analyzed to verify the design goals and inform efforts to reduce building energy use.

After two years of full occupancy and monitoring, the energy use intensity (EUI) of the ENERPOS building at the University of La Reunion is exceeding expectations at 14.4 kWh/m² · yr (4.6 kBtu/ft²), meaning ENERPOS consumes one-tenth the energy of a standard university building.

The French Agency for Environment and Demand Side Management (ADEME) and the Regional Council of La Reunion funded extensive metering that measures energy by end use and PV production. Comfort conditions, i.e., air temperature, humidity and occupancy are also measured in all classrooms and offices. A post-occupancy evaluation assessed the thermal comfort of the users.

Exceeding Expectations
When the design of the ENERPOS building started in 2005, the aim was to show that using one-third of the annual energy consumption of a standard building could be easily reached by using passive techniques. A standard university building on La Reunion has an average EUI of 140 kWh/m² · yr (44.4 kBtu/ft² · yr). The

<table>
<thead>
<tr>
<th>Name</th>
<th>ENERPOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Saint-Pierre, La Reunion, France (500 miles east of Madagascar)</td>
</tr>
<tr>
<td>Owner</td>
<td>University of La Reunion</td>
</tr>
<tr>
<td>Principal Use</td>
<td>Classrooms, offices</td>
</tr>
<tr>
<td>Includes</td>
<td>Two buildings: seven classrooms, seven offices, one meeting room, car park, planted patio</td>
</tr>
<tr>
<td>Employees/Occupants</td>
<td>Thirteen staff members (administration, teachers, Ph.D. students) plus students in the classrooms</td>
</tr>
<tr>
<td>Occupancy</td>
<td>52%</td>
</tr>
<tr>
<td>Gross Square Footage</td>
<td>1,425 m² (15,339 ft²)</td>
</tr>
<tr>
<td>Air-Conditioned Space</td>
<td>246 m² (2,648 ft²)</td>
</tr>
<tr>
<td>Spaces with Natural Ventilation and Ceiling Fans Only</td>
<td>435 m² (4,682 ft²)</td>
</tr>
<tr>
<td>Total Net Floor Area</td>
<td>681 m² (7,330 ft²)</td>
</tr>
<tr>
<td>Performance Standards</td>
<td>PERENE 2004 (Local standard for efficient buildings in La Reunion)</td>
</tr>
<tr>
<td>HQE—High Quality Environmental standard (standard for green buildings in France)</td>
<td></td>
</tr>
<tr>
<td>Total Cost</td>
<td>$ 1.7 million</td>
</tr>
<tr>
<td>Cost Per Square Foot</td>
<td>$111 (gross)/$232 (net floor area)</td>
</tr>
<tr>
<td>Substantial Completion</td>
<td>August 2008</td>
</tr>
<tr>
<td>Occupancy</td>
<td>September 2009</td>
</tr>
</tbody>
</table>

Opposite The planted patio in ENERPOS creates a microclimate around the building by decreasing the air temperature. It also brings conviviality in a crossing point of the building.

Above The main materials of the building are concrete and wood for shading. ENERPOS is surrounded with native plants on all sides.
the car park under the building, patio, exterior entrance and exterior walkways.)

Classes taught in the building cover social issues, banks and insurance. Engineering students in the Department of Sustainable Design and Environment also take classes in the building and study its sustainable features and energy use.

Passive Design
The main façades are north and south oriented (to use the thermal breezes during summer and to reduce the solar energy gained by the building on the western and eastern façades). The building is surrounded by native plants to prevent the air from heating up before entering the building. The car park is located under the building to avoid the excess heat that occurs from having pavement around the building, and to increase the soil permeability to prevent flooding after heavy tropical storms.

The building design places priority on the passive components/technologies. The building is naturally cross-ventilated with a window to wall ratio (WWR) of 30% by using glass louvers, which have the advantage of allowing natural ventilation and cross-ventilation of the rooms.

ENERPOS opened in January 2009, was partially occupied Sept. 2009–Sept. 2010 and has been fully occupied since September 2010. The building is located in the University Institute of Technology (IUT) on the campus of Saint Pierre (south side of the island). The Regional Council of La Reunion funded the $1.7 million project.

The two-story building splits into two parallel blocks separated by a green patio. The blocks are composed of an administration zone on the ground floor (seven offices and a meeting room), two computer rooms and five classrooms for a total net floor area of 681 m² (7,330 ft²). (All EUIs are calculated based on net floor area, which excludes the car park under the building, patio, exterior entrance and exterior walkways.) Classes taught in the building cover social issues, banks and insurance. Engineering students in the Department of Sustainable Design and Environment also take classes in the building and study its sustainable features and energy use.

La Reunion
La Reunion, a French mini-Hawaii 500 miles east of Madagascar, boasts Creole architecture and sophisticated cuisine. Only about 30 miles wide, La Reunion’s diverse geography flows from beaches to forests to mountains. The island’s rainfall broke records in 2007 at 12.9 ft in 72 hours.

Sugar was long the chief industry of La Reunion, which since has been supplanted by tourism. Major attractions include one of the world’s most active volcanoes and an extinct volcano. Forty percent of the island is on the UNESCO World Heritage List, which includes 936 properties forming part of the cultural and natural heritage that are considered as having outstanding universal value (http://tinyurl.com/unescolist).

Most of the 800,000 residents descended from people from France, Madagascar and other parts of Africa, India and China. Politically, the island is part of the French Republic with five deputies sent to the French National Assembly and three senators to the Senate.
of allowing regulation of the airflow while also providing protection against cyclones and break-ins.

In the administration zone, the central corridor around which the offices are located was cutting off the ventilation. The installation of indoor louvers enhances interior airflow, providing an interior WWR of 30%.

Large ceiling fans are installed in all spaces, including those with air conditioning. The use of ceiling fans guarantees additional air speed during windless days and allows a transitional period before using active air-conditioning systems.

The building team aimed to prove that a comfortable working space can be designed without extra costs and that an NZEB can be comfortable.

The desks are placed perpendicularly to the windows, leaving a 50 cm (1.6 ft) gap to avoid glare and direct solar radiation on desks. The backs of chairs are made of breathable fabric to ventilate the backs of the users. To avoid using white, which is common in educational buildings, all the walls were painted with green organic colors.

**Energy Efficiency**

The building saves energy mostly because of its bioclimatic and passive design. Energy management strategies are used to decrease the total consumption of the active systems.

The installed electric density for artificial lighting is lower than in a standard building (7 W/m² [255 Btu/ft²] in the classrooms and 3.7 W/m² [134 Btu/ft²] in the offices). Low energy T-5 luminaires provide indirect ambiance lighting, while LED desk lamps in the offices provide additional lighting as needed. Timers in the classrooms turn the lights off automatically after two hours.

Ceiling fans are used in conjunction with the natural ventilation strategy to create air movement on the skin of the occupants, increasing their comfort. A total of 55 ceiling fans with a 132 cm (4.3 ft) blade diameter are installed in the offices and classrooms.

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**ENERGY AT A GLANCE**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Energy Use Intensity (EUI) (Site)</td>
<td>14.4 kWh/m²</td>
</tr>
<tr>
<td>Annual Source Energy</td>
<td>47.5 kWh/m²</td>
</tr>
<tr>
<td>Electricity (From Grid)</td>
<td>14.4 kWh/m²</td>
</tr>
<tr>
<td>Annual On-Site Renewable Energy (PV) Exported</td>
<td>104.4 kWh/m²</td>
</tr>
<tr>
<td>Heating Degree Days (base 65˚F)</td>
<td>9 (May 2010–April 2011)</td>
</tr>
<tr>
<td>Cooling Degree Days (base 65˚F)</td>
<td>4,539 (May 2010–April 2011)</td>
</tr>
</tbody>
</table>

**WATER AT A GLANCE**

Annual Water Use: Water use is not measured because initial efforts focused on energy use only. Plans call for adding a water meter in the future.

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All walkways are outside to allow cross natural ventilation of the classrooms. The car park is located under the building to increase the soil permeability to prevent flooding after heavy tropical rains.

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To reduce plug load energy consumption, the use of laptops and nettops, which consume much less energy than desktop computers, is encouraged in the offices.

**Renewable Energy**

The very low consumption of the building is balanced by 350 m² (3,767 ft²) of building-integrated photovoltaic roofs. The PV panels serve as over-roofs, with half oriented north and half south. The graffiti on the gable was designed by Jace, a street artist from La Reunion. It represents the Gouzou repairing the Earth. The Gouzou is a small humoristic character that can be seen throughout La Reunion.

Ceiling fans are controlled individually (offices) or in groups of two or four (classrooms) from wall-mounted switches and have three speed levels. The maximum power used for one ceiling fan is 70 W (239 Btu/h), which represents 7 W/m² (255 Btu/ft²) (assuming one ceiling fan per 10 m² [108 ft²]).

A variable refrigerant flow (VRF) air-conditioning system is installed to cool the offices and the computer rooms. Its cooling capacity is 25.3 kW (89 tons) and the energy efficiency ratio is 4.8 (provided by the manufacturer). Designers reduced the predicted cooling period for the computing rooms to six weeks by using natural ventilation and ceiling fans. However, air conditioning has only been used about one week per year.

A building management system controls the air-conditioning system (operating period, setpoint temperature); the schedules of exterior lighting; and energy consumption by type of end uses (lighting, ventilation, plug loads, air conditioning, elevator). Plug loads represent the highest energy end use, accounting for 46% of the total energy consumption of the building.

Plug loads represent a higher percentage of energy consumption than usual, in part because energy used for cooling and lighting is significantly reduced compared to standard university buildings. To reduce plug load energy consumption, the use of laptops and nettops, which consume much less energy than desktop computers, is encouraged in the offices.

**ENERPOS: Part of a Larger Project**

**ENERPOS** is one of 11 research projects selected by the French National Research Agency as part of an effort to reduce building energy use by a factor of four by 2025. Researchers hope to apply knowledge gained from ENERPOS to the design and construction of other net zero energy buildings in French overseas departments in hot and humid climates, including La Reunion, two Caribbean islands (Martinique and Guadeloupe), French Guiana, located north of Brazil, and Mayotte in the Comoros Islands off the eastern coast of Africa. France also has overseas collectives in tropical climates where the same methods can be applied. As the populations of these French tropical islands continue to grow, so does energy demand. But energy production capacity is limited and cannot increase indefinitely.
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oriented south. The slope of the PV cells is 9° for both roofs.

Besides electricity production, the PV panels provide a ventilated double roof, which creates solar shading of the terrace roof of the building.

Because of the PV layer, the solar factor (the percentage of solar heat that penetrates the roof to the building's interior) of the roof is 0.003 whereas the PERENE requirement is 0.02. (PERENE is the French acronym for ENergy PERformance of Buildings, which is the local standard for labeling energy-efficient buildings.)

The underlying philosophy of ENERPOS is to balance the final energy consumption of all its uses with its PV production and to reduce the stretch of time until the energy balance is reached. The advantage of a tropical climate is that the peak energy consumption (that corresponds to the use of ceiling fans or air conditioning) and the maximum potential production (solar radiation for the PV panels) occur simultaneously.

**Annual Energy Balance**

The overall energy use of the building between May 2010 and April 2011 was 9,824 kWh (33 million Btu). The EU1 for this year was 14.4 kWh/m² yr (4.6 kBtu/ft²).

This EU1 can be compared with the PERENE standard to evaluate the consumptions of ENERPOS with a standard building of the same type on La Reunion. According to PERENE, a university building has an energy index of 140 kWh/m² yr.

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**KEY SUSTAINABLE FEATURES**

- **Water** Car park located underneath building to increase soil permeability and prevent flooding.
- **Low-flow toilets.**
- **Recycled Materials** Chairs made from recycled plastic.

**Daylighting**

- **North and South Façades** solar protected with wooden strips (simulated with 3-D software, optimized for daylighting).
- **Useful Daylight Index** of 90% in most spaces. No artificial lighting in two classrooms on the first level facing the sea.

**Individual Controls** Individual controls for office ceiling fans and lighting. Use left at the discretion of occupants.

**Classroom Controls** Grouped controls for ceiling fans. Timers turn off lighting after two hours.

**Vegetation** A 3 m (9.8 ft) band of native plants around the building helps prevent the surrounding air from heating up. Native plants have low water needs and are adapted to cyclones.

**Natural Ventilation and Ceiling Fans**

- **Cross Natural Ventilation** (window to wall ratio: 30%).
- **Indoor Louvers** Between the offices and the central corridor.

**Ceiling Fans** (one per 10 m² [108 ft²]) in all spaces.

**Artificial Lighting**

- **Offices** Wall mounted neon tubes (100 Lux) plus 9 W LED desk lamps (300 Lux) = 3.7 W/m² (134 Btu/ft²).
- **Classrooms** 7 W/m² (255 Btu/ft²)

**Building Management System** 15 energy and power meters; 15 temperature and humidity sensors and presence detectors (in all classrooms and offices).

**Occupant Surveys** More than 2,000 thermal comfort surveys during three summer seasons to assess comfort of the occupants without air conditioning.
yr (44.4 kBtu/ft² · yr) (final energy). ENERPOS consumes one-tenth the energy of a standard building.

*Figure 1* represents the consumptions month-by-month for all of the end uses. Consumption is lower during July and August (which corresponds to the school holidays). The plug load consumption remains more or less constant over the year. The consumptions that vary the most are the air conditioning (particularly the use of the split systems in the technical rooms), ceiling fans and interior lighting. Exterior lighting consumption increases during austral winter (May to October except July and August due to the holidays). The ceiling fans are used during the summer (November to April) and the air conditioning is used during one week in February.

The overall consumption of the ceiling fans and the split systems units is only 3.7 kWh/m² · yr (1.17 kBtu/ft² · yr), whereas in a standard building air conditioning usually consumes 80 kWh/m² · yr (22.2 kBtu/ft² · yr). The strategy of using cross natural ventilation with ceiling fans represents a massive potential energy savings.
The architect who designed the building wanted architectural homogeneity, with half the over-roof facing north and the other half facing south. Both slopes are 9°, which is not the best choice in terms of photovoltaic efficiency as the optimum position for PV panels on La Reunion is a north orientation with a slope of 21°.

Comparing the PV yield of the north field with the south shows that the difference in orientation is not very important (about 10% more for

The PV system is not part of the overall cost of the building. It is a financial agreement between the building owner, the University of La Reunion, and a manufacturer. The terms of the contract specify that the university rent its roofs for 15 years. The manufacturer installed the PV systems and supports all of the costs and risks (including typhoons and maintenance) during that period, but gets the benefits of the electricity fed into the grid (US$0.33/kWh). After 15 years, the university becomes the owner of the PV system.

**PV Production**

The PV production measured over the year was 71,118 kWh (242 million Btu) compared to an overall consumption of 9,824 kWh (33.5 million Btu). The resulting surplus is 90 kWh/m² · yr (28.5 kBtu/ft² · yr).

ENERPOS has produced seven times its electrical consumption over the year, which means ENERPOS is net zero on an annual, monthly and daily basis. The PV system is oversized, but the design meets the goal of incorporating an architecturally integrated PV roof.

The west side of the patio is protected from solar radiation by wooden strips that filter the trade winds as well.

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Comparing the PV yield of the north field with the south shows that the difference in orientation is not very important (about 10% more for
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LESSONS LEARNED

The lessons learned from ENERPOS will be useful in the design of future net zero energy buildings or high performance buildings, especially in tropical climates.

Post-Occupancy Evaluation. To assess the comfort level of ENERPOS, a post-occupancy evaluation was conducted during three hot seasons (October to April). It involved surveying students and lecturers during the hours of occupancy. Students were asked to complete a questionnaire at the same time that the environmental parameters were being recorded (air temperature, wet-bulb temperature, globe temperature, relative humidity and air velocity).

More than 2,000 questionnaires were filled in by 600 students and their teachers. The main results are that the occupants usually don’t complain about the heat and generally feel comfortable, even during the hottest period of the year.2

Elevator Energy. Data from the energy monitoring system (put into service in January 2010) showed that energy consumption of the elevator accounted for 13% of the overall energy use of the building (which represents 120 kWh/month [409 kBtu/month]).

All the inside lights were constantly turned on even if the elevator was closed with no one inside. A standby mode was activated, and this measure cut the energy used by the elevator in half, reducing it to 55 kWh/month (188 kBtu/month).

Air Conditioning and Natural Ventilation. The air conditioning (VRF system and ceiling cassette units) and the air treatment unit (ATU) are installed in the offices and in the two computer rooms. During the design phase, a dynamic thermal model of the building was undertaken in the building modeling simulation tool.2

Using Givoni’s comfort diagram on a psychrometric chart, it was possible to predict the different operational periods for natural ventilation, ceiling fans or air conditioning.3 The offices were supposed to be air conditioned for 1.5 months and the computer rooms for three months (15 days in December and from the start of February to mid-April, which represents 42 working days). In fact, using ceiling fans instead of air conditioning reduces the energy consumption by a factor of 20.

Because the air conditioning has only been used two days from May 2010 until April 2011, its consumption should be very close to zero. And yet, the variable refrigerant flow (VRF) system and the ceiling cassette units represent 15% of the overall energy use of the building. In fact, it was discovered that the small display screens installed in the offices and computer rooms have a power of 7 W, with a monthly consumption of 20 kWh (68 kBtu). The only solution found to avoid these useless consumptions was to break the circuits of the VRF system, ATU and ventilation on the general electrical panel.

As a result of measurements conducted on the ceiling fans’ performance, it was proved that the grouped commands lead to a lower air speed in the classrooms than the ceiling fans controlled individually (in the offices). The wiring should be soon modified to have individual commands for each ceiling fan.

Interior Lighting. Another improvement could be made on the interior lighting switches of the classrooms. Daylighting measurements showed that three parallel areas can be defined: The daylighting is very good (above 500 lux during the hours of occupancy) near the windows overlooking the exterior, slightly weaker (below 300 lux a few hours per day) in the middle and even weaker (below 300 lux several hours per day) on the side of the building overlooking the green patio into the other part of the building. Three different switches control the three rows of lighting to light only the darker part (or parts) of the classrooms and optimize the lighting consumption.

Occupant Behavior. The ultimate objective is to get active people in a passive building, instead of passive people in an active building. To do this, people need to be educated and to adapt their behavior.

Signs in classrooms explain how to properly use the building by opening the louvers or turning on ceiling fans, switching off unnecessary lights, and using the stairs, rather than the elevator. Signs also provide suggestions for reducing waste by printing on both sides of paper, using reusable cups and glasses, sorting the garbage for recycling, etc.
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the north field over the year). And, in summer, the south PV array produces more than the north one. This is mostly due to a higher solar radiation in summer and because the sun path faces south during summer.

In conclusion, the architectural choice of designing two PV arrays with two orientations does not have a significant impact on the overall PV production of the building.

**Conclusion**

ENERPOS shows that with current technologies and only 9% additional cost, it is possible to build a building that consumes 10 times less energy than a standard building and produces seven times more energy than it consumes. Occupant surveys show that the occupants find this NZEB to be comfortable.4

In general, the performances of the building far exceeded the expectations during design. But improvements are still possible to decrease the energy use of the building, some of which depend on the users of the building.

**Acknowledgments**

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**References**


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