Zero Energy Buildings in France: Overview and Feedback

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ABSTRACT

This paper presents an overview of the first positive/near Zero Energy Buildings in France -NZEB. The aim is to study the design methods and to identify the innovative solution sets. Nineteen French zero energy buildings and projects have been identified so far. Innovative solutions sets in terms of design and conception that emerge from this state of the art have been highlighted and are presented in the first part of the paper. For instance, a general trend concerns the shape of NZEB that are narrower in terms of width. This allows using passive solutions such as cross natural ventilation and natural lighting on both sides of the building. Then, as few Net ZEBs around the world are already built so far, the three first French NZEBs will be presented in a second part in order to give a feedback on their construction, utilization and energy consumptions. The comparison of the energy consumptions during design phase and occupancy given in the last part shows that it is always complicated to forecast the consumption of a building. One of the major problems to specify the energy consumption during the design stage is the definition of a timetable to evaluate the occupancy of the future building. This work is part of a joint international program supported by the International Energy Agency "Towards Net Zero Solar Buildings".

INTRODUCTION

It is widely known now that the building sector has a significant impact on the energy use and the environment. Commercial and residential buildings use 43% of the final energy and are responsible for 25% of the CO_2 emissions that represents 120 million tons in France. In the context of global warming and fossil fuels decline, the energy consumes by the building sector must decrease significantly and renewable sources of energy need to be found.

In 2002, the EU adopted the Energy Performance of Buildings Directive (EPBD 2002), which set minimum efficiency standards for both residential and commercial buildings. As climate and energy security concerns have come to the forefront of EU policy-making, the Commission proposed a recast of the directive as part of its Second Strategic Energy Review in November 2008. The second article of the directive of the 14th of April 2010 (EBPD 2010) gives the definition of a “nearly zero-energy building”. This is a building that has a very high energy performance (each member states should determine these minimum energy performance requirements). The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby. According to article 9, “by 2020, all new buildings are nearly zero-energy buildings”.

As for France, the thermal regulations in 2000 and 2005 defined levels of performance which must be reached for the consumptions of new buildings. From 2012, all buildings will be very low-consumption buildings which means that the energy ratio for heating, DHW, cooling, ventilation and lighting must be less than 50 $kWh_{PE}/m^2.y$ (15,850 $BTU/ft^2.y$). By 2020, the buildings will be energy-positive by balancing their low consumption by the production of renewable energy.

WHAT IS A NET ZERO ENERGY BUILDING?

The concept of Net/Near zero energy building - Net ZEB is now often used and is most of the time included as a specific topic in all the renowned congresses involved in the energy efficiency of buildings (ASHRAE, Clima2010, Eurosun, IBPSA etc.).

Despite this, the concept is still generic and there is no harmonized understanding about what is really a Net Zero Energy Building (Torcellini 2006-2010). This is why an international work has started in 2008 within the framework of the International Energy Agency “Towards Net Zero Solar Energy Buildings” (Task40/Annex 52 2008). The objective of this work is to study current net-zero, near net-zero and very low energy buildings and to develop a common understanding, a harmonized international definitions framework (Sartori 2010a), new design tools (Athienitis 2010), innovative solutions sets and industry guidelines. Indeed, many questions may arise: should the energy taken into account be primary or final? (Voss 2010) What use should be included in the balance (heating, DHW, cooling, ventilation, lighting, outlets...)? What energy can be considered as renewable (solar, wind, wood)? Which perimeter should be considered (building, parcel, district...)? (Voss 2007) Should a LCA or a carbon footprint study be included in the definition? How should the comfort of the occupant be taken into account and evaluated? (Sartori 2010b) How should be evaluated and monitored the energy consumption and production in the building?

This study was carried out within this framework. A list of French zero energy buildings and projects was established. Innovative solutions sets in terms of design and conception that emerge from this state of the art have been highlighted and are presented at first. As few Net ZEBs around the world are already built so far, the idea of the last part is to present the three first French NZEBs and to give a feedback on their construction, utilization and energy consumptions.

OVERVIEW OF THE FRENCH NZEB

In all nineteen projects have been identified (see Figure 1), the aim being to record innovative solution sets to describe the new design features accompanying the industrial revolution leading to zero energy buildings. The values of the energy consumed and produced given in the charts below come from the studies during the design phase of the project.

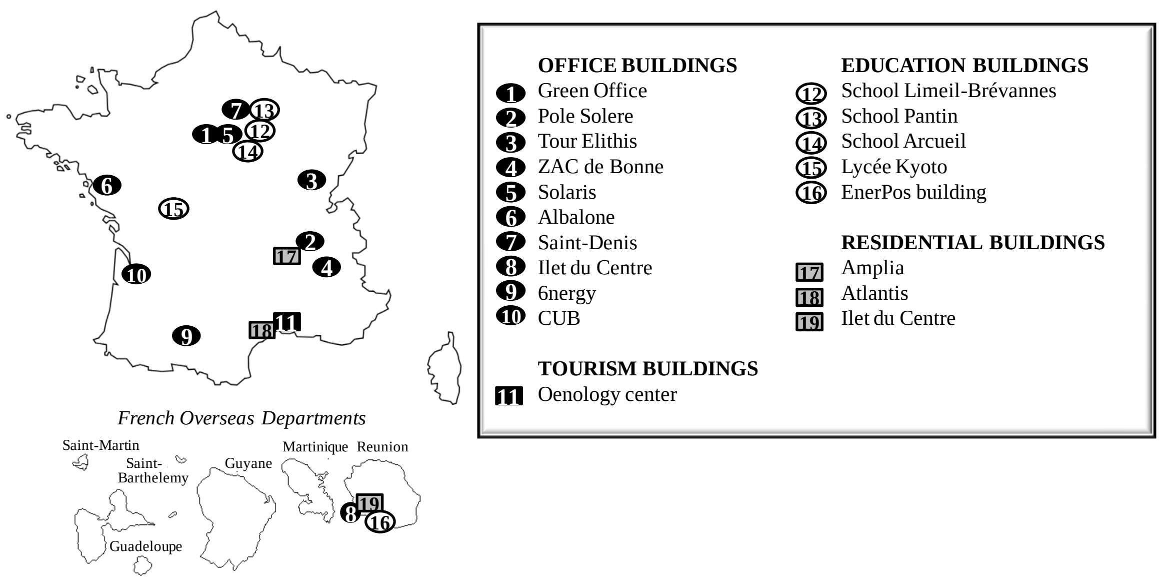

Figure 1. Location of the French Net Zero Energy Buildings

Table 1. Residential Buildings

Project	Location	Completion	Area	Energy production	Production in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)	Energy use in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)	Balance in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)
Amplia	Lyon	2011	66 housings 11 456 m² (63378 ft²)	PV – Heat pump – Solar DHW	72 (22827)	58 (18246)	-14 (-4581)

Atlantis	Montpellier	2009	21 housings 1 200 m² (12917 ft²)	PV – Heat pump – Solar DHW	77 (24535)	38 (12046)	-39 (-12490)
Bretigny	Bretigny (ouside Paris)	2012	54 housing 4 000 m² (43056 ft²)	PV	75 (23775)	75 (23775)	0 (0)

Table 2. Office Buildings

Project	**Location**	**Completion**	**Area**	**Energy production**	**Production in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**	**Energy use in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**	**Balance in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**
Green Office	Meudon (Paris)	2011	20 000 m² (231426 ft²)	PV + CHP (oil)	165 (52342)	121 (38293)	-44 (-14049)
Pole Solere	Lyon	2009	4 500 m² (48438 ft²)	PV	97 (30719)	106 (33538)	9 (2819)
Tour Elithis	Dijon	2009	5 000 m² (53820 ft²)	PV + Wood boiler	45 (14265)	66 (20922)	21 (6657)
ZAC de Bonne	Grenoble	2009	2 000 m² (21528 ft²)	PV + water table heat pump	86 (27358)	81 (25762)	-5 (-1595)
6NERGY+	Toulouse	2009	850 m² (9149 ft²)	PV + geothermal heat pump	142 (44982)	139 (44164)	-3 (-818)
Solaris	Clamart (Paris)	2009	31 000 m² (333684 ft²)	PV + geothermal heat pump	46 (14444)	44* (13853)	-2 (-591)
CUB	Bordeaux	2013	8 300 m² (89341 ft²)	PV	42 (13401)	45* (14265)	3 (864)
Abalone	Nantes	2010	1 320 m² (14208 ft²)	6 wind turbines + PV	66 (21017)	48 (15216)	-18 (-5801)
Mediacom	Saint-Denis (Paris)	2011	4 000 m² (47738 ft²)	PV + Heat Pump	40 (12765)	39* (12379)	-1 (-387)
Ilet du Centre	Saint-Pierre, Reunion Island	2009	312 m² (3358 ft²)	PV	317 (100585)	208 (65903)	-109 (-34682)

* Only the consumptions for space conditioning are taken into account (heating, cooling, ventilation, and lighting). The definition of zero energy building in this case only includes the conventional consumptions of the French Thermal Regulation (RT 2005) in the energy balance ie only space conditioning consumptions; the outlets for example are not taken into account in the balance.

Table 3. Education Buildings							
Project	**Location**	**Completion**	**Area**	**Energy production**	**Production in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**	**Energy use in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**	**Balance in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**
Primary school Limeil	Limeil-Brévannes (ouside Paris)	2007	3 137 m² (30139 ft²)	PV – Water table heat pump	65 (20446)	62 (19654)	-3 (-792)
Primary school Pantin	Pantin (ouside Paris)	2010	3 560 m² (31851 ft²)	PV – Heat pump – Solar DHW	96 (30541)	57 (18132)	-39 (-12409)
Primary school Arcueil	Arcueil (ouside Paris)	2010	4 700 m² (50591 ft²)	PV	57 (17923)	no data	no data
Kyoto high school	Poitiers	2009	19 600 m² (170071 ft²)	PV + CHP (oil)	120 (38039)	59 (18576)	-61 (-19464)
EnerPos	St Pierre, Reunion Island	2009	781 m² (8407 ft²)	PV	296 (93759)	99 (31383)	-197 (-62377)

Table 4. Tourism Building							
Project	**Location**	**Completion**	**Area**	**Energy production**	**Production in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**	**Energy use in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**	**Balance in $kWh_{PE}/m^2.y$ ($BTU/ft^2.y$)**
Oenology Center	Lunel (near Montpellier)	2009	3 560 m² (9537 ft²)	Wood boiler	no data	no data	no data

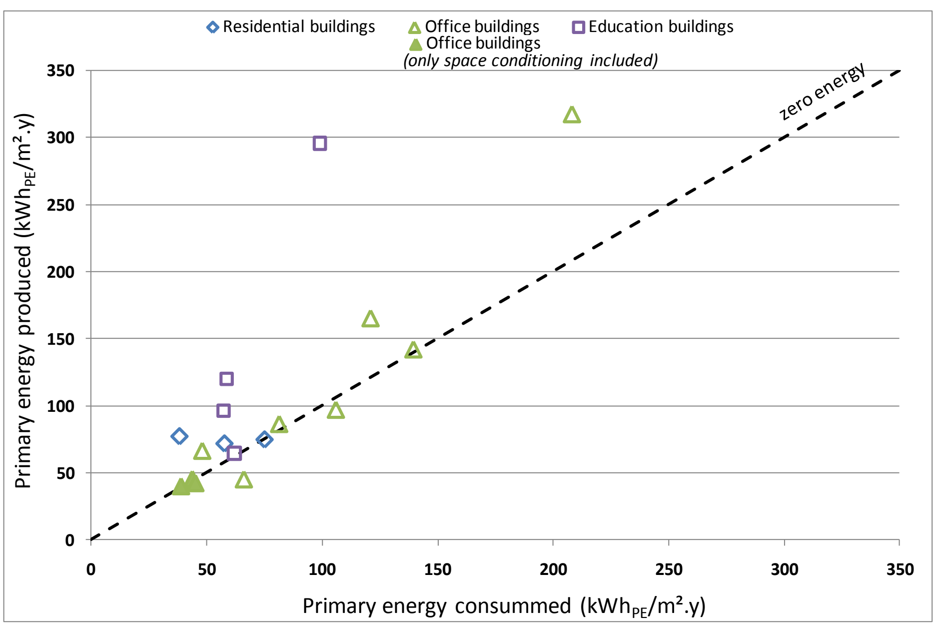

Figure 2. Compendium of primary energy consumption and credit generation

CONCEPTION OF A NZEB: INNOVATIVE SOLUTION SETS

Reducing the width of the buildings to improve bioclimatic conditions

The width of the buildings is reduced to improve natural ventilation and daylighting. “Green-Office” building’s width is 14 m (46 ft) instead of 18 m (59 ft) for a classical office building. In the “EnerPos” building, two small parallel buildings allow the classrooms and the offices to be naturally ventilated as well as the offices thanks to interior louvers between the corridor and the offices on each side (see Figure 3).

The buildings are bioclimatic. At “Ilet du Centre”, the apartments are cross naturally ventilated with exterior walkways, deported to preserve privacy (see **Erreur ! Source du renvoi introuvable.**). The same concept has been used in “Amplia” with the addition of balconies equipped with shutters which allow the use of the space differently depending on the season: summer balcony, greenhouse in winter.

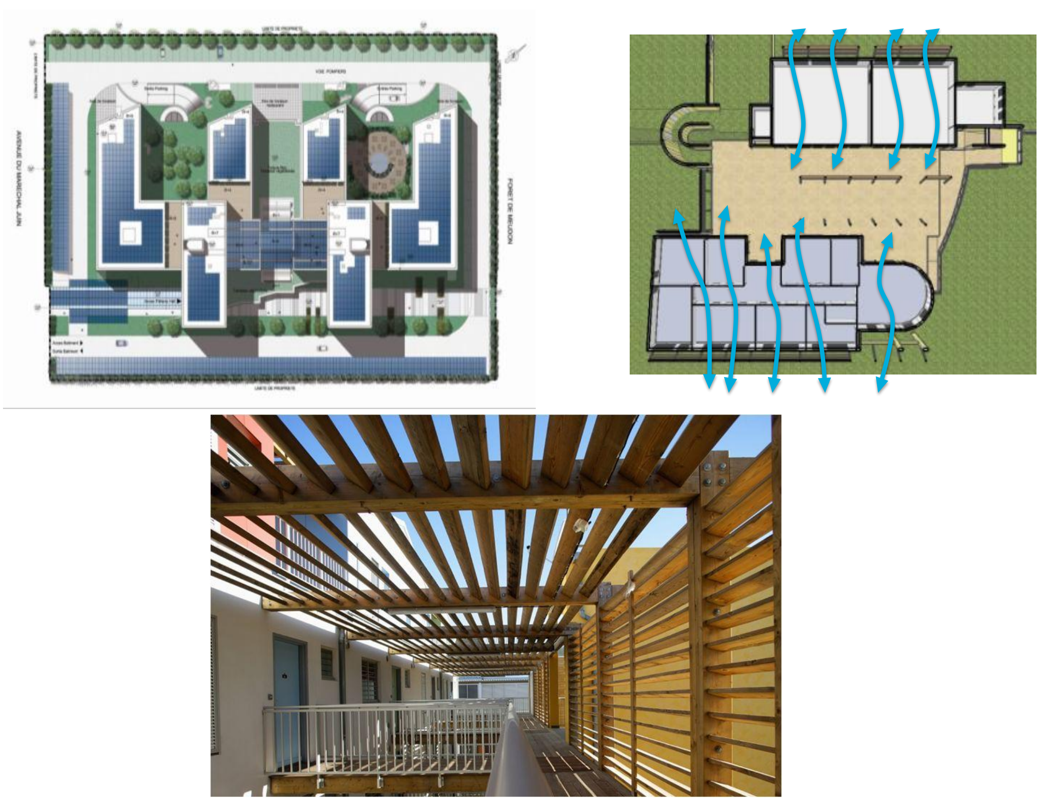

Figure 3. Top left : Green Office Building (outside Paris) – Top right : EnerPos Building (Reunion Island); the width is reduced to use natural resources (wind, sun…) – Bottom center : Ilet du Centre (Reunion Island); exterior walkways are deported from the facade to preserve privacy

A multi-functional envelope that takes into account summer comfort

The envelope is not only used to insulate the building, but it becomes multi-functional (CSTB 2009). It allows both to protect from the outside environment, but also to draw its energy (from the sun, the outdoor air, the soil, the wind…). The choice of the orientation of the different part of the structure is capital to reach this goal. Thermal insulation, solar protection, ventilation, daylighting are thus associated. Investments are transferred from the systems to the envelope. Indeed, a well-designed envelope can avoid or remove the use of traditional installations of heating or air-conditioning.

In the building of “ZAC de Bonne”, the envelope has a very high inertia and an exterior insulation; mechanical shutters that enclose when the room is unoccupied where also installed, they allow to store the heat while providing daylighting when the office is occupied. For the “Elithis” Tower, the outer solar shield reduces the cumulative needs in hot and cold of 40% while providing sufficient daylighting. The function of the envelope in “EnerPos” (under tropical climate) is to protect the inside from the sun (solar protections) but also to allow cross natural ventilation and daylighting (very porous) (Garde 2006-2009) (see Figure 4). In the “Green-Office” building, an innovative solution consists of a set of three windows. An opening is used for dual flow CMV (in winter) and natural ventilation (in summer); the second one can be opened manually by the user and the third one is a large bay that provides daylighting. The three windows are fitted with external solar shadings (see Figure 4).

Summer comfort also becomes an important point (Sartori 2010b): the problems for winter comfort are easily solved in very low consumption buildings, but the high insulation and the airtightness can lead to a risk of discomfort during summer. This issue is especially important in a long term vision because climate change is likely to intensify this problem. The techniques used to ensure summer comfort in mainland France are the same as those in tropical climates. Fixed or mobile solar protections are added to the buildings, as in “Pole Solere”, “Kyoto” highschool or the primary school in Pantin. In the residence “Ilet du Centre”, a buffer zone is created with a double skin made of strips of wood and a planted area that create a heat protection from the street.

 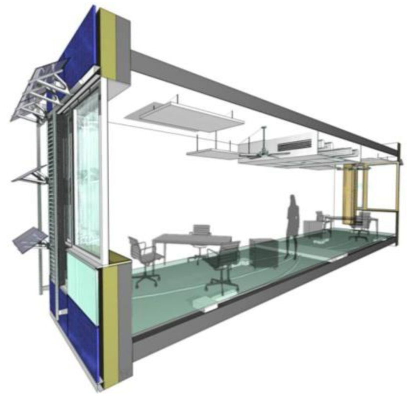

Figure 4. Left: ENERPOS building (Reunion Island); the building envelope provides solar protection but also allows cross natural ventilation. Right: Office Unit of the Green Office Project (outside Paris); an innovative concept of window integrating ventilation, solar protection and daylighting. Source: http://www.green-office.fr

High-performance and combined systems

The systems used are more efficient, conventional heating systems are often replaced by heat pumps. For example the “Pole Solere”, the primary school in Pantin and the “Solaris” building use geothermal heat pumps. In both the primary school of Limeil-Brevannes and the building in “ZAC de Bonne”, a water table heat pump is used.

The systems are also combined to produce at the same time electricity and heat, which increases the thermodynamic efficiency. Thus, cogeneration systems with vegetable oil are used in the “Green-Office” building and in the “Kyoto” high school.

Regarding the artificial lighting, the systems are frequently equipped with dimmer switches and motion sensors (“Kyoto” highschool and primary school in Pantin). In “EnerPos”, there is a mood lighting (about 100 Lux) combined with a spot lighting (LED desk lamp) to reach 300 Lux (27,9 lm/ft²) on the working area. The lighting of the classrooms is equipped with a timer that turns the light off automatically after 2 hours.

Concerning the ventilation, dual flow CMV is more and more often used, with high performance exchangers (“Pole Solere”), combined with natural ventilation during summer (“Green-Office”), with night cooling natural ventilation (primary school in Pantin) or even triple flow CMV (Elithis Tower). High performance ceiling fans also appears in office buildings (“Green-Office” or “EnerPos”, see Figure 5).

Figure 5. High-performance ceiling fan - used in ENERPOS and Green Office

Management of energy consumption and production

Regulation devices allow the management of heating, ventilation, lighting, air conditioning systems needed by the occupants (that become very small), but also allow to use in priority the systems using renewable energy instead of the additional systems using fossil fuels.

The buildings are monitored with the energy use and the production, the level of comfort, the air quality… The Elithis Tower and “EnerPos” which are research buildings are equipped with thermo hygrometer sensors to assess the indoor conditions, as well as energy meters by category of end-use to identify the most energy-consumer items and to correct them if necessary.

Energy production is mainly photovoltaic

The integration of photovoltaic in the building increases, whether on a pitched roof (primary school in Pantin, “EnerPos”), on a flat roof (Elithis Tower) or used as a cladding in front of mineral wood (primary school in Limeil-Brévannes).

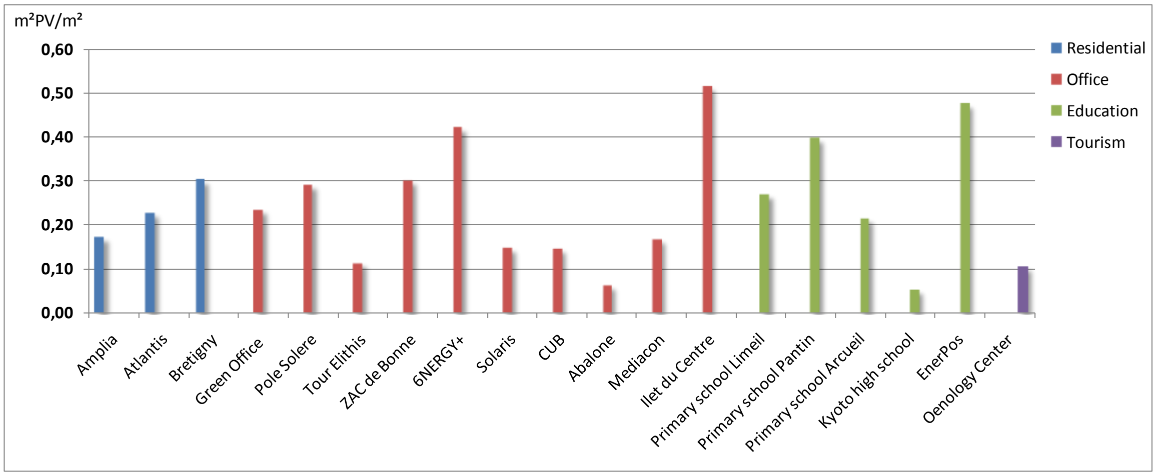

Figure 6. Development of PV per building floor area

The electricity is also produced by CHP systems as explained in paragraph “high-performance and combined systems”. Geothermal sources allow the production of heat.

FEEDBACK ON THE THREE FIRST FRENCH NZEB

In the last few years, many zero energy projects arose, at least twenty in France and many others around the world (Musall 2010). But there are only few feedbacks on constructed buildings. In France, the three first NZEBs (built between 2007 and 2009) have now at least a whole year of operation. All three where monitored and a feedback in terms of energy balance, but also users satisfaction was established.

Two by three are education buildings and the last one is an office building. One is located in tropical climate (French overseas department) whereas the other two are situated in mainland France (continental climate).

The underlying philosophy of these three NZEBs was first to reduce the energy use by adopting a passive design and secondly to choose high efficient systems and to add renewable energy to balance the low consumption of the building. In all three buildings, a sensitization of the occupants was set to teach the users the operating mode of their building.

Primary school in Limeil-Brevannes (Paris suburbs)

The primary school of Limeil-Brevannes is composed of 12 classes for a net floor area of 2,800 m² (30,139 ft²). It was inaugurated in 2007 being the first zero energy school in France. The cost for the work was 2 070 €/m² (192 €/ft²).

Envelope design.

1. Orientation. The school includes three buildings north-south orientated. The main spaces (classrooms, dining hall, library) are situed at the south which is the most favourable orientation in terms of solar radiations. In the back (north façade), the staff room, the tearoom and the toilet block act as buffer spaces. An original feature of the project is that the roof of one of the buildings is used as a playground to avoid the overheat due to the tarmac and to keep porous a large part of the ground.
2. Façade. The building is composed of a concrete structure insulated with 21cm (8,2 in) of mineral wool on the outside, allowing a high inertia, very efficient during winter season. A system of cross ventilation shutters on the main façade allows a good ventilation of the spaces during summer. A planted roofing contributes to the insulation of the envelope with 5 to 8 cm (1,9 to 3,1 in) of earth.
3. Windows. The glass are tripled-glazed (4/12/4/12/4 mm – 0,16/0,47/0,16/0,47/0,16 in) filled with argon. The solar factor of the glass is different function of the north or south orientation. The windows can be covered over by outside shutters.

HVAC design. The heating system is composed of two heat pumps on water table installed in parallel. The total power is 90W and covers the entire needs of the school. The primary network is connected to two drillings ; one to suck water and the other to throw it back. The water from a 65 m-deep (213 ft) water table run through an heat exchanger. The energy is distributed through two networks: the radiators and the ventilation system. The flow of the mechanical ventilation system varies with the occupancy of the rooms. Presence detectors are placed in all classrooms in the form of CO_2 sensors that determine the occupancy rate and control the ventilation system.

Lighting design. The main façade orientated south/south-east is composed of large bay windows to have a lot of daylight in the classrooms. Those are also opened on the north side. Moreover to increase this light contribution, a strip of glass cobblestones has been integrated in the circulation on the first floor.

Whence a minimized artificial lighting achieved by fluorescent tubes which effectiveness is higher than 80 lumens per watt. The daylight autonomy is superior to 60% (on the hours of occupancy).

Figure 7. Left: cross section of the school in Limeil-Brevannes with the playground on the roof and the large bay windows to bring daylight in the classrooms and the library. Right: Picture of the glass cobblestones integrated in the circulation on the first floor. Source: http://www.ekopolis.fr

Plugs and miscellaneous loads. The number of equipment and their power is reduced especially in the dining hall for example the dishwasher is supplied directly by hot water leading to a much low electrical consumption.

Renewables. A PV installation of 75 kWc produces about 65 000 kWh per year that balances the whole consumption of the school. On the south façade, 200 m² (2153 ft²) of panels are integrated as a cladding in front of the layer of mineral wool. A part of the panels are covering the courtyard and the rest is integrated on the roof. The domestic hot water is supplied thanks to 30 m² (323 ft²) of solar collectors on the roof.

Sensitization of the public. Afterwards the conception of the zero energy school, the sensitization of the users on the environmental issues is a capital phase of the project. Because the energy consumption of a building depends mainly on its users, it is essential for the future occupants to be sensitized to its innovative operating mode. The pedagogic step is as important as the technical step, with the aim of pressing upon the children the importance of the operating mode of the school and the impact of an eco-citizen behavior. The struggle against wastefulness needs indication of usage of the places and the installations for the technical staff as well as teachers. An accompaniment by the environmental design office during the first two years of occupancy is also an essential step.

Concerning the electrical consumptions, the efficiency is function of the use of lighting by the staff, but also the use of the kitchen, the lights lefts switched on, the choice and the use of computers… For instance, a coffeemaker left turned on in each of the tearooms can increase the consumptions of 5% ; the same for the computers on waking state.

The consumptions calculations were evaluated by taking into account a normal utilization of the building, but depending on the use, the energy consumption can be modified of 50%.

Once all efforts on the optimization of the building and its installations have been done, the most important consumptions are not depending on the building but on the users, that is why the key of succes resides in the education and the sensitization of the occupants.

Feedback. The feedback from the users (teachers and children) is rather good; they appreciate this new kind of school. More discussions between the designers and the users should lead to a better exploitation of the building and its opportunities to sensitize to the environment.

Concerning the functioning of the building itself, an important problem has concern the heat pump on water table. First, during the design phase, it was forecasted to use a 6m (19,7 ft) deep water table. But the productivity turned out to be insufficient so it was necessary to carry out 70m (230 ft) deep drillings. Secondly, during the second summer of use of the building, the pump of the heat pump was stucked into the mud when turned off. It was necessary to change it at the beginning of the next winter. Since, the temporary solution found was to leave the pump turned on during all summer, even if the heat pump is not functioning. This caused a large increase in the total energy consumption of the building. No other solution was found at the moment to solve this problem.

Elithis Tower in Dijon

The Elithis Tower is the first zero energy office building in France. It was inaugurated in 2009. The floor area is 5,000 m² (53,820 ft²) on ten floors. The cost of the project was 1 400 €/m² (130 €/ft²).

Envelope design.

1. Location and orientation. The building is very compact in order to avoid dispensable square meters midtown a city already loaded.
2. Façade. The construction materials were chosen function of their global environmental impact. The envelope is composed of wood, recycled insulating materials as cellulose wadding and a large number of bay windows. Aluminum which has a high environmental impact was used parsimoniously.
3. Windows. The main feature of the project is the glazing rate of 75% and the solar shield to exploit the benefits of the sun (heat and daylight) without suffering from the detriments (overheats, glare effect). Its shape covers the main exposed surface in function of the sun path and the surrounding. The leads structure acts on the drawbacks while saving the sun benefits. The daylighting and the outside view are thus spared.

   The bay windows are composed of a double-glazing filled with argon which provides a high thermal insulation.

Figure 8. Pictures of the Elithis Tower: the solar shield and BIPV roof. Source: htpp://tour-elithis.fr

HVAC design. Thanks to a "triple-flow" ventilation system, energy savings are achieved by recovering the heating produced by the office automation (computers, photocopiers…) but also by the users of the building. The energy produced in the kitchen (range hoods, refrigerators, cold storage) is also recovered and redistributed in the building.

A wood pellet boiler is also used to heat the building during winter.

Lighting design. In order to minimize the artificial lighting needs, all offices have a direct access to daylight. A "nomad lighting system" guarantees visual comfort in conformity with the regulation without energy waste.

Renewables. The underlying philosophy of the project was to contradict the basic definition for a net zero energy building: "in order to balance the energy consumption of a building, it is sufficient to produce more energy than the consumptions". For the Elithis Tower, the inverse argument was adopted: the goal was above all to minimize the energy consumption before setting a production technology.

A small surface of PV panels compared to the total floor area are thus integrated to the roofing to insure a large part of the electrical needs. The heating of the building is provided thanks to a wood pellet boiler.

Sensitization of the users. In order to sensitize the users, an environmental charter was signed to encourage them to respect the environmental advices and the consumption objectives. A notice board, located in the entrance of the building, displays the daily energy consumptions and the savings realized (in kWh and tons of CO_2).

The Elithis tower was designed as an experimentation laboratory with the aim of evaluating, understanding and modeling the impact rather positive or negative of the users' behavior. In order not to rely only on technology, the choice was made to leave the users to meet this challenge. It is thanks to them that the last 20 $kWh_{PE}/m^2.y$ (6,340 $BTU/ft^2.y$) needed in order to reach zero energy should be saved. It is the opportunity to test new sensitization systems not only in terms of energy savings, but also low-emission transports, paper or water savings, waste sorting…

Energy feedback. The Elithis Tower is a real experimentation laboratory. It is equipped of more than 1600 sensors spread all around the building. All consumptions are being examined and analyzed. After one year of occupancy of the building, it has been possible to establish a first energy report (ADEME 2010). Figure 9 gives a comparison between the design phase and the measured energy consumptions. The forecast gave a ratio of 65 $kWh_{pe}/m^2.y$ (20,605 $BTU/ft^2.y$) but measurements during the first 12 months of occupancy (8 months of measurements, 4 months extrapolated) show a ratio of 96 $kWh_{pe}/m^2.y$ (30,432 $BTU/ft^2.y$).

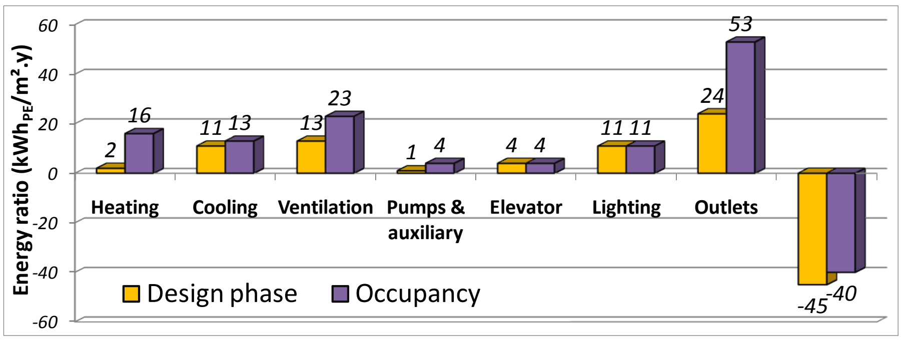

Figure 9. Energy consumption and production of the Elithis Tower (predicted / measured data)

The high consumption of heating can be explained by several reasons:

- the building was only partly used therefore the internal charges were less important than expected,
- the wood pellet boiler was not necessarily a good choice because the combustion cycle is too long whereas the needs of heating during the mid-seasons are very small,
- the winter 2009-2010 was particularly cold.

For the consumption due to ventilation, the higher value is explained by the fact that there was a temporary failure in the building management system and thus the ventilation was turned on when not needed during a few months. This consumption should thus decrease in the next years.

Concerning the outlets consumption, it shows that the sensitization of the users should be carried on and that the zero energy can only be reached by the users and their behaviour inside.

ENERPOS building in Saint-Pierre (Reunion Island)

ENERPOS (French acronym for POSitive ENERgy), the first zero energy building of La Reunion was inaugurated in January 2009 in the campus of Saint-Pierre (in the south of the island). It is a two-floors university building (split into two parallels wings separated by a vegetated patio, which is actually a “green patio” underneath which there is a car park) composed of an administration zone (7 offices and a meeting room), 2 computer rooms and 5 classrooms for a total net floor area of 625 m² (6,727 ft²). The main feature of the building is to use passive means and natural resources such as sun and wind to achieve thermal and visual comfort in the building (see Figure 10). Active energy consuming systems such as air-conditioning and artificial lighting should be used as a last resort (Garde 2006). All rooms and spaces are cross naturally ventilated and equipped with high efficient ceiling fans. Solar shadings have been designed and optimized thanks to 3D simulations. Consequently the building is 5 times less consumming than a standard office building in La Reunion (160 $kWh_{FE}/m^2_{NFA}.y$ ie 50,719 BTU/ft².y). The renewable energy production is provided by 350 m² (3,767 ft²) of BIPV roofs (50 kWc). The cost was 2,300 €/m² (214 €/ft²).

Envelope design.

1. Location and orientation. The building is surrounded by a 3 meters (10 ft) band of native vegetation in order to avoid the air to heat up and enter into the building when used in natural ventilation mode. The car park is located under the building to avoid overheat due to the tarmac around the building, but also to increase the soil permeability and thus to prevent from flooding in case of heavy rainfall. The main facades are north-south orientated (to exploit thermal breezes during summer and to avoid east or west walls orientation, subject to high solar radiations)
2. Façade. Concerning the envelope, the roofing is insulated with a 10 cm-layer (25 in) of polystyrene and a ventilated BIPV over-roof; the walls are made of concrete; the north and south facades are solar protected with shadings made of wooden strips; the east and west gables are insulated with mineral wood and a wooden siding. The solar shadings have been designed thanks to 3D simulations and optimized to find a compromise between thermal efficiency and daylighting.
3. Windows. Their porosity of the outside façades is 30% thanks to glass louvers which have the advantage of allowing regulation of the airflow, while also providing protection against cyclones

and break-ins. The porosity is defined as the percentage of opening in a facade. In the administration zone, the central corridor around which the offices are located was cutting off the ventilation. The original feature of the project was to install indoor louvers which enhance the interior airflow, providing an interior porosity of 30%.

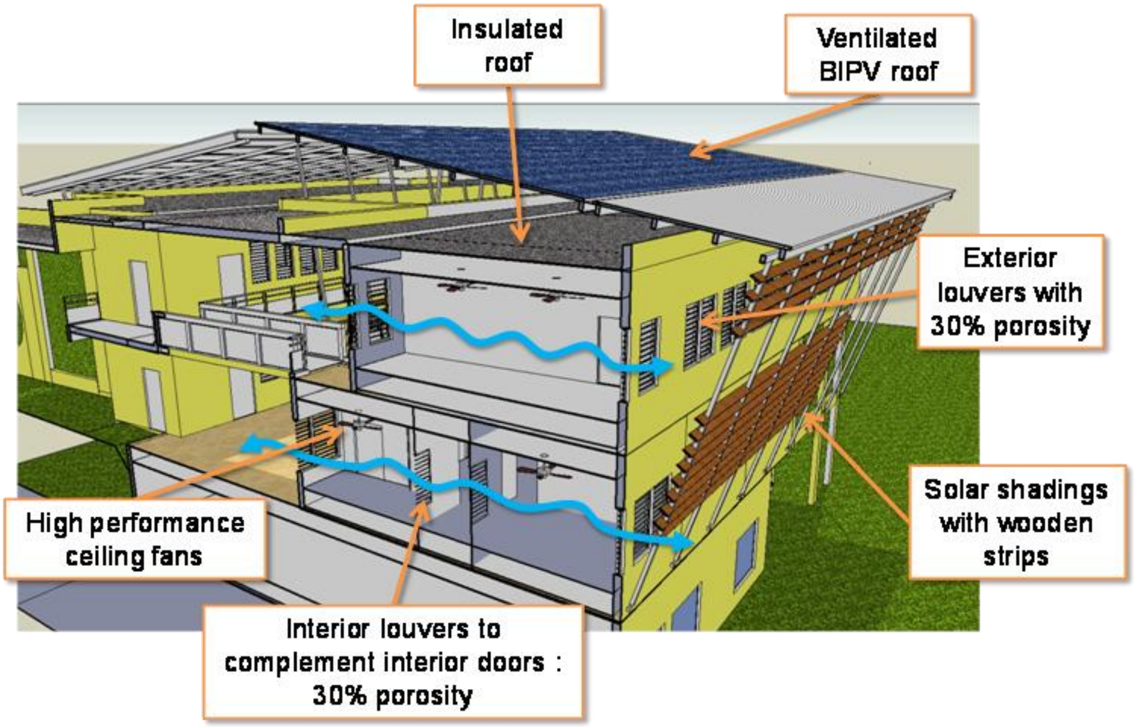

Figure 10. Cross section of ENERPOS: passive design such as cross natural ventilation, solar shadings and insulated roof.

HVAC design. The energy efficiency of the building relies mainly on its bioclimatic design. But the systems used are also very efficient and several actions of energy management are conducted to decrease the total consumption.

Ceiling fans are used in the EnerPos building to complete natural ventilation and to create an air speed on the skin of the occupants and thus to increase the comfort temperature and thus to allow a transitional period before the use of active air-conditioning systems. A total of 55 ceiling fans with 132 cm (335 in) blade diameter are provided in all spaces, including those with air-conditioning. Figure 5 shows the type of 3-blades ceiling fan used in the building. For the offices whose area is less than 15 m² (161 ft²), one ceiling fan was installed and two were placed for larger offices. In the classrooms six ceiling fans are arrayed in 50 to 60 m² (538 to 646 ft²). Fans are controlled individually (in the offices) or in groups of two or four (in the classrooms) from wall-mounted switches and have three speed levels. The maximum power used is 80 W.

A VRV (variable refrigerant volume) air-conditioning system (high COP) is installed only in the offices and computer rooms. But thanks to natural and mechanical ventilation, the cooling season is drastically reduced compared to a classical office building in La Reunion in which it would lasts 6 months or even the whole year. At the EnerPos building, the air-conditioning is running less than six weeks during the hottest days of summer (January-February).

A building management system allows the control and the regulation of the air-conditioning (operating period, set point temperature); the schedules of exterior lighting and the monitoring of the consumptions by type of use (lighting, ventilation, outlets, air-conditioning, elevator…) to target the actions of energy management on the most consumer items.

Lighting design. The ergonomics of the offices has been studied to achieve visual comfort for the occupants and to increase daylighting autonomy. The desks are placed perpendicularly to the windows leaving a 50 cm (127 in) gap to avoid glare effect and direct solar radiation on the work plan.

Concerning lighting installation, the installed power is lower than in a conventional building. It is about 6 W/m² for the classrooms. A 2-hours time delay insures that the lights are off at the end of the class. For the offices, the choice made was to use a mood lighting of 150 Lux (14 lm/ft²) and a desk lamp that provides the 300 Lux (28 lm/ft²) on the work plan.

Plugs and miscellaneous loads. The most consumer use remains the outlets with approximately 50% of the total consumption of the building. To reduce this, the use of laptop and mini-computers (much less consumers than desktop computers) is encouraged in the offices.

Renewables. The very low consumption of the building is balanced by 350 m² (3,767 ft²) of BIPV roofs. The PV panels are distributed on the roofs of both buildings, half of them is north orientated while the other half is south orientated. The tilt angle of the PV cells is 9° for both roofs. According to the simulations, the BIPV roof allows the production of 70 000 kWh/y.

Besides electricity production, the PV panels provide a ventilated over-roof which creates a solar shading of the roof and increases the protection from the solar radiations.

Sensitization of the users. The atrium is equipped with a screen indicating the energy produced by the BIPV roofs and the CO_2 savings realized. This allows the students, teachers and visitors of the building to notice the impact of renewable energy on a building. A website internal to the university displays the energy consumptions by type of use. The occupants can be sensitize day-to-day and realize the impact of the use of the building on its energy efficiency.

Wall notice boards in the classrooms explain how to properly use the building by opening the louvers or turning on the ceiling fans ; to switch off the unnecessary lights ; to use the stairs rather than the elevator but also how to decrease wasting day-to-day by printing on both sides of paper, by using reusable cups and glasses, by sorting the garbage for recycling…

Feedback. Thermal comfort has been monitored during the first two years of use of the building. It consisted in a survey carried on the students during the classrooms hours of occupancy. Students were asked to fill in a questionnaire at the same time as the environment variables were being recorded. The study was carried out during two hot seasons (October - April), overall nearly 2000 questionnaires were filled in by 600 students and their teachers.

After nearly two years of occupancy, some improvements have been made or forecast.

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.

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 near (above 500 Lux (46 lm/ft^2) during the hours of occupancy) the windows overlooking the exterior, slightly weaker (below 300 Lux (28 lm/ft^2) during a few hours per day) in the middle and even weaker (below 300 Lux (28 lm/ft^2) several hours per day) on the side of the windows overlooking the other part of the building. To light only the darker part (or parts) of the classrooms and thus to optimize the lighting consumption, there should be three different switches for the three rows of light fittings.

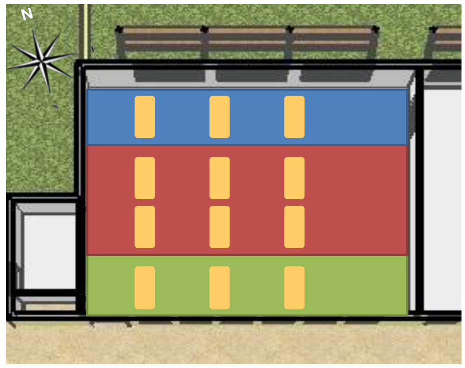

Figure 11. Daylighting measurements showed that three parallel areas can be defined: the daylighting is very good near the windows overlooking the outside (blue), slightly weaker in the middle (red) and even weaker on the side of the windows overlooking the other wing of the building (green).

Thanks to the energy measurements, a glitch was detected with the elevator consumption. The lights inside were constantly on even when the elevator was not used. A standby has been set up therefore the ratio of this use has decrease by half.

Energy feedback. Figure 12 gives the first results of the end-uses consumption (the PV energy meter was not installed yet). The first months of data point out very encouraging results. Unlike the Elithis Tower, the consumption has been rather overstated during the studies (50 (15,850) instead of 32 $kWh_{fe}/m^2.y$ (10,144 $BTU/ft^2.y$) in operation). Only one (on two) splits systems in the technical room is used and explains the difference of consumption. The high consumption of the elevator is due to the fact that the lights inside were constantly put on without any standby mode. In any case, the overall consumption of this NZEB building is around five time less than the consumption of a conventional university building in La Reunion (around 150 $kWh_{fe}/m^2.y$ ie 47,549 $BTU/ft^2.y$).

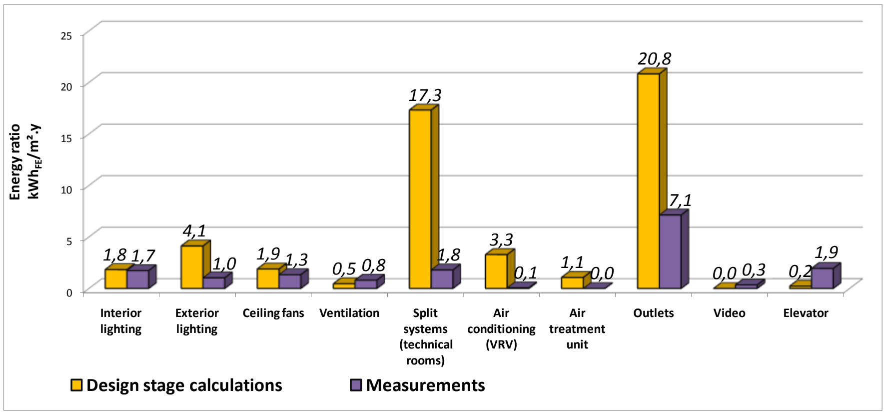

Figure 12. Comparison of the energy ratios by type of use in kWh$_{fe}$/m^2.y (design phase / occupancy) for ENERPOS

CONCLUSION

The overview of the French NZEBs carried out in the framework of IEA Task 40/Annex 52 led to the identification of the new ways of designing this innovative type of building. The building of the future should be bioclimatic with a passive design approach; their width should be reduced compared to conventional buildings in order to improve natural ventilation and daylighting. Their envelope should be not only dedicated to thermal insulation but becoming multi-functional to protect from the outside environment while drawing from the free sources of energy such as wind, sun, soil… Summer comfort should be studied because it becomes an issue in air-tight low consumption buildings. The systems used should be more energy efficient and combine several types of energy production to improve their efficiency. Building Management Systems should be installed to regulate heating, ventilation, cooling, lighting systems for them to be used only when natural resources are not sufficient to achieve the comport of the occupants.

The elevators are often a large source of consumptions representing 5 to 10% of the total energy use (as showed on Figure 9 for the Elithis Tower and on Figure 12 for ENERPOS). In NZEBs it is necessary to encourage the users to take the stairs at least to reach the first floors. The building organization should be thought accordingly by placing a large and nice stairwell at the center of the building and to move the elevators from the central lobby.

The sensitization of the users is also essential in this new type of building to explain the specific operating mode. It is also important to show to the occupants the impact of their behavior on the energy consumption. The real outlets energy consumption of the Elithis Tower compared to the predicted values shows that the energy balance can only be reached by the users of the building. The best designed building in the world can consume more than a conventional building if users are not informed and supported in the use of the building. Only a change of mindset of the people can lead to a decrease of the energy consumptions. The aim is to build passive rather than active buildings, with active rather than passive occupants.

The comparison of the energy consumptions during the design stage and occupancy given in the last part shows that it is always complicated to forecast the consumption of a building. One of the major problems to specify the energy consumption during the design stage is the definition of a timetable to evaluate the occupancy of the future building. For the office buildings it is a key element. This occupancy and use of equipment scenario should be considered as a primary input data regarding the energy consumption calculations to attain the maximum energy ratio objective. In the building standards, the energy ratio takes into account some specific uses of consumption (e.g. for the French thermal regulation: heating, DHW, cooling, ventilation, lighting), a detailed floor area but never include the occupancy scenario parameter. The impact on the final energy ratio result can be considerably modified by this parameter. Therefore this scenario must absolutely be integrated as an input data of the project.

There is a few Net ZEBs built around the world so far. Few work is available about the design of Net ZEBs in hot/tropical regions as well. The study of the “first generation” of net zero energy buildings -ie already built in 2010 or under construction will allow to get a feedback about the definition, the solutions sets and the energy requirements for the second NZEB generation in the upcoming years.

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