Net zero energy building in France: from design studies to energy monitoring. A state of the art review

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Abstract

In 2020, French energy policy plans that every new building will be positive energy. It is then essential to develop new methods for the design of such buildings. In addition, energy monitoring should be studied on existing positive or near zero energy buildings to ensure that they really respect these characteristics but also to estimate the impact of certain improvements made on the building design towards energy consumptions.

The paper presents the state-of-the-art regarding positive or near zero energy building projects in France. This work is part of the research made by the IEA SHC Task 40 / ECBCS Annex 52 on net zero energy solar buildings [1]. The aim is to study net-zero and near-zero energy buildings in terms of design methods and tools, innovative solution sets and energy monitoring.

1. Introduction

In 2002, the EU adopted the Energy Performance of Buildings Directive (EPBD), which set minimum efficiency standards for both residential and commercial buildings. As climate and energy security concerns have come to the forefront of EU policymaking, 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 [2, 3] 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 low-consumption which means that the energy ratio for heating, DHW, cooling, ventilation and lighting must be less than 50kWh$_{ep}$/m^2.y. By 2020, the buildings will be energy-positive by balancing their low consumption by the production of renewable energy.

However, at the present time, there is no concrete definition of what a zero energy building or positive energy is [4, 5]. Indeed, many questions may arise: should the energy taken into account be primary or final? 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...)? 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? How should be evaluated and monitored the energy consumption and production in the building?

The International Energy Agency SHC Task 40 / ECBCS Annex 52 [1] research program’s theme is “Towards net zero energy solar buildings". The objective of this program is to study the net zero energy, near zero energy or very low energy buildings in order to develop a common understanding and harmonized international definitions; to identify and develop tools, technical solutions sets and new guidelines for the industry. These examples are the keys of the industry adoption of new technologies and concepts associated with the construction of positive energy building.

This study was carried out within this framework. A list of French zero energy buildings and projects was established that is presented in the first part. The second part focuses on innovative solution sets that emerge from this state of the art. The last part shows the current difficulty in properly assessing the real energy use of a building during the studies of the project, through two examples of buildings.

2. State of the art of the French Net Zero Energy Buildings

Eighteen projects have been identified (fig.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.

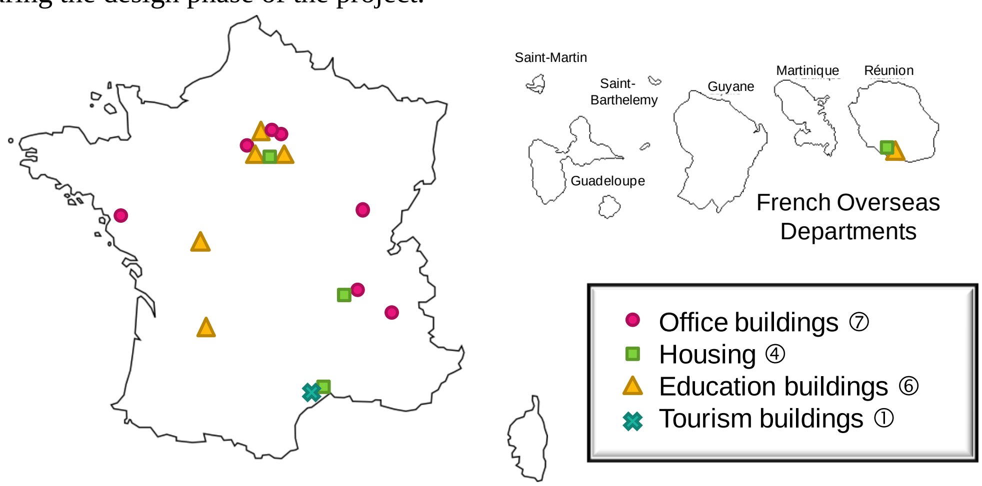

Fig. 1. French Zero Energy Buildings recorded for this study

Table 1. Residential buildings

Project	Location	Completion	Area	Energy use	Energy production
Amplia	Lyon	2011	66 housings 11 456 m²	11,4 $kWh_{fe}/m^2.y$	PV – Heat pump – Solar DHW
Atlantis	Montpellier	2009	21 housings 1 200 m²	18 $kWh_{fe}/m^2.y$	PV : 36 000 kWh/y – Heat pump – Solar DHW
	Brétigny	2012	54 housing 4 000 m²	75 $kWh_{pe}/m^2.y$	

Table 2. Office Buildings

Project	Location	Completion	Area	Energy use	Energy production
Green Office	Meudon (92)	2011	20 000 m²	52 $kWh_{fe}/m^2.y$	PV + cogeneration (oil) : 64 $kWh_{ef}/m^2.y$
Pole Solere	Lyon (69)	2009	4 500 m²	106 $kWh_{ep}/m^2_{SHON}.y$	PV : 140 000 kWh.y
Tour Elithis	Dijon	2009	5 000 m²	30 kWh/m².y	PV : 82 000 kWh/y + Wood boiler
ZAC de Bonne	Grenoble (38)	2009	2 000 m²	25 $kWh_{ef}/m^2_{SHON}.y$	PV + water table heat pump : 30,6 $kWh_{ef}/m^2_{SHON}.y$
Solaris	Clamart (92)	2009	31 000 m²		PV + geothermal heat pump
Albalone	Nantes	2010			6 wind turbines + PV
Mediacon	Saint-Denis	2011	4 000 m²		PV + Heat Pump
Ilet du Centre	Saint-Pierre, Réunion Island	2009	312 m²	50 $kWh_{ef}/m^2.y$	

Table 3. Education buildings

Project	Location	Completion	Area	Energy use	Energy production
Primary school	Limeil-Brévannes	2007	3 137 m²	24,2 $kWh_{fe}/m^2.y$ 63 $kWh_{pe}/m^2.y$	PV : 70 000 kWh/y – Water table heat pump
Primary school	Pantin	2010	3 560 m²	22,9 $kWh_{fe}/m^2.y$	PV : 100 000 kWh/y – Heat pump – Solar DHW
Primary school	Arcueil	2010			
Kyoto high school	Poitiers	2009	19 600 m²	38,7 $kWh_{fe}/m^2.y$ 64 $kWh_{pe}/m^2.y$	Electricity : 25 $kWh_{pe}/m^2.y$ Heating : 30,5 $kWh_{pe}/m^2.y$
EnerPos	St Pierre, Reunion Island	2009	617 m²	50 $kWh_{fe}/m^2.y$	PV : 70 000 kWh/y

Table 4. Tourism building

Project	Location	Completion	Area	Energy use	Energy production
Oenology center	Lunel		3 560 m²		Wood boiler

3. Innovative solution sets

3.1. 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 14m instead of 18m 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.

The buildings are bioclimatic. At “Ilet du Centre”, the apartments are cross naturally ventilated with exterior walkways, deported to preserve privacy. 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.

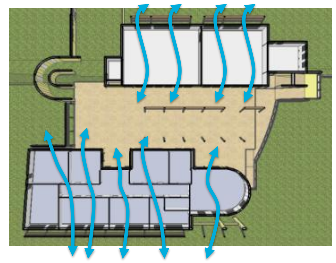

Fig. 2. Green Office and EnerPos building: the width is reduced to use the natural resources (sun, wind...)

3.2. A multi-functional envelop that takes into account summer comfort

The envelope is not only used to insulate the building, but it becomes multi-functional [6]. 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…). 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.

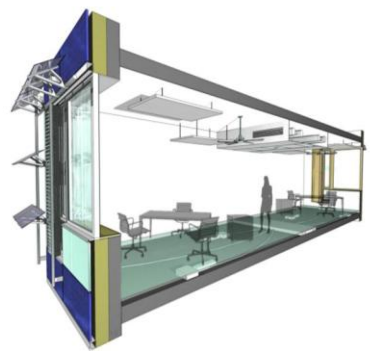

Fig. 3. Left: EnerPos Building - Right: Office unit from the Green-Office project with an innovative concept of window integrating ventilation, solar protection and daylighting. Source : green-office.fr

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) [7, 8] (fig. 3). 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 (fig.3).

Summer comfort also becomes an important point: 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.

3.3. 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-Brévannes 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 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”, fig. 4).

Fig. 4. High-performance ceiling fan

3.4. 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.

3.5. 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).

The electricity is also produced by CHP systems as explained in paragraph 3.3. Geothermal sources allow the production of heat.

4. Comparison between design phase and occupancy

4.1. The Elithis Tower (Dijon)

The Elithis Tower was inaugurated in 2009. After one year of occupancy of the building, it has been possible to establish a first energy report [9, 10]. Figure 5 gives a comparison between the design phase and the reality. The forecast gave a ratio of 65 $kWh_{pe}/m^2.y$ but measurements during the first 12 months of occupancy (8 months of measurements, 4 months extrapolated) show a ratio of 96 $kWh_{pe}/m^2.y$.

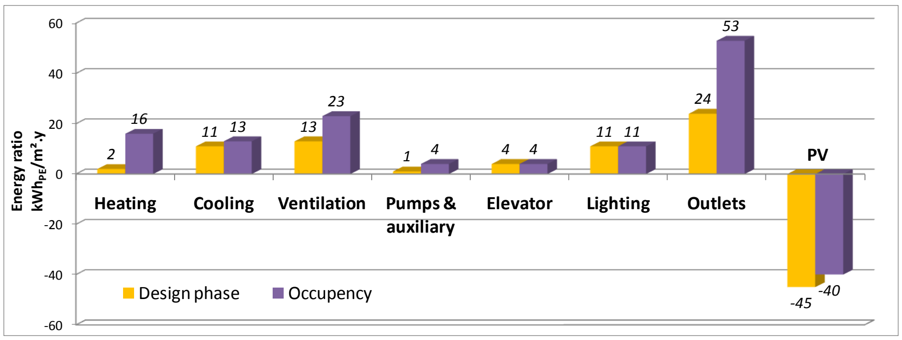

Fig. 5. Consumption and production for the Elithis Tower (design phase / occupency)

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

- the building was 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.

4.2. The EnerPos Building (Saint-Pierre, Reunion Island)

The EnerPos building was inaugurated in October 2008. It is the first NZEB built in the French overseas territories (the second in mainland France). It is one of the few NZEBs listed by the IEA as NZEB in a tropical climate.

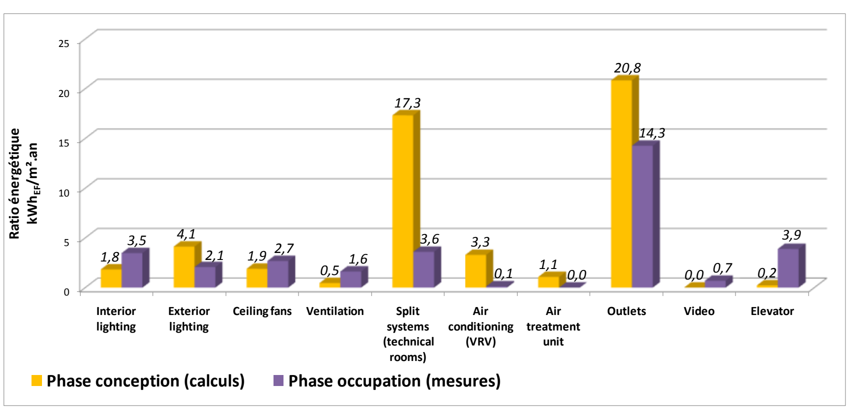

Fig. 6. Comparison of the energy ratios by type of use in $kWh_{fe}/m^2.y$ (design phase / occupancy) for “EnerPos”

Figure 6 gives the first results of the end-uses consumption (the PV energy meter was just installed in May 2010). The first months of data point out very encouraging results. Unlike the Elithis Tower, the consumption has been rather overstated during the studies (51 instead of 32 $kWh_{fe}/m^2.y$ 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. A standby has been set up therefore the ratio of this use should decrease. Another improvement could be to have three different switches for the interior lighting of the classrooms because daylighting measurements showed that the classrooms being opened on both sides can be divided into three parallel areas (Fig. 7). In any case, the overall consumption of this NZEB building is around five time less than the consumption of a standard university building in La Reunion (around 150 $kWh_{fe}/m^2.y$).

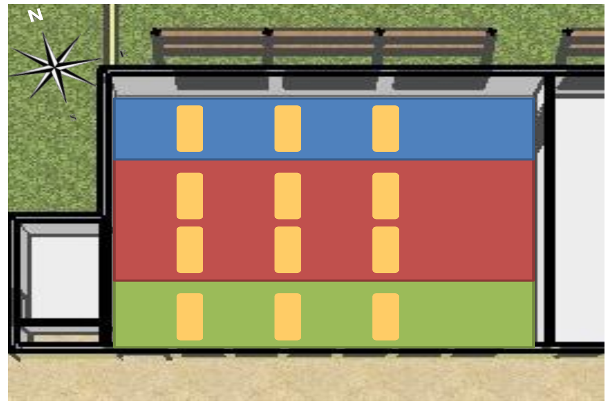

Fig. 7. Daylighting measurements showed that three parallel areas can be defined: the daylighting is very good near the windows overlooking the exterior (blue), slightly weaker in the middle (red) and even weaker on the side of the windows overlooking the other part of the building (green)

5. Conclusion

The state of the art of the French Zero Energy Buildings carried out in the framework of IEA SHC Task 40 / ECBCS Annex 52 has identified the new methods of construction for this type of building. One can notice that the buildings are all bioclimatic with a passive design approach; their width is reduced compared to classical buildings, to improve natural ventilation and daylighting. The envelope is not only dedicated to thermal insulation, but becomes multi-functional to protect from the exterior environment while drawing from the external sources of energy such as the wind, the sun, the soil… A study is conducted on summer comfort that becomes an issue in low consumption buildings that are too insulated and too tight. The systems used are more efficient than conventional systems and combine several types of production to improve efficiency. Building Management Systems allow the regulation of heating, ventilation, lighting to be used only when necessary and when the natural resources are not sufficient to achieve the comfort of the occupants.

A comparison was made between the data of consumption and production between the design phase and the occupancy for two buildings (Elithis Tower and EnerPos Building). This study shows the difficulty to assess the consumption of a building during the design phase. The designers therefore need new design tools to improve the accuracy of the simulations.

A major problem 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.

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 of in the upcoming years.

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