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Towards Net Zero Energy Buildings in Hot Climates : Part 1, New Tools and Methods

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ABSTRACT

The paper presents the results of a French National research project on Net zero energy design that just ended in December 2009. The project named « ENERPOS »has focused on the development of new methods and tools for the design of Net Zero Energy Buildings in hot climates. Three French university research laboratories and two HVAC practices have been involved in the project. The initial objectives of the ENERPOS project were :

- to develop new methods and tools for the design of net zero energy buildings in hot/tropical climates;

- to point out that the factor 3 is easy to meet. The energy index must be below 55 kWhe/m².year (net floor area);

- to gather the world of research and the professional sector for improving the use of new simulation tools;

- to do a transfer of knowledge from research to the professional fields once the proposed method validated.

The methods and tools have been applied to the design of the first zero energy building of the French overseas departments located in La Reunion. The design and the construction of the building has perfectly matched with the realization of the ENERPOS project. The completion was in October 2008, just one year before the end of the ENERPOS project.

The ENERPOS building, named similarly as the project itself, is a very low energy buildings. The main features are listed below : All rooms and spaces are cross naturally ventilated and equipped with high efficient ceiling fans. The tutorial classroom have no air-conditioning at all. solar shadings have been designed and optimized thanks to 3D simulations. The building meets the PERENE requirements (PERENE, acronym of Energy Performance of Buildings) is a local standard for labeling energy efficient buildings. 350 m² of BIPV roofs (50 kWp) produce the renewable energy of the building.

In terms of tools to use, the proposed method is innovative : the use of free softwares commonly used either by the architect or the engineer was the key stone of the process. Then, once the building was modeled or imported from CAD tools, thermal or energy simulations have been conducted. Daylight simulations have also been done to improve the daylight autonomy. The method has been tested and validated by professional partner IMAGEEN involved in the project. IMAGEEN now uses it for all its new buildings projects. This guarantee the reproducibility and efficiency of the method.

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INTRODUCTION

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 etc.). Despite this, the concept is still generic and there is no harmonized understanding about what is really a Net Zero Energy Building. This is why an international work was 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, innovative solutions sets and industry guidelines. This includes new requirements on comfort and energy performances (Sartori 2010b), the management load matching and grid interaction (Voss 2010) and an exhaustive benchmarking about the existing Net ZEBs already built around the world. There are few Net ZEBs built around the world so far. Very little work is available about the design of Net ZEBs in hot/tropical regions as well. This is why a 3 years programme has been launched in France about this specific topic under the name "EnerPos", French acronym for POSitive ENERgy building.

ENERGY CONTEXT IN THE FRENCH OVERSEAS DEPARTMENTS

A standard non-residential building in the french tropical regions is often badly designed with no respect to the basic bio climatic principles. The active systems such as air-conditioning and artificial lighting are often over-sized and therefore are very energy consuming. The average energy index for an office building is 160 kWh/year/m² (net floor area) in terms of annual electricity consumed. The three main sources of energy usage are air-conditioning (50% of the power bill), artificial lighting (11%) and computers (25%) for a standard office building. The efforts for energy savings must focus on these end-uses, all the more than lighting and computers are mainly responsible of the indoor thermal loads in the building to evacuate by air-conditioning. Turning to the energy background of the French overseas departments, the situation is extremely complicated because the energy demand is increasing regularly with an annual growing percentage of 4%. The means of electricity production are restricted, mainly fuel powered and can not spread indefinitely. The electricity is dear and generates important greenhouse gas emissions. The kWh is extremely polluting with 820g of CO_2 per kWh of the electricity produced. The proportion of renewable energy used for electricity production dropped from 100% in 1982 (thanks to hydro power) to 34% in 2009. The energy demand has increased by 2.5 during the same period. The demography remains important in these departments and will be stabilizing in 2010. The electricity shortages occur more and more often because the French public utility EDF can not face the energy demand in summer. More specifically to Reunion Island, the Regional Council encourage the construction of 'green' buildings; indeed, the Regional 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.

Therefore, because of the energy and environment weight of the building sector in the french overseas departments, the set-up of a research program around the low/zero energy building like EnerPos is of prime interest in these tropical regions. The results and the principles issued from this project could be applied to any country that endures a hot climate.

AIMS AND SCOPE OF ENERPOS

How to reach the near/net zero energy target in hot/tropical climates ?

First of all, the question is what is a Net ZEB? As there is still no harmonized definition, here is one that is applied at La Reunion. A Net Zero Energy Building is a very low energy building that balances its low energy consumption by the use of renewable energy on site and on a annual basis. As for the requirements in terms of energy consumption, it is asked that the energy index must be equal at least to 50% of the energy consumption of a building compliant to the local thermal regulation.

Second, the main characteristics of buildings in hot climates are listed below:

- the main source of energy is electricity only;

- in terms of energy consumption and for non-residential buildings, the most important (by order of importance) end-uses are air-conditioning (50%), computers/plug loads (25%) and artificial lighting (11%). That implies that efforts must focus on the modeling of thermal and visual comfort in terms of simulation tools;
- in terms of passive design, there are two main principles in tropical climates : a good solar protection and an efficient cross natural ventilation to ensure a good level of comfort.

Then, according to these principles, the design of a low energy building relies on several basic steps which are :

- A good knowledge of the local climate (for tropical climates, direction of thermal breezes, orientation of the sun, TMY files available);
- A good design of the surroundings (vegetation around the building to avoid overheating) -eg car parks not allowed in front of the main facades of the building, a 4m band of vegetation around the building must be planned;
- Priority must be given to the passive design (roof insulation, solar shadings for windows, cross natural ventilation, use of daylighing);
- Innovative or alternative solutions sets must be proposed;
- Energy efficiency of systems are mandatory (high SEER for chillers if necessary, Energy Efficient light bulbs etc.).

Then, once these steps have been taken into account, the use of renewable energy can be considered as part of the building design process. This process is necessary to avoid getting a so-called Net ZEB with very bad energy index but with an important surface of PV panels to balance solely its high energy index.

The main idea of all this is that the building itself must operate as long as possible with passive techniques -ie without any energy consumption. And this is a huge step to climb because this implies a dramatic change into the design methods that are used by the design practices which mainly focus on the sizing of active systems (air-conditioning, artificial lighting) rather than focusing on how and how long can the building operate on the passive mode.

Issues in the design process of Net ZEB in tropical climates

So far the design process in France is not well adapted to the design of Net ZEB and does not allow the easy achievement of energy efficient buildings. A reorganization from the brief to the construction of the building itself is therefore necessary. Several issues must be sorted out to improve the design process of Net ZEB and are briefly listed below :

1. The lack of discussion between the people involved in the design process –ie the architect and the engineers is an obvious weakness for optimizing the passive design of the envelope and the systems. In some cases, the design teams selected by public owners –the Regional Council, the University and the City Councils have most of the time an overall good level of knowledge but unfortunately the brief of the building is not accurate enough in terms of objectives and energy performance requirements to meet.
2. Most of the time, the CAD tools used by the Architect can't communicate with the simulation tools used by the energy consultants. The building needs to be re-modeled either because the programs used does not read the dxf/dwg file format or the building file is too detailed. This is unfortunately a very time-consuming process.
3. These tools are often used by the Architects under their maximum potential. They mainly focused on the presentation of their projects rather than use it to optimize the solar shadings devices for example.
4. The working habits of the HVAC design practices and their knowledge in terms of top design tools have to be upgraded. As said before, there is a gap between the Net Zero Energy goal and the tools used by the common engineers. The working habits focus more on the sizing of the systems (air-conditioning, artificial lighting) and not on the passive optimization of the building. This radical change into the building design process implies that new simulation tools must be used -eg the simulation programs must be capable of modeling the airflow transfers to take into account the effect of cross natural ventilation or the useful daylight index for daylight performances. As for lighting, only programs mostly developed by manufacturers are used to determine the number of luminairs required to reach the minimum luminance level. The requirements in terms of luminance are not adapted to tropical climates for certain buildings and lead to an over-sizing of the

lighting devices. Moreover, the level of daylight factor required are suitable for European country only and lead to wrong results under tropical climate where the diffuse radiation remains fierce even during cloudy conditions. The concept of sky classification must be adapted to these climates.

5. Lots of countries experiencing a tropical climate are developing countries. That means that the basic HVAC practice can't afford expensives CAD or simulation tools. This implies that open source and efficient simulation tools must be suggested.

So the question is "How to bridge the gap ?" Which design tools are suitable with which methodology ? That is one of the reason why the EnerPos project has been launched.

The EnerPos programme

EnerPos is one of the 11 research projects that have been selected by the French National Research Agency_ANR after the 2006 PREBAT call for proposals. PREBAT is the ANR Branch dedicated for all that concern Building Research in France. The aim of PREBAT is to reach the Factor 4 by 2025 for the building sector. Enerpos concerns the design of zero energy building in the French overseas departments –ie DOM under hot and humid climates with a particular emphasizes on the transfer of knowledge from research to the professional practices. Enerpos is a 3 year running project that started in early 2007 and ended in December 2009. The team was composed with three French university research laboratories and two HVAC practices.

The initial objectives of the ENERPOS project were :

– to develop new methods and tools for the design of net zero energy buildings in hot/tropical climates;
– to point out that the factor 3 is easy to meet. The energy index must be below 50 kWhe/m².year (kilowatthour of electricity per m² of net floor area, all end-uses included);
– to gather the world of research and the professional sector for improving the use of new simulation tools;
– to do a transfer of knowledge from research to the professional fields once the proposed method validated.

To meet the above objectives, complementary skills coming from either professional engineers or academic researchers have been pooled together, so that everybody can share everyone's experience. This is why private and public partners are involved in EnerPos. The EnerPos team has gathered two design practices; IMAGEEN and TRIBU. They are all specialized in Energy Management and Green Building design respectively. Three academic research centers are part of ENERPOS as well : LPBS, LOCIE and PHASE, specialized in the passive design of buildings in hot climate, day-lighting and thermal comfort respectively.

METHODOLOGY

The EnerPos methodology of work has focused on the whole process of the building design, from the brief until the completion of the building. The work has been organized into different tasks ranging from Task A to Task H, each partner being involved in one or several tasks function of their field of expertise. The different tasks are listed below :

- Task 0 - "Improvement the brief phase of the project" ;
- Task A : "Sketch design ; Optimization of the solar shading and the level of accuracy of the 3D file";
- Task B : "Reduction of the period of air-conditioning";
- Task C : "Reduction of the period of artificial lighting";
- Task D : "Assessment of thermal comfort conditions under tropical climates";
- Task E : "Indoor design and ergonomics in working spaces";
- Task F: "Reduction of the consumption due to workstation";
- Task G : "Modeling of the hourly power profile of the building";
- Task H : "Modeling and reliability of PV simulation programs".

As there is not enough space in this paper to describe precisely each task, more detailed informations are given in (Garde 2007) and (Garde 2009).

MAIN RESULTS AND DISCUSSION

As said before, the entire results of the EnerPos project are available in French and downloadable at (Garde 2009). The reflexion has lead to a guideline relying into three important steps that must follow the building design process :

Requirements during the brief stage

The brief step is essential because it defines the expectations of the building owner in terms of energy index, energy efficient systems, performances of the building envelope. It provides the objectives to reach and must be as accurate as possible. If the brief is not clear enough, the design team can produce a project that does not fill in all the "green" specifications. IMAGEEN and TRIBU were in charge of defining a typical brief where the energy requirements and the mandatory passive design principles are as accurate as possible. This typical brief will allow any building owner to have a reference document. For example, as one of the basic principles in building design under tropical climate is cross ventilation, this point is specified in the brief as mandatory in all spaces.

Below are some examples of mandatory requirements for Net ZEB listed in the brief document :

- Cross natural ventilation mandatory;
- Level of solar shadings compliant to the local labeling rating system -ie PERENE Standard for La Reunion (Garde 2010);
- Minimum level of performance for energy efficiency of systems -ie SEER > 3 for chillers, power density < 7W/m² for artificial lighting;
- Energy index < 80 kWh/m².year for all end-uses ;
- Energy Monitoring by end-uses mandatory;
- Band of 4 m of vegetation around the building.

Proposal of a new architecture and new tools for the design of Net ZEB

Once the previous step has been done and the mandatory requirements have been checked, then the use of simulation tools can be useful and can justify the level of performances required. Function of the objectives given in the previous section the reflexion has lead to a methodology in terms of simulation tools that is represented by Figure 1.

In terms of tools to use, the proposed method is innovative : the use of free softwares commonly used either by the architect or the engineer is the key stone of the process. After having tested several softwares, it appears that the recent development of the Energy Plus simulation program around the Google Sketchup Environment is a real innovation for several reasons :

- Google Sketchup is widely used by most of the Schools of Architecture worldwide. This 3D CAD program has a very friendly interface and is easy to learn. The program reads all dxf and dwg files and a free version is available on the internet. In that sense, Sketchup appears to be the solution of the issue mentioned early in this paper about the lack of communication between the tools used by the Architect and the Engineers;
- The US Department of Energy has recently released a free Sketchup plugin version of the Energy Plus simulation program. Energy Plus is the most used simulation program all around the world and is a free software ;
- The Daysim software is also a free sotfware that gives interesting outputs such as the daylight autonomy.

New outputs

Two types of outputs are used in the design process. They concern the assessment of thermal comfort and the daylight performance. In terms of comfort criteria, the EnerPos project has suggested the use of resultant temperature and the Givoni comfort zones as a well adapted tool for the assessment of thermal comfort in the tropical regions (Givoni 1998).

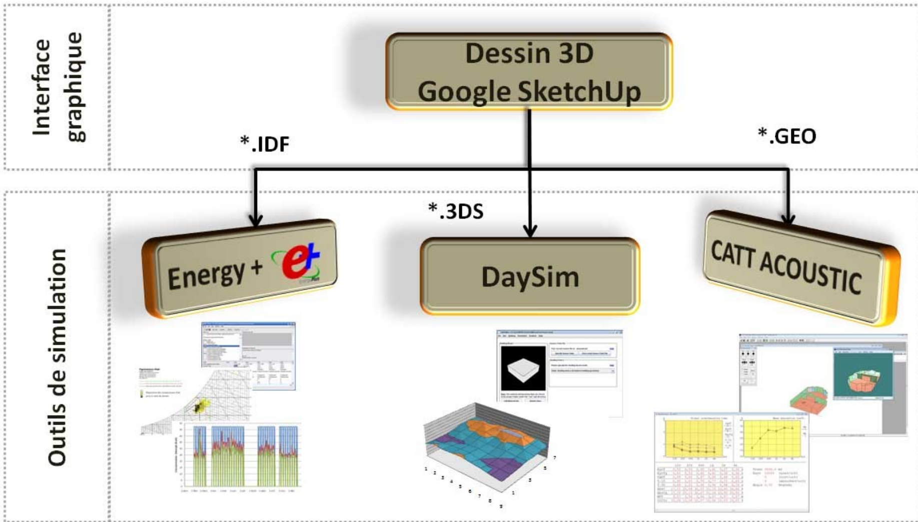

Figure 1 *Proposed organization of the simulation process. Google Sketchup is the front-end that links the CAD tools of the Architect with the simulation tools used by energy consultants for the assessment of the thermal comfort (Energy Plus), visual comfort (Daysim) and acoustic comfort (Catt Acoustic).*

The resultant temperature gives a good indication about the strategy to use in terms of air treatment (see Figure 4). The design criteria was to get less than 100 hours of discomfort, -ie less than indoor humidity/air temperature pairs outside the comfort zone for a velocity of 1 m/s. The feedback from the design teams was very good because the Givoni zones is a very easy to use and pedagogical tool.

The output for daylighting is the Useful Daylight Index or Daylight autonomy, which represents the percentage of time where artificial lighting is not required on a basis of a minimum level of 250 lux above the working space.

Application of the method to a case study : The EnerPos building

The proposed methods and tools developed within the framework of the EnerPos project have been applied to the design of the first zero energy building of the French overseas departments located in La Reunion. The design and the construction of the building has perfectly matched with the realization of the ENERPOS project. The completion was in October 2008, just one year before the end of the project. The ENERPOS building (see Figure 2), named similarly as the project itself, is a very low energy building. The main features are listed below : All rooms and spaces are cross naturally ventilated and equipped with high efficient ceiling fans. The tutorial classrooms have no air-conditioning at all. Solar shadings have been designed and optimized thanks to 3D simulations. The building meets the PERENE requirements (PERENE, acronym of Energy Performance of Buildings) is a local standard for labeling energy efficient buildings (Garde 2010). 350 m² of building integrated photovoltaics (BIPV) roofs (49 kWp) produce the renewable energy of the building.

In terms of design process of the envelope, the local solar diagram has been used to pre-size the solar shadings. Sketchup was then used to optimize the solar shadings . Figure 3 illustrates the accuracy of the rendering of Sketchup.

The change in the resultant temperature shown by Figure 4 (left picture) comes from simulations run using the Energy Plus plugin. Figure 4 gives a good example of the use of design tools and the passive approach that is mentioned in the beginning of the paper. The building operates in the passive mode only. It is thus possible to assess 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 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.

Figure 2 *Ground floor (left), first floor (middle) and Northern Facade (right) of the EnerPos building. All rooms are cross-ventilated. All windows are protected by efficient wooden strips and the BIPV roof.*

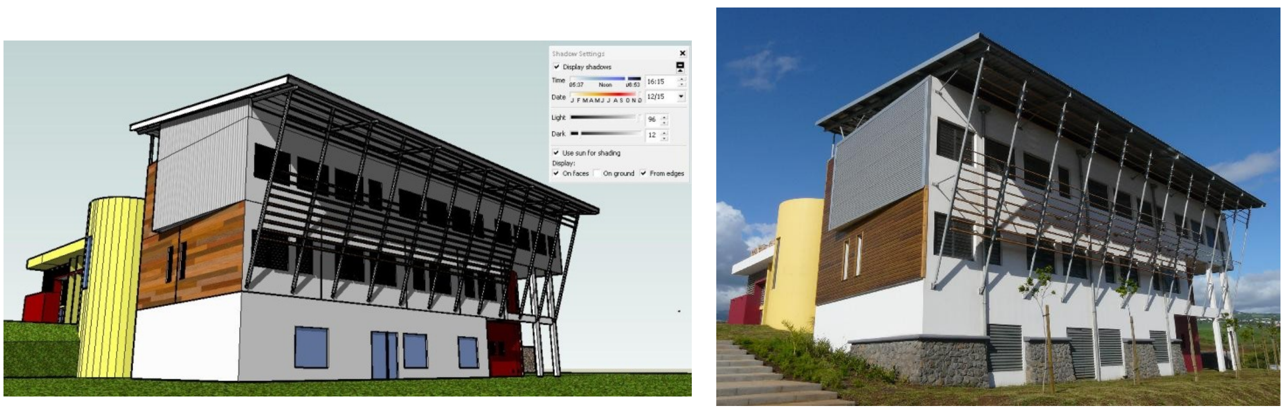

Figure 3 *Use of Sketchup to optimize the solar shadings of the South-West facade. The picture (right) has been taken in mid-December 2008 at 4:30pm. The modeling rendering (left) reproduces the shadows at the same day and at the same time. The shadows due to the solar shading systems match perfectly.*

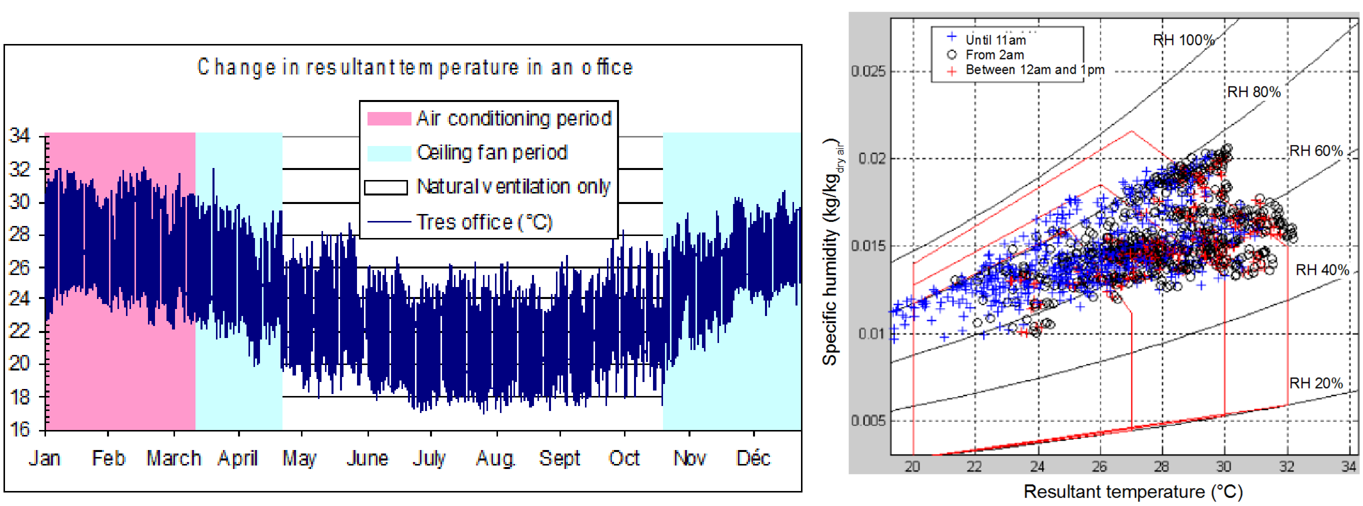

Figure 4 *Change in resultant temperature in a typical office (left). The air conditioning period is limited to 9 weeks. Assessment of thermal comfort in the same office by using the Givoni zones (right). The number of hours of discomfort is around 160.*

The transition from air fans to air conditioning was made when the resultant temperature exceeded 30°C. The picture on the left gives a good illustration of the assessment of thermal comfort by using the Givoni zones. In the example, the number of hours of discomfort is limited to 160 hours.

Overall, the first simulation results conducted by using the proposed methodology has lead to a energy index below 50 kWh/m².year and a PV supply of 78 kWh/m².year for the EnerPos building. As an accurate energy monitoring system has been set up, a real scale feedback has been made as well as a Post Occupancy Evaluation (Lenoir 2011). In fact, it appears that the building is much more comfortable than what was first indicated by the simulations. The actual energy index after one year of operation is around 31 kWh.m².year instead of 50 kWh/m².year.

CONCLUSION

The current scientific knowledge of the design of low/zero energy buildings in hot and tropical climates has been improved thanks to the Enerpos Project. In terms of design tools to use, an innovative method has been proposed based on a passive design approach : the use of free softwares commonly used by the architect and the engineer is the key stone of the process. The proposed method has been applied to the first Net Zero Energy Building in the French overseas territories. The most significant results is that the factor 3 is easy to meet. The energy index of the building is less than 50 kWhe/m².year (net floor area). The transfer of knowledge from research to the professional fields is effective as the method has of course been used for the Enerpos building but has been tested, applied and validated by professional partner IMAGEEN involved in the project. IMAGEEN now uses it for all its new buildings projects. This guarantees the reproducibility and efficiency of the method.

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