ENERPOS: A FRENCH RESEARCH PROGRAM FOR DEVELOPING NEW METHODS FOR THE DESIGN OF ZERO ENERGY BUILDINGS IN HOT CLIMATES


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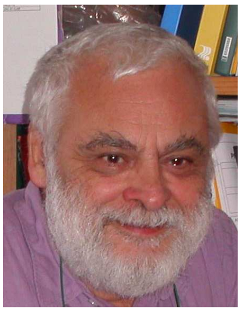
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Summary

The paper deals with a French national project named ENERPOS which involves three research laboratories and two design practices. The project concerns the development of new methods for the design of zero net energy buildings in French tropical overseas departments under hot summer conditions. This new approach will rely on the use of new dynamic simulation tools and the study of the connections between all the building design team – ie the architect, the HVAC design office etc. Research tools and design tools will be pooled altogether in order to improve their accuracy and then to make a transfer of knowledge from research to the professional fields. This two-year funded project has been selected within the framework of the PREBAT-ANR program which is dedicated to building research and funded by the French National Research Agency ANR. The paper will present the adopted methodology and the objectives to meet. Some preliminary results will be eventually presented as ENERPOS has just started in April 2007.

Keywords: Tropical and hot climate, zero energy building, photovoltaic, natural ventilation, thermal comfort

1 Introduction

ENERPOS is one of the 11 research projects that have been selected by the French National Research Agency after the 2006 PREBAT call for proposals. PREBAT is the ANR Branch dedicated for all that concern Building Research [1]. 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. There are four French overseas Departments (DOM): two islands are located in the Caribbean (Martinique and Guadeloupe), one situated 400 km to the East of Madagascar in the Indian Ocean (Reunion Island) and the fourth Department is in the North of Brazil (French Guiana). Each experiences a hot climate, tropical and humid in the islands of Guadeloupe, Martinique and Reunion and equatorial in French Guiana.

One of the aims of ENERPOS is to show that with a better approach of the building design in hot climates in terms of passive design principles and use of adapted simulation programs, the objective of the factor 3 can be easily reached. The factor 3 means that the annual consumption of the building can be divided by three. A standard building in the French tropical regions is often badly designed with no respect to the basic bioclimatic principles. The active systems such as air-conditioning and artificial lighting are often over-sized and they have bad energy efficiency. The average energy index for an office building is 160 kWh/year/m² in terms of annual electric energy spent. A recent survey has pointed out that the three main sources of energy waste are air-conditioning (50 % of the power bill), artificial lighting (20 %) and computers (20 %) for a standard office building. [2]. The efforts for energy savings must focus on these sources, 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 7%. The means of electricity production are restricted and can not spread indefinitely. The electricity is dear and generates important greenhouse gas emissions. The kWh is extremely polluting with 680 g of CO_2 per electric kWh. The proportion of renewable energy used for electricity production dropped from 100 % in 1982 (thanks to hydro power) to 36 % in 2006. 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 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 [3].

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

2 Main features of the design process

First of all, the ENERPOS project has been set-up to gather the world of research and the world of design and professional practices in terms of methods and simulation tools. The actual statement is that the goal of low/zero energy building must rely on a new engineering process in the building design and on the use of adapted dynamic simulation tools.

2.1 Reorganization of the design process

So far the design process in France is not well adapted to the design of the zero energy buildings and do 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 reasons can explain this statement. First, no thermal standards are mandatory in Reunion Island as most of the French overseas territories. This leads to the construction of energy consuming buildings. However, a guideline named PERENE has been set-up but the prescriptions are not mandatory [4]. They concern the thermal conception of buildings as well as the energy performance of buildings and are specific to each climatic zone that has been defined in PERENE. Despite that, the PERENE rules give only a minimum level of performance and can not be considered as the optimum design. Second, the lack of knowledge in the HVAC design practices about the last design tools and 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.

2.2 Towards an improvement of the design and modeling tools

The simulation tools used by the design practices, the design methods, the follow-up of the design process must be improved as well. The 3D CAD tools are often used by 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. Dynamic simulation tools are still not widely used, especially for the estimation of natural lighting and even for the determination of the annual cooling loads. As for lighting, only programs mostly developed by manufacturers are used to determine the number of luminaries 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 oversizing 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. Next concerns the assessment of annual energy consumption and maximum power which are often determined by simple index without taking into account the real behavior of the building – ie occupancy ratio and operating time of systems. The lack of a real scientific approach based on statistics and realistic assumptions based on real scale feed back experience mislead the actual performances of the building and leads to oversizing the HVAC and lighting systems, at least by a factor of 1.5. Thus, the design of passive cooling concepts should consider the user behavior realistically according to a statistical data analysis [5].

Another point concerns the diversity of tools and simulation programs currently used by the design teams ranging from 2D or 3D-CAD modeling to daylighting or thermal programs. Most of the time, the engineers need to remodel the building either because the programs they use does not read the dxf file format or the building file is too detailed and to time-consuming in terms of calculation time.

2.3 The need to reconsider the thermal comfort requirements for hot climates

Optimizing the energy needs must take into account another constraint which is optimizing the indoor comfort conditions to meet the ideal thermal comfort conditions of the occupants. Most of the requirements related to this field have been conducted only in temperate climate under closed and steady conditions. Even so, the optimum comfort conditions under hot climate must be reassessed because of the variability of these particular conditions where the indoor air velocity and the relative humidity are of prime importance.

For hot climates, the indoor conditions of passive buildings can vary very rapidly. In these particular conditions, one must consider the development of appropriate models to assess the thermal comfort conditions. The current trends are to reconsider the set temperature as in the only mean to meet an acceptable level of thermal comfort and to use the adaptive approach. The adaptive approach considers that the occupant can modify himself the comfort conditions by using the systems at his disposal in an appropriate way while minimizing the energy needs. Thus, the comfort conditions in a naturally ventilated building don’t vary in the same way an air-conditioned building does (see **Fig. 1**). The SCAT project – ie Smar Controls and Thermal Comfort funded by the European Union has pointed out that the set temperature depends on the outdoor temperature [6]. Last, the international standards on thermal comfort are currently being modified by the proposals only focus on the Northern hemisphere in temperate climates [7]. The results of a study conducted in tropical/hot regions could be integrated as part of the new requirements.

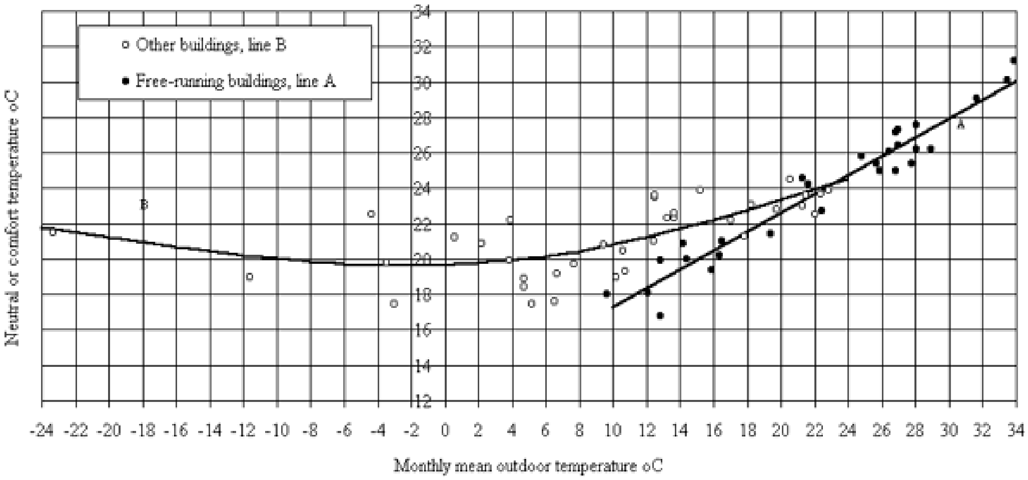

Fig. 1 Change in the comfort temperature as a function of the outdoor temperature for mechanically cooled buildings and naturally ventilated buildings (dark dots) [8]

In summary, the current scientific knowledge of low/zero energy buildings in hot and tropical climates is poor. For that reason, the ENERPOS project aims to optimize the working methods between the design persons, to encourage the use of common tools and to enhance a better modeling of the project in which people are involved in. A systematic use of dynamic programs for thermal and daylighting purposes is required as well in order to optimize the operating time where passive solutions are only needed.

3 Methodology

The objectives of ENERPOS are to demonstrate that the factor 3 is possible to meet in terms of electricity consumption. Whereas a standard office building has an energy index of 160 kWh/year/m², the target is 55 kWh/year/m². To do that, 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 gathers three design practices; IMAGEEN, TRIBU and Atelier Faessel-Bohe They are all specialized in Energy Management and Green Building design and architecture 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, daylighting and thermal comfort respectively (see **Tab. 1**).

Lastly, the methodology focuses on the whole process of the building design, from the brief until the completion of the building.

Tab. 1 Field of expertise of the partners involved in the ENERPOS Project

Company	Name of contact	Field of expertise
LPBS	François Garde	Thermal and airflow transfer. Passive design of buildings in tropical climate. CFD modeling.
	Alain Bastide	
LOCIE	Etienne Wurtz	Zero energy buildings
	Gilbert Achard	Natural lighting
PHASE	François Thellier	Thermal comfort
IMAGEEN	Eric Ottenwelter	HVAC design
TRIBU	Alain Bornarel	Green building design
Atelier Faessel-Bohe	Thierry Faessel-Bohe	Architecture

3.1 The brief phase

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 not fill in all the „green“ specifications. Moreover, the French civil building act imposes for a public owner to consult at least three different design teams. Then, the best project is chosen by a jury composed with technical experts, politicians and future users. Designing a zero energy building means new rules and guidelines to give, new documents to produce, new layouts to render. This will facilitate the comparison of different projects and the selection of the best one. IMAGEEN and TRIBU are 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, one of the basic principles in building design under tropical climate is cross ventilation. If cross ventilation is not specified in the brief as mandatory in all spaces, it may have a risk that some of them are not well designed.

3.2 The design steps

The design stage is the logical following of the brief phase. It comprises several steps from the sketch of the project to the detailed project. This progression towards a better definition of the project (environment, building envelope, technological systems) is represented, in real world practice, by the evolution of design tools and their use at each step of the project by the different actors involved in. In other words, we could say that each stage of the project corresponds to a particular category of design tools that does not communicate necessarily between them [9]. Asking for zero energy building implies asking for using new tools and new methods of modeling and file sharing. In order to improve the waste of time and the interaction between the architect, the engineers and the tools they use, different tasks ranging from Task A to Task H have been defined within the ENERPOS framework. The methodology will be applied on a zero energy project in order to test it and to have a feed back about it… The project is a 1300 m² university building located in Saint-Pierre, Reunion Island.

Task A: Sketch design; optimization of the solar shading and the level of accuracy of the 3D file
This task consists in creating a 3D-CAD version of the project in order to optimize the solar shadings made with wooden strips in this case (see **Fig. 2**). Hourly simulations will be conducted for specific typical summer days to verify the effectiveness of the blinds and optimize their number. Another aim is to define with the architect and the engineers the level of accuracy of the file in order to reduce the calculation time and to facilitate its reading by other simulation programs that will be used for thermal or lighting purposes.

Fig. 2 View of the northerly facades (solar protection with wooden strips) of the studied project

Task B: Reduction of the period of air-conditioning
The period of air-conditioning in a standard building can last at least ten months. Air conditioning represents 50 % of the power bill. Then aim of Task B is to reduce this period to three months either by using natural cross ventilation or alternative low energy consuming systems such as ceiling fans. Simulations with a thermal and airflow simulation program will be carried out. The determination of the indoor air velocities will be completed with CFD modelling. The coupling between the two programs will allow determining the different periods of active or passive cooling for different typical rooms (office, classroom or computing room).

Task C: Reduction of the period of artificial lighting

The modeling of natural lighting will be reviewed and adapted to the context of hot and tropical climates where diffuse radiation is higher than in European countries. With a good natural lighting design, it is possible to meet at least 90 % of daylight autonomy. Daylight autonomy is a new dynamic daylight performance metric based on annual time series of indoor illuminance that can predict the percentage of time where artificial lighting can be avoided [10]. In terms of zero/low energy goal, this parameter is really interesting, more than the daylight factor because it does not need a typical cloudy sky. The groupe responsible of this task will have to use a program capable of predicting this output. The values of illuminance given by the Agence Française de l'Electicité –AFE will be discussed as well. Eventualy, new objectives in terms of system sizing, power density will be discussed, modeled and validated.

Task D: Assessment of thermal comfort conditions under tropical climates

It seems interesting that determining the needs for air-conditioning may rely on the human thermal perception rather than on physical values only – ie temperature, humidity, air velocity. Indeed, the evaporation of perspiration is of prime importance for adjusting the thermal balance of the human body under hot climates. Sweating strongly depends on human physiology and indoor conditions. Moreover, some recent studies have shown that the adaptive approach has allowed some significant cut-of in cooling energy demand in naturally ventilated buildings [11]. This approach will be considered in ENERPOS. Other studies have point out that there is important discrepancies between the results given either by the current thermal standards (ASHRAE 55 [12] or ISO 7730) or indoor controlled conditions and the results given by real scale on-site surveys [13], [14].

For that reasons, the work conducted on this task will focus on:

- Bibliography on fields studies and on adaptive comfort for the last five years in hot regions
- Development of an accurate assessment tool that models the thermal comfort conditions while taking into account the adaptive approach and the specificity of hot climates. This tool will be easily integrated into any hourly simulation program as well.
- Development of „rules of thumbs“ or simplified tools for the design practices. The final aim of this task is to give to the design practice a reliable easy-to-use tool for the assessment of thermal comfort under tropical regions.

Task E: Indoor design and ergonomics in working spaces

The new requirements in terms of lighting density or reduction of the period of air-conditioning imply that some changes in the indoor design must certainly be made. These changes in indoor design will affect the working spaces. For example, a ceiling fan in an office implies that ceiling lighting must be avoided because of the troboscopic effect of the rotating blades. An architect will work in this task with IMAGEEN to propose a new organization of the working spaces to take into account all these new aspects. A specific layout will be proposed as well for each typical working space – ie office, classroom, computing room.

Task F: Reduction of the consumption due to workstations

The energy consumption due to computers represent at least 25 % of the power bill in a standard office building. For a zero/low energy building, this percentage will increase between 33% to 45%. Some recent surveys conducted in an educational building have shown that 50 % of energy savings are easy to get just by a better management of the standby mode. Another point to consider is the heat-release at due to the computers (about 150 W per unit) which is a cause of discomfort and impose air-conditioning almost all-year round. A partship has been set-up with IBM France to conduct this task to think about a new organization of a typical computing room and an energy efficient computing network, including the inverter efficiency.

Task G: Modeling of the hourly power profile of the building

A hourly model of the building power profile will be proposed and compared with the standard method of sizing used by the professionals design offices… The power profile allows sizing the entire electric network and the building power station. The new power profile will take into account the actual use of the building in terms of occupancy, natural lighting and air-conditioning. New proposals for the methods sizing of the electric network will be discussed in this task.

Task H: Renewable energy

A zero energy building means that it can produce as much energy as it consumes. In hot French regions, solar heating and photovoltaic are the two most reliable technologies adapted to the building sector. In Reunion Island, the number of PV roofs has increased significantly in the last three years, with about 3 MW installed only for 2006. Nevertheless, there is no actual feed back about the accuracy of the simulation tool that is used by the sizing of PV system. A recent study has point out a discrepancy of more than 10 % between the model and measurement results. The first conclusions pointed at a problem of inverter sizing and PV performance under tropical climates which are different from the European conditions.

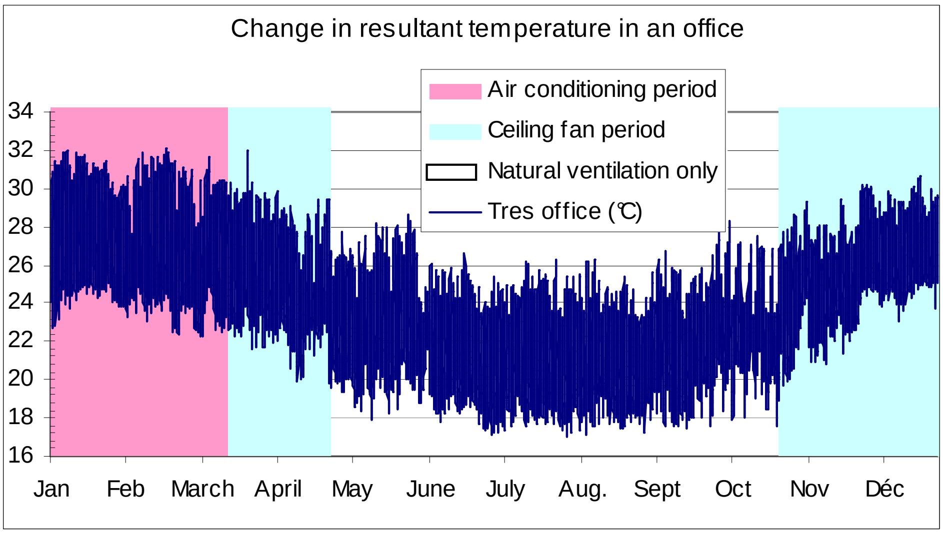

Fig. 3 Change in resultant temperature in a well-designed office during a typical year to determine the different operational periods of natural ventilation, air fans or air conditioning [15]

Therefore, the objectives of this task are to:

- list the existing PV simulation programs and check which one is well adapted to got climates;
- check which one can be easily integrated into a building simulation program;

- propose an energy index to score a zero energy project for hot climates. This index will take into account the annual building consumption (in kWh/year/m²) and the renewable energy production as well as all embodied energy considerations.

4 Preliminary results

To demonstrate that air-conditioning can be avoided significantly, a first set of dynamic simulations have been carried out to predict the different operational periods of natural ventilation, air fans or air conditioning. A thermal and air flow simulation program was used with a model of large openings for taking into account the effect of natural ventilation. **Fig. 2** shows that an office only requires active cooling from January, and that air fans are sufficient until the end of the calendar year. This is a first stage as the indoor air velocity has been determined by using a simple correlation between the opposite openings area and the wind speed. CFD simulation will allow having a better prediction of the indoor air velocity. This work will be part of Task B.

5 Conclusion

The ENERPOS project is a real opportunity to improve the design process of zero energy buildings in terms of simulation tools and in terms of methodology from the brief until the completion of the construction work. The project will last two years and starts by April 2007. The involvement of professional design offices will allow to produce results that can be immediately used by the professional fields. At the end of the project, two others tasks that are not mentioned in the paper are planned. They concern the set-up of a global monitoring of the zero energy projects to assess the real performances of the building in terms of energy performance and comfort level. This will allow having an experimental feed back to validate the ENERPOS methodology and the predictions of the simulation tools.

References

[1] PREBAT. www.prebat.net
[2] PERENE Performance énergétique des Bâtiments : http://lpbs.univ-reunion.fr/grandsprojets/PERENE.htm
[3] LOPEZ, J. OTTENWELTER, E. 2000. ICE, INSET. PRERURE report, www.arer.org.
[4] GARDE, F., DAVID, M., ADELARD, L. *Elaboration of thermal standards for French tropical islands. Presentation of the PERENE Project.* In Proceedings of Clima2005, 2005, Lausanne, Switzerland.
[5] PFAFFEROT, J. HERKEL S. Statistical simulation of user behavior in low-energy office buildings. Solar Energy doi:10.1016/j.solener.2006.08.011.
[6] NICOL, F., McCARTNEY K. *SCATS – Smart Controls and Thermal Comfort Project*. Oxford Brookes University, UK.
[7] DE DEAR R., BRAGER G. *Thermal comfort in naturally ventilated buildings: revision to ASHRAE Standard 55*. Energy and Buildings 34 (2002) 549-561.
[8] HUMPHEYS, M. Outdoor temperature and comfort indoors. Building research and practice, Journal CIB, 6(2) (1978) 92-105.
[9] GARDE-BENTALEB, F. et al. *Bringing scientific knowledge from research to the professional fields: the case of the thermal and airflow design of buildings under tropical climates.* Energy and Buildings 34 (5) (2002) 511-521.
[10] REINHART, C., FITZ A. *Findings from a survey on the current use of daylight simulation in building design*. Energy and Buildings 38 (2006) 824-835.

[11] NICOL F. Et al. *Climatic variations in comfortable temperatures: the Pakistan projects*. Energy and Buildings, 30 (1999) 261-279.
[12] ASHRAE, 1992. ASHRAE Standard 55: Thermal Environmental Conditions for Human Occupancy. Ed. ASHRAE
[13] KWOK, A.G., CHUN, C. 2003. Thermal comfort in Japanese schools. Solar Energy 74 pp 245-252.
[14] WONG, N.H, KHOO S.S. 2003. Thermal comfort in classrooms in the tropics. Energy and Buildings. 35, pp 337-351.
[15] GARDE, F. et al. *The construction of a zero net energy building in Reunion Island. Presentation of a new approach to the design studies*. 2006 ASME International Mechanical Engineering Congress and Exposition, November, 2006, Chicago, Il.

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