TOWARDS THE AERAULIC CHARACTERIZATION OF ROOF WINDOWS ?

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ABSTRACT

Low energy buildings, being highly insulated, are subject to important overheating risks. Thermal simulation as well as experimental studies have shown the large potential of ventilative cooling. One barrier against this approach is the difficulty of evaluating air flows. Appropriate calculation methods and characterization of openings are needed, so that these systems can be dealt with in design, regulation and certification tools.

The present study is based upon the monitoring of a 135 m2 zero energy house situated near Paris. Temperature profiles have been measured when varying the ventilation pattern, i.e. opening or closing vertical windows, roof windows and internal doors. A dynamic thermal simulation tool is used to evaluate temperature profiles in the house under the climatic conditions corresponding to on site measurements (external temperature and solar radiation). The model accounts for the conductive, radiative and convective heat transfer, as well as energy storage in the building envelope related to solar and internal gains. In this highly insulated new construction, the most uncertain parameter is the natural ventilation flow rate. This parameter, and the related aeraulic characteristics of the openings, can be calibrated by minimizing the discrepancy between calculated and measured temperature profiles. Given the small window height, and the large height between ground floor and roof windows, a one way flow model is considered.

The roof window characteristics will also be evaluated in a laboratory benchmark. A cell (3m x 3m x 2m) is divided into two compartments by a slanting wall including the window. A ventilator blows air into one space and the pressure difference is measured between both sides of the window. Varying the air flow rate allows a relationship between the flow rate and the pressure difference to be identified. This relationship may depend on the pressure difference between both sides of the openings, therefore calibration using on site measurement is helpful. The air exchange rate estimated by this method will be compared to measurements using tracer gas, performed in the house as well as in the laboratory benchmark. The possibility to use anemometers will also be tested.

The method proposed here, combining a benchmark in a laboratory with numerical simulation and on site monitoring may bring a supplementary input, complementing the existing knowledge in the field of passive cooling of buildings. The feasibility of using this method in order to prepare appropriate input data for numerical models implemented in regulation, design and certification tools will be studied.

KEYWORDS

Ventilative cooling, energy performance, roof windows, characterization

INTRODUCTION

Low energy buildings, being highly insulated, are subject to important overheating risks. Thermal simulation as well as experimental studies have shown the large potential of ventilative cooling [1]. One barrier against this approach is the difficulty of evaluating air flows. Appropriate calculation methods and characterization of openings are needed, so that these systems can be dealt with in design, regulation and certification tools.

The present study is based upon the monitoring of a zero energy house situated near Paris. Temperature profiles have been measured when varying the ventilation pattern, i.e. opening or closing vertical windows, roof windows and internal doors. Measurements will be compared with dynamic thermoaeraulic simulation results in order to identify an air change rate and calibrate aeraulic characteristics of the openings. These characteristics will also be evaluated in a laboratory benchmark, but may depend on the pressure difference between both sides of the openings, therefore calibration using on site measurement may be helpful. The air exchange rate estimated by this method will be compared to measurements using tracer gas, performed in the house as well as in the laboratory benchmark. The possibility to use anemometers will also be tested.

1 DESCRIPTION OF THE ZERO ENERGY HOUSE

1.1 Architectural concept

The 130 m² floor area extends over one and a half storeys, with the spaces under the roof put to full use. Maison Air et Lumière, using a design principle that integrates architectural quality and energy efficiency, manages to place the emphasis on interior comfort whilst respecting the energy and environmental objectives for new detached houses for 2020. A model of the building is shown in Figure 6

1.2 Daylight

Particular attention has been paid to daylight to ensure the physical and psychological health and well-being of the residents, and to enlarge the visual perception of the indoor spaces whilst saving energy by reducing the need for artificial lighting. The amount of daylight and the quality of its distribution have been carefully studied using VELUX Daylight Visualizer 2.

1.3 Ventilation

According to the season and weather conditions, ventilation is provided by a hybrid system that combines the advantages of mechanical ventilation with heat recovery in winter and, in summer, natural ventilation by window opening (supplemented by mechanical extraction in bathroom and kitchen).

1.4 Energy design

The energy concept of Maison Air et Lumière is based on the maximum use of renewable resources (solar energy, natural light, passive cooling) in order to minimise the need for air conditioning in summer, to reduce heating in winter and to reduce artificial lighting and energy use for ventilation. The combination means a neutral environmental impact and maximum comfort for the residents. The house, which is built on a concrete slab on an earth platform insulated on the underside, is constructed with a well-insulated wooden frame and with a window-floor ratio of nearly 1:3. All windows are equipped with dynamic solar protection and the operation of all systems in the building (heating, ventilation, shading window-opening, lighting etc) is fully automated.

With its interplay of roof structures, the building is compact and very well insulated and, in order to create a stable and comfortable room temperature, the interior walls are lined with terracotta tiles, appreciably improving the thermal mass of the building. Heating and hot water are provided by a heat pump connected to thermal solar panels and a low-temperature underfloor heating system. The artificial lighting, domestic appliances and multimedia equipment were selected on the basis of their low consumption. Moreover, to reduce electricity consumption further, the washing machine and dishwasher can be directly connected to a cold and hot water inlet. All electric power consumption will be offset by the contribution from 35 m² of photovoltaic panels integrated in the roof. In normal use of the building, the overall annual energy balance is positive.

2 EXPERIMENTAL PROTOCOLE AND DESCRIPTION OF THE MONITORING

2.1 Measurements in a laboratory facility

A benchmark is installed at the CEP laboratory in order to identify the characteristics of a roof window. A ventilator is used to create a pressure difference in a test cell divided in two compartments. The roof window is installed on a 45° sloped wall between these compartments. The pressure difference (P_2-P_1) is measured, as well as the air flow rate Q: a diaphragm and Pitot tubes are used in the inlet air pipe in order to get a reference value of the flow rate (see fig. 1).

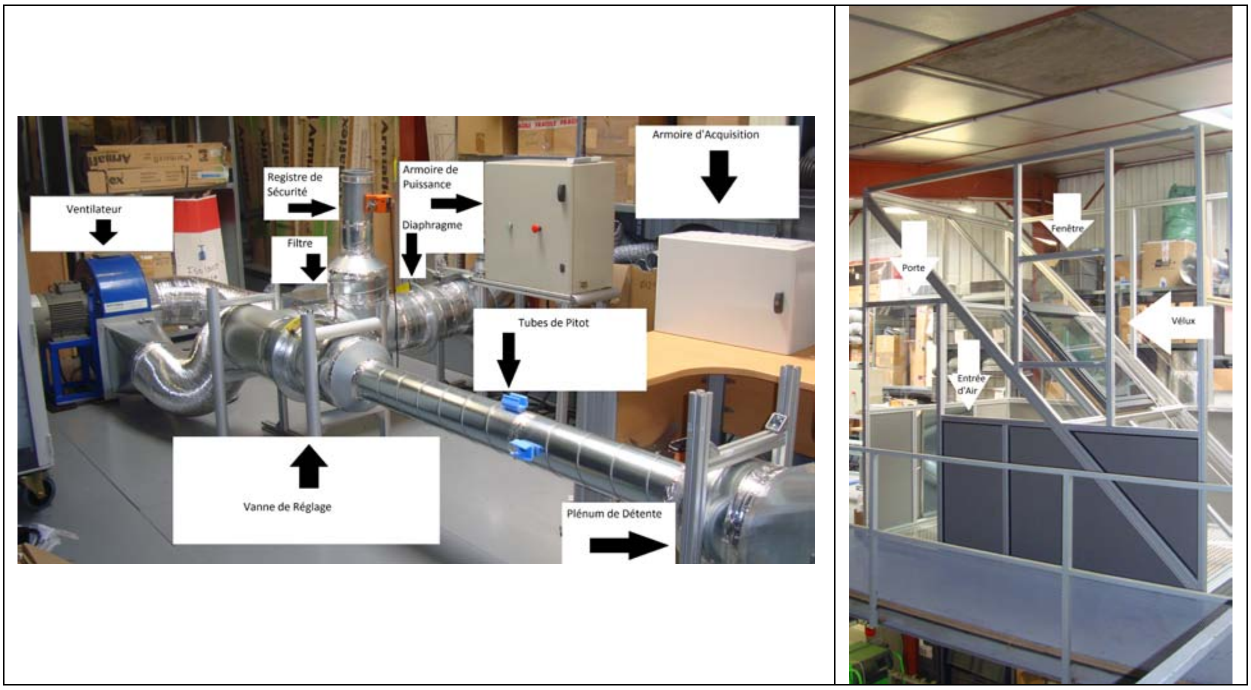

Figure 1. Air inlet of the laboratory benchmark, including flow rate measurement

This reference value will be compared to the air flow rate obtained from analyzing CO_2 concentration profile (tracer gas method). First a profile will be measured with the window closed in order to identify the air infiltration flow rate. Then the window will be open and the additional flow rate will be derived by difference.

A one way flow is assumed in the conditions of this experiment. The ventilation flow rate and therefore the pressure difference will be varied in order to draw a curve relating the flow rate Q to the section S and pressure difference, and to derive characteristics of the roof window Cd and n [2]:

$$Q = S.Cd\,(P_2 - P_1)^n \qquad (1)$$

The section S considered is the geometrical opening section. The difference $P_2 - P_1$ will be in the range from 0.05 to 1 Pa. In the real house, it may be lower, depending on wind conditions, but it is hoped that the values of Cd and n will not vary too much. The laboratory test will therefore provide two parameters that can be used in the analysis of on site measurements, and that can be refined using a calibration step.

Anemometers will be used in order to study the possibility to measure the air speed at different locations of the opening, and to derive the flow rate. A CFD model of the benchmark has been developed [3] in order to know if some position of the anemometers leads to a more precise evaluation of the flow rate, see Fig. 2. The velocity is assumed uniform on the inlet section (0.1 m/s), which corresponds in the experiment to the use of a honeycomb structure.

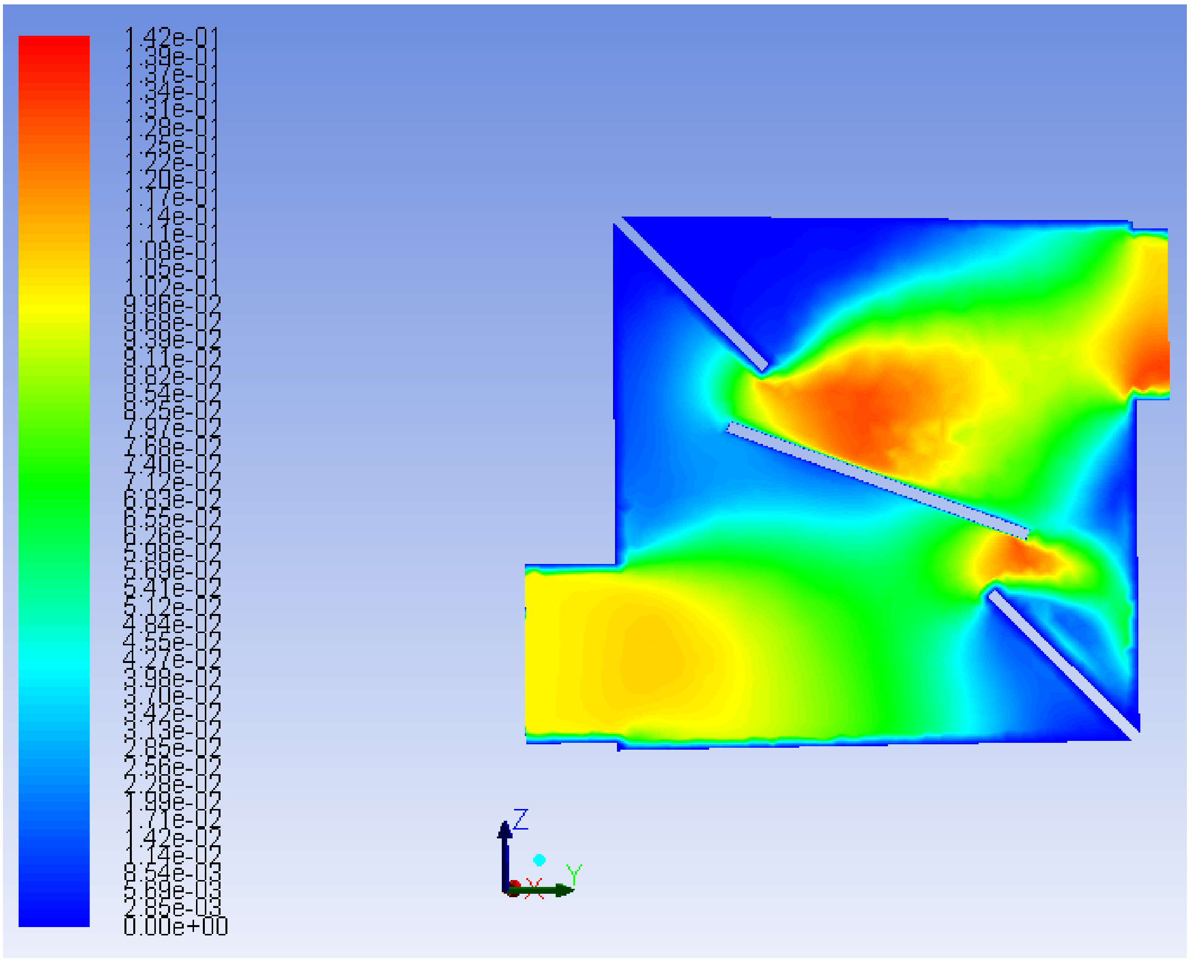

Figure 2. Example CFD model of the bench mark and air velocity results

CFD can also be helpful to choose the position of pressure gauges, see Fig. 3.

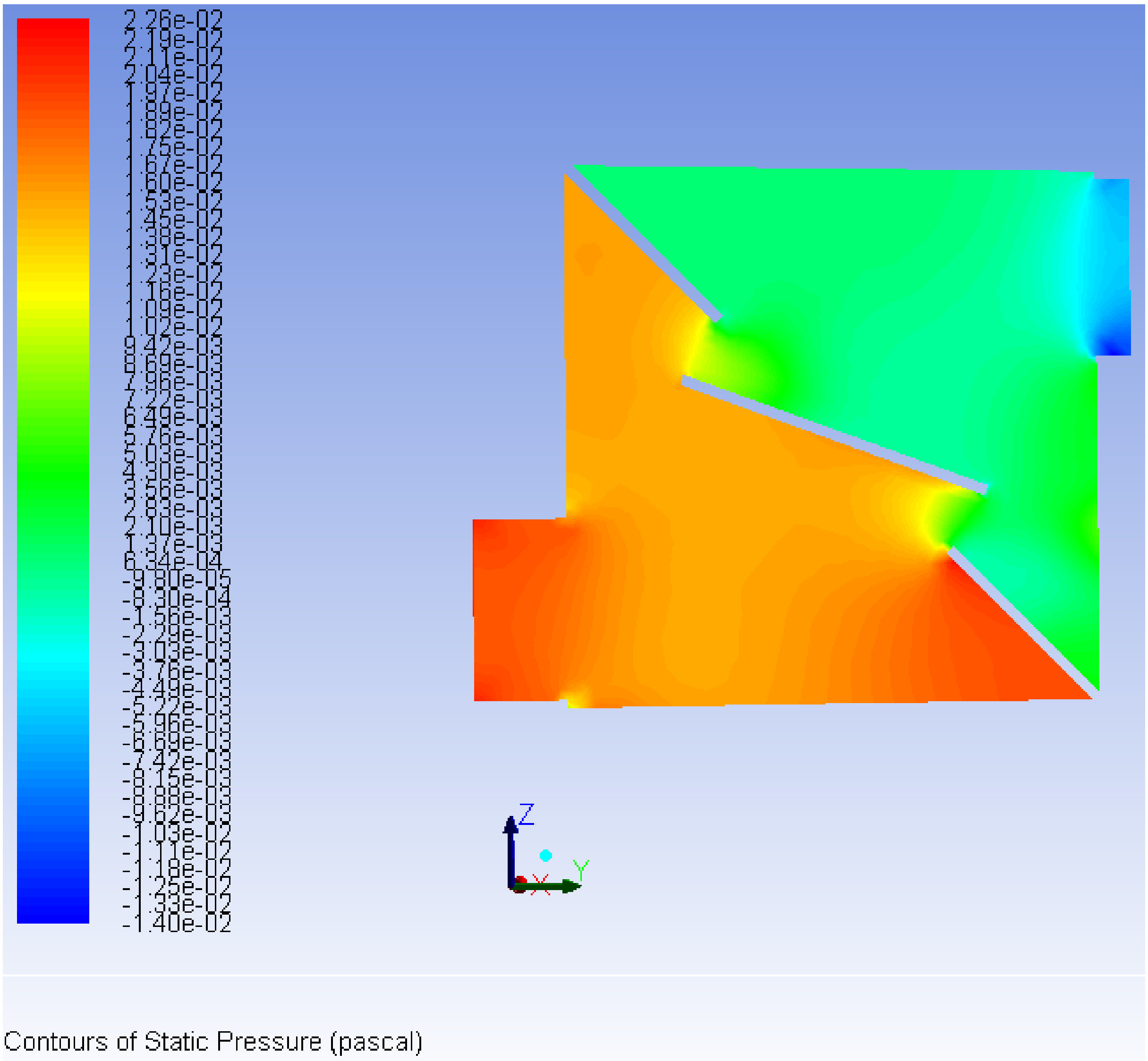

Figure 3. Example CFD results, Static pressure in the benchmark

2.2 Monitoring of the house

The measurements have been performed from 20 July to 20 August 2012, according to four scenarios successively:

- Without natural ventilation (all windows are closed), in order to obtain a reference,
- With natural ventilation (all roof windows and top vertical windows are open), without movable shading and with internal doors open (to get the maximal effect of natural ventilation),
- With natural ventilation, with movable shading and internal doors closed (to get the minimal effect of natural ventilation),
- With natural ventilation, with controlled movable shading and internal doors closed (to get the more realistic effect of natural ventilation).

Figure 4 shows temperature profiles in different rooms without ventilation (first period), with uncontrolled ventilation (second period, doors open), and with controlled ventilation (fourth period).

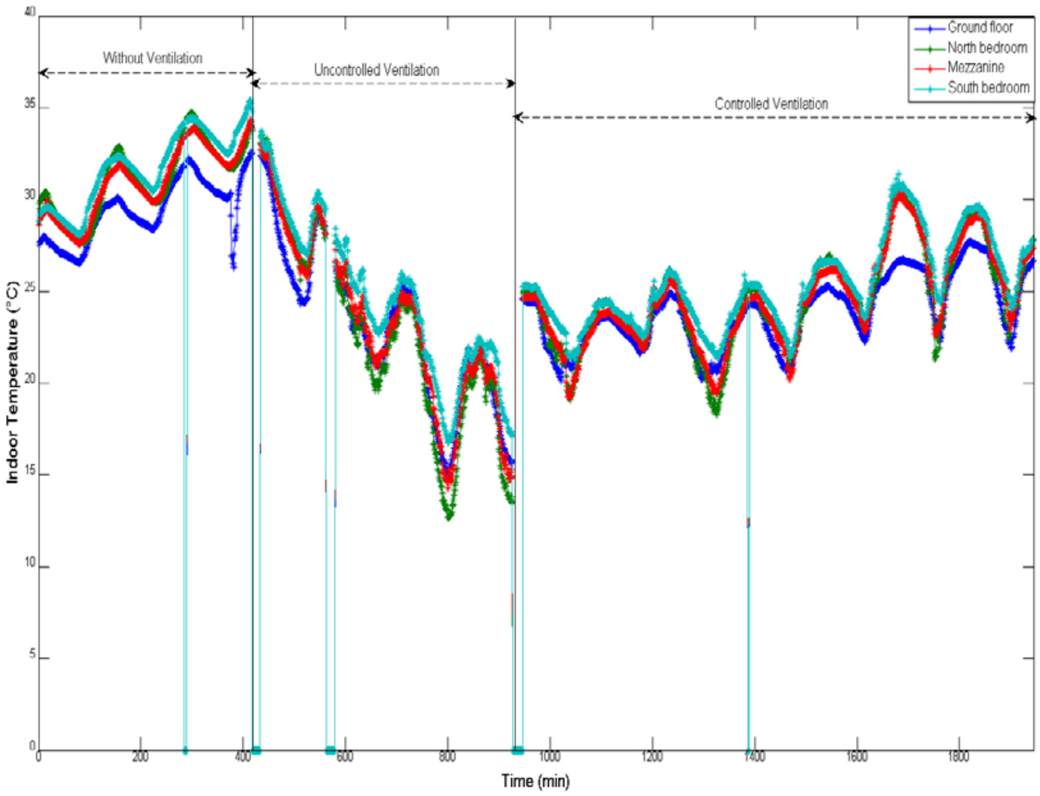

Figure 4. Example measured temperature profiles in Maison Air et Lumière

Pressure differences between outside and inside will be measured at certain times (not continuously) through windows situated on the different facades. Wind velocity and direction are also measured, so that pressure coefficients can be derived, allowing pressure on the different facades to be estimated over the whole period.

Given the small window height, and the large height between ground floor and roof windows, a one way flow model is considered. Discharge coefficients Cdi and exponents n, identified for roof windows using the laboratory benchmark presented above, or collected in the literature for other windows, allow the air flow rates through the different windows to be evaluated in terms of the internal pressure. The sum of inlet and outlet flow rates being zero, this internal pressure can be derived. An air exchange rate can then be evaluated.

The global air exchange rate can also be evaluated using a tracer gas method, which provides a second estimation of this parameter, but the precision is also questionnable as it will be addressed in the discussion §. In a homogeneous zone (volume V), the internal concentration Cint depends on the emission from the source So, the fresh air flow rate Q, internal and external air densities ρint and ρext, and external concentration Cext [4]:

$$\rho_{int}\, V\, dC_{int}/dt = S_o - \rho_{ext}\, Q\, (C_{int} - C_{ext}) \qquad (2)$$

In a steady state, the concentration is constant (dCint/dt = 0) so that:

$$S_o = \rho_{ext}\, Q\, (C_{int} - C_{ext}) \qquad (3)$$

Due to the high flow rate in the house when opening all roof windows, using the steady state option would require a large quantity of gas. It seems therefore preferable to inject a certain quantity of gas and to measure the decrease of gas concentration. Equation (2) allows the air flow rate to be identified.

Example measurement results are shown in Fig. 5 for two configurations: internal doors being closed or open. The logarithm of the concentration has been derived, so that the air flow rate Q can be identified using a least square method. In the example below, the result is around 4.5 air change per hour (ach) when the doors are closed and 5.5 ach doors open.

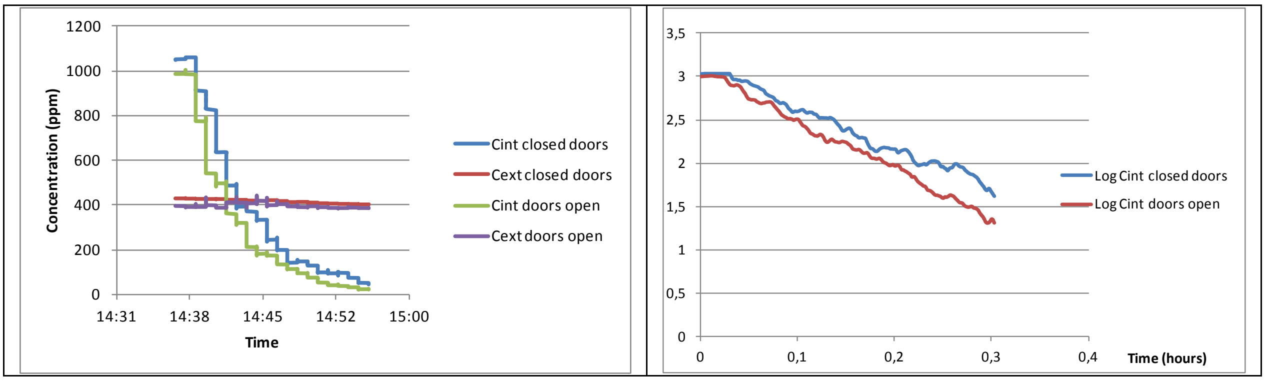

Figure 5. Example tracer gas concentration measurements in Maison Air et Lumière

3 DYNAMIC THERMOAERAULIC SIMULATION

Complementing monitoring results, numerical simulation constitutes another way to better understand the behaviour of a building. A dynamic thermal simulation tool is used to evaluate temperature profiles in the house [5], which has been modelled using 7 thermal zones : the living space (on two levels), three bedrooms (with different orientations), a garage, and other rooms (ground floor and first floor), see Fig. 6.

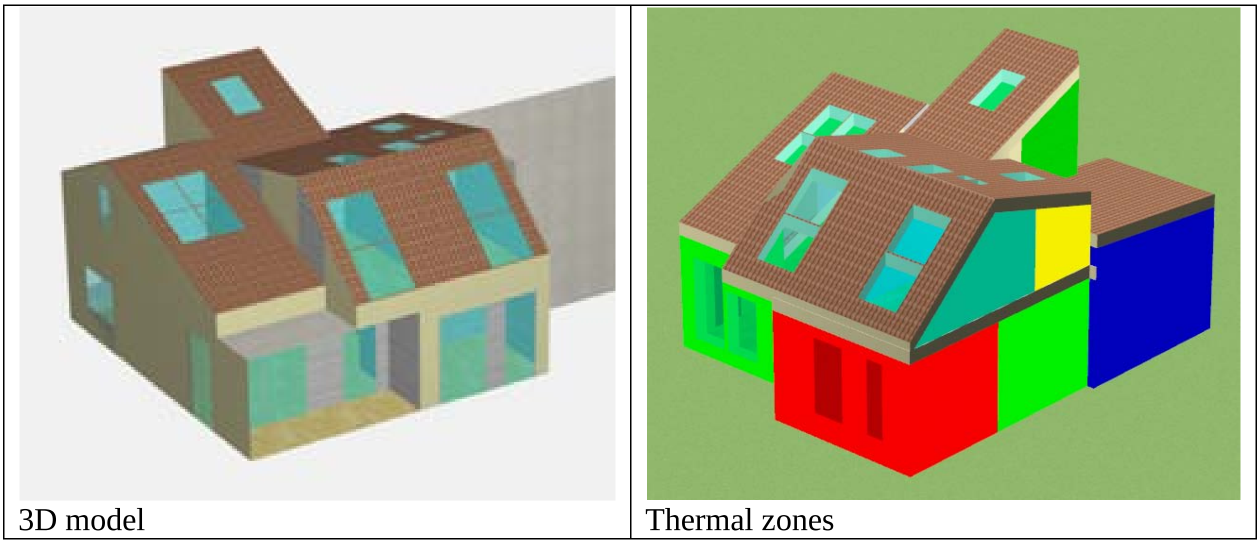

Figure 6. Thermal model of Maison Air et Lumière, graphic modeler ALCYONE

The model accounts for the conductive, radiative and convective heat transfer, as well as energy storage in the building envelope related to solar and internal gains. In this highly insulated new construction, the most uncertain parameter is the natural ventilation flow rate. Figure 7 shows simulation results for a typical summer week in Greater Paris Area, considering three levels of ventilation flow rate (no ventilation, 5 ach and 20 ach).

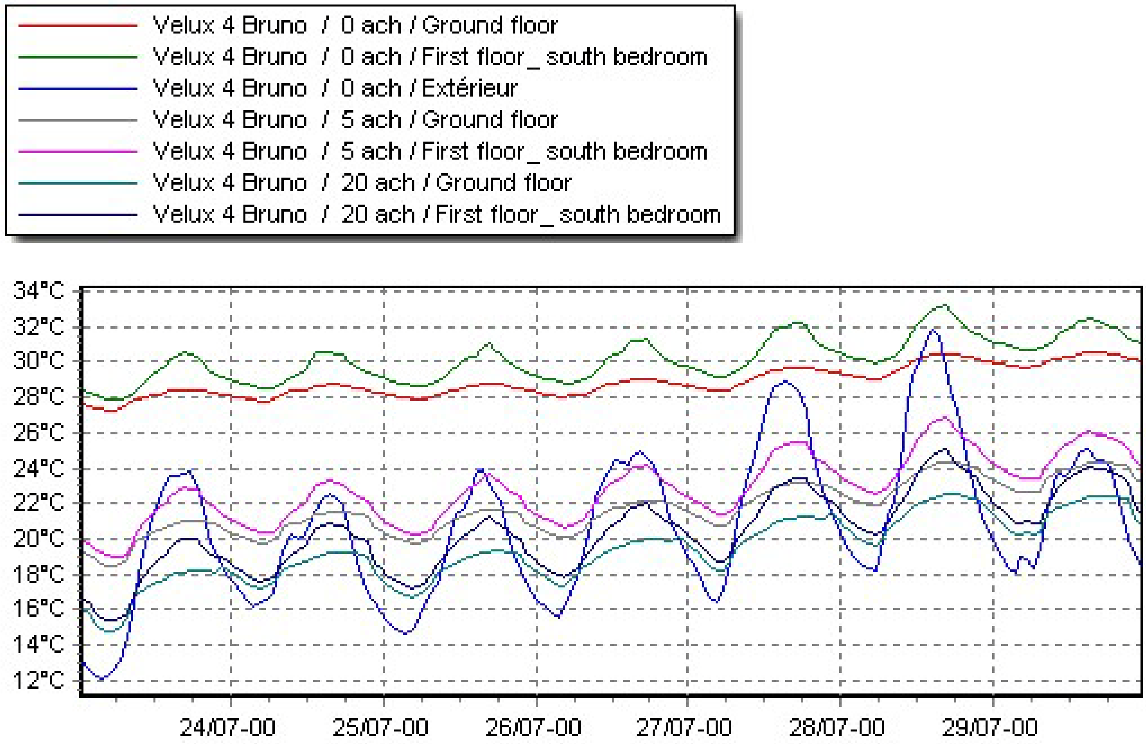

Figure 7. Example simulation results of Maison Air et Lumière, dynamic thermal simulation tool COMFIE

According to these results, this parameter has a large influence on the temperature profiles. It can therefore be calibrated by minimizing the discrepancy between measured temperature profiles and simulation results [6] using the climatic data corresponding to on site measurements (external temperature and solar radiation). This constitutes a third way to evaluate the global air exchange rate, and may be helpful to refine the characteristics evaluated in the laboratory benchmark, by taking into account the actual conditions in the real house.

Another added value of numerical simulation is, once the model has been calibrated, to compare, under the same climatic conditions, temperature profiles with and without ventilative cooling in order to evaluate the benefit of this approach. Such evaluation would otherwise require the construction of two identical houses, which is technically difficult and of course expensive.

4 DISCUSSION, STUDY OF A CHARACTERIZATION METHOD

Evaluating the interest of ventilative cooling requires simulation methods with at least hourly time steps because monthly or annual methods are not able to evaluate temperature profiles. Such methods need input data regarding the aeraulic properties of openings. The most common models for one way flows consider two characteristics: a discharge coefficient and an exponent, relating the air flow rate to the pressure difference on both sides of the opening (see equation 1).

As seen in § 2, using on site monitoring in a real house to determine these parameters is very difficult due to very low pressure differences on both sides of windows, therefore measurable with a high uncertainty. Air flow rates are also difficult to measure: velocities can be measured, but a flow rate is an integration of these velocities over the opening section. Anemometers can be used to measure velocities, but they have to be placed in specific points in order to obtain an average value through the whole section. The precision of such measurement is then very low. If both the pressure difference and the flow rate are not precisely known, it is very difficult to derive the two parameters Cd and n of equation (1).

A benchmark in a laboratory has two advantages:
- the flow rate can be higher than in the real building, so that the pressure difference is higher and therefore easier to measure;
- the flow rate can be measured using e.g. a Pitot tube, constituting a reference value.

The exponent n of equation (1) may be somewhat different in real conditions, because it depends on the pressure difference. On site measurement is therefore needed to calibrate this parameter. At the moment the tracer gas method is used in practice, but there is a large uncertainty due to possible uncomplete mixing following the density difference between the air and the most common gases (CO_2, SF_6, N_2O). These gases being heavier, they accumulate in the lower part of the building so that their concentration is not varying as modelled in equation (2). The measured air change rate may therefore be underestimated. Other gases like some VOCs might be used in the future, provided that they are not emitted by building elements (e.g. painting, glue etc.).

Calibrated window characteristics allow the ventilative cooling potential in a building to be evaluated, using thermoaeraulic simulation. This procedure may be validated thanks to a comparison between calculated and measured temperature profiles. Calibration of the simulation model using the measured temperature profiles may also constitute an alternative to using tracer gases: measuring temperatures is simpler and cheaper than measuring gas concentration.

CONCLUSIONS

The method proposed here, combining a benchmark in a laboratory with numerical simulation and on site monitoring may bring a supplementary input, complementing the existing knowledge in the field of passive cooling of buildings. The feasibility of using this method in order to prepare appropriate input data for numerical models implemented in regulation, design and certification tools will be studied.

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REFERENCES

[1] Ghiaus C., Allard F., 2005, Natural Ventilation In The Urban Environment: Assessment And Design, *Earthscan, London, 241 p*
[2] Axley J. W. Emmerich S. J. and Walton G. N., 2002, Modeling the Performance of a Naturally Ventilated Commercial Building with a Multizone Coupled Thermal/Airflow Simulation Tool, *ASHRAE Transactions 2002, V. 108, Annual Meeting. Proceedings. Honolulu, 1-16 pp*
[3] http://www.ansys.com , accessed September 2012

[4] Sherman M.H., 1990, Tracer gas techniques for measuring ventilation in a single zone, *Building and Environment 25-4 365-374*
[5] Peuportier B. and Blanc Sommereux I., 1990, Simulation tool with its expert interface for the thermal design of multizone buildings, *International Journal of Solar Energy 8 109-120*
[6] Mejri O., Palomo Del Barrio E., Ghrab-Morcos N., 2011, Energy performance assessment of occupied buildings using model identification techniques, *Energy and Buildings 43 285-299*