LESSONS LEARNED ON VENTILATION SYSTEMS FROM THE IAQ CALCULATIONS ON TIGHT ENERGY PERFORMANT BUILDINGS

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ABSTRACT

During the project QUAD-BBC, several ventilation systems have been studied in residential (individual house and collective dwellings) and non-residential (school, offices) and assessed by the evaluation of an IAQ multi-criteria.

These calculations have shown some typical evolution of pollutants in very tight low consumption buildings and can alert on some possible effects.

For instance, formaldehyde and VOCs criteria are increasing at night when ventilation is shut off which indicates that passive measurement methods are in this case evaluating an average exposure not representative of occupation. It also shows how much airflow should be maintained to reduce the exposure to these pollutants or how much time before occupation the system should be started. Other lessons can be learnt from the pollutions in the kitchen during cooking, the humidity of drying clothes in houses and the impact of occupant behaviour…

Humidity evolution in case of insufficient ventilation in rooms with a high density of occupation (classrooms, meeting rooms…) has also a much stronger impact in a very tight building. The study also shows that the ventilation performance can be improved, especially in main rooms when improving building airtightness. While we could fear the contrary, improved airtightness appears to be beneficial to IAQ in our test cases.

This paper presents the main lessons learnt from the calculation analysis in these buildings.

KEYWORDS

IAQ, Air tightness, ventilation efficiency, simulation

INTRODUCTION

Low-energy buildings are built with well-insulated envelope in order to reduce the energy demand. In France, the conventional primary energy consumption should be inferior to 50 kWh/m^2/year for the residential low-energy buildings. This consumption takes into account the energy demand for heating, which includes the energy demand of ventilation and infiltration, space lighting, air-conditioning, ventilation auxiliaries and hot water production.

The up-coming French thermal regulation RT2012 will apply this specification for the new built buildings. Nevertheless, the regulation on ventilation does not specially deal with low energy buildings. One then can wonder about the energy impact of ventilation in such buildings. This concept of buildings brings out additional questioning on the link between innovative ventilation systems and indoor air quality (IAQ). The main concern is: which ventilation systems are suitable for low-energy buildings? In these conditions, the part of ventilation in the energy consumption would increase in these buildings The adequate ventilation system should meet the energy requirements while providing acceptable indoor air quality.

During the project QUAD-BBC[1] several ventilation systems have been studied in residential (individual house and collective dwellings) and non-residential (school, offices) and assessed by the evaluation of an IAQ multi-criteria.

This criteria takes into account:

- Humidity (number of hours above 80%) linked to occupants and their activities

And 4 specifics indexes related to common activity or impact

- A CO_2 as index of confinement linked to occupation,
- B NO_2, SO_2 (dwellings) and O_3 (offices) linked to occupant activities,
- C CO and 7 VOC linked to materials, activities and occupants behaviour,
- D $PM_{2.5}$ and PM_{10} linked to activities.

The specific indexes are built for each group of pollutants.
For example, the index for occupant activities (Group B) is calculated as followed:

$$I_B = \frac{[NO_2]}{ref\ value\ NO_2} + \frac{[SO_2]}{ref\ value\ SO_2}$$

The lowest index correspond to the best Indoor Air Quality regarding this type of pollutant. These calculations have shown some typical evolution of pollutants in very tight low consumption buildings and can alert on some possible effects.

METHOD

We use, for the simulations, SIMBAD, a Building and HVAC Toolbox developed by CSTB (Husaunndee et al., 1997)[2]. This tool implements multizone and nodal building models in MATLAB/Simulink environment by combining heat and mass transfer phenomena. On the one hand, the thermal model is composed of detailed wall models describing the material layers and their properties, window models, heating and cooling devices, lighting systems, etc. It so deals with conduction, convection and radiation phenomena for calculating surface temperatures, mean radiant and indoor air temperatures.

On the other hand, the airflow model is made of airflow paths. In order to assess the performances of ventilation systems, this model includes the following systems: balanced ventilation with heat recovery and free-cooling, demanded-controlled ventilation based on humidity, CO_2 concentration or presence detection, and natural ventilation. It also deals with the characteristics of fans, ducts, heat exchanger, filters, and airflow paths.

The coupling of both models is done through the "ping-pong" method in which both models run in sequence and each model uses the previous time step results of the other (Hensen, 1999)[3]. The obtained simulation tool is then able to predict energy consumption and indoor air quality according to the pollution schedule and the ventilation system.

MATERIAL EMISSIONS

In offices and school, all ventilation systems simulated show an increase of formaldehyde concentrations at night and during week-end, when ventilation is shut off after occupation. Figure 1 shows for the classroom the fluctuation of formaldehyde concentration on one typical week.

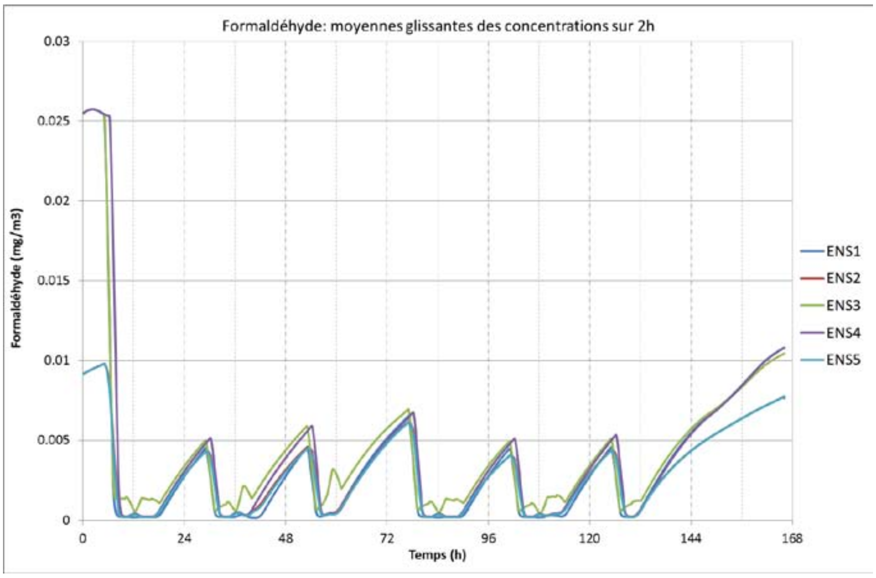

Figure 1 : Evolution of formaldehyde in a classroom on one week for the 5 ventilation systems simulated, all shut off at night.

The systems ENS 2 and ENS 5 are supply and exhaust mechanical ventilation (blue and red curves). Figure 2 shows the formaldehyde fluctuation when 10% of nominal airflow is kept at night to deal with the material emissions.

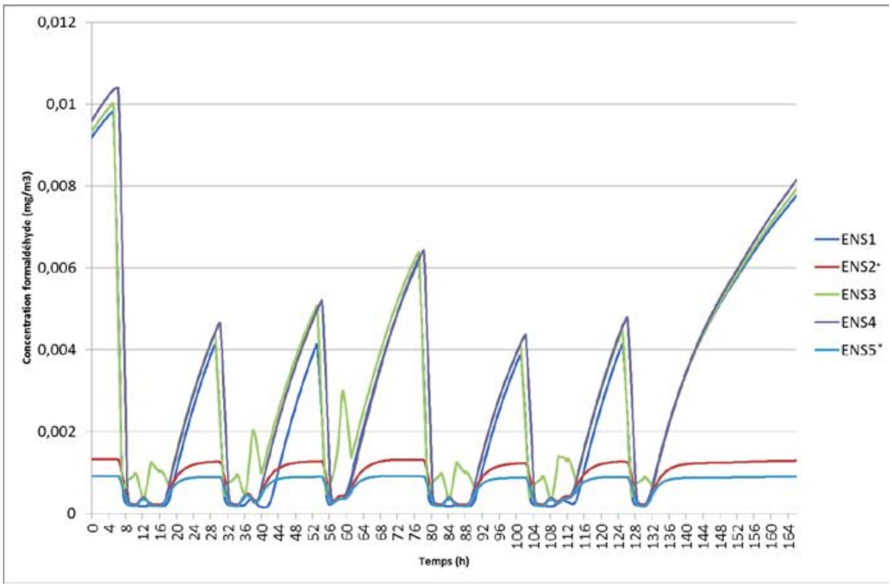

Figure 2 : Evolution of formaldehyde in a classroom on one week for the 5 ventilation systems simulated, ENS 2* and ENS 5* kept at 10% nominal flow, others shut off at night.

When a minimum airflow is maintained at night, the fluctuation is strongly reduced. Yet from the energy point of view, starting ventilation 1 hour before occupants' arrival leads to the same result and will spend less energy.

In France, a new law[4] plans to reduce by 2015 the maximum value of formaldehyde and to measure on site the results. At the moment, passive tubes are considered as the most reliable measurement and tubes are left generally 3 to 5 days on site. Due to the possible losses during this duration on site, the values can be underevualeted in regard of the real values.

It is often asked for DCV (Demand Control Ventilation) if the decrease of airflow when occupants are absent is consistent with maintaining of a good air quality taking into account the emission of materials. In France to get a technical agreement, these systems must have a clock to restart before occupation, stop after occupation and maintain 10% of nominal airflow when occupants are absent of the room but still during the occupation hours of the building. We note that these requirements are enough to correctly deal with the material emissions that have been chosen for our calculations. Recently, the Observatory of IAQ in France has launched a campaign on schools. On site measurements are in average at higher concentrations that in our calculations which would indicate that our scenario of emission may be underestimated. Yet to reach this average amount of formaldehyde in school (the limit from the law is at a concentration of 30 µg/m^3 since 2013), we note that the systems answering the technical agreement are still satisfactory. We note also that satisfactory target values of formaldehyde for health can be achieved at much lower flow than those indicated for low polluting materials in the Perceived Air Quality method of EN 15251[5].

AIRING

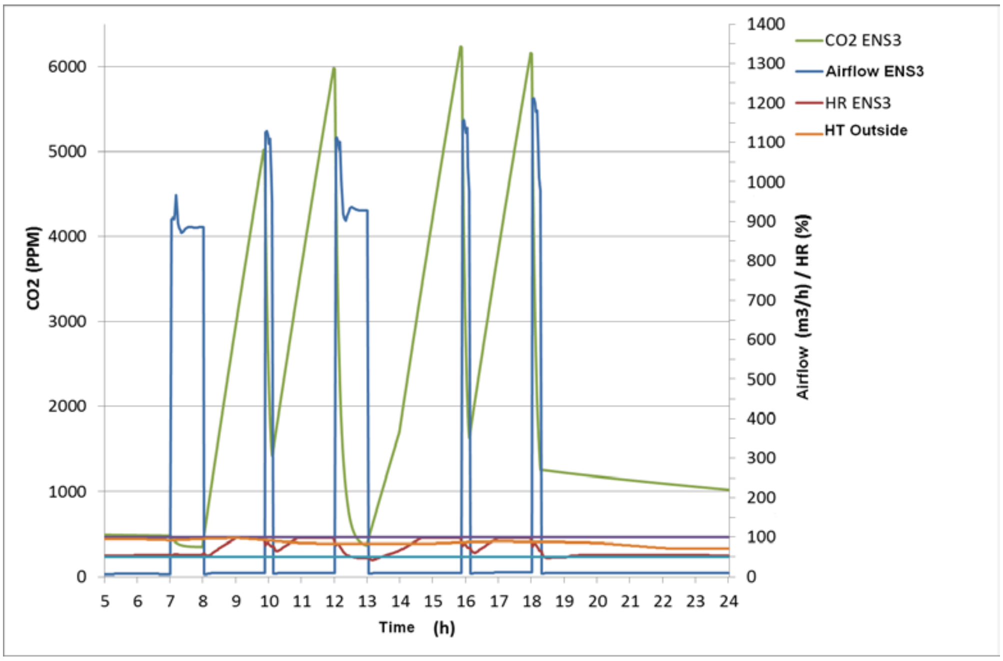

Figure 3 : system ENS 3 (windows airing) - CO_2, indoor and outdoor humidity and ventilation airflow on a winter day (average temperature 11°C, 5 m/s wind) in a 35 children classroom.

Using window airing in school is not sufficient to ensure a correct IAQ. Windows are manually opened from 7h till 8 h, from 12h till 13h and one quarter during the breaks of 10 and 4 pm. Confinement is too high (35 students in a 60m2 room) and the different indexes are incorrect. CO_2 levels reach 6000 ppm 15 minutes after the window is closed; this has already been shown many times. But in this quite tight building (1,7 m^3/h/m²@4 Pa), it is important to note that indoor humidity increases strongly. On the full year, more than 3000 hours are reported over 75% HR, which shows that in highly occupied rooms of tight building, there is a severe risk of condensation which is both unhealthy for occupants and doesn't preserve the building itself.

BUILDING AIR TIGHTNESS

Enhancing building air tightness can improve the ventilation system performance, mainly for single exhaust, by improving air transfer and allowing air to enter where it's planned by design.

For both systems (single exhaut, supply & exhaust), in individual house for instance, improving air tightness slightly improves air quality by decreasing the pollutant concentration.

In this 2 floors' house, air entering the first floor goes down to ground floor to be extracted in the kitchen when air tightness is between 0,3 and 0,6 m^3/h.m² @4Pa while above, stack effect leads and air going up from the ground floor reduces the entrance of fresh air in the first floor bedrooms.

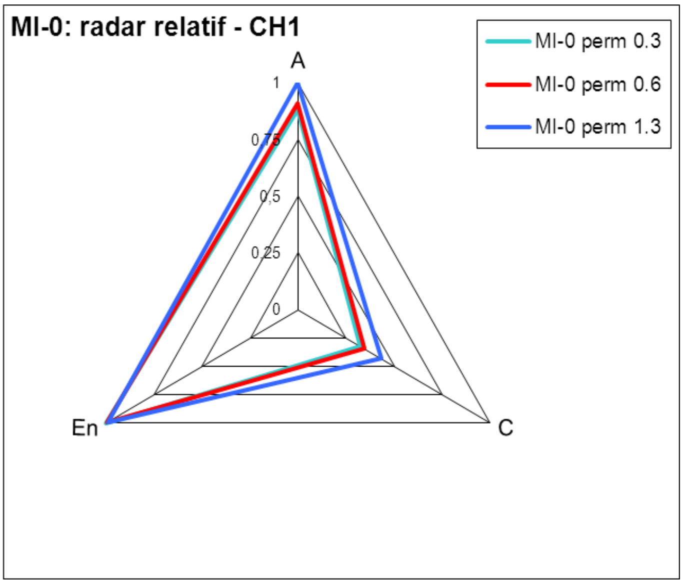

Figure 4 : example of savings on IAQ indexes (A and C) and energy for single exhaust (MI-0) (1st floor of the individual house studied)

It is interesting to note that improving air tightness doesn't reduce IAQ and on the opposite, tends to reinforce the designed air transfer and the efficiency of ventilation in the house. For instance, for single exhaust system in the house, the IAQ linked to material emissions is increased by 20 to 25 % (index C reduced from the same pourcentage as shown in figure 4 MI-0) and index A (concerning CO2 concentration) by around 10%.

In collective dwelling, we had similar conclusion: when leakages are reduced from 1,7 down to 0,3 m3/h/m²@4 Pa, index A decreased by 11% and index C decreased by 17%, which represent better IAQ.

KITCHEN VENTILATION

5 ventilation systems (single exhaust and supply & exhaust) have been studied in the house, 2 of them (LC3 and LC4) including a kitchen hood with a specific air inlet in the kitchen, opened only when hood is switched on. Figure 5 shows that the ventilation system (single or balanced) has no influence in the kitchen, but the presence of hood is efficient on combustion products.

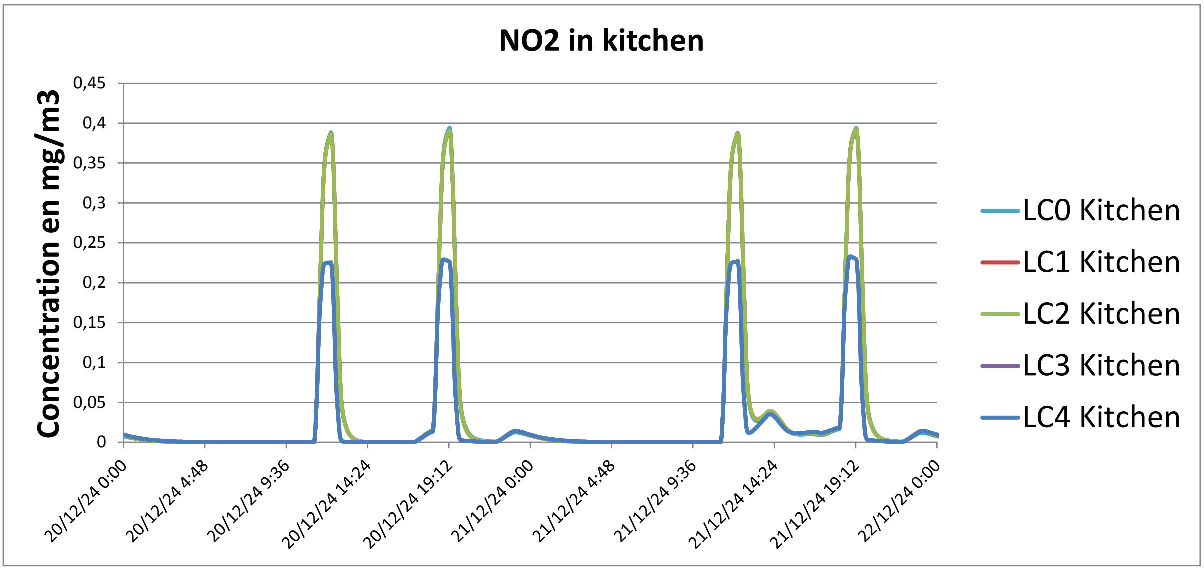

Figure 5 : NO_2 Concentrations in the collective dwelling kitchen for the various ventilation systems studied.

In airtight houses and dwellings, the boost airflow in kitchen and the presence of hood with integrated air inlet are absolutely needed to deal with pollutants load. This conclusion is obvious on combustion products (but also depend on emissions scenarii) but also valid for formaldehyde and material emissions in the kitchen.

OCCUPANTS BEHAVIOR

The use of encens or tobacco has much more impact (more than 10 time bigger) on IAQ indexes than material emissions. Figure 6 shows this effect on formaldéhyde only. A better knowledge of real emissions indoor is needed because today, only a few studies exist and show a lot of discrepancies in their results.

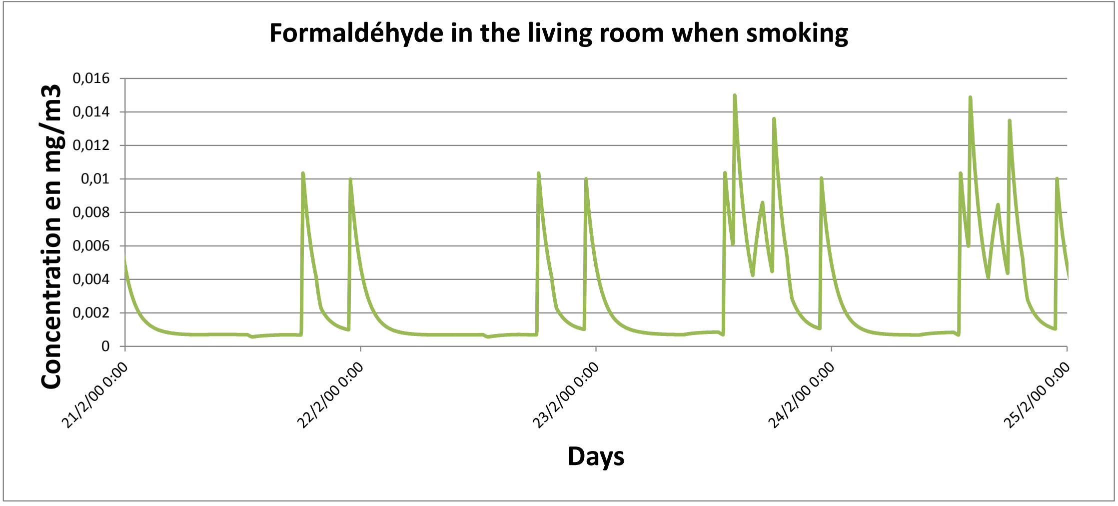

Figure 6 : Formaldéhyde concentration in the collective dwelling living room when
2 cigarets are smocked per day and 6 during the week-end

CONCLUSION

As we can note, some interesting conclusions are possible from this study based only on simulations. The absence of measurements need however to be careful of the impact of hypotheses assumed on emissions scenarii. The evolution of building toward more tightness can be an asset for the performance of ventilation but also need to design and install correctly the ventilation system to rely on it. Humidity may be the first adverse effect visible in case of low ventilation in a tight building before any increase of other pollutants may be noticed.

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