Occupancy Calculation for the Control of Mechanical Ventilation

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ABSTRACT

Ventilation is essential for health and comfort of building occupants. It is particularly required to dilute and/or remove pollutants emitted by occupant's metabolism. The concentration of metabolic CO_2 is well correlated to metabolic odor intensity. Therefore CO_2 concentration can be efficiently chosen as an indoor air quality indicator when occupants are the main pollution source inside the buildings. The aim of the research presented in this paper was to estimate through calculation based on measurement data the occupancy level in an experimental device (HybCell one-zone test cell) in order to control the ventilation system accurately. We first developed an analytical control function to estimate occupancy and control the fan speed. Then, we tested this controller by implementing it both in a numerical model and in the test cell. Additionally, the overall performance of this controller has been investigated through an aggregated function. The results revealed fine control accuracy, a good system stability, and a reduced setting and tuning period.

KEYWORDS

Comfort, ventilation, regulation.

INTRODUCTION

Ventilation is the method by which clean air is provided to a room. On the one hand, it is essential for reaching the metabolic requirements of occupants and for diluting and removing pollutants emitted by indoor sources. On the other hand, unnecessarily high rates of air change can present a huge energy cost for building heating or cooling needs. So it is variously expected that ventilation account for 30% or more of space conditioning energy demand (Liddament 1992). Currently, high carbon dioxide concentrations in offices can be an indirect indication of poor ventilation and contaminant build-up. At CO_2 levels above 1000 parts per million (ppmv), occupants experience decreased satisfaction, perception of poor air quality, and increased physical symptoms. Seppanen and al (1999) indicates that reducing the level to at least 800 ppmv can further improve occupant satisfaction and reduce symptoms.
Yet it may be almost difficult for the designer to anticipate ventilation needs vary on a day to day throughout the occupation density. To control Indoor Air Quality, control device like On/Off controller thanks to CO_2 could be a simple way but problems with fan and/or openings actuator stability could appear. Moreover, techniques based on PID or fuzzy controllers have been testing by El Mankibi (2003), but there setting and tuning period is relatively long to be enough attractive.
In order to get a good compromise between precision and equipments stability, we intend to develop and test an analytical control function to measure the quantity of

emitted CO_2 by occupants. Then, this information is used to control the appropriate extractor fan speed at a suitable rate.

OCCUPANCY LEVEL EVALUATION

Theory and equations

First of all, we consider an office (volume V0) with a number N_{occ} of occupants. Each person produce metabolic carbon dioxide with a rate of Q^i_{pol}, production directly linked to their level of activity (Liddament 1996).
Moreover, the room has been equipped with a regulated fan speed extractor and a CO_2 sensor. If an inert gas like CO_2, is released by occupants and perfectly mixed, the concentration at any time is given by the continuity Eqn (1):

$$\sum_{i=1}^{N_{occ}} Q^i_{pol} = V_0 \left(\frac{\partial C^{int}}{\partial t}\right) + Q_{cv}\left(C^{int} - C^{ext}\right) \qquad (1)$$

Where:

- Q^i_{pol}: metabolic carbon dioxide production rate for person I
- Q_{cv}: Air flow rate [$m^3 \cdot s^{-1}$]
- C^{int}: interior CO_2 concentration [ppmv]
- C^{ext}: exterior CO_2 concentration [ppmv]

The knowledge of the occupation level can be helpful for an airflow extraction sizing and Eqn (1) could help us to evaluate the global pollutant emission. Thereafter, we aim at measuring CO_2 emitted by occupants on a test cell called HybCell (El Mankibi and al 2002), designed at the LASH/ENTPE (France) laboratory. HybCell is 5.1 m long by 3.5 m wide and 2.9 m high and is equipped with hybrid ventilation system (fan and motorized openings), sensors (CO_2, temperature, relative humidity...), and virtual occupancy (metabolic heat and CO_2 supplies).

Occupancy detection test on HybCell

$$N_{occ} = \frac{V_0 \left(\frac{\partial C^{int}}{\partial t}\right) + Q_{cv}\left(C^{int} - C^{ext}\right)}{Q_{pol}} \qquad (2)$$

In the situation where each occupant of an office has the same constant activity, Q^i_{pol} has been considered as a constant term. Therefore, the equation (1) becomes (2) with Q_{pol}: metabolic carbon dioxide production rate.

On the assumption that the ambient outside C^{ext} value is approximately 350 to 450 ppmv, the Eqn (2) represents the formulation of a three-input numerical function to estimate occupancy. These inputs are:

1. C^{int} given by the sensor
2. The numerical first derivative evaluation of C^{int}
3. Q_{cv} the controlled ventilation rate used

Then, Eqn (2) has been tested for Q_{pol} =18 l/h per occupant corresponding to a light working activity. We used a 60 sec data capture step, a gradient evaluation on 5 points for the numerical first derivative of C_{int}. In addition, a waiting time of 10 minutes is chosen to update the occupancy evaluation, in order to include all the time delay measurements (CO_2 sensor, air flow mixing...). Figure 1 presents a comparison between ”real” and ”measured” occupation of HybCell thanks to Eqn (2) for two check protocols, such as:

- Condition n°1: Variation of the occupation with a same ventilation rate
- Condition n°2: Variation of the ventilation rate with a same occupation

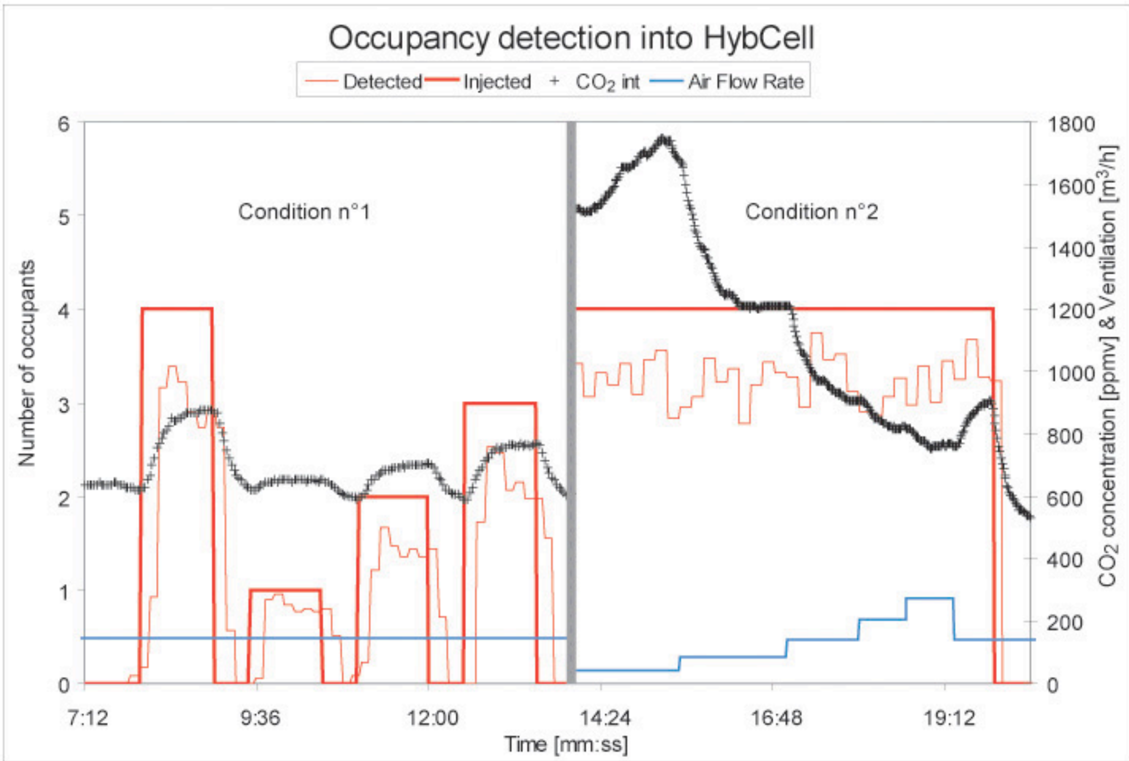

Figure 1: Comparison between ”real” and ”measured” occupancy of HybCell

The ”measured occupation” is relatively close to what was actually injected for the first condition as well as the second. However, the test in condition 2 shows a slightly underestimation that can be explained by the not-catch into account infiltrations of the cell, for a standard deviation from 0.2 to 0.3 occupants. On this subject, we could easily prove that mechanical ventilation is used as a supplement to air flow leaks. From now on, we will see how to take into account this ”measured occupation” in order to control a variable speed extractor fan.

REGULATION OF A VARIABLE SPEED EXTRACTOR FAN

Analytical control function

From now on, we are able to evaluate the quantity of emitted CO_2 in the room. A suitable ventilation rate Q^{new} is looked for to stabilize the CO_2 concentration at the rough value C^{target}. Then, during the stationary period the Eqn (1) becomes (3):

$$\sum_{i=1}^{N_{occ}} Q^{i}_{pol} = Q^{new}_{cv} . (C^{target} - C^{ext}) \tag{3}$$

By eliminating the known term $\sum_{i=1}^{N_{occ}} Q^{i}_{pol}$, (1) and (3) give relation (4):

$$Q^{new}_{cv} = \frac{V_0}{C^{target} - C^{ext}} \left(\frac{\partial C^{int}}{\partial t} \right) + \frac{C^{int} - C^{ext}}{C^{target} - C^{ext}} Q^{old}_{cv} \tag{4}$$

Following the example of (2), Eqn (4) represents again the formulation of a three-input analytical function to control a variable speed extractor fan. In addition, the desired target C^{target} and the volume V_0 of the room are needed to initialize this analytical controller. The applicability of this function (4) is studied on HybCell and its numerical model.

Controller test on HybCell

A test on an intermittently occupied office (from 0 to 5 occupants) has been prepared during a one day long period, in order to test and analyze the regulator precision and stability. We consider the same data capture step and gradient evaluation as for the ”occupancy detection test”. The experimentation required on top of a 10 minutes waiting time, the addition of a break loop to stop updating actuator position, as soon as the CO_2 concentration belongs to the limit bande C^{target} more or less 50 ppmv. The evolution of the control sequence is shown on figure 2.

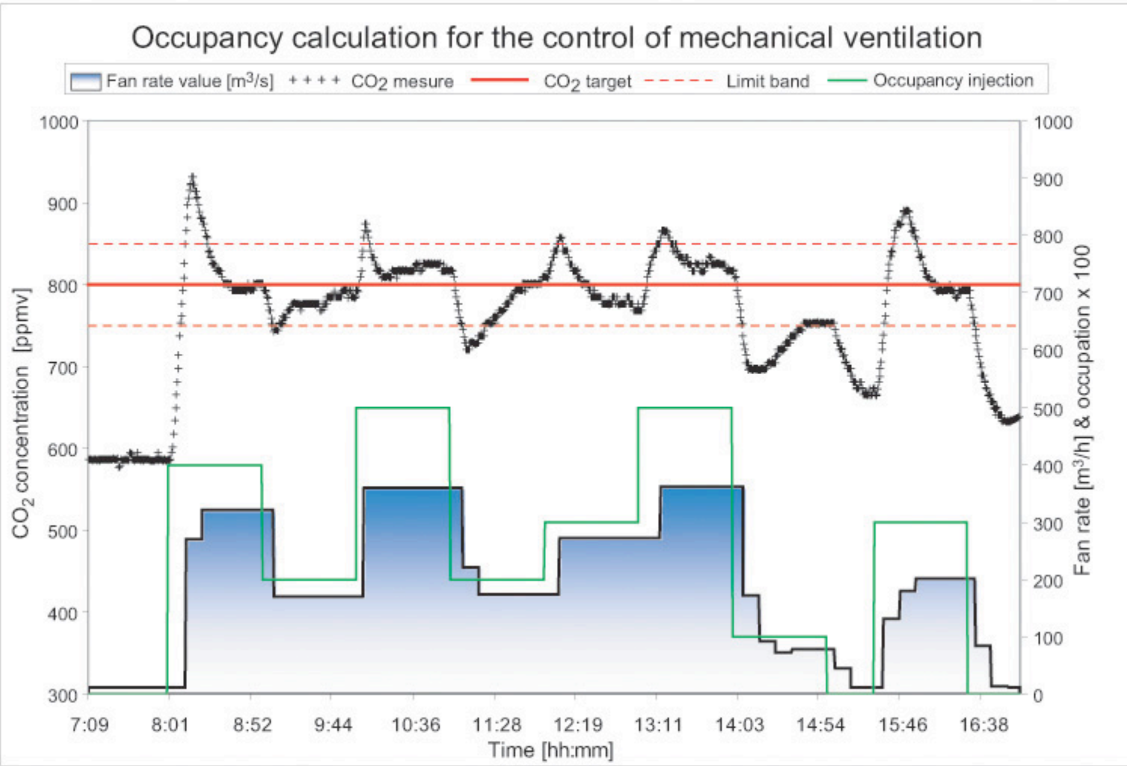

Figure 2: Experimentation of the analytical control function on HybCell

Therefore, a direct relation between occupation changes and fan speed adaptation has been noticed. At 8 am, a four occupants arrival is scheduled and the controller assesses a first level of ventilation. Only one or two updates are necessary to adjust and stabilize the suitable fan speed, according to the indoor air quality choice. Others tests have been proceeded for different C^{target} with no degradation of the actuator stability. Lastly, we have a confirmation that the indoor air quality control can be at the same time precise, reliable (maximum of 930 ppmv during a few minutes), stable and easy to parameterize.
Finally, the period of experimentation has showed a quick reaction to find the occupancy density in Hybcell and then to command the suitable airflow rate.

PERFORMANCE EVALUATION ON THE HYBCELL 1.0 MODEL

Simulation tools

In order to compare the controller performances, two reference mechanical systems were considered and tested with the numerical model of HybCell, such as:

- ”Ideal controller”: The system ”knows exactly” the number of occupants in HybCell, and controls the proper fan speed to reach 800 ppmv.
- ”Permanent ventilation”: A constant supplied airflow rate of 108 $m^3 h^{-1}$ for a maximum of 3 persons occupancy is kept.

Lastly, HybCell temperature is controlled by On/Off controller to maintain the PMV inside [-0.5;0.5] with a 2000 W convector heater. Table 1 below summarizes the cost evaluation in winter on Lyon (France), for a 15 day long numerical simulation for different CO_2 targets, following a multicriteria analysis (El Mankibi and al 2004).

C^{target} [ppmv]	**800**	**900**	**1000**	**1100**	**1200**	**Ideal**	**Permanent**
Overall Performance	27.6	26.8	26.5	26.6	26.8	27.5	32.1
PMV $>$ 0.5	0.01	0.01	0.01	0.01	0.01	0.01	0
PMV $<$ -0.5	0.01	0.01	0.01	0.01	0.01	0.01	0
Indoor Air Quality	0.02	0.32	0.74	1.29	1.74	0	0
Ventilator stability	0.83	0.84	0.85	0.87	0.92	0.71	0.14
Windows stability	0.99	0.99	0.99	1.01	1.09	0.99	0.20
Energy cost	23.9	22.8	22.1	21.5	21.2	23.9	30.1
Energy profit	20%	24%	27%	28%	30%	20%	0%

Table 1: Evaluation of the fan speed controller thanks to an aggregated function

Actuators stability

The actuators stability of HybCell active equipments is mainly dependent on their lifespan. Actually if the HybCell fan starts, the motorized window opens until the fan stops. Furthermore, the fan speed changes depend on the regulator demand. The fan actuator stability will be hit harder within the framework of the ”ideal controller” than for ”permanent ventilation”.
The actuator stability costs, compared with ”ideal” case, are quite similar. Others tests have been carried out to evaluate the stability of our controller compared to an On-Off controller for fan. Results have shown that the use of such controller could

generate, according to the parameter setting, an important increase of the frequency of the cycles Open-Close for the commanded window.

Energy saving

The last line of Table 1 shows the energy gains according to the ventilation system. Therefore the energy aspect dominates the overall performances of the controllers. A fall in the heating consumption (about 20 % to 30 %) is expected with respect to the ”Permanent ventilated building” according to the indoor air quality chosen. As a result, that kind of techniques could be an efficient tool to reduce energy saving.

Overall performance

Table 1 shows an improvement in the overall performance for the control function from 14% to 17 % compared with ”Permanent ventilation” (from 26.5 to 27.6 compared with 32.1). Then, we can notice that its performance for an 800 ppmv target is close to the ”ideal” case (27.6 against 27.5), even slightly better for a 1000 ppmv target (26.5). However, the energy gains become insufficient in relation to the deterioration in the indoor air quality. As a result, we can consider this controller as a good compromise to improve the working conditions.

CONCLUSIONS

A three input regulated system of the mechanical ventilation has been tested and evaluated with experimental and numerical tools (HybCell and its model). Its large advantage remains mainly the fan actuator stability contrary to ON/OFF controllers, and a regulation adapted as well to the number of occupant, as its occupation schedule. The air quality target can be freely chosen and airflow extraction is independent of natural air exchange rate due to leakage. Thus, the only approximate knowledge of the room volume is necessary to the phase of setting parameter, which avoids us the long ones and expensive periods of adjustment such as PID controller. In addition, energy savings are about 20% to 30% according to the indoor air quality considered.

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