Assessment of Ventilation's Control Strategies adapted to Large Buildings

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ABSTRACT

The absolute necessity of air renewal to maintain indoor air quality and thermal comfort in buildings faces the major issue of energy consumption reduction and optimisation in building sector. Many studies carried out so far point out the performances improved thanks to the recourse to ventilation strategies and control algorithms in the aim of optimising the energy consumption of air renewal, but very few of them could assess the performances in the particular case of large buildings despite the potential energy gains it represents considering the great volume and huge air flow rates induced. Due to particular geometry, dimensions and occupancy in large buildings, new parameters have to be integrated in the development of ventilation's control strategies adapted to such buildings that the work presented aims to assess.
The studied controllers adapted to large buildings and the results of their assessment are described, analysed and discussed throughout this paper.
Through experimental set-up and numerical development of a CFD model of a study case of large building, ventilation's control strategies, integrating fuzzy logic, are first worked out, then assessed with both experimental measurements and numerical simulations. The strategies are based on the human occupancy considered unsteady in large buildings and changing in both space and time, which allows not uniform air change rates inside the air distribution system.
Results of assessment, by means of definition of performances functions, stress the good performances of the developed controllers in terms of indoor air quality, thermal comfort and energy consumption limitations. It has appeared that the ventilation's control strategies allowed to reach satisfactory interior environment regarding indoor air quality and thermal comfort criteria, while the energy consumption of air renewal and air conditioning device could be largely reduced.

KEYWORDS

Ventilation, Control, Large Buildings, CFD, Fuzzy logic, Indoor Air Quality, Thermal Comfort.

INTRODUCTION

Large buildings, due to specific geometry, dimensions and uses, induce particular unsteady occupancy changing both in space and time. The link between occupancy and renewal air flow rates needs allows non uniform air change rates throughout the whole building. The development of ventilation's control strategies, defining local air flow rates, could then determine flow rates in direct relation to the effective local needs. As an aim to the controllers, indoor air quality and thermal comfort have to be reached with the lowest energy consumption. Regarding the highly intermittent and localized activities, large buildings could offer high potential gains on energy consumptions by means of local control ventilation strategies (Barbat, 2000).

Considering the issue of developing such strategies, both pollutant dispersal and heat transfer models, based on CFD codes have been developed in Science Buildings Laboratory (LASH) in Lyon and used for testing of established control ventilation strategies by means of performances functions.

EXPERIMENTAL AND NUMERICAL SET-UP

A premise of the Science Buildings Laboratory (LASH) was used for the setting of the experimental device. It presents all the geometrical characteristics of a large building as well as a complete ventilation, warming/cooling system with an air distribution network perfectly adapted to field testing.

A global heat transfer and pollutant dispersal model of the experimental premise has been developed, using commercial CFD code Fluent®, to perform numerical testing of the ventilation control strategies. The model can provide air flow rates, CO_2 concentrations and air temperature inside the all premise such as shown below (Figures 1 & 2).

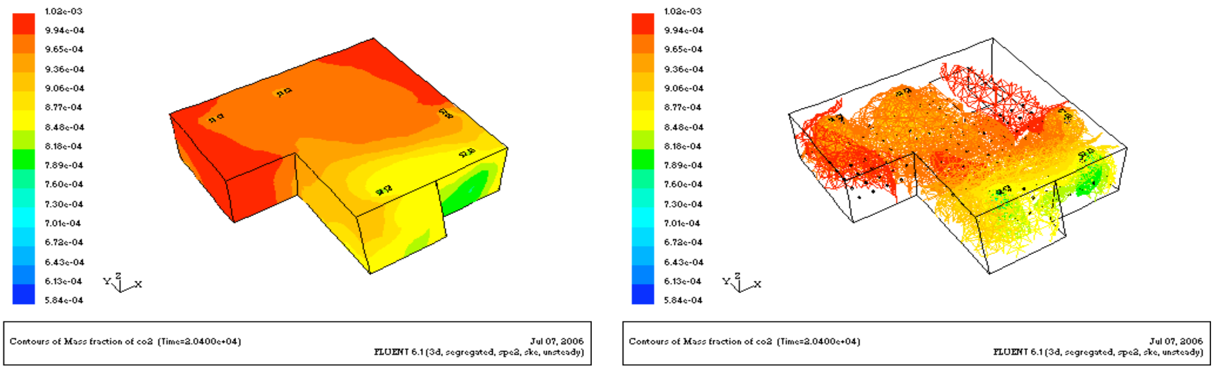

Figure 1 : Visualization of CO_2 dispersal simulations

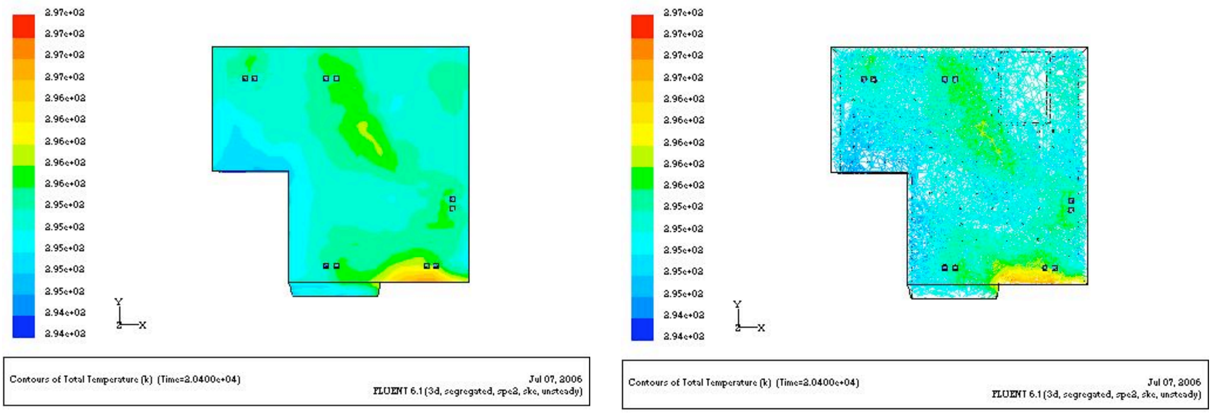

Figure 2 : Visualization of temperature distribution simulations

VENTILATION CONTROL STRATEGIES AND PERFORMANCES FUNCTIONS

Strategies definition's principles

Ventilation control strategies presented below define a global air renewal flow rate equal for each strategy. A local air flow rate is then calculated depending on the occupancy and the strategy considered. Practically, local air flow rate is obtained thanks to VAV and diffusers at the end of the air distribution network.
The occupancy is calculated by means of a geometrical decomposition of the experimental premise. Five areas are defined corresponding to one diffuser and VAV associated as presented on next figure (Figure 3).

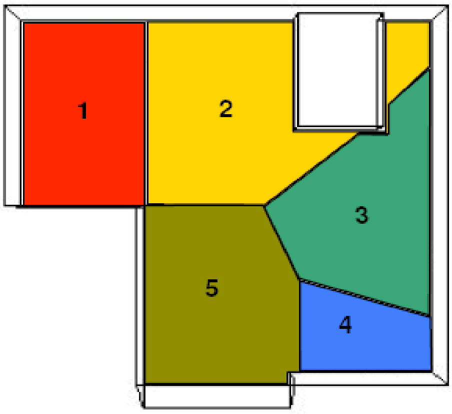

Figure 3: Geometrical decomposition of the experimental premise.

The global air flow rate is defined by taking into account two values of CO_2 concentration's consign of 800 ppm and 1000 ppm. The recommendations, given by AIVC's guide (Liddament, 1996), offer for each consign the corresponding global air renewal of 10 and 7,5 $l.s^{-1}.person^{-1}$.

The local air flow rate is calculated depending on the strategy by means of fuzzy logic. Four main strategies are studied forward. The first one, considered as a reference, does not take into account the local occupancy and define the same air flow for each of the five areas described above. Second one consisted in blowing and extracting air in the only occupied areas. Third one blows new air in occupied areas, depending on fraction of local occupancy compared to global occupancy, and extracts vicious air in unoccupied areas. Fourth one blows new air in unoccupied areas and extracts vicious air in occupied areas, depending on fraction of local occupancy compared to global occupancy.

Performances functions development

Two kinds of performances functions have been developed to assess ventilation control strategies depending on the issue of assessment. The First one would take care of indoor air quality only while the second one would consider global performances.

The performances function F_1 described below aims to assess control ventilation strategies regarding indoor air quality criteria, based on a relation between CO_2 concentrations and dissatisfied percentage (Bienfait et al., 1992).
To be more precise in assessment of strategies, F_1 is determined both in the all premise with $F_{1,GLO}$ and in the only occupied areas $F_{1,LOC}$.

$$F_{1,GLO} = \frac{\sum_{i=1}^{N} 395 exp\left(-15,15\left(\left[CO_2^{int}\right]_{i,GLO} - \left[CO_2^{ext}\right]_i\right)^{-0,25}\right)}{N}$$

$$F_{1,LOC} = \frac{\sum_{i=1}^{N} 395 exp\left(-15,15\left(\left[CO_2^{int}\right]_{i,LOC} - \left[CO_2^{ext}\right]_i\right)^{-0,25}\right)}{N}$$

A second performances function F_2, described below and based on previous works (El Mankibi, 2003), aims to assess globally the control ventilation strategies thanks to multi criteria considerations. It integrates indoor air quality, thermal comfort, energy consumptions and equipments stability criteria by defining pounds for each.

$$F_2 = \frac{1}{Ndt}\sum_{i=1}^{N}\left(\alpha_{IAQ}C_{IAQ}^{i} + \alpha_{Th}C_{Th}^{i} + \alpha_{Energy}C_{Energy}^{i} + \alpha_{Stab}^{Ventilators}C_{Stab}^{Ventilators\,i} + \alpha_{Stab}^{Engines}C_{Stab}^{Engines\,i}\right)$$

Indoor air quality criterion considers the difference between indoor CO_2 concentration and consign defined and pound associated is calculated determining air renewal needs to reach the consign :

$$C_{IAQ} = max\left\{\left[CO_2\right] - \left[CO_2\right]_{cons} ; 0\right\}$$

$$\alpha_{IAQ} = \frac{6}{6000}\left(\frac{3600.V}{C_{cons} - C_{ext}}\right)\left(\frac{C_{kWh}}{3600}\right)$$

Thermal comfort criterion and pound are defined on the same way by :

$$C_{Th} = \left|T_a - T_{cons}\right|$$

$$\alpha_{Th} = \frac{\rho.V.c}{3600.1000}.cost$$

Energy consumption criterion and pound are calculated by :

$$C_{Energy} = \sum_{Equipments} P_k$$

$$\alpha_{Energy} = \frac{0,103.dt}{3600.1000}$$

Equipements stability criterion and pounds are defined as below:

$$C_{Stab}^{Equipment} = \begin{cases} 1 & if\ change\ of\ state \\ 0 & if\ not \end{cases}$$

$$\alpha_{Stab}^{Engines} = 1,5.10^{-3} \quad €/operate$$

$$\alpha_{Stab}^{Ventilators} = 1,43.10^{-2} \quad €/operate$$

CFD SIMULATIONS AND STRATEGIES ASSESSMENT

CFD Simulations

CFD Simulations have been performed in order to assess the developed ventilation's controllers. The simulations have been defined so as to provide a wide panel of limit conditions in terms of meteorological conditions and human occupancy's conditions.
As a result, simulations of successively light, heavy, grouped, separated occupancy during summer time and winter time have been used to assess controllers.
As an illustration, next figure (Figure 4) gives a graphical representation of a two days long simulation during summer time with various occupancy for controller n°3. It represents the CO_2 concentration evolution in each of the five areas and in the global premise.

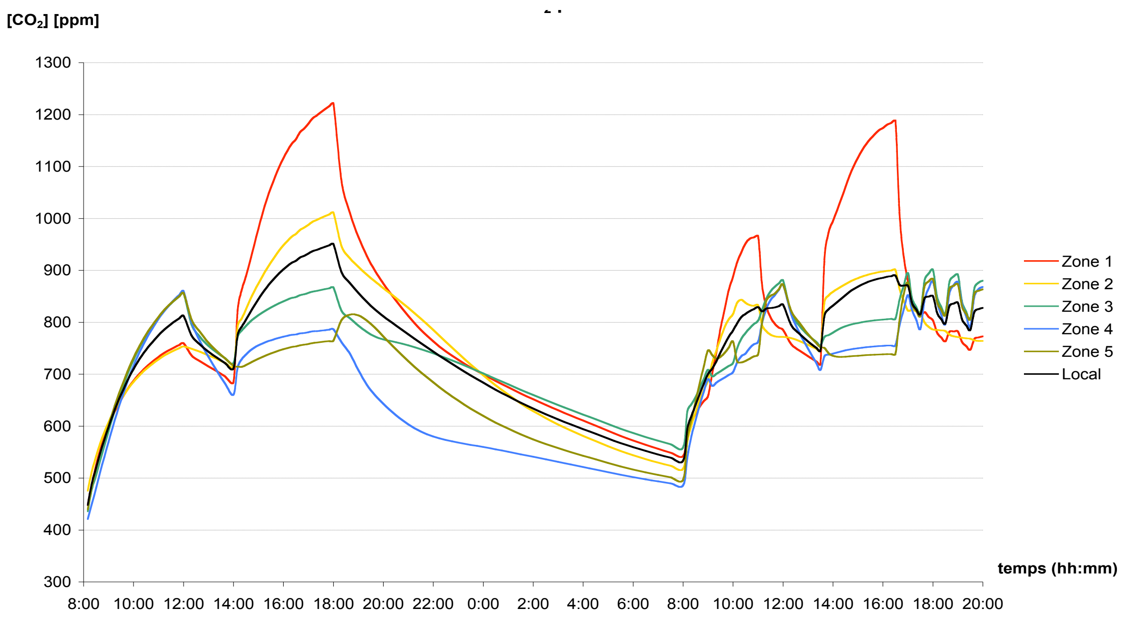

Figure 4 : CFD Simulation of controller n°3.

Controllers assessment and conclusions

Next table illustrates the result of performances functions F_1 and F_2 for a same simulation during summer time with various occupancy for the four controllers.

TABLE 1
Assessment of controllers

	Controller n°1	Controller n°2	Controller n°3	Controller n°4
$F_{1,GLO}$ [%]	10,34	13,10	12,52	9,51
$F_{1,LOC}$ [%]	11,22	12,38	11,15	11,21
F_2 [€.s^{-1}]	3,79.10^{-5}	4,61.10^{-5}	2,82.10^{-5}	2,77.10^{-5}

Regarding table 1, the performances of the controllers appear to be various from one controller to one another. Table 1 stresses the good performances of controller n°3 and n°4 both in terms of indoor air quality, considering function F_1, and in terms of global performances, considering function F_2. Comparing to controller n°1 defined as a reference controller, the global gain of controller n°3 reaches 25% and the global gain of controller n°4 reaches 27%.

Results of assessment, by means of definition of performances functions, stress the good performances of the developed controllers in terms of indoor air quality, thermal comfort and energy consumption limitations. It has appeared that the ventilation's control strategies allowed to reach satisfactory interior environment regarding indoor air quality and thermal comfort criteria, while the energy consumption of air renewal and air conditioning device could be largely reduced.

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