EXPERIMENTAL EVALUATION OF SUPPLY-ONLY VENTILATION EFFECTIVENESS

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ABSTRACT

Nowadays, indoor air quality has become a major concern. Regarding the fact that people spend most of their time indoors, it is necessary to study the performance of the ventilation system in order to limit the risks on occupants' health. This study evaluates the ventilation effectiveness of supply-only ventilation (SOV) and extract-only ventilation (EOV) in terms of air exchange efficiency and contaminants removal effectiveness. These indicators are measured as function of air change rate and inlet/outlet devices positions using the gas tracer technic. The results show that air change rate has no influence on the air change efficiency but on room mean age of air. Also it shows that the effectiveness of SOV could be better than EOV.

KEYWORDS
Supply-only ventilation, contaminant removal effectiveness, Air change efficiency.

INTRODUCTION

Several decades ago, dwelling's ventilation wasn't an important issue for builders. Indeed, houses were leaky enough to provide adequate air exchange. Yet, air leaks were at the same time energy leaks representing an important problem and especially after the crisis in 1973. And since the thermal discomfort and high energetic bills are more noticed by occupants than poor indoor air quality (IAQ), building's airtightness took more designer's attention and became essential in construction design. However, more dwellings are made airtight, greater the impact of internal pollutant sources on IAQ and occupants health unless ventilation is effective. This emphasizes the need for good ventilation design. Today, beside the natural ventilation, there are three basic types of residential ventilation system: exhaust-only, supply-only and balanced.

In this context, several studies have been dedicated to the improvement and characterization of different ventilation systems [1][2][3]. However, there is a critical lack of information and knowledge regarding the supply only ventilation (SOV).

This study is about evaluating the SOV effectiveness as a function of air exchange rate and diffuser location. Also, it shows the major differences that impose exhaust only ventilation positioned in the same conditions. The experiments were carried out in a full scale laboratory cell test where the gas tracer technic is used to assess the ventilation effectiveness.

VENTILATION EFFECTIVENESS

As awareness and concern about efficient ventilation increase, so does the research for developing different methods and IAQ indicators to evaluate the ventilation process. For example, we find in the literature [9]:

- Number of air changes (N_{AC}) which gives information about the intensity but not the quality of ventilation system
- Ventilation effectiveness (Ev) as a function of recirculation rate (r) and a fraction of the supply air (s) that bypasses directly to the exhaust. Still, there's no information provided by standards for the calculation of (s).
- Also, we can find large number of new IAQ indicators that have been developed by Japanese researchers, who concentrated on airflow characteristics such as SVE1 and SVE2.

Nevertheless, the most common used indicators are those defined by Sandberg and Sjoberg in 1983 which are based on the air age concept [5][6][7]: the air change efficiency ε^a and the contaminant removal effectiveness ε^c. These indices appear to be the most suitable for use in design and standards because they are wide and almost all other indicators are an extension of both of them [9]. In addition, considering average or local values, ε^a and ε^c can provide information about the overall room ventilation quality or in a particular point in the room or maybe larger such as breathing zone.

Furthermore, Skaaret [6] has defined 3 basic rules for effective ventilation. At the design stage, the ventilation should be designed to give an (1) ε^a above 50%, (2) a local age in the breathing zone lower than the room average, i.e. ε_p^a>1 and (3) ε^c greater than 1 and a lower concentrations of contaminants in the zone of occupation than the room average i.e. ε_p^c>ε^c.

Air change efficiency ε^a

Air change efficiency characterises the mixing behaviour of incoming air with the air already present in the room [8] and it is independent of the distribution and emission characteristics of pollutants.

ε^a is defined as the ratio between the shortest possible time needed for replacing the air in the room $\tau_n/2$ and the actual air change time $<\tau>$

$$\varepsilon^a = \frac{\tau_n}{\bar{\tau}_r} = \frac{\tau_n}{2 < \bar{\tau} >} \qquad (1)$$

Where $<\tau>$ is calculated by measuring the tracer gas concentration at the exhaust:

$$< \tau > = \frac{\int_0^{\infty} t.C_e(t)dt}{\int_0^{\infty} C_e(t)dt} \qquad (2)$$

Local air change efficiency (ε_p^a) is defined as follows:

$$\varepsilon_p^a = \frac{\tau_n}{\bar{\tau}_p} \qquad (3)$$

Where $\bar{\tau}_p$ is the local mean age of air at point P.

Contaminant removal effectiveness ε^c

Contaminant removal effectiveness characterizes the ability of the ventilation air to dilute and remove pollutant from the room. It depends on the source intensity and location. This index is defined as the ratio between the nominal time constant of the ventilation air and the turnover time for the contaminant (τ_t^c)

$$\varepsilon^c = \frac{\tau_n}{\tau_t^c} \qquad (4)$$

Also, it can be expressed in terms of steady state pollutant concentrations:

$$\varepsilon^c = \frac{C_e - C_s}{< C > - C_s} \quad (5)$$

Where: C_e, C_s *and* $< C > C_e, C_s$ *and* C_p are the pollutant concentrations in the exhaust, supply and the average room concentration.

The local air quality index can be obtained by substituting $< C >$ in the equation (5) by C_p, the pollutant concentration in the point of interest p:

$$\varepsilon_p^c = \frac{C_e - C_s}{C_p - C_s} \quad (6)$$

METHOD

Experimental set-up

Measurements were carried out in a 35m^3 test cell (4.28 × 3.14 × 2.6) composed of steel panels (Figure 1). The airtightness of the room was determined by a BlowerDoor test and with a pressure difference of 50 Pascal, (n50) is about 1.4 vol/h. Air temperature (type K thermocouple), air velocity (TSI 8475 omnidirectional transducer) and carbon dioxide concentrations (Vaisala GMM 222) were acquired at three different heights: 0.1m (ankle), 1.1m (head of a sitting person) and 1.7m (head of a standing person) and at nine different positions in the room, resulting in 27 sampling positions inside the room. Additionally, temperature and carbon dioxide concentrations were measured in the inlet and exhaust ducts, and the temperature of the walls were estimated with five type K thermocouples per wall to ensure that the tests were performed in isothermal conditions. The inlet flow was determined with a Höntzsch ZS25 vane anemometer. The measurements were performed every 30 seconds and acquired on two Campbell Scientific CR1000 data loggers. Occupancy was modelled by two cylindrical manikins, with carbon dioxide being supplied at a height of 1.1m for each manikin, through a diffusing device.

Two types of ventilation strategies were assessed: supply-only and extract-only, and three ventilation configurations were taken into account (Figure 2):

- Configuration A: upper wall supply/extract and lower-opposite air output/input,
- Configuration B: upper wall supply/extract and lower-side air output/input,
- Configuration C: Ceiling supply/extract and lower air output/input.

For each configuration, four different air change rates were considered (0.5, 1, 1.5, 2.5 ACH). Depending on the configuration, the air terminal device employed varied. For A and B, part of the air was supplied toward the ceiling at an angle of 270° and the other part was supplied axially. For C, 10% of the air was supplied axially and the remaining part was supplied toward the ceiling at an angle of 360°.

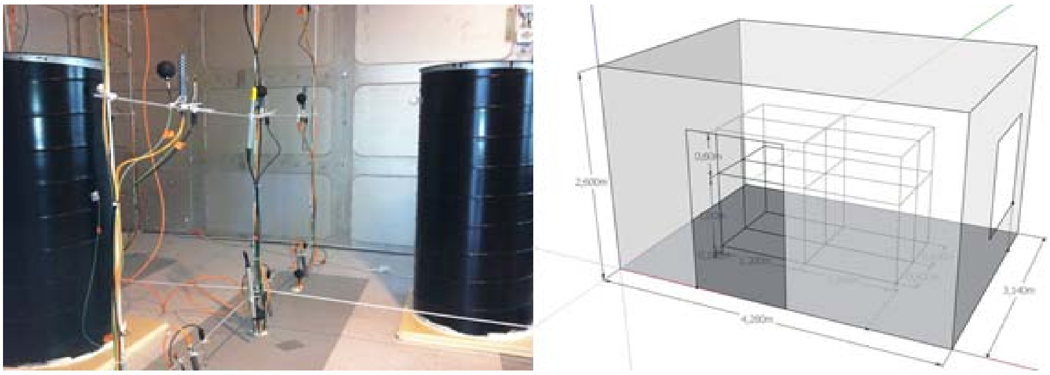

Figure 1-Experimental chamber

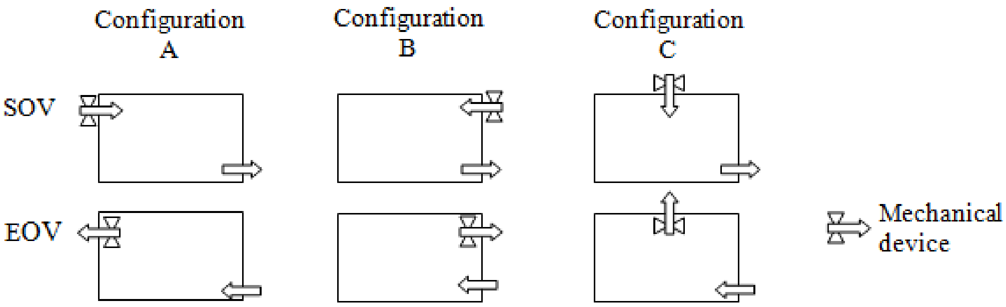

Figure 2- Three different configurations in combination of two types of ventilation

Test procedure

The tracer gas concentration decay technic (step-down method) was used to measure the ability to exchange air in the room. The mixing fan was turned on and the CO2 released rapidly. After obtaining a suitable level and homogenous concentration in the room, the gas supply and the mixing fan was switched off along with switching on the ventilation system. Then the concentration decay at the 29 sampling points is recorded every minute.

For measuring the ability of the ventilation system to remove pollutant, the CO2 is released continuously by both occupants at a rate of 18 L/h/occupant while the ventilation system was kept on. When steady-state conditions are reached, the concentration in the 27 sampling points and in the exhaust are measured for local $\varepsilon_p^c \varepsilon^c$ calculations. The CO2 sources were then stopped and the decay concentration at the exhaust is recorded for the calculation of the turnover time of contaminant τ_t^c meanwhile of global ε^c. Each test was repeated in order to verify the repeatability of the measurements.

ANALYSIS OF AIR CHANGE EFFICIENCY

Influence of air change rate N_{AC}

The configuration A was chosen to study the influence of the air change rate on the ventilation effectiveness in term of replacing the existing air in the room by new fresh air. Figure 3 (a) and (b) present the results for the room mean age of air $\langle \tau \rangle$ and the air change efficiency ε^a respectively for SOV and EOV systems.

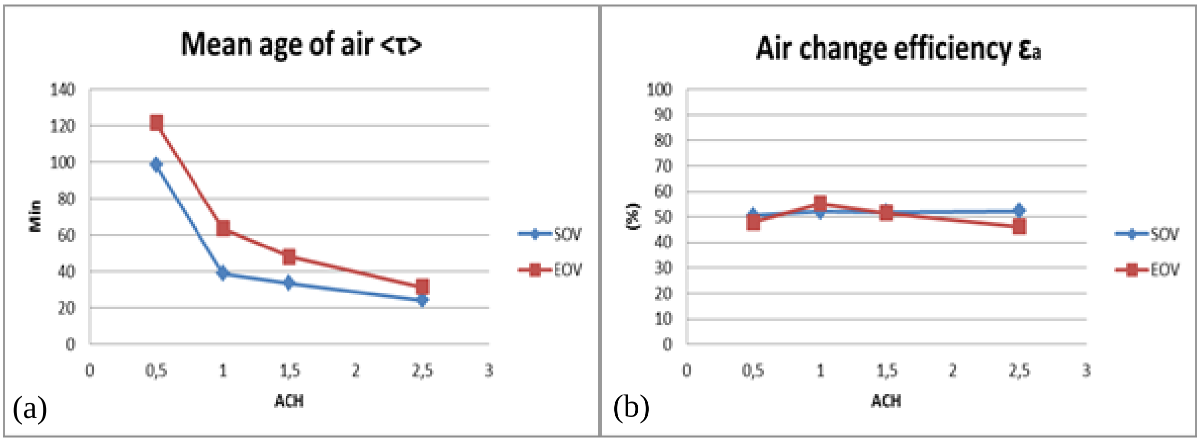

Figure 3-(a) Mean age of air and (b) air change efficiency of configuration A as a function of air change rate

For the EOV system, the room mean age decreases with increasing the N_{AC}, which returns to the fact that the air velocity is proportional to the air flow rate. Therefore by increasing the N_{AC} the new air reaches the entire room rapidly. In addition, it's so remarkable that for 0.5 Ach, an air change rate typically used in residential ventilation, <τ> is much higher than for the other N_{AC}. The difference between 0.5 and 1 Ach (~58 min) is almost 2 times greater than between 1 and 2.5 Ach (32 min). As for the air change efficiency ε^a, it varies slightly around 50 % which correspond to the usual value of perfect mixing ventilation.

On the other hand, the SOV system presents the same decay of room mean age as for EOV but with lower values. The difference is ranged between 10 min for 2.5 Ach and 24 min for 0.5 Ach. Also, the ε^a is almost constant and equal to 50%, which means that, for both systems, the air change rate (N_{AC}) has no influence on the air change efficiency.

Finally, the two systems present the same efficiency, though the measurement of the room mean age shows that SOV replaces the born air faster than EOV. It's believed that the evaluated τ_n of SOV is lower than the real value. Indeed, the SOV maintains a positive pressure in the room, so the air leakages contribute in the evacuation of the CO2 resulting in lower concentration at the exhaust.

Influence of air terminal devices position

The ventilation effectiveness depends on the air flow pattern which in its turn is related to the inlet and outlet devices positions. Therefore a comparison between three different and realistic configurations (A, B and C) was performed. An N_{AC} of 1 Ach was chosen, since it implies a lower mean age of air than for 0.5 Ach and above it, the decay of <τ> is small

For the EOV system, Figure 4 (a) shows that configuration A presents the lowest room mean age (~62 min) followed by B (~78 min) then C (~90 min). For the SOV system, A also presents the lowest <τ> (~40 min) while it is the same for B and C (~50Min). Whereas comparing the two mechanisms (supply/extraction), it's found that for EOV <τ> is globally higher than for SOV.

Figure 4(b) is a representation of the air change efficiency of the different configurations. The results displayed by configurations A and B, for both systems, are typical of perfect mixing ventilation (ε_a~50%). For configuration C, ε_a is about 40% for EOV system which indicates a short circuiting of the air while for the SOV, ε_a is about 62% (>50%) which means that the flow pattern tends to a unidirectional flow [9].

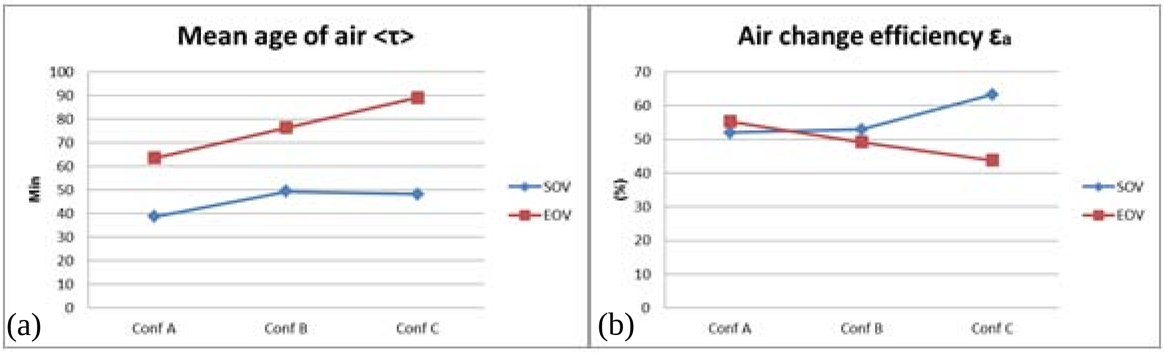

Figure 4-(a) Mean age of air and (b) air change efficiency of the three configurations

ANALYSIS OF CONTAMINANT REMOVAL EFFECTIVENESS

Influence of air change rate N_{AC}

These following results provide information about the ability of the studied ventilation systems to remove the pollutant emitted by a specific source (2 occupants releasing 18 L/h of CO_2).

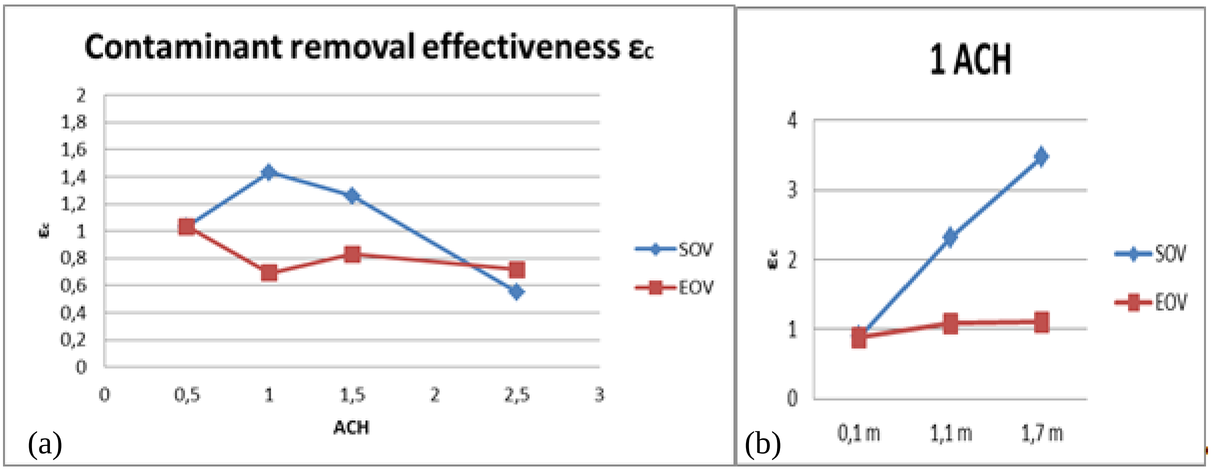

Figure 5-The results of contaminants removal effectiveness for configuration A

In the Figure 5 (a), the contaminant removal effectiveness is plotted as a function of the air change rate. It's noticed that for 0.5 ACH the two systems present an effectiveness of 1 which indicates that the mixing is complete and instantaneous and the pollutant source position does not have an influence [9]. In contrast, for the other N_{AC} values, their behaviour is different: as it is illustrated, for the SOV system, ε^c increases till a maximum value (1.4) for 1 ACH then decreases by increasing the air change rate till 0.6. It's believed that by increasing the velocity of the air flow, the air flow is short-circuited and the pollutant source is in the recirculation area, which is completely separated from the bypass area. As for the EOV, ε^c decreases till a minimum value (0.68) for 1 ACH then increase slightly with N_{AC}.

This different behaviour of the two systems can be referred to different reasons: position, form, and type of the air terminal devices. The SOV has a mechanical circular inlet positioned in the top of the wall and free rectangular outlet representing the bottom of the door while it's the opposite for the EOV.

In the other hand, Figure 5 (b) presents the contaminant removal effectiveness at different levels (0.1, 1.1 and 1.7m) for 1 ACH. The measurements show that for EOV system, ε^c is equal to 1 in the breathing zones of a standing and sitting person while for the SOV, ε^c is greater than 1 (~2.5 at 1.1m and 3.5 at 1.7m height). The latter meets the rules of Skaaret for effective ventilation [6]. These results can be explained by the fact that the air inlet for SOV is in the upper part of the wall, so the new air push the CO2 down to the outlet device. While for the EOV the inlet is in the lower part of the wall, so the pollutant is pushed up to the breathing zones before reaches the outlet.

Influence of air terminal devices position

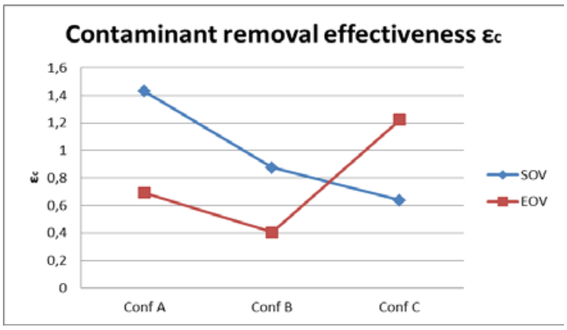

Figure 6- Contaminant removal effectiveness for the three configurations

For 1 ACH, Figure 6 illustrates the contaminant removal effectiveness for the three studied configurations. The results show that for configurations A and B, the SOV present the highest effectiveness while for the configuration C, it's the EOV. In fact, for SOV in configuration C the ceiling supply is radial and it's directly above the occupants, thus the new air can't reach the pollutant source rapidly. Finally, we can conclude that configuration A using SOV system presents the highest ε^c (1.4).

CONCLUSION

In this study, the ventilation effectiveness of supply-only ventilation (SOV) and extract-only ventilation (EOV) systems has been investigated by assessing two indicators: air change efficiency and contaminant removal effectiveness. The results show that 1 ACH can be a suitable air change rate for residential ventilation. In addition, the combination SOV-configuration C seems to be the most efficient in terms of replacing the air in the room while the combination SOV-configuration A is more adequate for removing contaminants released by occupants. The reason that the two indicators did not give the same tendency is that the behaviour of air and pollutant are different, especially when the pollutant is not uniformly distributed.

In the other hand, it's easier to measure ε^a than ε^c which depends not only on the airflow pattern but also on the intensity, area, and positions of contaminant sources relatively to this airflow pattern. Besides, the use of CO2 as a tracer gas has caused difficulties in evaluating the two indicators since it exists in the supply air.

More studies will be done to evaluate the SOV effectiveness in a passive house with real conditions (non-isothermal environment, effect of wind, more types and sources of contaminants).

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REFERENCES

[1] Koffi, J. F., Allard, F. Akoua, J. J., 2011. *Numerical Assessement of the performance of Ventilation Strategies in a Single-Family Building*. The international journal of Ventilation ISSN 1473-3315, vol. 9, No 4 march 2011, 337-350.

[2] Pavlovas, V. 2004. *Demanded controlled ventilation: A case study for existing Swedish multifamily buildings*. Energy and Building. 36. 1029-1034

[3] Olesen, B.W. et al., 2011. *Experimental Study of Air Distribution and Ventilation Effectiveness in a Room with Combination of Different Mechanical Ventilation and Heating/Cooling Systems*. International Journal of Ventilation ISSN 1473-3315, vol.9, No 4 march 2011, 371-383.

[4] Roberson, J.A. et al., *Recommended ventilation strategies for energy-efficient production homes.* 1998. Lawrence Berkeley National Laboratory LBNL-40378

[5] Sandberg, M. and Sjoeberg, M. 1983. *The use of moments for assessing air quality in ventilated rooms*, Build. Environ. 18, 181-97.

[6] Skaaret, E. 1986. *Contaminant removal performance in terms of ventilation effectiveness. Environment International*. 12, 419-427.

[7] Etheridge, D., and Sandeberg, M. 1996. *Building ventilation: theory and measurement.* John Wiley & Sons. 607-626.

[8] Liddament M.W. 1996. *A guide to energy efficient ventilation*. Air Infiltration and Ventilation Centre AIVC.

[9] Srebric J. 2003. *Comparison of air exchange efficiency and contaminant removal effectiveness as IAQ indices*. ASHRAE transactions, vol.109, part 2, 339-349.