AIR RENEWAL EFFECTIVENESS OF DECENTRALIZED VENTILATION DEVICES WITH HEAT RECOVERY

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ABSTRACT

Central ventilation systems with heat recovery have shown their limits especially within the context of building energy retrofit. The difficulties to install these systems in existing buildings, to find available space for devices, air ducts, silencers and fire dampers and to independently control the air flow in each room according to the real ventilation needs have led to an increasing market for decentralized ventilation devices.

A frequent criticism of decentralized devices is the poor ventilation effectiveness due to a high short-circuiting risk. Therefore, the University of Applied Sciences of Offenburg and the Frauhofer Institute for Solar Energy Systems are evaluating together the inside air quality reached with decentralized ventilation systems.

The tests described in this paper were performed in a test lab representing a single room were a decentralized ventilation system with heat recovery, heating and cooling functions was implemented. In a first part of the evaluation process, tests are realized to characterize the air distribution provided by the decentralized device by smoke visualization. The results are showing interesting differences between isothermal, heating and cooling cases.

The characterization of air distribution in the volume of the room is not enough to evaluate the capacity of a ventilation system to provide a good inside air quality. Therefore, a second series of tests was performed with CO_2 as a tracer gas, enabling a more precise quantification of the ventilation effectiveness. The results show the CO_2 concentrations over time in zones with different air renewal levels for each of the 3 modes.

KEYWORDS

Decentralized ventilation, Ventilation effectiveness, Heat recovery, Inside air quality

1 INTRODUCTION

The work presented in this paper is included in a research program aiming at evaluating ventilation concepts for the energy retrofit of residential buildings. Central and decentralized ventilation are compared on the basis of a full list of criteria including their energy performances, comfort, acceptance and life cycle costs.

As a part of this work, an analysis of the inside air quality provided by decentralized ventilation systems will be detailed here.

As no ductwork is necessary, decentralized ventilation systems are a very interesting solution to provide fresh air in retrofitted buildings where place is rarely available to install voluminous equipment. A frequent criticism against decentralized devices is their low ventilation effectiveness since the air inlets and outlets are often very close to each other risking a short-circuit inside the ventilated room as well as outside.

Decentralized ventilation systems have already been evaluated (Mahler, Himmler et al. 2008; Haase and Gruner 2013) but only a few studies have a specific focus on the ventilation effectiveness of these systems (Ender, Gritzki et al. 2004; Ajaji and André 2013). At the Wuppertal University, the microclimatic influence of the external side of the façade was investigated (Voß and Voss 2012) but not the short-circuiting risk.

At last, the combination of heating by warm air and ventilation was investigated by the Technical University of Denmark and the Slovak University of Technology but in a context of central ventilation (Krajčík, Simone et al. 2012).

The main goal of the study presented here is to evaluate a decentralized ventilation system including heating and cooling functions in different running modes.

In order to describe the capacity of decentralized ventilation to provide a good inside air quality, one parameter, the ventilation effectiveness, is often used with different definitions. A first possibility, related to smoke visualisation of the ventilation air movements, is based on time measurements describing how long the fresh air needs to reach each point of a room. A second definition, related to tracer gas evaluations, is based on concentration measurements in different points of the room and in the fresh and exhaust air (Mats 1981; Recknagel, Sprenger et al. 2007/2008).

2 DESCRIPTION OF THE TESTS AND EVALUATION METHODS

2.1 Ventilation device

The decentralized ventilation system tested here and shown on Figure 1 is foreseen to provide fresh air, to heat and to cool office rooms until 6m deepness. It includes 2 fans, 1 heat exchanger, 1 heating/cooling coil, 2 filters and can run with 3 different airflows.

Figure 1 Tested decentralized ventilation device

2.2 Test room

The decentralized ventilation device was evaluated in the test facilities of the University of Applied Sciences Offenburg. The room dimensions are 5,2 x 3,8 x 3 m^3. Two walls are producing heating or cooling loads.

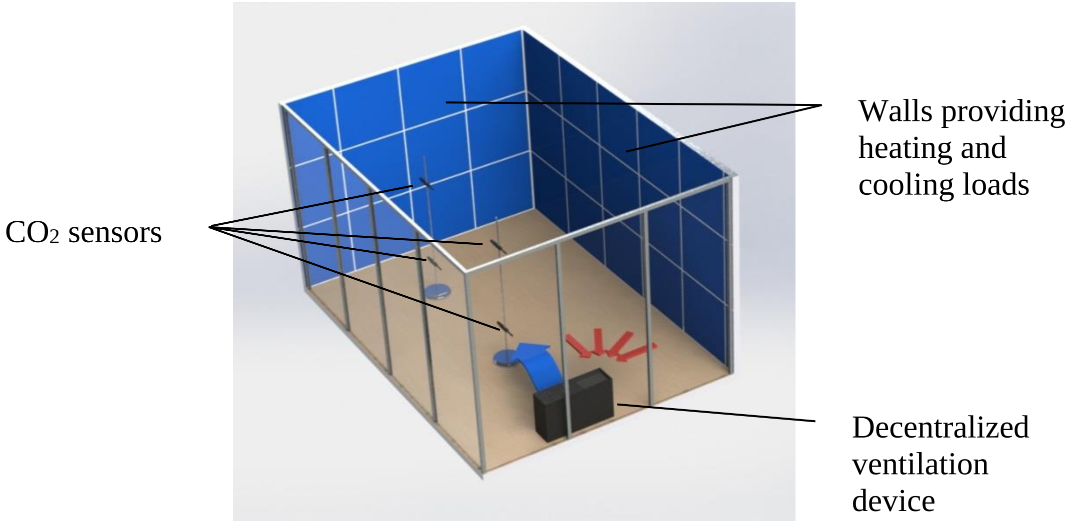


Figure 2 3D view of the test room and positions of the CO_2 sensors

2.3 Smoke visualisation

The first series of tests was done with smoke visualisation. We focussed on two dimensions in the area directly placed in front of the device. The first dimension was the deepness of the room so that we could verify that the device was able to treat a 5m deep room. The second dimension was the height which allows describing an eventual stratification of the fresh air provided by the ventilation device.

Figure 3 View of a smoke visualization test

In many test cases, the smoke was not visible any more before it filled the entirety of the room volume and in particular before it reached all of the four points were CO_2 sensors were placed. This phenomenon made it impossible to determine a ventilation effectiveness based on time measurements and could lead to the conclusion that the ventilation device is not able to treat the air in the whole room volume.

2.4 CO_2 measurements

The second series of tests was done with a tracer gas. As the main pollutants removed by ventilation systems are humidity and CO_2, we choosed CO_2 as a tracer gas. The choice of another tracer gas could have led to errors in the evaluation due to different behaviors of gases regarding the diffusion and mixing phenomenons in the air. To compare the results with the smoke visualisation, we used 4 CO_2 sensors placed in front of the ventilation device at horizontal distances of 1,5 m and 4 m and at 2 different heights (“Down”: 0,5 m and “Up”: 1,8m).

The room was filled with CO_2 and the analysis began after homogenisation of the 4 measured CO_2 concentrations as shown on Figure 4.

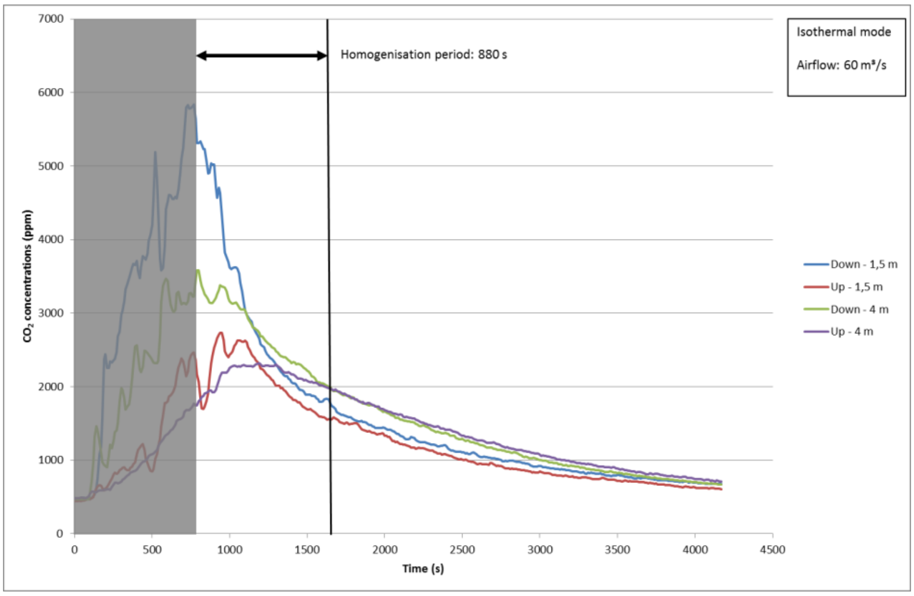


Figure 4 Example of CO_2 measurements including filling and homogenisation periods Isothermal mode (60 m^3/h)

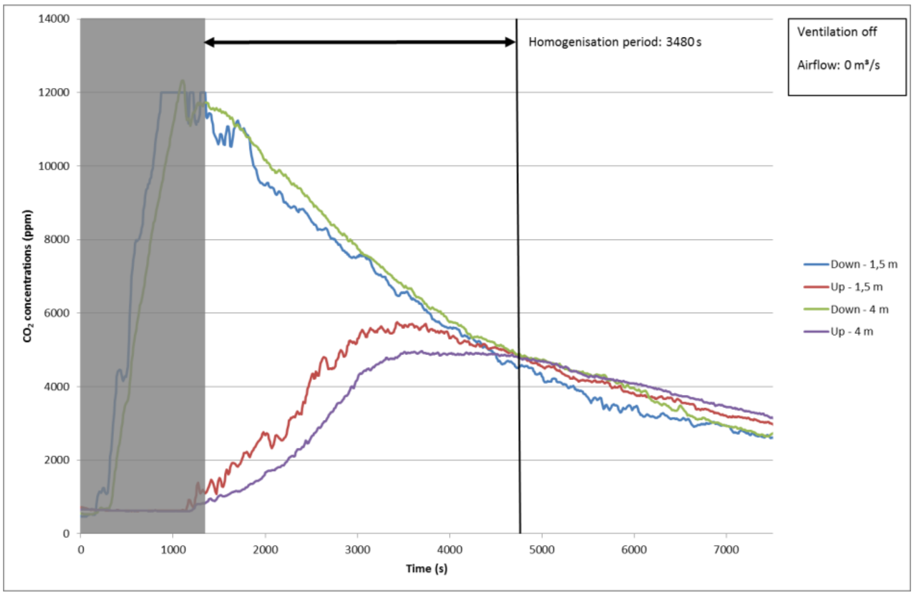


Figure 5 CO_2 homogenisation period without ventilation

A first conclusion can be drawn from the measurement of the homogenisation period which is the period where the CO_2 concentrations dynamyc is still due to the initial concentration differences. In order to define this homogenisation period, we used the theoretical evolution of each CO_2 concentration, having an exponential form ($c_{CO2} = c_0 + A.e^{-b.t}$). After the homogenisetion period, the measured concentration is actually close to the theoretical one. We considered that the end of the homogenisation period occurred as the difference between theoretical and measured CO_2 concentrations were lower than 5% of the initial difference.

We compared 2 different cases:

- ventilation off – corresponding to Figure 5
- ventilation on – minimal airflow (around 60 m³/h) – corresponding to Figure 4

The first one lasted around 3480 s, whereas the second one lasted only 880 s. This means that even set on its minimal airflow, the device is able to homogenise pollutant concentrations in the room which reduces short-circuiting risks.

In order to compared the diferent cases, we used the definition of the ventilation effectiveness proposed by Mats and Recknagel (Mats 1981; Recknagel, Sprenger et al. 2007/2008):

$$\eta = \frac{c_{\text{exhaust}} - c_{fresh}}{c_{average} - c_{fresh}} \qquad (1)$$

Where:

- η: ventilation effectiveness
- $c_{exhaust}$: CO_2 concentration in the exhaust air
- c_{fresh}: CO_2 concentration in the fresh air
- $c_{average}$: average CO_2 concentration of the 4 measured points

In our case, this effectiveness does not describe the capacity of the device to ventilate the whole volume of the room, but only the vertical plane situated in front of the ventilation device.

3 ANALYSIS OF ISOTHERMAL, HEATING AND COOLING MODES

An important part of the work is to compare isothermal, heating and cooling modes with both evaluation methods. The results presented here were obtained with a middle airflow (around 80 m³/h) with following temperatures:

- isothermal mode: $T_{\text{supply air}} = 22$ °C $T_{\text{room inside}} = 22$ °C
- heating mode: $T_{\text{supply air}} = 40$ °C $T_{\text{room inside}} = 23$ °C
- cooling mode: $T_{\text{supply air}} = 12$ °C $T_{\text{room inside}} = 24$ °C

3.1 Smoke visualisation

Figure 6 is presenting the results of the smoke visualisation tests. As mentioned in 2.3, the measurement of the time needed by the fresh air to reach each of the 4 points corresponding to the CO_2 sensors was not possible especially for the cooling mode. These pictures are showing important differences between each case. The repartition in the room of the fresh air provided by the ventilation device is good in the isothermal mode but in the cooling mode, the fresh air is only filling the lower part of the room and in the heating mode, only the upper part.

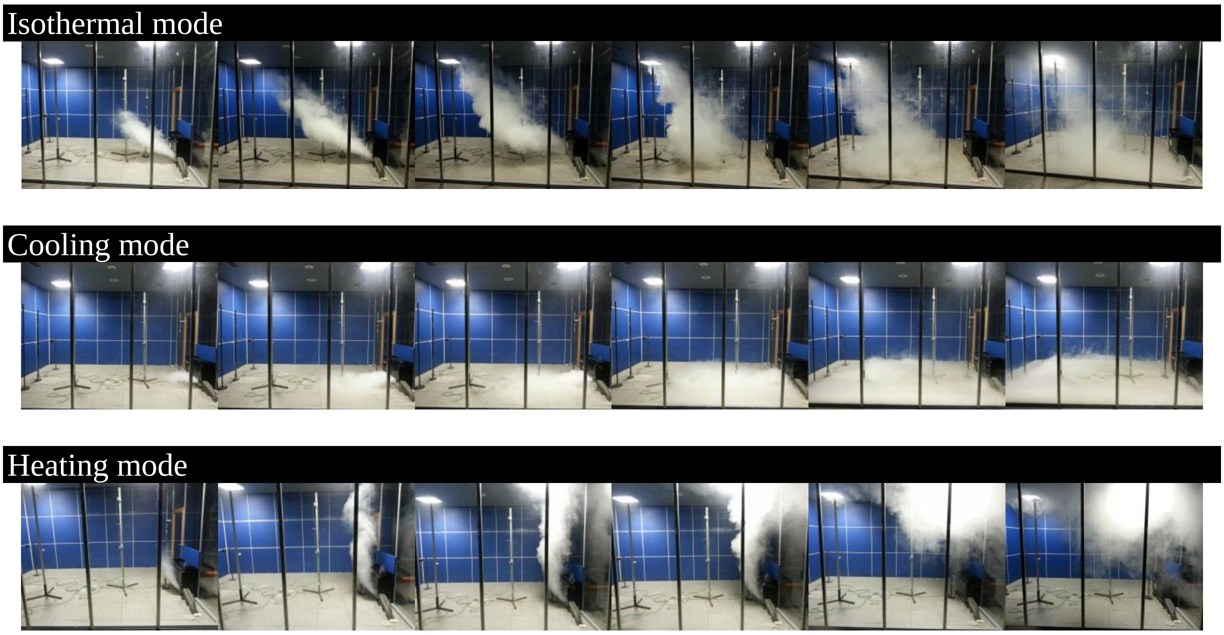


Figure 6 Smoke visualisations after 5, 10, 15, 20, 30 and 50 s for the 3 different modes

A purely qualitative analysis of these pictures leads to the conclusion that only one of these cases presents an acceptable air distribution.

3.2 CO_2 measurements

In order to quantitatively verify these results, Figure 7, Figure 8 and Figure 9 are presenting the CO_2 measurements obtained for the same cases.

A first observation can be done regarding the differences between the 4 sensors:

- Isothermal mode:
  The lowest CO_2 concentrations after homogenisation were obtained at the 2 points situated near the device. No stratification of the CO_2 concentration is appearing for this case (no difference between the upper and the lower sensors for both locations).
  The differences between the 4 measured concentrations and their average value remains under 15 %.

- Heating mode:
  The lowest CO_2 concentration after homogenisation was obtained at the upper point situated near the device. A vertical stratification of the CO_2 concentration only appears at the nearest location.
  The differences between the 4 measured concentrations and their average value also remains under 15 %.

- Cooling mode:
  The lowest CO_2 concentration after homogenisation was obtained at the lower point situated at 4 m from the device. A vertical stratification of the CO_2 concentration only appears at this location but not at 1,5 m from the device.
  The differences between the 4 measured concentrations and their average value are reaching 40 %.

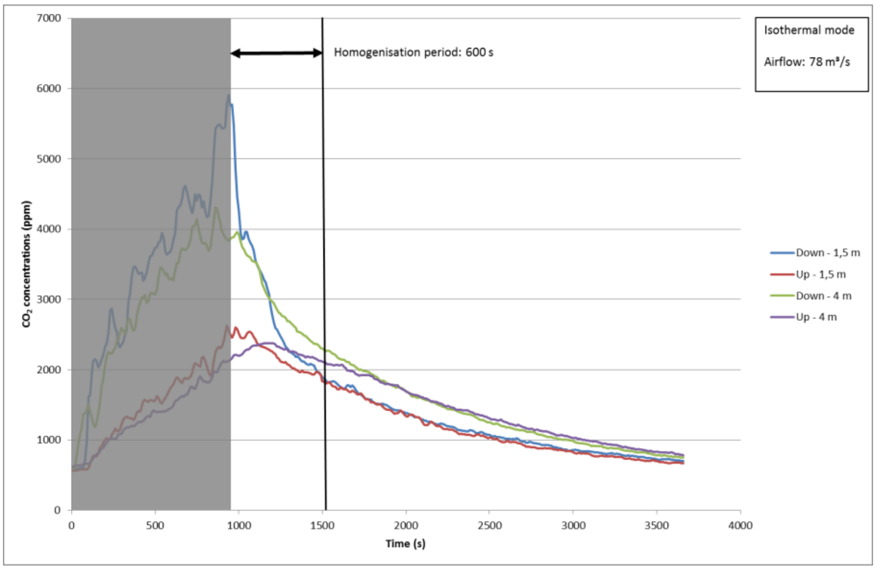


Figure 7 CO$_2$ measurements in isothermal mode (80 m^3/h)

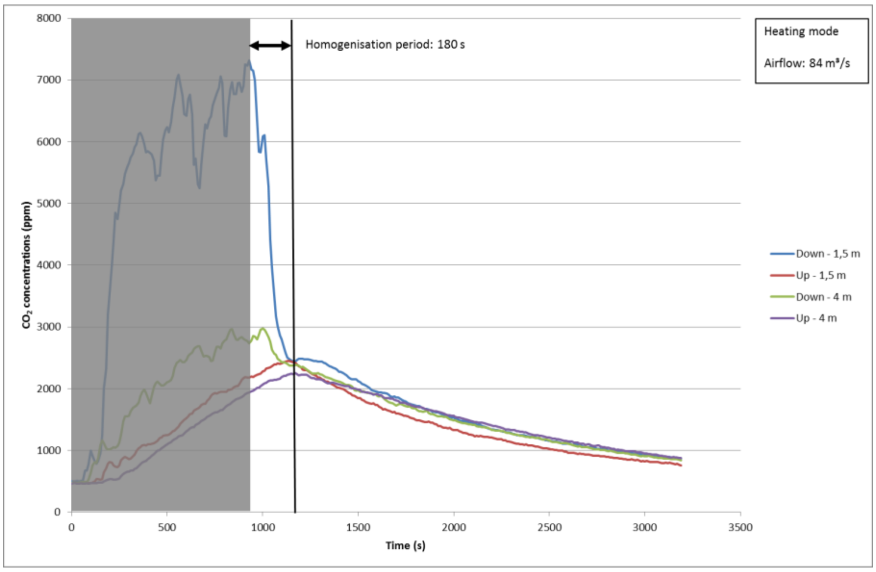


Figure 8 CO$_2$ measurements in heating mode (80 m^3/h)

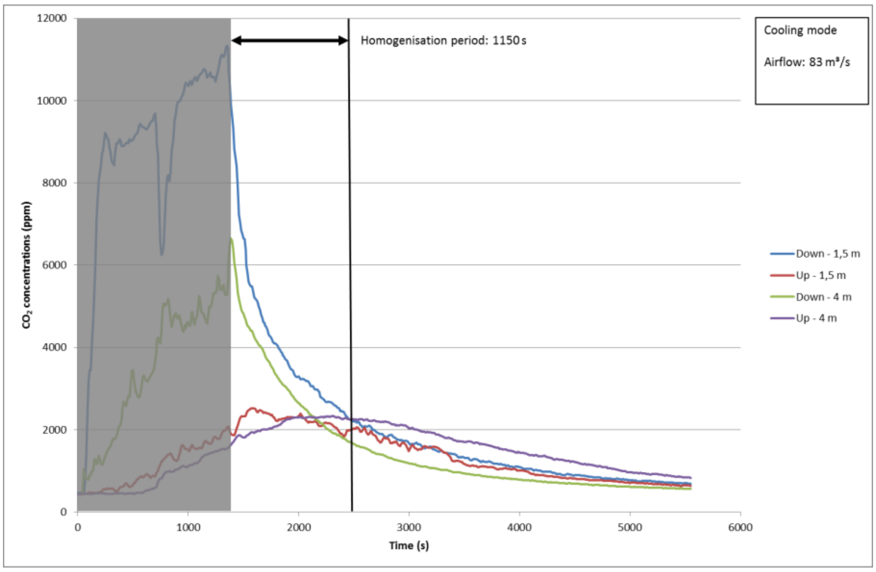


Figure 9 CO$_2$ measurements in cooling mode (80 m^3/h)

The ventilation effectiveness was calculated for each measurement and is represented on Figure 10. On this figure we can see that the values obtained during the homogenisation period are not relevant.

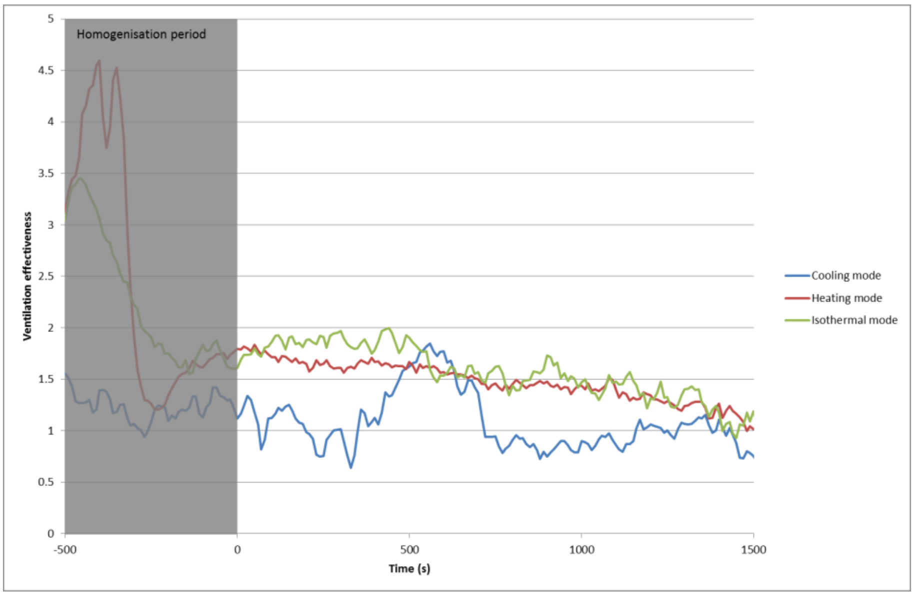


Figure 10 Comparison of ventilation effectiveness in isothermal, heating and cooling modes

For all 3 modes, values above 1 can be found on the chart. This is due to the position of the CO_2 sensors used for the determination of the average concentration in the room. As they are positioned in the vertical plane directly aligned with the fresh air direction, they are in the best ventilated part of the room. This means that no conclusion can be drawn from the absolute values but only comparisons between the 3 cases.

The average values of the ventilation effectiveness are:
- isothermal mode: 1,6
- heating mode: 1,5
- cooling mode: 1,1

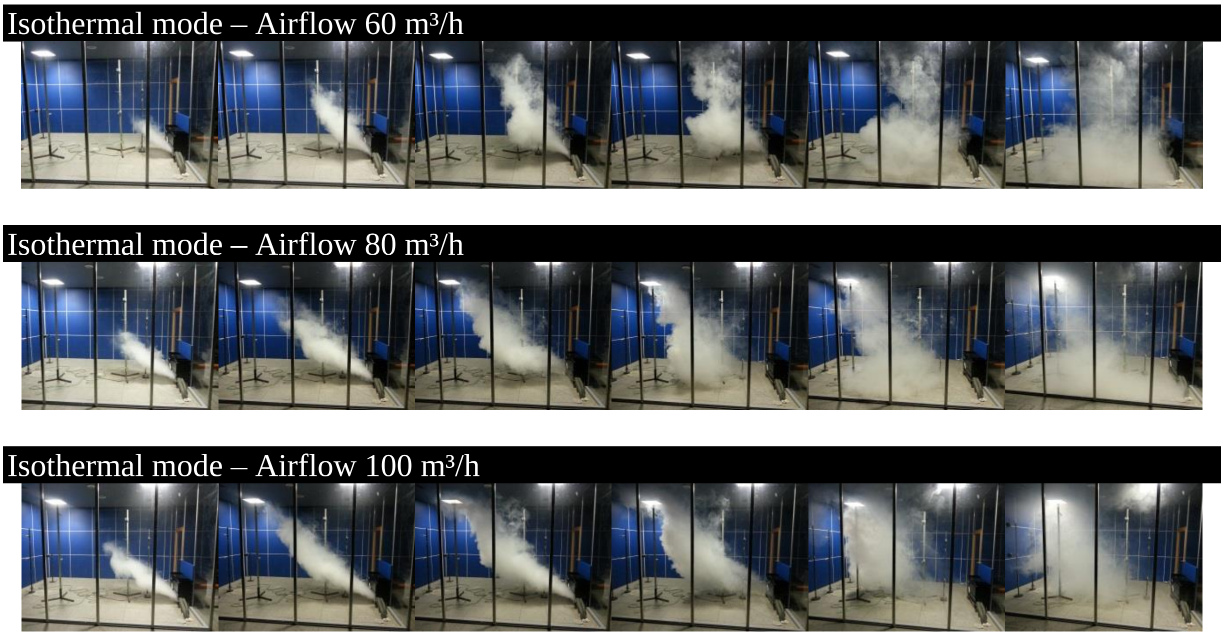
These results confirm that the best air distribution is obtained for the isothermal mode and the worst for the cooling mode. They show that the air distribution obtained for the heating mode is quite similar to the isothermal mode.

4 INFLUENCE OF THE AIR FLOW RATE

The same investigations were made to analyse the influence of the airflow rate on the ventilation effectiveness. These investigations are presented here for the isothermal mode.

4.1 Smoke visualisation

Figure 11 presents the results of the smoke visualisations for the 3 different airflows. On these pictures, we can see that the air speed allows a faster penetration of the smoke in the room after 5 seconds, but no real difference can be seen in the repartition of the smoke in the room volume between the 3 cases after 20, 30 or 50 seconds.


Isothermal mode – Airflow 60 m³/h

Isothermal mode – Airflow 80 m³/h

Isothermal mode – Airflow 100 m³/h

Figure 11 Smoke visualisations after 5, 10, 15, 20, 30 and 50 s for the 3 different airflows

4.2 CO_2 measurements

The CO_2 measurements can be seen on Figure 4 (60 m³/h), Figure 7 (80 m³/h) and Figure 12 (100 m³/h). The repartition is by each case identical: no vertical stratification of the CO_2 concentrations and a notable difference between both locations (1,5 m and 4 m).

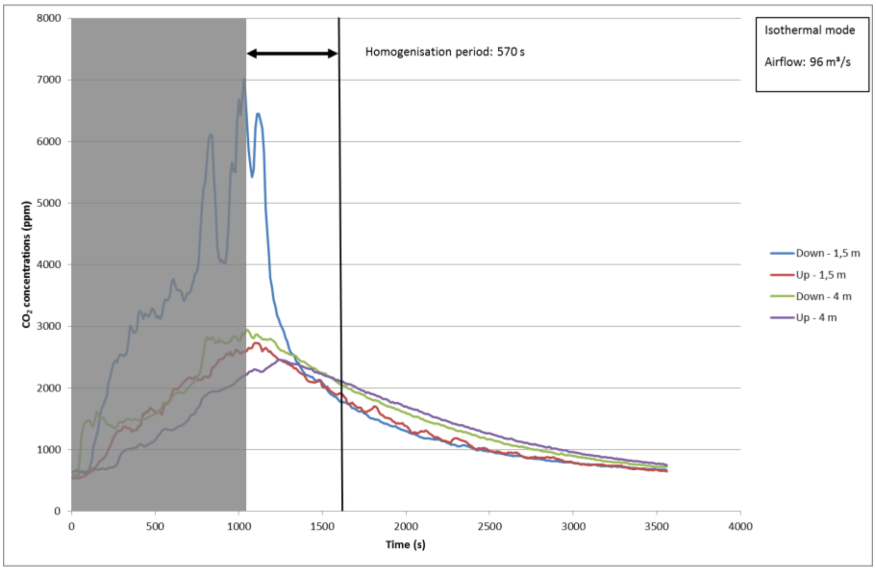


Figure 12 CO_2 measurements in isothermal mode (100 m³/h)

The average values of the ventilation effectiveness obtained with each airflow are:

- 60 m³/h: 2,0 - 80 m³/h: 1,6 - 100 m³/h: 1,3

The results are showing a higher effectiveness for the lowest airflow. We suppose that there is an optimal airflow for which this effectiveness would be the highest. It would be interesting to test airflows lower as 60 m³/h in order to verify that this optimum exists. We also suppose that the results would be different if the effectiveness had been determine using sensors in the whole volume of the room.

5 CONCLUSIONS

The main goal of a ventilation system is to remove pollutants like CO_2 from a room. In order to quantify its capacity to reach this goal, smoke visualisation is not the right tool. Indeed, we have seen for the heating mode that the smoke seems to stay in the highest layers of the air volume but the CO_2 concentrations are still reduced at each measured point with a similar speed.

One important conclusion is about the cooling mode for which the ventilation effectiveness was the lowest obtained in our tests. It might be interesting to equip the air inlet of such a reversible device with a system adapting the speed and direction of the airflow to the inlet temperature of the air.

6 ACKNOWLEDGEMENTS

Part of the work presented was funded by the German Ministry of Economics and Labour BMWi under the reference 03ET1035A and 0327400 P. Other parts were funded by the European Commission under the contract number 314229 – RETROKIT in the FP7 Programme.

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