MONITORING OF AN INNOVATIVE ROOM-BY-ROOM DEMAND CONTROLLED HEAT RECOVERY SYSTEM ON FOUR LOCATIONS

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ABSTRACT

Demand controlled heat recovery ventilation systems, which combines heat recovery (HRV) and demand controlled (DCV) is growing fast among ventilation manufacturers.

Several categories can be identified, from global dwelling regulation, to fine room-by-room regulation of the airflow rate. Simulations show that room-by-room demand controlled heat recovery ventilation is the best compromise to optimize at the same time indoor air quality, comfort, and energy savings.

To reinforce this assessment, four room-by-room demand controlled HRV have been monitored since May 2013. The system is an innovative ventilation for individual treatment, which modulates automatically the supply airflow according to CO_2 concentration in the main rooms, and exhaust airflow according to humidity concentration in the wet rooms. The balance of the airflow is made using two specific compensation valves at the exhaust and at supply.

Three projects are located in Germany: Nuremberg, Dortmund and Frankfurt, and one takes place in France, near Paris. The dwellings have from three to five main rooms, and a real occupancy of two to five people. They are all existing dwellings. The comparison was made between three different types of installation: two in the heated space, one in the attic (slightly insulated), and one with the heat recovery unit in the heated space and the ductwork in the attic (non insulated).

The results have shown the good functioning of the system in terms of balancing, adaptation of the airflow rates to the needs, and filtration. The relevance of using CO_2 concentration to modulate the airflow rate at supply has been verified by presence sensors in the main rooms. Temperature sensors revealed the necessity to carry on the installation in the heated space to optimize energy savings. Besides, the collected data gave the opportunity to validate a simulation model of the system using CONTAM (multizone indoor air quality and ventilation analysis program developed by NIST).

The monitoring also demonstrated the good performance of this type of heat recovery, in terms of indoor air quality, comfort and energy savings. The CO_2 and the humidity level stayed in the comfortable range thanks to demand controlled ventilation. The supply temperature, when the HRV is located in the heated space, is mostly between 18 and 20°C, thanks to heat recovery (the outdoor temperature being in the range of 0 to 14°C). In-situ measures and surveys occupants supplied complementary information regarding the acoustic and thermal comfort.

1 KEYWORDS

Heat recovery ventilation; demand controlled ventilation; indoor air quality; energy savings

2 INTRODUCTION

The need to reduce more and more the energy consumption in residential buildings has lead several manufacturers of ventilation systems to associate heat recovery ventilation (HRV) with demand controlled ventilation (DCV). Some systems control the supply or the exhaust only, and some other control both, room by room or in a global way. Simulations made on CONTAM (a multizone indoor air quality and ventilation analysis program) show that room-by-room demand controlled heat recovery ventilation is the best compromise to optimize at the same time indoor air quality (IAQ), thermal comfort, and energy savings. A monitoring of this last type of HRV was carried out in four dwellings. This study shows the results of this monitoring campaign and some of the results of the simulations.

3 SIMULATIONS

3.1 Energy efficiency / Indoor air quality

The simulations compare five types of HRV systems on the energy and IAQ aspects in a three bedroom house occupied by three people (Table 1). As CO_2 concentration results are very low in the dwelling (no exposure over 2 000 ppm for none of the HRV systems), the CO_2 comparison level has been set to 1 200 ppm.

Table 1: Simulated HRV systems

System	Exhaust	Supply	Balance
Fixed airflow rate	Fixed airflow in the wet rooms according to French regulation	$Q_{supply\_room}=Q_{extr.}/4$	Fixed balanced airflow rates
Preset speed level	Humidity sensor in the wet rooms	CO_2 sensor in the parents' bedroom	Q_{tot} = f (Max(RH; CO_2)) Instantaneous distribution of the total airflow rate between the rooms
Exhaust DCV	Humidity controlled exhaust units in the wet rooms	$Q_{supply\_room}=Q_{extr.}/4$	Instantaneous distribution of the total airflow rate in the main rooms
Supply DCV	$Q_{extr.\_room}=Q_{supply}/3$	CO_2 controlled supply units in the main rooms	Instantaneous distribution of the total airflow rate in the wet rooms
Exhaust and supply DCV	Humidity controlled exhaust units in the wet rooms	CO_2 controlled supply units in the main rooms	Supply and exhaust compensation valves

Looking at the results below (Figure 1, Figure 2, Figure 3), the supply DCV is the best system regarding energy and CO_2 aspect (very few heat losses and acceptable CO_2 concentration), but the RH (relative humidity) in the bathroom and in the kitchen is very high. The exhaust DCV has a good RH level in the wet rooms but it has more hours of exposure over 1200 ppm (which is easily satisfactory), and the fixed airflow and the preset speed level systems have too many heat losses. According to the simulation results, the exhaust and supply DCV seems to be the best compromise to optimise at the same time the indoor air quality and the energy consumption.

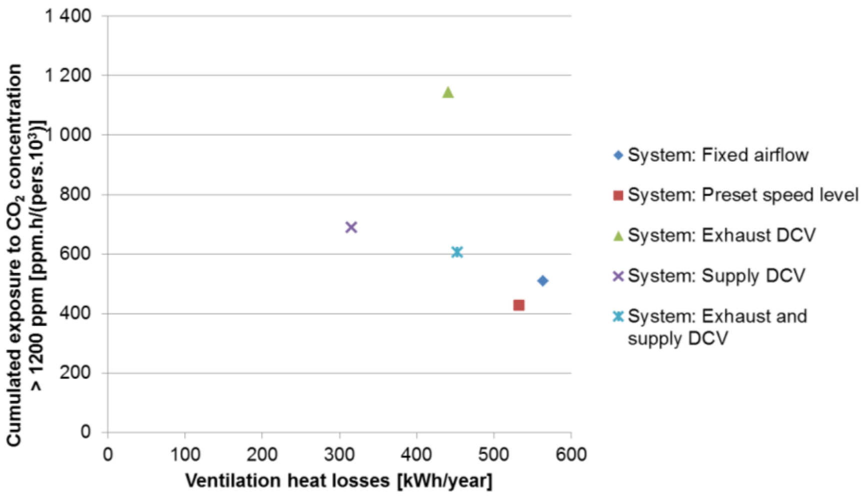

Figure 1: HRV energy / CO_2 exposure over the heating season (CONTAM simulation)

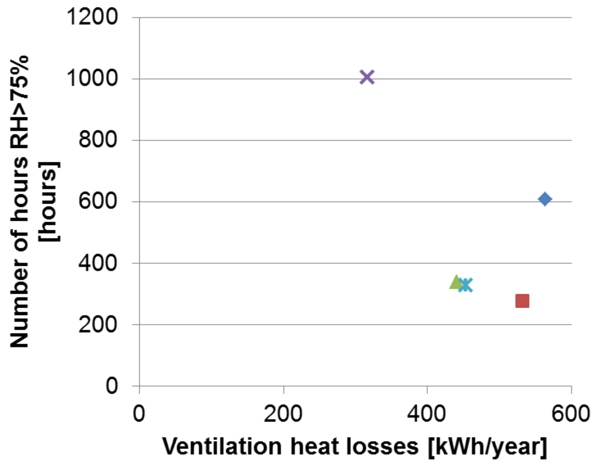

Figure 2: HRV energy / RH in the bathroom (CONTAM simulation)

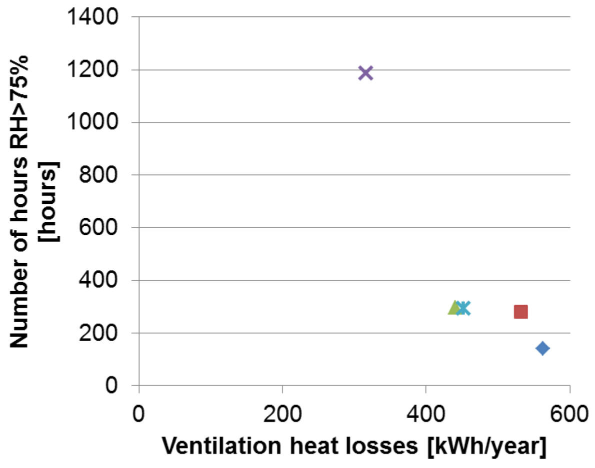

Figure 3: HRV energy / RH in the kitchen (CONTAM simulation)

3.2 Filter clogging

The monitored system tests the total pressure drop of the HRV every two months in order to give a signal to change the filters if necessary. This filter test has been simulated on 5 HRV systems using G4 + F7 filters at supply. The results are showed for filter F7 only (Figure 4).

During the four first months of the simulation, the pressure drop is more or less the same for all the systems. The dust mass of the filter increases a lot after eight months of operation in the system with fixed airflow and in the preset speed level system. DCV systems have almost the same dust mass increase, which is the slowest of the five simulated systems, thanks to the modulation of the airflow rates.

In Dortmund, after eleven months of functioning, filter F7 has a pressure drop of 21.5 Pa, which is even less than the result showed by the calculation. In Nuremberg, the filter F7 has a pressure drop of 26.4 Pa after 9 months of functioning.

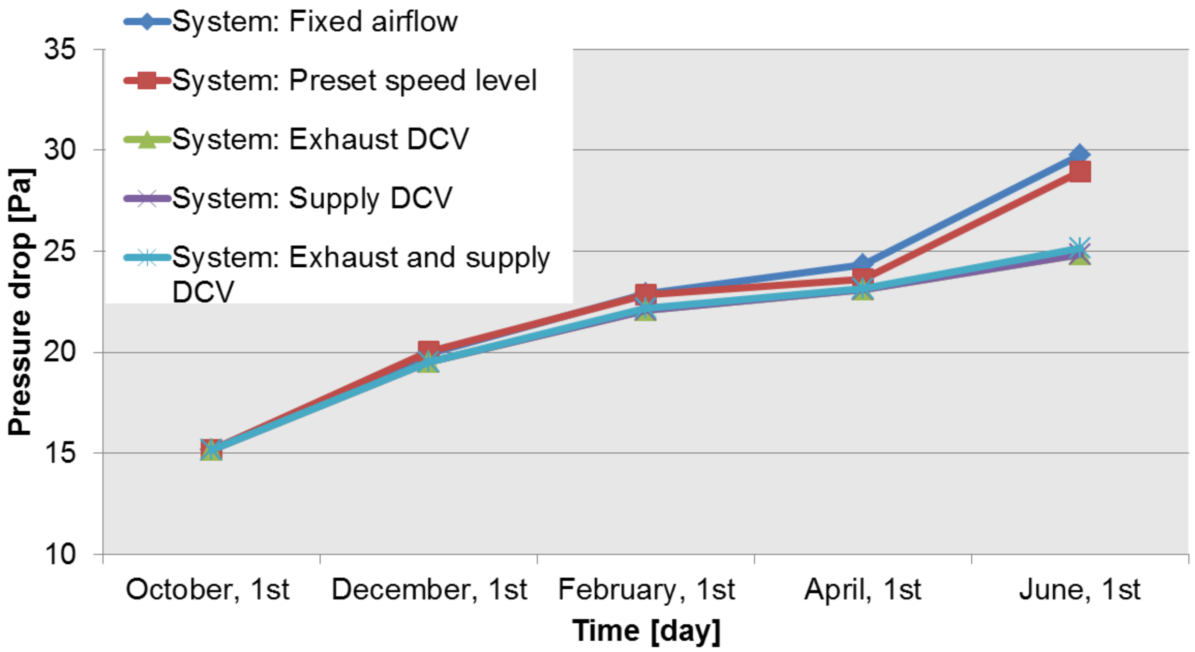

Figure 4: F7 filter tested at 170 m^3/h every 2 months (CONTAM simulation)

4 MONITORING

4.1 Monitored room-by-room demand controlled HRV

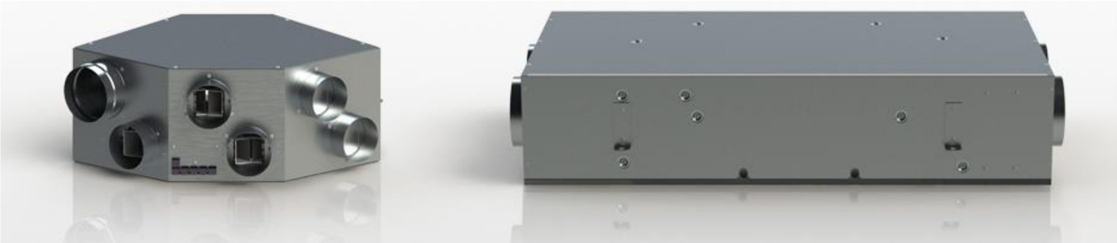

Figure 5: Monitored room-by-room demand controlled HRV

The ventilation is a heat recovery system involving a heat recovery unit connected to exhaust units and a distribution box that modulates the supplied airflows (Figure 5).

The airflows are automatically modulated according to the needs of each room in the dwelling: the air supplied to the bedrooms and living room and the air exhausted from the kitchen, the bathroom, and the WC. Each supply unit is directly connected to the distribution unit, which adjusts the supplied airflow in the main rooms according to the level of CO_2. On the exhaust side, the units adjust the airflow, according to parameters that depend on the room concerned: humidity in the bathroom, occupancy in the WCs, humidity and switch for the boost airflow in the kitchen.

At all times, the total supplied and exhausted airflows are measured in the heat recovery unit and balanced by two controlled compensation valves that are located in the living room, the kitchen, or a corridor. For example, when the need increases in the kitchen as a meal is being prepared, and is not accompanied by high demand in a bedroom or in the living room, the exhaust airflow can be balanced by opening the compensation valve of the supply ductwork.

4.2 On-site installations and monitored values

Figure 6: Monitored dwelling in Dortmund

Three projects are located in Germany: Nuremberg, Dortmund (Figure 6) and Frankfurt, and one takes place in France, near Paris. The dwellings have from three to five main rooms, and a real occupancy of two to five people. They are all existing dwellings. The comparison was made between three different types of installation: two in the heated space (Figure 8), one in the attic (slightly insulated, Figure 7), and one with the heat recovery unit in the heated space and the ductwork in the attic (non insulated).[1]

[1] As the last installation in Paris was installed in the beginning of May 2014, there is not enough data to include its results in this study for the moment.

Figure 7: Installation in the attic

Figure 8: Installation in the false ceiling

Every parameter of the system has been monitored every 1:30 minute in Nuremberg and in Dortmund, and every minute in Frankfurt and in Paris (Table 2). The first projects in Nuremberg and Dortmund have presence sensors in every main room (presence detection measure every 1:30 minute). The last projects in Frankfurt and Paris have temperature and relative humidity sensors in every main room (measure every minute).

Table 2: Monitored parameters

Parameter	Location	Monitoring project	Parameter	Location	Monitoring project
CO_2 sensors	In every main room	All	Exhaust airflow rate	At the main unit	All
Opening of the damper at supply	At the supply dispatching box	All	Supply airflow rate	At the main unit	All
Fresh air temperature	At the main unit	All	Pressure at the exhaust	At the main unit	All
Supply air temperature	At the main unit	All	Pressure at supply	At the main unit	All
Exhaust air temperature	At the main unit	All	Speed rotation of the exhaust fan	At the exhaust fan	Nuremberg, Dortmund
Used air temperature	At the main unit	All	Speed rotation of the supply fan	At the supply fan	Nuremberg, Dortmund
Opening of the exhaust compensation valve	At the exhaust compensation valve	All	Defrosting state	At the main unit	All
Opening of the supply compensation valve	At the supply dispatching box	All	By-pass state	At the main unit	All
Exhaust fan setting	At the exhaust fan	All	Supply fan setting	At the supply fan	All
Presence sensors	In every main room	Nuremberg, Dortmund	Temperature and humidity sensor	In every room	Frankfurt, Paris

4.3 Check of the working of the HRV

The graph presenting the total supply airflow rate as a function of the total exhaust airflow rate shows a positive and linear correlation between supply and exhaust airflow rate (Figure 9). These results allowed to highlight a program default for airflow rates under 40 m^3/h, which was corrected on the standard mass-production product.

Considering the total airflow rate over 40 m^3/h only, the correlation coefficient is 0.86. Moreover, the peak of correlation happens with no interval, so the balance of the airflow is instantaneous. The instantaneous difference between supplied and exhaust airflow rate is mainly around zero, and is 97.98 % of the time included in the interval [-10; 10[m^3/h (Figure 10).

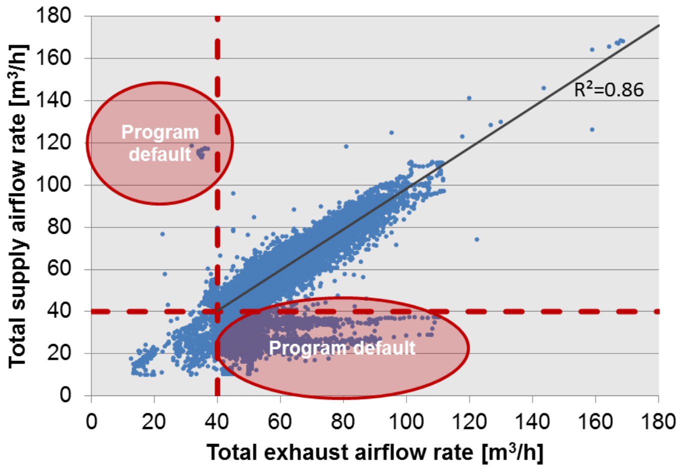

Figure 9: Relationship between total exhaust airflow rate and total supply airflow rate.
(Frankfurt, from 2014/01/03 to 2014/05/31)

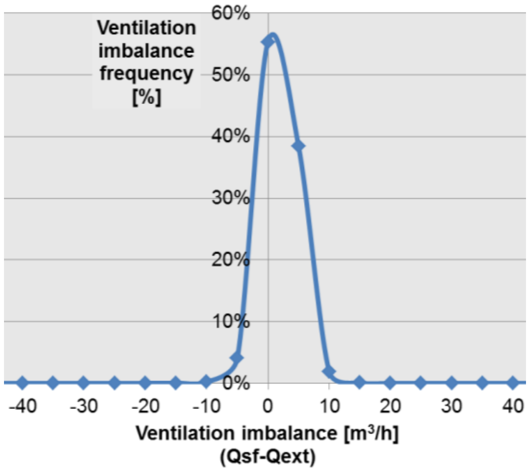

Figure 10: Balance of exhaust and supply airflow rate.
(Frankfurt, from 2014/01/03 to 2014/05/31; above 40 m^3/h).

Four preset supply airflow rate are defined, according to the concentration of CO_2 in each main room. The results show that the supply airflow is well distributed among the 4 preset rates, depending on the occupancy of the room (Figure 11, Figure 12).

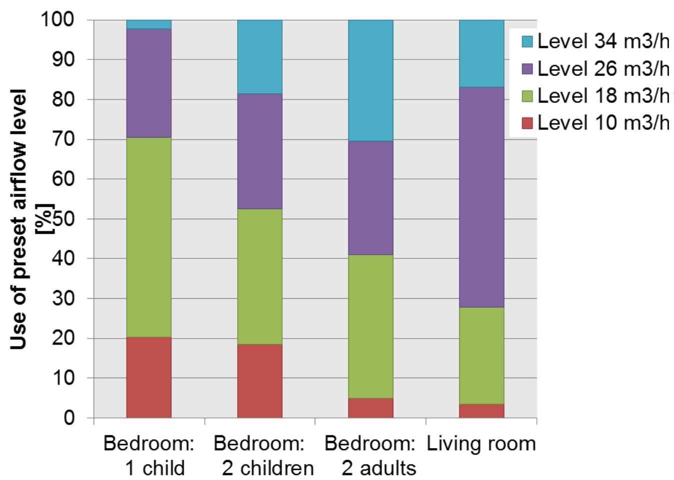

Figure 11: Use of preset supply airflow rate
(Frankfurt, from 2013/11/15 to 2014/05/31)

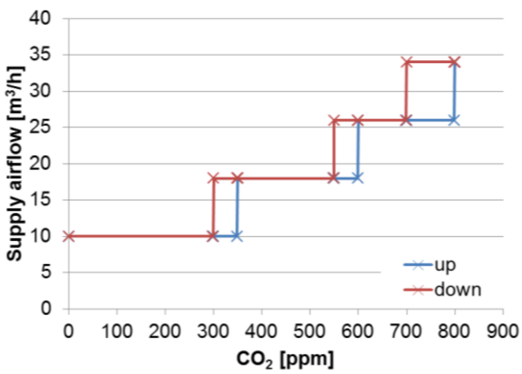

Figure 12: Preset CO_2 level
(Above ambient concentration)

5 PERFORMANCE OF THE ROOM-BY-ROOM DCV HRV

5.1 Indoor air quality

The RH distribution in the dwelling shows that the concentration is between 30 and 60 % for the considered period (from 2014/02/13 to 2014/05/31). This range of RH concentration is comfortable according to ASHRAE comfort zones (Figure 13).

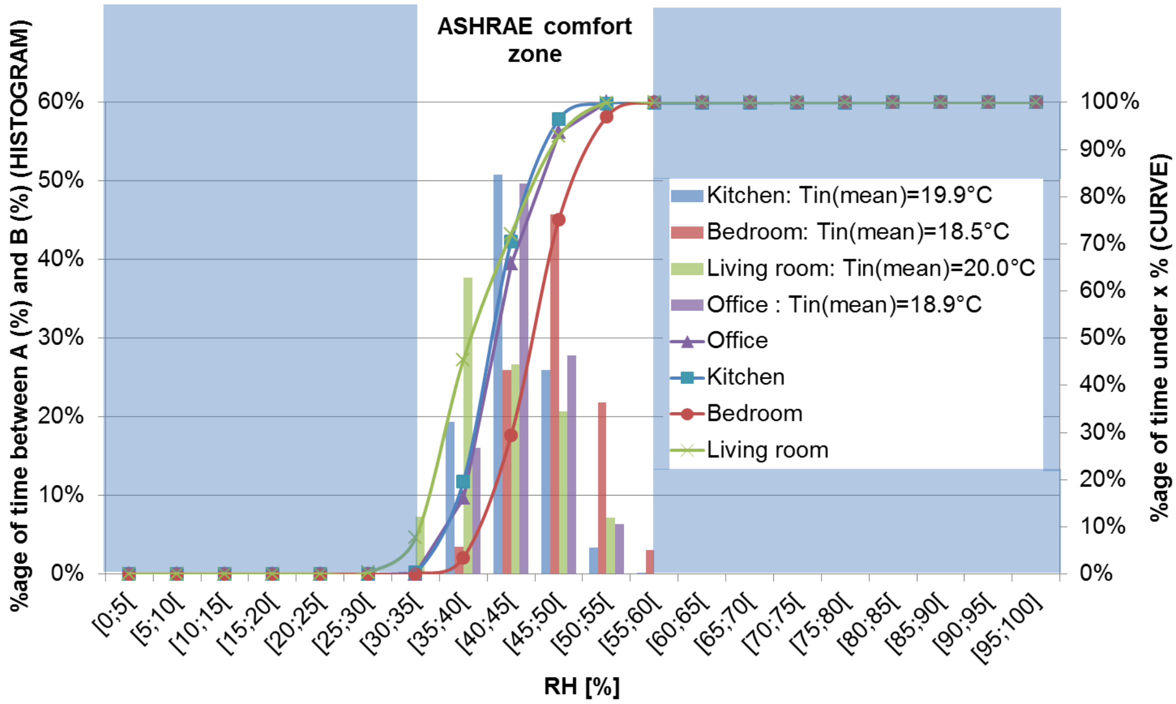

Figure 13: RH distribution (Frankfurt, from 2014/02/13 to 2014/05/31)

The risk of condensation in the dwelling is almost null if we consider that such an efficient HRV system should be installed in a dwelling having an energy efficient envelop (Table 3). The worst case would occur in the kitchen, with a maximum of 2 hours of condensation risk on a PVC double glazing with an air space of 12 mm (note that the bathroom has not been monitored). All the main rooms have nearly zero risk of condensation, independently of the external wall composition.

Table 3: Risks of condensation in the dwelling (Frankfurt, from 2014/02/13 to 2014/05/31)

Room (Mean dew point temperature [°C])	**Mean internal wall temperature [°C] (March 2014)**				**Risk of condensation [number of minutes] (From 2014/02/13 to 2014/05/31)**			
	Double glazing U=1.2 W/(m².K)	Double glazing U=2.3 W/(m².K)	Insulated ext. wall U=0.51 W/(m².K)	Non insulated ext. wall U=2.25 W/(m².K)	Double glazing U=1.2 W(/m².K)	Double glazing U=2.3 W/(m².K)	Insulated ext. wall U=0.51 W/(m².K)	Non insulated ext. wall U=2.25 W/(m².K)
Kitchen (6.5)	16.2	12.6	18.5	12.8	26	116	3	112
Bedroom (6.2)	15.1	11.9	17.1	12.1	0	2	0	2
Living room (5.7)	16.4	12.7	18.7	12.9	0	0	0	0
Office (5.5)	15.4	12.1	17.4	12.3	0	0	0	0

CO_2 distribution in the bedrooms has been observed thanks to the sensors located in each main room, which control the supply airflow rate. In the bedrooms with an occupancy of one person, the CO_2 concentration is less than 1 150 ppm 80 % of the time. In the bedrooms with an occupancy of two people, the CO_2 concentration doesn’t exceed 1 250 ppm 80 % of the time. In any case, CO_2 concentration won’t exceed 1 650 ppm, whatever the occupancy (Table 4).

Table 4: CO_2 distribution: main results in bedrooms

Monitoring ref.	Max distributed area (peak %)	100 % of time under X ppm	90 % of time under X ppm	80 % of time under X ppm
Nuremberg: 1 child	950-1000 ppm 26.7 %	1 400	1 150	1 100
Nuremberg: 2 children	1100-1150 ppm 25.5 %	1 600	1 300	1 200
Nuremberg: 2 adults	1150-1200 ppm 15.0 %	1 650	1 350	1 250
Dortmund: 1 adult	1000-1050 ppm 19.8 %	1 250	1 150	1 100
Dortmund: 1 child	1100-1150 ppm 23.1 %	1 550	1 250	1 150
Frankfurt: 2 adults	950-1000 ppm 10.9 %	1 600	1 200	1 050

The CO_2 concentration distribution shows a fast reduction on the right side of its peak, which implies a good management of the air renewal in case of high CO_2 concentrations (Figure 14).

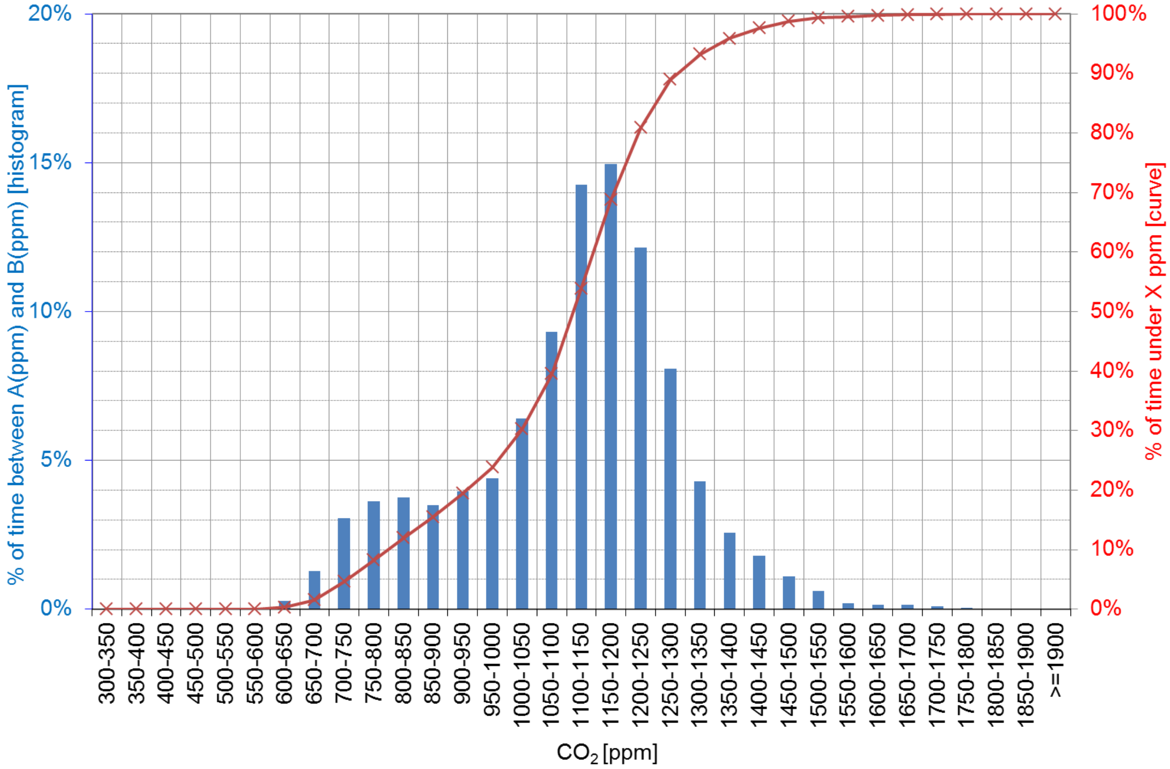

Figure 14: CO_2 distribution in a bedroom occupied by 2 adults (Nuremberg, from 2013/11/15 to 2014/05/31)

5.2 Thermal comfort

The survey fulfilled by the occupant in February showed no annoyance due to the supply air in the main rooms in Nuremberg and in Dortmund. If we look at the supply temperature distribution, we can observe that during the heating period the supply temperature is between 16 and 26°C 99.3 % of the time in Nuremberg, 95.6 % of the time in Dortmund, and 39.5 % of the time in Frankfurt.

These results show the huge impact of the location of the installation. In Frankfurt, the ductwork is insulated with 2*30 mm of glass wool, and the main unit is also insulated with blocks of polyurethane foam. The thermal efficiency is decreased by more than 50 % for an insulated installation located in the attic compared with an installation located in the heated space (Figure 15).

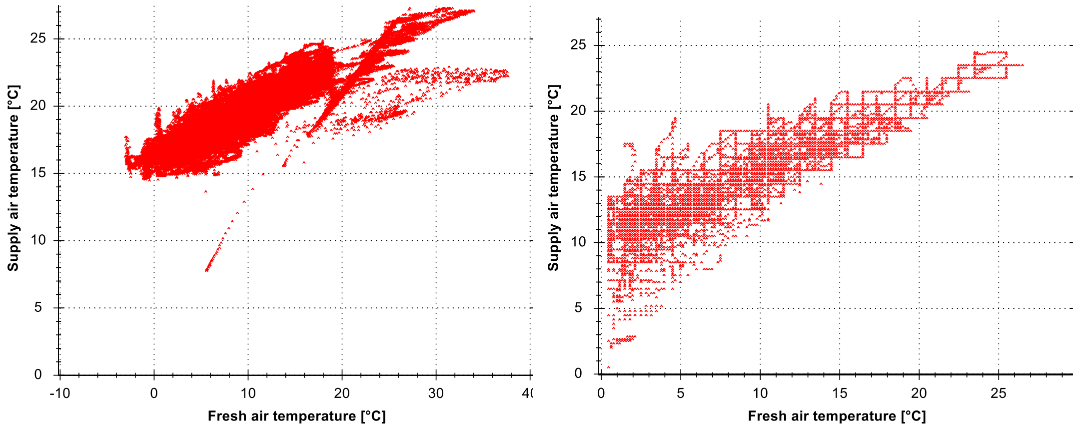

Figure 15: Supply air temperature as a function of fresh air temperature (From left to right: Dortmund and Frankfurt)

The discomfort due to draught can be expressed as the percentage of people predicated to be bothered by draught. This criterion is called draught rate (DR) and is calculated through empirical values. According to the draught rate and some other parameters, it is possible to define the comfort level category (ISO 7730:2005). An estimation of this criterion has been calculated at 2 meters from the unit, using the instantaneous airflow rate, the local air temperature being the supply and the extract air temperature average at the main unit. The DR is less than 15 % almost 100 % of the time in Nuremberg and in Dortmund, as recommended by the scientific literature. In case of an installation in the attic (as showed in Frankfurt), the DR which depends on the supply temperature is higher than for an installation in the heated space (Figure 16).

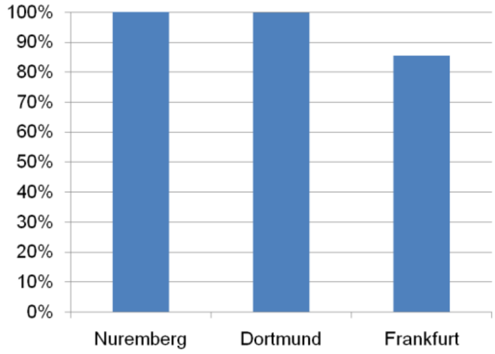

Figure 16: DR < 15% in parents' bedroom (at 2 meters)

5.3 Energy efficiency

An estimation of heat losses due to the ventilation system has been calculated, using the temperatures and the instantaneous total airflow rates at the main unit. The calculation is not made for fresh air temperature over 15°C, and the extract air temperature is taken as an estimation of the inside temperature. The monitoring in Dortmund has very low heat losses in comparison with the monitoring in Nuremberg, because the extract air temperature is about 3°C more in Nuremberg than in Dortmund[2]. The electrical consumption of the fans has also been estimated, using the instantaneous speed level of the fans and the total airflow rates (Table 5).

Table 5: Mean airflow rates, heating needs, and electrical consumption of the fans over the considered period

Monitoring ref. (Surface m²)	Considered period	Mean airflow rate [m³/h]	Mean extract /supply temperature [°C]	Heat losses (final energy) [kWh/(m².an)]	Mean fan power (exhaust + supply) [W]
Nuremberg (106 m²)	2013/11/15 to 2014/05/31	101.6	23.6/19.4	6.5	21.9

[2] The monitoring in Frankfurt is not presented because its data doesn't include the whole heating period (beginning of the results in January).

Dortmund (111 m²)	2013/11/15 to 2014/05/31	116.9	20.3/19.1	2.2	30.7

Considering a gas appliance for heating, with a mean cost of 6.89 c€(incl tax)/kWh, and a cost of 29.21 c€(incl tax)/kWh for electricity, the mean monthly cost due to the monitored HRV would be 10.13 €(incl. Taxes)/month in Nuremberg, and about 6.91 €(incl tax)/month in Dortmund during heating season. Prices of S2-2013 in Germany (Eurostat European comission, 2014).

6 ADDITIONAL SENSORS

The two first monitoring (Nuremberg and Dortmund) have been equipped with presence sensors in the main rooms. From these data, two analyses can be made: Is CO_2 a good indicator of human presence? Is it possible to use presence sensors instead of CO_2 sensors to control the supply airflow rate?

In addition, relative humidity and temperature sensors have been added in monitoring Frankfurt since the middle of February, and in Paris since May. There are located in the main rooms (bedrooms, living room, office) and in the wet rooms. These sensors have been added in order to study the possibility of using humidity sensors instead of CO_2 to control the supply airflow rates.

The results confirm the fact that CO_2 is a good indicator for presence detection, the CO_2 concentration increasing in the dwelling when a detection of presence occurs. Presence sensors, as an alternative to CO_2, could be relevant using more accurate sensors. In the same way, relative humidity sensors could be used instead of CO_2, but they would need to be corrected from outside humidity variation, like the humidity controlled air inlets currently used in MEV (mechanical exhaust ventilation) systems for instance.

7 CONCLUSIONS

This monitoring campaign has shown the good working of the tested demand controlled heat recovery ventilation system. It has also helped to improve the management of the program for specific points. Regarding the efficiency of the system, the indoor air quality is very good: no hours over 2 000 ppm of CO_2, and a relative humidity between 30 and 60 % in the main rooms. For the installations in the heated space, the supply temperature is more than 95 % of the time between 16 and 26°C. Looking at the results for the installation in the attic, the study confirms that it is necessary to put the HRV in the heating space, in order to use the entire potential of the HRV system.

In terms of energy consumption, the results are very positive, with a maximum of 6.5 kWh/(m².year) for the ventilation heating needs, and a mean electrical power of 30.7 W in the worst case.

This monitoring is going to continue until spring 2015, in order to be able to study the summer functioning and to generalize the efficiency results of the HRV during winter.

8 ACKNOWLEDGEMENTS

This project would not have been possible without the agreement of the owners of the dwellings, that is why we would like to thanks a lot the occupants of the four monitored dwellings.

9 REFERENCES

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