Use of compact balanced single-room ventilation units with heat recovery in existing dwellings

Laure Schwenzfeier[1], Jean-Jacques Akoua[2], Martine Bianchina[3],
Serge Buseyne[4], Daniel Limoges[5], Raphaël Morel[6]

[1] CETIAT, BP 52042, 69 603 Villeurbanne, France
[2] CSTB, 77 447 Marne la Vallée Cedex 2, France
[3] COSTIC, BP 66, 78470 Saint Rémy les Chevreuse, France
[4] ALDES, 16 av. C. de Gaulle, Bât 14, 31130 Balma, France
[5] CETE de Lyon, BP 128, 38081 L'Isle d'Abeau, France
[6] Raphael MOREL Architecte, 144 Rue du Commandant Charcot, 69005 Lyon, France

ABSTRACT

Renovation of existing buildings, in order to reduce energy consumption, represents a big market in Europe. As the first efforts often concentrate in improving insulation and airtightness of the building envelope, important insufficiencies of ventilation can appear, generating health risks for the occupants and a degradation of the frame. Taking into account the difficulties to insert ductworks in existing buildings, it can be easier to use distributed ventilation systems for room-by-room ventilation instead of centralised systems. In addition, balanced mechanical ventilation systems with heat recovery minimize the energy loss due to air renewal.

Single-room balanced mechanical ventilation units with heat recovery are used in European countries. They include a air-to-air heat exchanger, two fans and filters and they take place on a wall with air inlet and outlet through the building façade. However, the performance of such devices is not well known and questions remain about their ability to ensure good ventilation of the whole room.

In the research project VENTIL'RENOV, supported by ADEME, two representative products from the market have been tested in laboratory as well as in an experimental full scale dwelling. Numerical modelling has also been performed. This paper summarises the results of this project, showing the impact of such ventilation systems on indoor air quality, energy consumption and noise.

KEYWORDS

Ventilation, Renovation, Heat Recovery, Single Room Units, Indoor Air Quality

INTRODUCTION

The implementation of the Energy Performance of Buildings Directive by EU countries concerns new buildings and also major renovation operations (EPBD Buildings Platform, 2008). Therefore the improvement of energy efficiency of existing buildings represents a big market in Europe. Renovations often begin by improving wall insulation, changing windows, and as a consequence increase air tightness of the envelope. For old buildings that have no specific ventilation systems, air inlets due to the leakage disappear. If no appropriate ventilation system is installed, disorders on building and degradation of indoor air quality occur, due to insufficient air renewal.

Therefore a new ventilation strategy has to be defined for each renovation. Mechanical ventilation can be ensured by centralised systems, or single room units, with or without heat recovery on exhaust air.

This paper reports about the Ventil'Renov research project (Schwenzfeier et al., 2009), whose objectives were to study the opportunity of using single room ventilation units with heat recovery for supply and exhaust air in renovated dwellings, and to make comparison with centralised exhaust ventilation systems.

A preliminary analysis has to be performed to decide in which situations these single room ventilation units are the best solution, taking into account size of the dwelling, requirements of national regulations or specific quality labels, cost of the systems, cost of installation and its feasibility, cost of maintenance, energy consumption due to air renewal, interaction with existing systems (ductwork, combustion appliances ...), esthetical criteria, condominium agreement …

For example in France, the Ventil'Renov project allowed to compare 5 solutions for ventilation for two renovated dwellings: a studio apartment and a 3 rooms dwelling. The conclusion, regarding all the criteria detailed above, is that single room units with heat recovery could be the best solution for studio if the unit is not too expensive. For 3 rooms dwelling, installing a centralised exhaust ventilation system with humidity controlled air flows (Savin, 2009) is more relevant. In some cases, the configuration of building or the use of heating appliances do not allow other solutions.

State of the art of the single room ventilation systems proposed on the market shows a very large offer, in terms of size of the systems, options to control air flow and filtering outdoor air, and also in term of price. Two systems have been bought and tested during the study, chosen to be representative of the variety of the offer and also satisfying the following requirements: evidence of commercialisation (no prototype), ventilation units only (no coupling with heating function), intended for use in dwellings. The two selected systems are both very compact (they can be included inside a cubic volume of 50 cm x 50 cm).

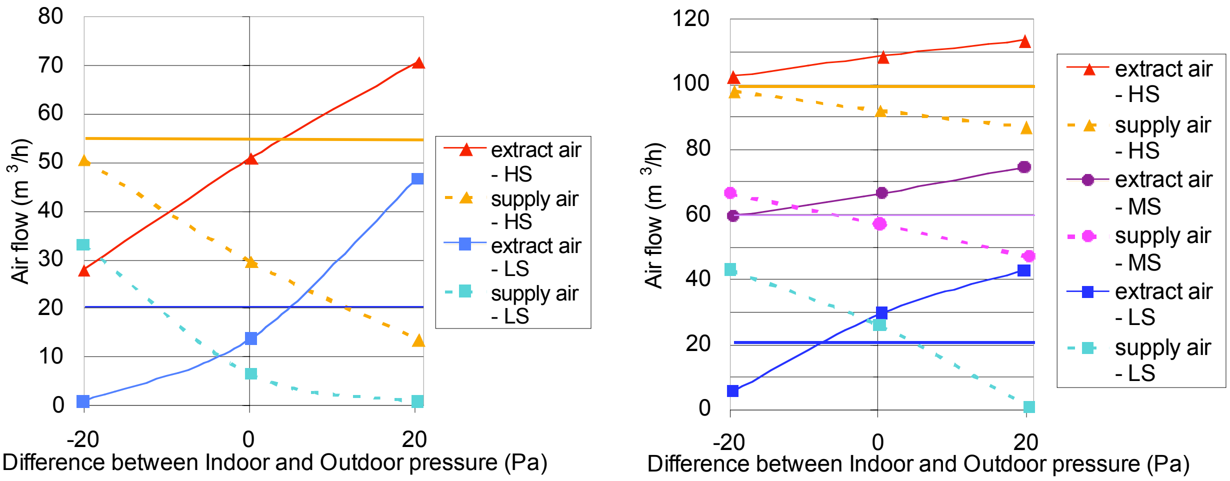
More than usual performances like air flows/pressures curves, electrical energy consumption or efficiency of heat recovery, those systems put specific questions. What is the influence of wind on the air flow supply? As those systems can be located in a sleeping room, is their noise low enough, otherwise the system can be switched off by the user? As they are compact with inlets and outlets close one to the other, are there possible air flow short cuts? As shown further, the performances of the two systems chosen to represent the market are very different.

PERFORMANCE TESTS ON TWO SYSTEMS

The European Standard EN 13141-8 describes the tests procedure for single room mechanical ventilation systems with heat recovery, used in residential buildings.

System A is cheap (300 €) and basic. Easy to install, it has two nominal air flows (controlled by fans speed): 20 and 55 m^3/h (on exhaust air). The maintenance procedure recommends washing the heat exchanger every 6 months. Energy consumption at low speed is close to 2 W and the heat exchanger is announced as high efficient. System B is more expensive (1700 €), is bigger, and proposes several options. The fans speed can be adjusted between 15 to 100 m^3/h ; for the test campaign, three settings were chosen that should provide according to manufacturer instructions 20, 60 and 100 m^3/h. Filters on fresh and exhaust air are Class G4. Electrical consumption at low speed is close to 4W and the heat exchanger is announced with an efficiency slight lower than system A.

The airflow/pressure curves have been measured for each system on supply and exhaust air (see Figure 1). It appears that the two systems are not well balanced and the air flow is not stable regarding the pressure difference between inside and outside (i.e. in case of wind for example). The system A is not robust against wind and the supply air flow is much lower than the extract one for both speeds. The robustness of system B against pressure variations and the balance between supply and exhaust air flows is better for high speed than for low speed. The effect of the poor balance between air flow supply and exhaust will be a better efficiency on heat recovery during the thermal tests. But when installed in existing buildings, this will induce non preheated air inlet from leakages, and so the global energy efficiency of the dwelling will decrease significantly.



System A
Settings: HS: 55 m^3/h, LS: 20 m^3/h

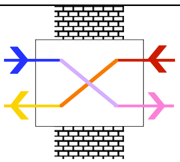
System B
Settings: HS: 100 m^3/h, MS: 60 m^3/h, LS: 20 m^3/h

Figure 1 : Aerodynamic tests: air flow / pressure curves for system A and B regarding set flows

Results for leakage, heat recovery, electrical power input and acoustics are presented in Table 1. Internal leakage test is relevant to determine if the exhaust air can go back to the dwelling because of leakages inside the appliance. The mixing is the parameter that quantifies the possible short-cut between exhaust air outlet and fresh air inlet outside of the building. The two tests use tracer gas method. They are both related to the quality of the air delivered to the dwelling, but also have some effect on thermal performance. If internal leakage is high, it induces that the air temperature of blown air is not only due to good heat recovery efficiency but also to the direct mixing with exhaust air. The external leakage has more impact on the energy performance of the system.
Because heat recovery measurement is not significant with high air leakages, the European standard EN 13141-8 recommends to stop the test campaign if leakages

are too important (class U5 or more). High leakages of system A would normally have not allowed to operate the thermal test but this latter was even so made. In order to go further in the analysis of System A, some other tests, not proposed in the standard, have been performed. It appears that System A presents high internal leakage from supply to exhaust air, which can explain also the very low value of supply airflow. On the other hand, system B has very low leakages.

Table 1 : Results of leakage, heat recovery, electrical load and acoustic tests for systems A and B

Outdoor  Indoor		System A		System B		
		LS 20 m^3/h	HS 55 m^3/h	LS 20 m^3/h	MS 60 m^3/h	HS 100 m^3/h
Leakages	Internal leakage	2.70%		0%		
	Mixing	0%		0%		
	External leakage	36%		10%		
	Class	U6		U3		
Heat recovery (temperature ratio)		84%	55%	55%	47%	40%
Electrical power input (W)		2	22	3	8	35
Lw Sound power level	indoor space (dB(A))	< 32.5	64.2	< 27.0	44.4	50.8
	outdoor space (dB(A))	< 32.2	68.2	< 35.5	48	56.4
Sound insulation	Dn,e,w (dB)	37		> 53		
	Dn,e,w + Ctr (dB)	34		> 48		

Thermal tests have been performed has described in EN 13141-8, but with other thermal conditions: the exhaust air is at 20°C instead of 25 °C, and the outdoor air is at 7°C instead of 5°C. The test is performed with dry air. The efficiency of heat recovery is calculated as a ratio of air temperatures, considering supply air circuit. The temperature ratio is higher for low speed settings, which is normal. High leakages of system A might explain the high level of heat recovery measured, which in fact is meaningless.

The electrical consumptions of the fans are very low at low speed. This means that even with several units (one by room), the overall electrical consumption of the ventilation system remains low.

Acoustic characteristics ensure the correct use of the system; the user disturbed by noise will be tempted to switch it off, despite the effects on indoor air quality. The sound power level radiated in the indoor space and in the outdoor space have been determined according to EN ISO 3741, and the sound insulation of the units has been tested according to EN 20140-10 and EN ISO 717-1. The acoustic tests show that system A shouldn't be installed in sleeping room. At low speed, its noise power level is very close to the background noise, but at high speed the noise generated could only be acceptable in a bathroom for a limited time. The acoustic insulation of system A is not enough to ensure the same insulation from outdoor noise than with the wall alone. Noise level of system B is acceptable for the low and medium speeds. The use of high speed should also be limited in time to be acceptable from the acoustical point of view. The insulation level from outdoor noise is very good. In order to compare, the French certification of air inlets requires that products intended to be used with high outdoor noise have a minimum sound insulation $D_{n,e,w + Ctr}$ of 36 dB.

NUMERICAL STUDY OF INDOOR AIR QUALITY AND THERMAL COMFORT IN A ROOM

On such compact single room ventilation units, air inlets and outlets on the indoor side are very close together. Whatever the air flow delivered, it is relevant to simulate the air circulation in the whole room in order to estimate the ventilation efficiency of the system. A CFD modelling has been used. The physical equations are based on turbulent, non-isothermal, “incompressible” fluid, using the □-□ *Realizable* turbulence model (Akoua, 2004). The grid has been optimized regarding the boundary conditions and the location of occupants. The room of 32 m^3 is represented by 1,500,000 hexahedral cells. An occupant, its activity and pollutant productions have also been simulated. Outdoor air is considered at 7°C, wall and ceiling temperatures are fixed at 20°C, and heating floor delivers 0.8 W/m^2. The two systems selected in the study have been modelled. The room does not communicate with other parts of the dwelling, air flows are balanced and fixed at 20 m^3/h; the efficiency of heat recovery is fixed by using thermal tests results. The two systems are compared to a centralised exhaust ventilation system, which is represented by typical air inlets and by an exhaust flow imposed at 20 m^3/h under the door.

Ventilation efficiency is the result of two parameters: the efficiency of air renewal and the efficiency of elimination of pollutants. Efficiency of air renewal is based on age of air and residual life time compared to the volume of the room and the air flow (Feller 1971, Sandberg 1983, Zwieterning 1959). Efficiency of elimination of air pollutants is estimated considering CO_2 concentrations in the room.

Air renewal efficiency calculated from simulation is 60% for system A, 68% for system B, and 62% for the centralised exhaust ventilation system. Air renewal efficiency is over 50% for each system, which means that the room is well ventilated, without any dead zone. The air blowing sections of the compact systems are small, which induce high air velocities, and therefore no mixing between inlet and outlet. The air velocity further in the room is very low, less than 0.5 m/s and therefore the air temperature in the room is quite homogeneous. The illustration of age of air is presented in Figure 2. Even if the flow patterns are different, the 3 systems can not be discriminated regarding simulations of CO2 concentrations to evaluate efficiency of elimination of pollutants, and simulations of Predicted Mean Vote (EN ISO 7730).

In conclusion, for same aerodynamic conditions (i.e. balanced 20 m^3/h), geometrical configuration of the two selected compact systems does not induce differences on indoor air quality compared to a centralised exhaust ventilation system.

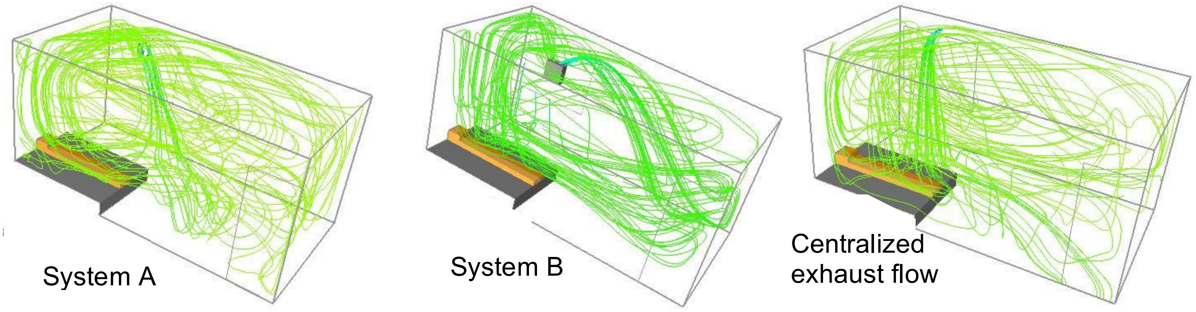


Figure 2 : Illustration of the age of air in a room: a view of the flow patterns

IN SITU EXPERIMENTAL STUDY OF VENTILATION EFFICIENCY IN DWELLING

Three ventilation systems, two with the single room systems selected, and one with an exhaust centralised system without heat recovery, have been installed and tested in the experimental full scale house MARIA in CSTB, in order to compare the energy use for a 4 rooms dwelling with a set temperature of 19°C. For decentralised systems, single room units have been installed in the three sleeping rooms, in the living room and in the kitchen. In addition, a small exhaust fan has been installed in the bathroom, which has no window. Air tightness of the building envelope, which can be adjusted on this experimental house, has been fixed at 1.15 $m^3/h.m^2$ under 4 Pa, which is the usual value for the French buildings energy regulation (2005). Electrical consumption of heating radiators has been recorded during a winter period. This electrical consumption is compared between systems for same levels of outdoor air temperatures. For similar air renewal efficiency, electrical consumption for heating and for fans operation is about 20% lower for system B than for the centralised ventilation system. This enhances the interest of heat recovery on supply air.

DISCUSSION

Single room balanced ventilation systems with heat recovery is a relevant solution for major renovation. By using well-designed appliances, the indoor air quality should the same as with centralised system, and the global energy consumption can be compared to the one of humidity controlled exhaust centralised ventilation systems. To ensure good indoor air quality and optimize energy consumption due to air renewal, appliances performances must ensure the stability of air flow rates, good acoustical characteristics and no leakages. The two tested units show very different performances, linked with their price.

REFERENCES

Akoua, J.J., Allard, F., Claudine, B., Collignan, B., Millet, J.R. (2004). Experimental and numerical studies on air quality in a real environment. *25th Conference on Air Infiltration and Ventilation Centre*. Prague, Czech Republic,

EPBD Buildings Platform (2008), *Implementation of the Energy Performance of Buildings Directive, Country reports 2008*, ISBN 2-930471-29-8

Feller. (1971). *An Introduction to Probability Theory and its Applications*. Vol. 2 John Wiley, New York, 1971.

Sandberg., M., and Sjöberg, M. (1983). The use of moments for assessing air quality in ventilated rooms. *Building and Environment*, **Vol. 18, issue 4**, p. 181-197.

Schwenzfeier,L., et al. (2009). *Ventil'Renov: Decentralized ventilation units with heat recovery, used in collective existing dwellings* (in French). ADEME Report, convention 0604C0061.

Savin J.L., Jardinier M. (2009). Humidity Controlled Exhaust Ventilation in Moderate Climate. *AIVC VIP* **n°31**

Zwietering, N. (1959). The degree of mixing in continuous flow systems. *Chemical Engineering Sciences*, **issue N0 11**, p. 1-15.

EN 13141-8. (2006) Ventilation for buildings. Performance testing of components/products for residential ventilation. Performance testing of un-ducted mechanical supply and exhaust ventilation units (including heat recovery) for mechanical ventilation systems intended for a single room

EN 20140. (1992). Acoustics - Measurement of sound insulation in buildings and of building elements - Part 10: Laboratory measurement of airborne sound insulation of small building elements

EN ISO 717-1. (2006). Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation

EN ISO 3741. (1999). Acoustics - Determination of sound power levels of noise sources using sound pressure - Precision methods for reverberation rooms

EN ISO 7730. (2005). Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

This study has been supported by ADEME in the context of the French Research Program on Energy in Buildings (PREBAT).