Temperature, draft and ventilation efficiency of room based decentralised heat recovery ventilation systems

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ABSTRACT

Mechanical ventilation systems with heat recovery are considered the most optimal systems for residential ventilation. This research focuses on decentralized ventilation which do not need any ducting. Therefore, this system is very suitable for use in retrofitting. The performance criteria of these units are similar to those of central systems. A recuperative and two regenerative ventilation units were tested in a double climate chamber where temperature, air velocity and contaminant concentration were monitored on a fixed 80 point grid. The results are reported in terms of thermal comfort, ventilation efficiency and energy consumption. The results showed that, by using decentralized ventilation, rooms can usually be efficiently ventilated at a good level of thermal comfort. The energy consumption of one ventilation unit is low, but several units have to be installed in order to adequately ventilate a residential building.

KEYWORDS

Please provide a maximum of five keywords which reflect the content of the paper

1 INTRODUCTION

As a result of the energy performance regulations in Flanders, buildings are becoming more and more airtight. This prevents the contaminated air from leaving the house in a natural way. However, sufficient fresh air is of great importance for the health of the residents. In order to supply fresh air to the residents and to remove polluted indoor air, a ventilation system is needed. Mechanical ventilation systems with heat recovery are considered the most optimal systems for domestic ventilation (Manz, 2000). Almost all of the new mechanical systems are ventilation systems with a central heat recovery and a network of ducting.

The need to find room for an elaborate duct system is a serious impediment to the incorporation of a well-designed traditional ventilation system in building refurbishments. This pushed a number of small, local, ductless ventilation systems (usually including some form of heat recovery) onto the market. In these systems, heat recovery is decentralized (per room) and can be recuperative or regenerative. The performance of these systems is usually characterized based on the effectiveness of the heat recovery unit, while the induced flow pattern in the space and associated air quality issues are largely ignored. In addition, the noise production and the energy consumption will also be investigated.

2 METHODS

2.1 Investigated units

Three different units were examined during this research. In the first unit, the heat recovery is regenerative (Endura Twist by Renson). The unit is placed in the joinery of a window. Two ventilation modules and two heat exchangers are the main parts. Each module consists of two little fans, which can be rotated to change the direction of the air flow. If air is extracted from the room, heat of this warm air flows into the heat exchanger. After the change of the flow direction, fresh air is supplied to the room. The cold fresh air is preheated by the heat exchanger. By default, always one module is extracting air from the room while the other module is supplying air into the room. The direction of the air flow over each module changes every 30 s. This unit can be modified so the air is blown vertically upwards or vertically downwards into the room. Both possibilities were examined.

In the second unit, the heat recovery occurs recuperatively in a counterflow heat exchanger (Provent D-luxe by Profel). This unit can be mounted on the inner side of an external wall or in the joinery of a window. Only the last option was examined.

In the third and last unit, the heat recovery is also regenerative (Tempero eco 150 ceram by O.ERRE). One fan and a ceramic heat exchanger are the main parts. As with the first unit, the heat from the indoor air will be partly stored in the heat exchanger when the air flows from the inside out. If the air subsequently flows from the outside to the inside, the fresh air will be preheated by the heat exchanger. The direction of the air flow changes every 70 s. The unit can be placed in a gap with a round cross-section within an external wall.

2.2 Experimental setup

All units were examined in terms of thermal comfort, ventilation efficiency, acoustics and energy consumption.

Thermal comfort was analyzed for each unit in a test room at two different ventilation rates and with temperature differences of 0°C and 20°C. Therefore the temperature, the velocity and the turbulence intensity had to be measured in the test room for each set-up.

Also ventilation efficiency was analyzed for each unit in the test room at two different ventilation rates. Therefore the concentration of tracer gas had to be measured for each set-up at regular intervals during a certain period of time.

Afterwards, the sound production of each unit was measured at different ventilation rates in the test room.

Finally, the energy consumption at different ventilation rates was measured for each unit for one hour.

2.3 Criteria

In this section, the evaluation criteria that are used to benchmark the experimental results are described:

A. Thermal comfort

In the NBN EN ISO 7730 standard, thermal comfort is determined by global and local thermal comfort. The global comfort is determined on the basis of the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD). The local thermal comfort is studied on the basis of the draught rate
(DR). Depending on the desired thermal comfort, the standard gives maximum values for these parameters in three different categories. The most commonly used category is category B, which means that the PPD has to be limited to 10% and the DR to 20%.

The PMV and the PPD depend on many different parameters. These values are therefore usually calculated using a computer program.

Local thermal discomfort is usually caused by draught, which can be visualized with the draught rate (DR). The DR is the percentage of dissatisfied residents as a result of draught phenomena and is calculated as [3]:

$$DR = (34 - T_a).(v_a - 0{,}05)^{0{,}62}.(0{,}37.Tu.v_a + 3{,}14) \tag{1}$$

Where Ta is the average air temperature, va the average velocity and Tu the turbulence intensity. The turbulence intensity describes how much the air velocity fluctuates. It is defined as (Chao & Wan, 2004):

$$Tu = \frac{SD}{v_a}.100 \tag{2}$$

Where SD represents the standard deviation of velocities at the measured point.

B. Ventilation Efficiency

Ventilation measurements are mostly carried out by using tracer-gas techniques. In these techniques, a gas is injected into the studied zone and its concentration response is measured. These techniques can be applied for determining the air age distributions and the ventilation efficiency in this space. Several tracer gas methods can be conducted, but the concentration decay is the most commonly accepted since its implementation is the easiest (Cui. This method was also used during this research to calculate the air change efficiency (ε_a). The detailed description of this method can be found in the standard ISO/DIS 12569.
The air change efficiency (ε_a) represents the ratio between the nominal time constant (τ_n) and the average time for air exchange (τ_{exe}) (Cui, 2015):

$$\varepsilon_a = \frac{\tau_n}{\tau_{exe}} = \frac{\tau_n}{2.\langle\tau\rangle} \tag{3}$$

The average time for air exchange can be calculated as τexe = 2·‹τ›, where ‹τ› represents the average of local values of age of air [4]. The nominal time constant (τn) and the mean age of air (‹τ›) are defined as (Mundt, 2004):

$$\tau_n = \frac{\sum_{i=1}^{i=n}\left[\frac{c_i+c_{i-1}}{2}.(t_i-t_{i-1})\right]+\frac{c_n}{\lambda}}{c_0} \tag{4}$$

$$\langle\tau\rangle = \frac{\sum_{i=1}^{i=n}\left[\frac{c_i+c_{i-1}}{2}.(t_i-t_{i-1}).\frac{t_i+t_{i-1}}{2}\right]+\frac{c_n}{\lambda}.\left[\frac{1}{\lambda}+t_n\right]}{\sum_{i=1}^{i=n}\left[\frac{c_i+c_{i-1}}{2}.(t_i-t_{i-1})\right]+\frac{c_n}{\lambda}} \tag{5}$$

C. Accoustics

The Belgian standard, NBN S 01-400-1, specifies maximum noise levels (LAinstal,nT) in areas where noise-producing system components of mechanical ventilation are installed. These maximum noise levels are presented in table 1.

Table 1: Maximum noise levels from mechanical ventilation (Wuyts)

Room	Normal acoustic comfort LAinstal,nT [dB]	Increased acoustic comfort LAinstal,nT [dB]
Bathroom / toilet	≤ 35	≤ 30
Kitchen	≤ 35	≤ 30
Living room	≤ 30	≤ 27

3 RESULTS

For each set-up tested, the PMV and the PPD meet the conditions of category B according to ISO 7730.
It is noticeable that with a ventilation rate of approximately 60 m³/h, combined with a difference of 20°C between the indoor and the outside temperatures, the limit value of 20% for the DR is exceeded by each unit. Only when the air is blown upwards into the room by the Endura Twist, does draught not occur. In addition, no draught is measured at ventilation rates of approximately 30 m³/h or when the difference between the inside and outside temperature is 0°C.
For each set-up, the draught occurs in different places in the test room. That's because the air flow pattern that arises in the room is different for each unit. Figures 1 and 2 show, for each device, a vertical longitudinal section of the test chamber with the locations where draught occurs. The orange/red colored zones on the graphs are the zones where the DR is 20 % or greater. In these places, draught will be felt. On these figures, the devices are located at the top left, at a height of about 2.4 m.

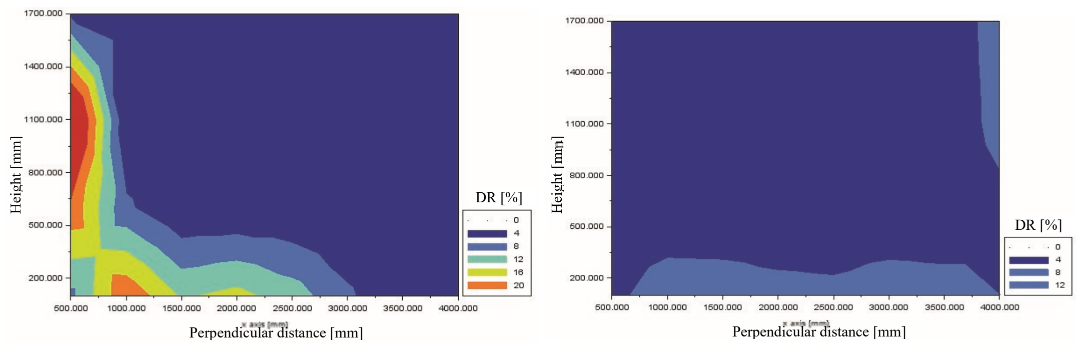

Figure 1: Locations where draught occurs when using the Endura Twist downwards (left) and upwards (right)

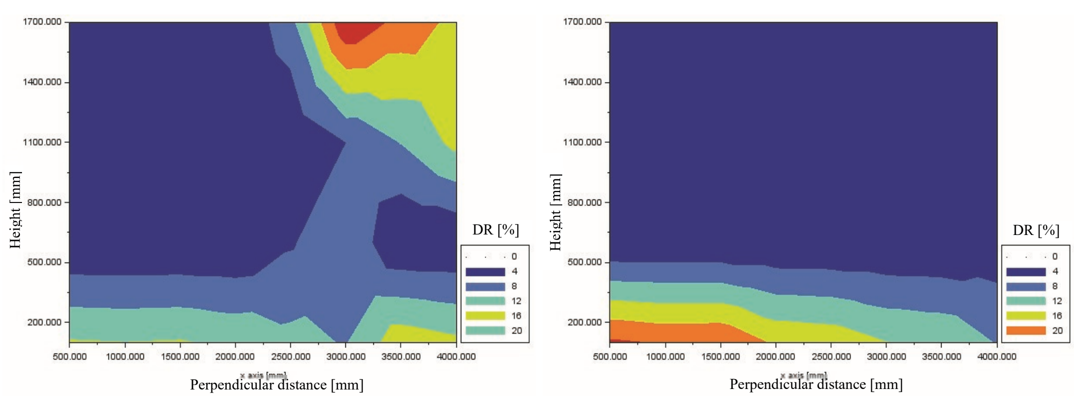

Figure 2: Locations where draught occurs when using the Provent Dluxe (left) and Tempero eco 150 ceram (right)

Before the measurements were started, a certain amount of tracer gas (CO_2) was released into the test room. By using a fan, the gas was mixed with the air. If the CO_2-concentration in the entire room had risen sufficiently, the measurements could be started. Ten sensors, distributed over the entire space, registered the concentrations at regular intervals (13 s.). If the concentrations in each point were sufficiently reduced again, the measurements were stopped. Table 2 shows the average air change efficiency (ε_a) for each set-up.

Table 2: Average air change efficiency for each set-up

Unit	Ventilation rate [m³/h]	Average ε_a [%]
Endura Twist (downwards)	30	54
	60	49
Endura Twist (upwards)	30	52
	60	48
Provent D-luxe	36	50
	50	43
Tempero eco 150 ceram	30	51
	60	53
Endura Twist (downwards)	30	54

In comparison with the other units, the differences between the different measuring points are much greater with the Tempero eco 150 ceram. The decay curves with this unit are more irregular than with the other units. That's because the Tempero eco 150 ceram is equipped with only one fan and therefore there's never simultaneous pulsation and extraction. To ensure proper operation, an even number of these units has to be installed. Two units of the Tempero eco 150 ceram must be installed to sufficiently ventilate a room.
Before measuring the average sound levels at different ventilation rates for each device, the background noise was measured in the test room. This background noise was 32.7 dB(A), with everything turned off in or around the test room. This means that, even without the devices being in operation, the standard is not met for several room types.
The average sound levels, measured at different ventilation rates of each device, are presented in table 3.

Table 3: Average sound levels at different ventilation rates of each device

Unit	Ventilation rate [m³/h]	Average sound level [dB(A)]
Endura Twist	30	33.3
	60	37.5
Provent D-luxe	36	36.7
	50	40.2
Tempero eco 150 ceram	30	34.5
	60	42.0

The Endura Twist produces the least noise and is the only one that, at a ventilation rate of 30 m³/h, meets the standard for normal acoustic comfort in the bathroom, toilet and kitchen during this research.
To measure the energy consumption of each ventilation unit at different ventilation rates, a power meter was used. When comparing the energy consumption of decentralized ventilation units with a central ventilation system, it is important to remember that an average of eight units are required to sufficiently ventilate a house [7].
The energy consumption of each unit at different ventilation rates was measured during one hour. Based on these measurements and because ventilation never works at a continuous ventilation rate during a whole year, only an estimate of the annual energy consumption can be made. As previously reported, two units of the Tempero eco 150 ceram are needed to adequately ventilate the room. The consumption of two devices is comparable to the consumption of one Endura Twist. The estimated annual energy consumption of one Provent D-luxe is 45% higher compared to one Endura Twist.

An example of the annual energy consumption of a central ventilation system with low system pressure (100 Pa at 300 m³/h) in a case study is 445 kWh (Camps, 2014). An installation of eight units of the Endura Twist results in an estimated energy consumption of 424 kWh, which is slightly less than the central system in the example. On the other hand, an installation of eight units of the Provent D-luxe results in an energy consumption of 616 kWh in one year. Finally, a comparable energy consumption to the central system can be achieved with an installation of sixteen units of the Tempero eco 150 ceram.

4 CONCLUSIONS

By using the Endura Twist by Renson or the Provent D-luxe by Provent, rooms can be efficiently ventilated at a good level of global thermal comfort. For each set-up, local thermal discomfort occurs in different places in the test room. That's because the air flow pattern that arises in the room is different for each unit. Only when the air is blown vertically upwards by the Endura Twist, no draught phenomena does occur.

The results of the tracer-gas test showed very irregular decay curves when using the Tempero eco 150 ceram. That’s because this device is equipped with only one fan and, therefore, there’s never simultaneous pulsation and extraction. Two units of the Tempero eco 150 ceram must be installed to sufficiently ventilate a room.

Limiting the noise production seems to be the main difficulty in the design of these units. The Endura Twist produces the least noise and is the only one that, at a ventilation rate of 30 m³/h, meets the standard for normal acoustic comfort in the bathroom, toilet or kitchen during this research. It should be noted that the background noise was 32.7 dB(A), without the devices being in operation. With reference to acoustic properties, further research and development of these units seems necessary.

The energy consumption of one ventilation unit is low, but several units have to be installed in order to adequately ventilate a residential building. The energy consumption of two units of the Tempero eco 150 ceram is comparable to the energy consumption of one Endura Twist. The estimated annual energy consumption of one Provent D-luxe is 45% higher compared to one Endura Twist.

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