Energy and Buildings 116 (2016) 376–383

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Field tests of centralized and decentralized ventilation units in residential buildings – Specific fan power, heat recovery efficiency, shortcuts and volume flow unbalances

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ARTICLE INFO

Article history:
Received 23 March 2015
Received in revised form
22 November 2015
Accepted 4 December 2015
Available online 12 December 2015

Keywords:
Mechanical ventilation
Specific fan power
Heat recovery
Recirculation

ABSTRACT

The energy efficient operation of mechanical ventilation systems depends on various parameters. In Luxembourg, field tests with 20 centralized and 60 decentralized mechanical ventilation systems in single- and multi-family homes were conducted in order to measure the actual performance of those systems in occupied buildings. The considered parameters were: Main air flows, internal and external recirculation, sensitivity to differential pressure, specific fan power and heat recovery efficiency. In many cases, the performance of the ventilation units was lower than expected. The systems showed deviations between supply and exhaust flows of up to 60%. In particular, the air flow in decentralized units was strongly influenced by pressure differences between the inside and outside due to wind or stack effects which leads to a decreased heat recovery efficiency. The total mean recirculation ratio was 6.5%, with a standard deviation of 12.5% for centralized and $13 \pm 6.2\%$ for decentralized devices. As a consequence, the delivered flow of fresh air is smaller by the amount of recirculation. The specific fan power, the ratio between air flow and power consumption, was measured with $0.475 \pm 0.37\,\mathrm{Wh/m^3}$ for centralized and $0.22 \pm 0.023\,\mathrm{Wh/m^3}$ for decentralized systems. The lower value for the decentralized systems can be explained by lower pressure losses due to the lack of ductwork. The heat recovery efficiency was 0.65 ± 0.24 for centralized systems and 0.7 ± 0.17 for decentralized systems which is significantly lower than nominal values provided by the manufacturers. The results of this study show that the overall energy efficiency of ventilation devices installed in residential buildings under real working conditions are often lower than expected. These findings could possibly serve as indicators for future research & development at manufacturer and commissioning level.

1. Introduction

In airtight buildings, often mechanical ventilation is used to ensure good indoor air quality and to avoid moisture problems, since it is very difficult or even impossible for the user to provide a sufficient amount of fresh air by natural ventilation. In terms of energy efficiency, the goal of mechanical ventilation is to transport the amount of air necessary to ensure sufficient indoor air quality at the lowest possible energy consumption and to make use of heat recovery to decrease ventilation losses. In previous studies it was shown, that the actual performance of ventilation systems on site was often lower than expected [1–3]. In order to obtain real field data about the performance of ventilation systems in residential buildings, field measurements were carried out in Luxembourg for 20 centralized devices and 10–67 (depending on the measured parameter) decentralized devices. The following parameters have been considered:

- Air flow in supply and exhaust ducts
- Parasitic airflows within the ventilation system
- Sensitivity to differential pressure and resulting deviations in air flows
- Electrical power consumption and resulting specific fan power
- Heat recovery efficiency

The measurements were conducted during the heating period of the years 2013/14 at outside temperatures between 0 and 4 °C on days with low wind speeds. Of course, the results can only be snapshots, but on the other hand, they reflect the actual performance of ventilation systems as a part of the global system “building”

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http://dx.doi.org/10.1016/j.enbuild.2015.12.008
0378-7788/

under normal conditions. Deriving real performance data from those parameters is not only helpful to identify possible shortcomings and potential for improvement, but it also contributes to an increased accuracy of input parameters for building energy calculation, where the results of energy demand calculations often differ from the measured consumptions [4].

2. Ventilation units and buildings

The field tests included measurements for centralized and decentralized ventilation units. For centralized ventilation units a ductwork is used to transport the supply and extract air, while decentralized systems are placed directly in the facade of the building (see Fig. 1). For decentralized systems, we can distinguish two different types, the first one being a pair-wise operating system with a regenerative heat exchanger and only one axial fan per device, hereinafter referred to as systems A and B. While the first device of a pair transports fresh air from the outside to the inside, the second device extracts air from the inside, which heats up the heat storage, made out of aluminium or ceramic. Every 60 s (the cycle time depends on the device and manufacturer) the fans switch their directions and the stored heat from the outgoing air is transferred to the incoming air. The second decentralized concept (hereinafter referred to as systems C and D) is often called single room ventilation unit. Each unit can be seen as a small centralized system since it provides supply air and extracts air using two fans and a cross counterflow heat exchanger to transfer heat and two radial fans.

All systems show advantages and drawbacks, the missing ductwork being the biggest advantage of the decentralized system, resulting in less pressure losses, easy installation and no maintenance of ducts. On the other hand, decentralized systems in general produce higher noise levels which often lead to user dissatisfaction and are more sensible to wind pressure on the facade and stack effects [5]. In Table 1, the specifications of the buildings are summarized. The buildings, in which the measurements were conducted, were low-energy or passive houses with a lower crack flow rate than 0.6 ach. All centralized units were installed in single-family homes, while the decentralized units were measured in multi-family homes. The nominal specifications of the ventilation units are presented in Table 2, according to data sheets provided by the manufacturers, certified by independent institutions [6–8]. The measurements were conducted for the "standard" air flow settings, used by the occupants throughout the year.

3. Theory and measurements

3.1. Volume flows

The volume flow was measured in extract and supply ducts using the constant emission tracer gas method [9–11]. For that, a Lumasense Innova™ system with a photo-acoustic gas monitor and a 6-channel sampling/dosing unit was used [12]. The tracer gas was injected at a constant rate of approx. 15 ml/s. For tracer gas, the synthetic gas R134a with a density of 1.21 g/cm^3 at 25 °C was chosen. The injection time for air flow and recirculation measurements was about 5–10 min until a solid steady-state concentration was achieved. First, the tracer gas was injected in the extract duct and the tracer gas concentrations in the air flow were measured in the outside, supply, exhaust and extract duct. After achieving a steady state, the tracer gas concentration in each duct was noted down and the measurement was stopped. Then, the same measurement was conducted in the supply duct.

The air flow in the extract and supply ducts can then be calculated as follows (please see Fig. 2):

$$\dot{V}_{extract} = \frac{\dot{I}_1}{C_{extract} - C'_{extract}} \tag{1}$$

$$\dot{V}_{supply} = \frac{\dot{I}_2}{C_{supply} - C'_{supply}} \tag{2}$$

With:
$\dot{V}_{extract}$ = Volume flow in extract duct [m^3/h];
$\dot{V}_{supply}$ = Volume flow in supply duct [m^3/h];
$\dot{I}$ = Tracer injection rate at point 1 or 2 respectively [m^3/h];
$C_{extract}$ = Tracer concentrations in extract duct post injection point 1;
$C'_{extract}$ = Tracer concentrations in extract duct pre injection point 1;
C_{supply} = Tracer concentrations in supply duct post injection point 2;
C'_{supply} = Tracer concentrations in supply duct pre injection point 2.

In Fig. 3 results of an exemplary air flow measurement in the supply duct of a centralized ventilation system in a single family home in Luxembourg are presented. The data was exported from the Lumasense® Software 7620. The measurement was stopped after 9 min. In this case the mean injection rate $\dot{I}$ was 0.0535 m^3/h and the supply air flow $\dot{V}_{supply}$ was calculated as follows:

$$\dot{V}_{supply} = \frac{0.0535\,\mathrm{m^3/h}}{0.000283 - 0.0000162} = 197.1\,\mathrm{m^3/h} \tag{3}$$

3.2. Recirculation ratios

There are two main recirculation ratios, the internal recirculation ratio R_{int} and the external recirculation ratio R_{ext}. The possible internal recirculation from extract to supply air R_{int} can happen within the ventilation device through leakage, while the external recirculation can occur outside the building when part of the exhaust air is mixed with the fresh outside air. In reality, there are several more possible recirculation flows, e.g. from the device to the technical room or inside the device from supply back to the extract, which were assumed to be zero. The concentration ratios below should be noted while injecting tracer gas at point 1 ($\dot{I}_1$) until achieving a steady state [3,1]:

$$R_{ext} = \frac{C_{outside} - C_{ambient}}{C_{exhaust} - C_{ambient}} \tag{4}$$

with:
$C_{outside}$ = Tracer gas concentration in the outside air duct;
$C_{ambient}$ = Tracer gas concentration in the ambient air outside the building.

$$R_{\mathrm{int}} = \frac{C_{supply} - C_{outside}}{C_{exhaust} - C_{outside}} \tag{5}$$

$$R_{tot} = R_{ext} + R_{\mathrm{int}} \tag{6}$$

3.3. Sensitivity to differential pressure

Since decentralized devices are installed in the facade of the building, their airflows are directly exposed to pressure differences induced by wind and/or stack effects. Previous studies have shown that supply and extract flows of decentralized devices can be highly sensitive to those pressure differences [5]. In order to measure the changes in the air flow, a simple set-up has been used during the field tests. In a small room with a volume of 30 m^3, a decentralized ventilation unit was installed in the outer wall. Previous blower door tests resulted in crack flow rate of of ≤0.2 ach at 50 Pa. As