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Testing the ventilation efficiency of room ventilation units with tracer gas methods

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Abstract

With the improvement of thermal building insulation the percentage of energy losses due to air exchange becomes an increasingly important factor in building energy demand. In order to optimize infiltration and ventilation and to minimize the energy demand of low energy buildings, it is necessary to install an appropriate mechanical ventilation system. Different ventilation strategies can be used: Extract ventilation and supply / extract ventilation systems for buildings as well as single-zone ventilation units with or without heat recovery. All systems will only operate correctly, if each component is working as expected. Several room ventilation units with heat recovery have been investigated by using the tracer gas technique. Severe malfunctions were discovered, which significantly influence indoor air quality and building energy performance.

1. Introduction

Ventilation within buildings is getting more important due to many reasons. To reduce the heat energy demand of buildings, one has to minimize the ventilation energy loss. On the other hand indoor air quality must be maintained by sufficient supply of fresh air. Thermal comfort can only be achieved, if the maximum air speed does not exceed about 0.5 m/s. As a result of all this, the air exchange rate should be kept within a small range of values. From the above mentioned aspects, the following ventilation concept for central european climates can be derived: Try to achieve a high standard of air-tightness of the building envelope to avoid uncontrolled air exchange, and construct and install a ventilation system considering the above mentioned restrictions [1].
There are three main types of mechanical ventilation systems. First simple extract ventilation without heat recovery. Fresh air enters the building through supply terminals in the facade. By using a fan and a system of ducts extract air is drawn out of pollution zones like kitchen and bathrooms. Mechanical supply / extract ventilation systems use ducts for the supply and the extract of air. Therefore, heat transfer from the warm extract air to cold fresh air by a heat

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exchanging device is possible. A disadvantage of this concept are comparatively high installation costs. Room ventilation units consist of an inlet and outlet for the air, a heat recovery system and an internal fan. Every zone can be ventilated by a separate unit. The installation of such units is rather simple and not very expensive. One objective of this work was to investigate the ventilation effectiveness and its influence on indoor air quality. Another aspect was focussed on energy-related considerations.

2. Description of tested room ventilation units

Three room ventilation units of different types and manufacturers have been examined. Technical data is summarized in Table 1.

Type	Power (W)	Air flow rate (m^3h^{-1})	Specific energy consumption (Wh/m^3)	Weight (kg)
unit A	8 / 13	15 / 30	0.47	2.5
unit B	19 / 27.5	65 / 95	0.29	5.5
unit C	40	85	0.47	13

Table 1: Technical data of the examined room ventilation units.

Unit A (shown in Figure 1): A small ventilation unit with heat recovering device made from metal sheets. Implemented is one motor activating two fans, driving both, the exhaust air and the supply air. Intake air and outlet air are conducted through one pipe which is divided by a separating wall in the middle of the pipe.

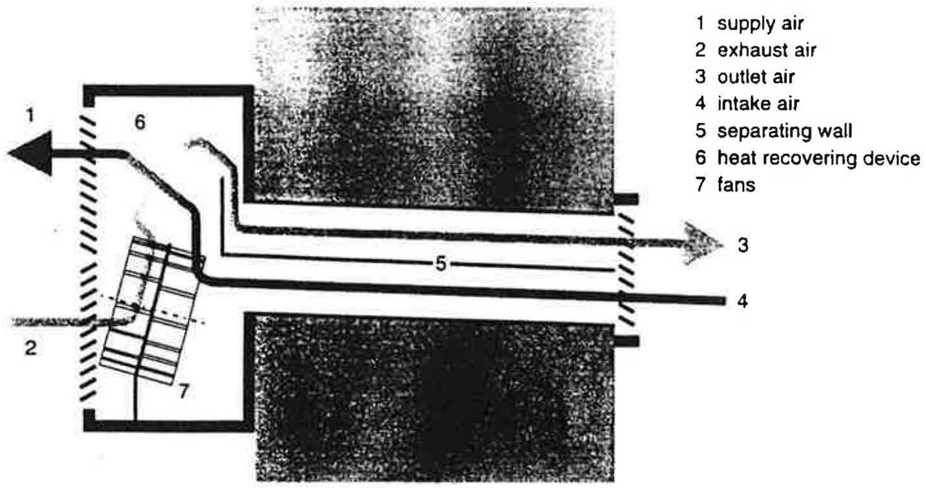

Figure 1: Side view of unit A.

Unit B: A mid-size ventilation unit with a one-motor, two-fans system, too, which is equipped with a heat recovering device made from plastic-coated paper. Ducts for exhaust air and supply air are two tubes of 10 cm diameter each. This unit has a very low specific power consumption (Table 1).

Unit C (shown in Figure 2): Uses two DC-fans for supply air and exhaust air. Ducts for outlet air and fresh air consist of two tubes of 15 cm diameter each. The ports of supply and exhaust air are well separated and air flow directions are opposite, so that good ventilation effectiveness can be expected.

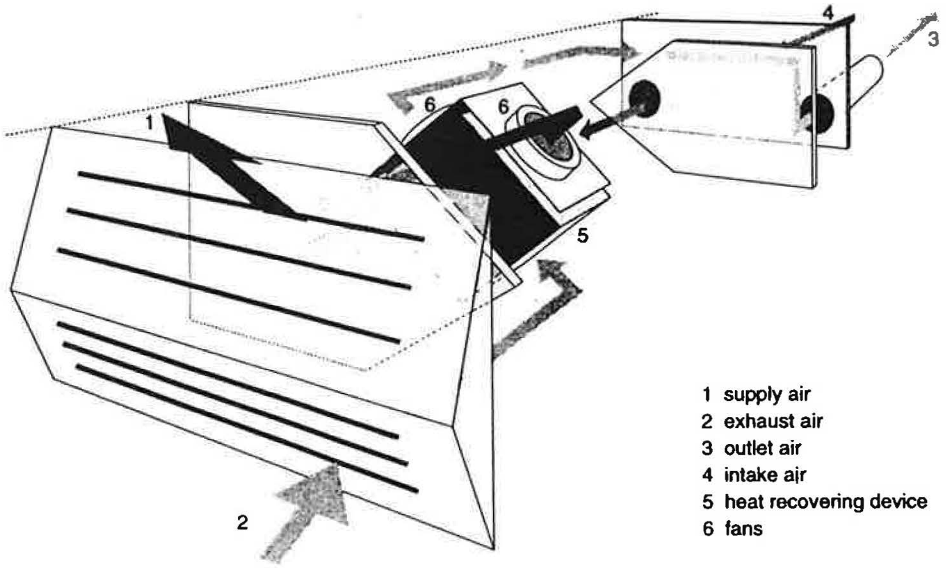

Figure 2: Sketch of unit C.

3. Performed Measurements

A suitable tracer gas is injected either into the measuring zone or into the ventilation system itself. From the analysis of the concentration data versus time, one is able to do several evaluations [2,3]. MULTI-CAT [4] is a fully automated measuring system controlled by a 80286 computer. N_2O serves as tracer gas. The system is able to perform controlled gas injections at up to 8 places and to measure tracer gas concentrations at other 8 different locations. Values of tracer gas concentrations are obtained from an infrared gas detector.

Internal and external cross flows of air
One major problem with room ventilation units is the difficulty to seal the internal air flow paths against crossflow. Based on mass conservation one can evaluate air flow rates at arbitrary locations, even though they are not accessi-

ble by mechanical measuring devices. A measurement setup (see Figure 3) was chosen, which allows the determination of unwanted internal and external cross flows of air.

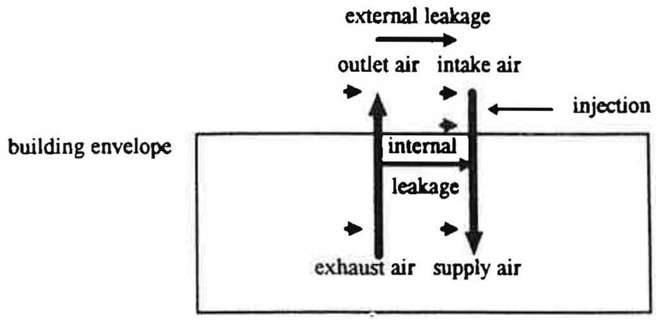

Figure 3: Principle of the measuring setup used to investigate cross flows of air inside and outside (internal, external leakage) the ventilation unit. The triangles show the places where tracer gas concentrations are measured.

In this case the tracer gas injection took place at the fresh air duct. Concentrations of tracer gas were measured at several locations indicated in Figure 3. The air flow rates at intake and outlet were determined by measuring the difference between static and dynamic pressure.

Heat recovery efficiency

The degree of recovering sensible heat is determined by measuring air temperatures at exhaust, intake and supply positions. Measurements were performed with high precision platinum resistors (Pt 100) and with data sampling over 24 hours. The heat recovery efficiency or heat recovery effectiveness ϕ is then given by

$$\phi = \frac{T_{Supply} - T_{Intake}}{T_{Exhaust} - T_{Intake}}. \qquad (1)$$

Notice that waste heat of the electrical components (fans, transformer) is included by this definition of ϕ. Furthermore it is important to emphasize that temperature data has to be corrected if there is recirculation of flows inside the ventilation unit. With 100 % recirculation of internal air (or $T_{Supply} = T_{Exhaust}$) one gets ϕ equal 1, although no real heat exchange between exhaust and supply takes place.

Therefore, temperature corrections must ensure that only values immediately before and after the heat exchanger are considered and mixing effects due to crossflows do not distort the value of ϕ.

4. Results

Internal and external leakage

Assuming isothermal boundary conditions air flow rates can be calculated from the concentration data given in Table 2. For example the flow rate of intake air $\dot{V}_{Intake}$ is determined by:

$$\dot{V}_{Intake} = \frac{\dot{V}_{Tracer}}{C_{Fresh,before} - C_{Intake,after}}. \quad (2)$$

$C_{Fresh,before}$ respectively $C_{Intake,after}$ are tracer gas concentrations before and after its injection. $\dot{V}_{Tracer}$ is the flow rate of tracer gas. In a similar way, one is able to calculate the air flow rates along other paths. Results are compiled in Table 3. Figure 4 shows a typical set of concentration data. The equilibrium concentrations are determined by numerical data analysis.

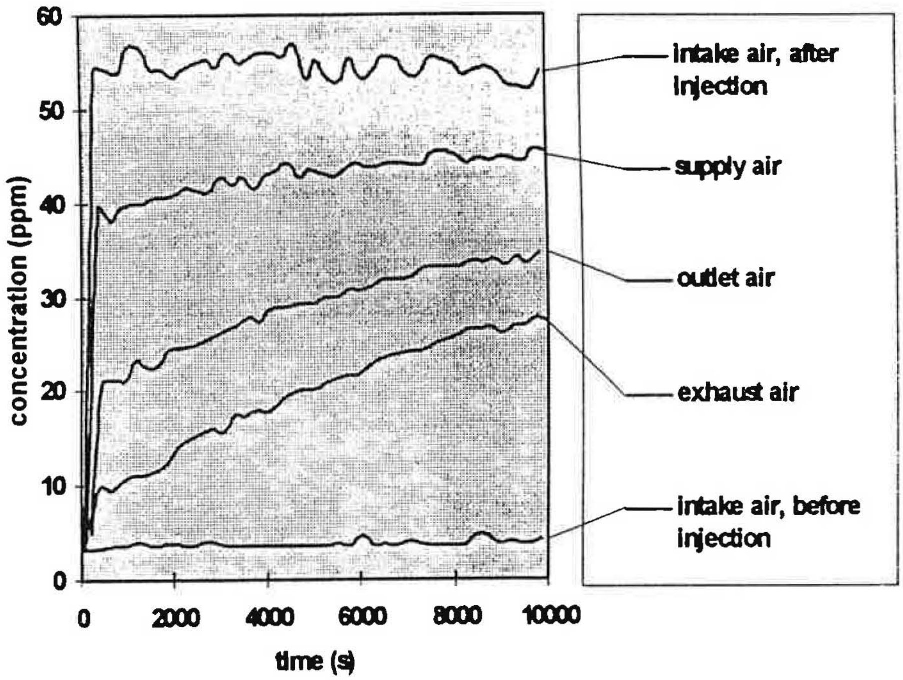

Figure 4: Concentration versus time for unit C, with measuring setup according to Figure 2. Notice that concentration of tracer gas in the outlet air is higher than in the exhaust air right from the start. This means that a part of intake air (after injection) is mixed to the outlet air (19 m^3/h). Tracer gas concentration of supply air is significantly lower than concentration of intake air. Therefore, exhaust air with low concentration must have been mixed to the supply air (32 m^3/h).

Device	Final tracer gas concentrations (ppm)				
	fresh air before injection	intake air after injection	supply air	exhaust air	outlet air
unit A	0.3	56	45.8	22	22
unit B	0.6	96.6	62	17	20.5
unit C	0.5	50.8	41	24	31.4

Table 2: Final tracer gas concentrations obtained from measurements according to the setup shown in Figure 2.

Device	Air flow rates (m^3/h)					
	intake air	supply air	exhaust air	outlet air	internal leakage	external leakage
unit A	25.2	36	34	23.9	10.8	22.3
unit B	42	75	74	41	33	0
unit C	74	87	87	74	19/32	0

Table 3: Air flow rates for different flow paths obtained from tracer gas measurements. The internal leakage of unit C consists of two leakage flows explained in the description of Figure 3.

The air flow rates of Table 3 reveal that for all units the supply air consists to a considerable amount of exhaust air. Therefore, a fresh air efficiency η is defined with:

$$\eta = 1 - \frac{\dot{V}_{Leakage}}{\dot{V}_{Supply}} \quad (3)$$

which results in η = 81 % (!) for unit A and 56 % or 63.2 % for units B or C, respectively.

Heat recovery efficiency

Table 4 displays air temperatures taken during the measurements of tracer gas concentrations. With them the efficiency of heat recovery is obtained from equation (1).

Device	Air temperature (°C)				Heat recovery effectiveness (-)	
	intake air	supply air	exhaust air	outlet air	$\phi_{eq.1}$	ϕ_{corr}
unit A	9.2	14.2	17.2	14.1	0.63	0.38
unit B	5.5	17.1	20	14	0.80	0.58
unit C	3	21	23	19	0.90	0.77

Table 4: Air temperatures and heat recovery effectiveness. For the calculation of ϕ_{corr} recirculation of air and warming by the fans was taken into account. This means that ϕ_{corr} is the real heat recovery efficiency.

The real heat recovery efficiency ϕ_{Corr} has to be calculated from equation (1) also, but with corrected values for supply and intake temperatures T'_{Supply} and T'_{Intake}. T'_{Supply} is usually lower than T_{Supply} measured at the outlet of supply duct, because waste heat from the fan motor warms up the supply air additionally. Therefore

$$T'_{Supply} = T_{Supply} - \frac{P}{\dot{V}_{Supply} \cdot \rho \cdot C} \qquad (4)$$

with P (W)[2] as electrical power demand of the ventilation unit, $\rho \cdot C$ (= 0.34 $Whm^{-3}K^{-1}$) the volumetric heat capacity of air and $\dot{V}_{Supply}$ the air flow rate at supply duct. On the other hand T'_{Intake} is usually higher than T_{Intake} due to mixing of leaking exhaust air with the intake air[3]:

$$T'_{Intake} = \frac{T_{Exhaust} \cdot \dot{V}_{Leakage} + T_{Intake} \cdot \dot{V}_{Intake}}{\dot{V}_{Leakage} + \dot{V}_{Intake}} \qquad (5)$$

Energy savings

To estimate the reduction of heat energy by heat recovery from ventilation a calculation based on EN 832 [5] using weather data of Würzburg (Germany) was performed. A heating period from September to May corresponding to 6.500 hours was assumed. Table 5 presents the nominal energy savings according to the uncorrected heat recovery effectiveness and nominal air flow belonging to the technical data. Real energy savings are calculated based on the corrected heat recovery effectiveness and the measured air flow rates.

Device	Electrical energy consumption (kWh)	Nominal primary energy savings (kWh)	Real primary energy savings (kWh)
unit A	84.5	329	-133
unit B	175.5	1816	312
unit C	260	1578	629

Table 5: Nominal and real energy savings for the single zone ventilation units. One kWh electrical energy is assumed to be equivalent to 3 kWh primary energy.

The results of this table demonstrate a big difference between nominal primary energy savings and real ones. This is due to the fact that only by heat exchange from exhaust to fresh air heating energy can be saved and both, fresh

[2] The values for the electrical power demand used to calculate this temperature correction depend on the placement of the electric components in the unit. The used values are 6.5 W for unit A, 13,5 W for unit B respectively 16 W for unit C.

[3] The correction for unit A has to be done in a more complicated way that is not explained in detail.

air efficiency η and real heat recovery effectiveness ϕ_{Corr} are lower than expected.

Indoor air quality

To demonstrate the importance of ventilation efficiencies on indoor air quality CO_2-concentrations in an airtight room of volume 60 m^3 and occupied by one person are calculated on the basis of the measured ventilation efficiencies of the units and a nominally required air change rate n = 0.5 h^{-1} (according to $\dot{V}_{Fresh}$ = 30 m^3/h for one person). With an outdoor concentration of carbon dioxide C_{out} = 350 ppm and a personal emission rate Q = 18 l CO_2/h the asymptotic equilibrium concentration of carbon dioxide C_∞ yields:

$$C_\infty = C_{Out} + \frac{Q}{\dot{V}_{Fresh}} \tag{6}$$

Device	Nominally expected concentration of CO_2 (ppm)	Really existing concentration of CO_2 (ppm)
unit A	950	6350
unit B	950	1734
unit C	950	1282

Table 6: Nominal and real equilibrium concentrations of carbon dioxide for a defined test room with different ventilation units.

Table 6 includes the equilibrium values of carbon dioxide for the above mentioned conditions and for all three units, both, under nominal and real rates of fresh air supply. The real volume rate of fresh air $\dot{V}_{Fresh}$ is given by:

$$\dot{V}_{Fresh} = \eta \cdot \dot{V}_{Supply} \tag{7}$$

In order to compare the different units under similar conditions all values have been related to $\dot{V}_{Supply}$ = 30 m^3/h. The nominal value of 950 ppm CO_2 is situated just below the so-called Pettenkofer limit of 1000 ppm, which is commonly regarded to be far away from any critical range. Values beyond 1000 ppm, however, exceed the conditions of physiologic comfort and are similar to the climate in a submarine.

5. Discussion of results and conclusions

Tracer gas experiments are well suited to examine and characterise ventilation units in terms of leakage flows and ventilation efficiency. For the units under investigation severe and even fatal malfunctions have been detected endangering a sufficient supply of fresh air and diminishing considerably the effectiveness of heat recovery. The energetic and economic assessment of such units must include this aspect. Heat recovery efficiency is - for its own - not sufficient for a characterisation of ventilation units. Fresh air efficiency is also needed to know.

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