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Use of tracergas to determine leakage in domestic heat recovery units (HRV)

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1. Introduction. (Abstract)

Tracergases provide a way to determine airflows in different situations. In some cases it is the only way to get quantitative information. This paper presents two cases in which tracergases are used for measuring the internal leakage in heat recovery units.
Internal leakage in heat recovery ventilators (HRV's) for domestic use may cause some problems:

- the real quantity of fresh air entering the building is unknown
- electrical power for the fans is used inefficiently
- smelling air a.g. from the kitchen may re-enter the building due to cross leakage from exhaust air tot supply air
- the efficiency of the HRV seems apparently better.

Most commonly used in domestic buildings in The Netherlands is a cross-stream HRV. The internal leakage in three types of HRV's is measured using N_2O as a tracergas. It is shown that major leakage occurs alongside the heat exchanger blok. Internal leakage in the heat exchanger itself however can not be neglected. The measurements show that an air leakage rate of less than 3 % of the total airflow can be obtained by careful design.

Secondly is shown how internal air leakage in a (rotating valve) back flow heat recovery ventilator is measured. This type of heat recovery ventilator uses an accumulating mass to recover heat. Due to this principle a certain amount of leakage from exhaust air to supply air is unavoidable. The exact amount of air leakage can be measured using a continually sampling infra-red absorption analyser. With the results it was proved that the efficiency of the heat recovery was only minimal influenced by the leakage.

2. Leakages in heat recovery units

All possible leakage flows for a cross flow heat recovery ventilator are give in figure 1. At first is being noticed that leakage flows I'_{12} and I'_{34} parallel to the head flows I_{12} en I_{34}, can never be determined by measuring on the outside of the heat recovery unit. The effect of this leakage flow is only a decreased efficiency. This could also be caused by a bad K-value (in $W/m^2.K$) of the heat recovery ventilator. Both causes ara disindistinguishable, therefor these leakage flows will be left out of consideration [1].

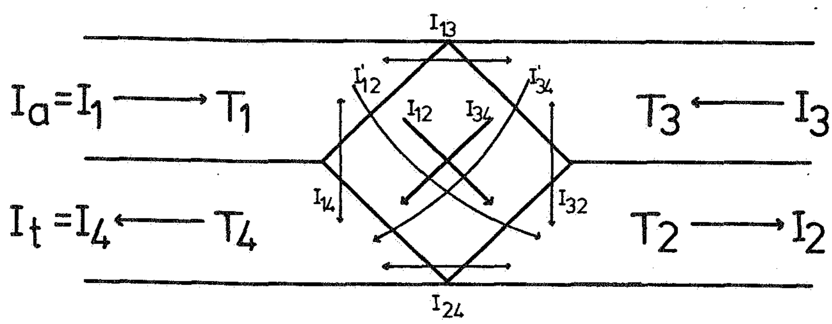

Figure 1. Leakage flow scheme.

The direction of the other 4 leakage flows are caused by the static pressures P_1 up to P_4 of the different compartments of the heat recovery unit.
The relation of these static pressures is dependant of the position of the ventilators in the unit. The pressure distribution of the examined heat recovery units was $P_3 > P_4 > P_1 > P_2$.

3. Theoretical background of the measuring procedure.

In a practice situation, whereby the behaviour of a unit is examined, the following measure values are known (see figure 2):

- temperatures T_1 up to T_4 in °C
- volume flows I_1, I_4 in m^3/h
- tracergasconcentration C_1, C_2 and C_4 in ppm
- ventilatorcapacity Q_2, Q_4 in W.

From the measured concentrations follow the leakfraction F_t (from exhaust domestic air to supplied fresh air) and F_a (from intake fresh air to exhaust domestic air).

$$F_t = (C_4/C_1) \quad (3.1a)$$
$$F_a = 1 - (C_2/C_1) \quad (3.1b)$$

On the basis of the known leakfractions can now be determined the resulting volume flows in the unit (I_{12}, I_{34}), the resulting leak flows (I_{14}, I_{32}):

$$I_{12} = I_1 - F_t \cdot I_4 \quad (3.2a)$$
$$I_{14} = F_t \cdot I_4 \quad (3.2b)$$
$$I_{34} = (1 - F_t) \cdot I_4 \quad (3.2c)$$
$$I_{32} = F_a \cdot (I_1 - F_t \cdot I_4)/(1 - F_a) \quad (3.2d)$$

and also the still unknown volume flows (I_2, I_3):

$$I_2 = I_{12} + I_{32} \quad (3.3a)$$
$$I_3 = I_{34} + I_{32} \quad (3.3b)$$

On the basis of the now known volume flows and the known electrical power of the ventilators the heating of the air through the ventilators can be known.

$$T_2' = T_2 - Q_2/(\rho \cdot C_p \cdot I_2) \quad (3.4a)$$
$$T_4' = T_4 - Q_4/(\rho \cdot C_p \cdot I_4) \quad (3.4b)$$

With ρ = the density of the air in kg/m^3
C_p = the heat capacity of air in W/kg°C

From these measured temperatures follow the corrected temperature efficiency of the heat recovery unit on exhaust (η'_a) and supply (η'_t)

$$\eta'_a = (T_1 - T_2')/(T_1 - T_3) \quad (3.5a)$$
$$\eta'_t = (T'_4 - T_3)/(T_1 - T_3) \quad (3.5b)$$

These efficiencies can be corrected for the occurring leakages assuming a worst case leakage situation.

$$\eta'_{a,c} = (\eta'_a - F_a)/(1 - F_a) \quad (3.6a)$$
$$\eta'_{t,c} = (\eta'_t - F_t)/(1 - F_t) \quad (3.6b)$$

The largest of both corrected efficiencies is equal to the **energy efficiency** of the heat recovery unit, the smallest of the both corrected efficiencies is equal to the **sensible heat recovery efficiency.**

Theoretical the corrected efficiencies are equal to equal volume flows. In case of unequal volume flows the corrected efficiency can be measured backward to an efficiency for equal design volume flows, assuming that the K-value of the heat recovery block is almost constant. Herefor the ratio of the volume flows will be calculated at first:

$$Y_t = I_{34}/I_{12} \quad (3.7a)$$
$$Y_a = I_{12}/I_{34} \quad (3.7b)$$

and calculating the heat-transfer-number:

$$Z_t = (I_{34}/I_o) \cdot \ln [(Y_t \cdot \eta'_{t,c} - 1)/(\eta'_{t,c} - 1)/(1 - Y_t)] \quad (3.8a)$$

$$Z_a = (I_{12}/I_o) \cdot \ln [(Y_a \cdot \eta'_{a,c} - 1)/(\eta'_{a,c} - 1)/(1 - Y_a)] \quad (3.8a)$$

With I_o as the design volume flow. The efficiency of equal design volume flows is:

$$\eta_{t',g} = Z_t/(1 + Z_t) \quad (3.9a)$$

$$\eta_{a',g} = Z_a/(1 + Z_a) \quad (3.9b)$$

The procedure is theoretical only correct for back flow heat recovery ventilators in a worst case leakage situation but also appears to be good in practice for cross flow heat recovery ventilators.

4. Internal leakage measurement in test set up among working conditions.

4.1. Measure situation.

In figure 2 is given the measure set up for the determination of internal leakage among working conditions. The air supply and air exhaust holes are provided with a rulable airresistance (f.i. a butterfly valve) and with a supply for measuring air volume flows.
The rulable air resistances are being set up so that the real pressure distributions in the canals around the units arise.

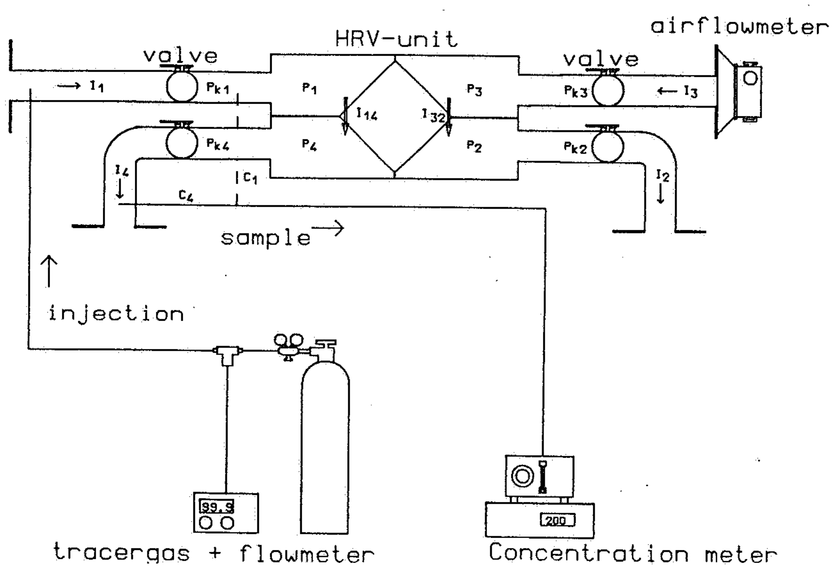

Figure 2. Measure set up

The exhausted volume flow (I_1) and the supplied volume flow (I_4) will be set up on practice values (225 m^3/h). The volume flows I_1 up to I_4 will be measured and also the pressures in the air canals P_{k1} up to P_{k4} and the pressures in the compartments of the heat recovery unit (P_1 up to P_4).
The resulting leakage flow $I_t = I_{14}$ from exhaust to supply will be determined by injection of a tracergas (N_2O) in the exhausted airflow.
After sufficient mixture the tracergasconcentration will be measured in the exhausted airflow (C_1) and in the supplied airstream (C_4).

If the external leakage can be neglected, the following resulting leakage flow will exist:

$$I_{14} = (C_4/C_1) * I_4 \quad (4.1)$$

This expression is only operative if the draw air volume flow I_{32} of draw to exhaust will be determined in the same way according:

$$I_{32} = (C_2/C_3) * I_2 \qquad (4.2)$$

4.2. Measuring results

The internal leakage is measured with 3 units (figure 3 up to 5). The measured resulting leakage flows; from exhaust to supply to the building (I_{14}) and supply from outside to exhaust out of the building (I_{32}) are mentioned for 2 measure situations in table 1.

Unit	measure situation	leakage flow [m³/h]	
		I_{14}	I_{32}
A (fig. 2)	(regular)	< 2	17
	(modified)	< 2	11
B (fig. 3)	(regular)	< 2	< 2
	(modified)	< 2	< 2
C (fig. 4)	(regular)	3	22
	(modified)	< 2	11

Table 1. Internal leakage on the basis of tracergas measurement.

From table 1 it appears that leakage from exhaust to supply almost doesnot exist. This is accountable in the ground of the occurring pressure distributions in the unit (see figure 2).
Leakage from exhaust to supply can only be measured with unit A and unit B. The rest leakage in the improved situation is ascribed to a part leakage via the heatrecovery block and a part leakage along the sides of the heat recovery block and the cover. The leakage via the heat recovery block will be small. On the basis of measure information these leakage is about 3 to 5 m^3/h in case of 300 Pa pressure difference.

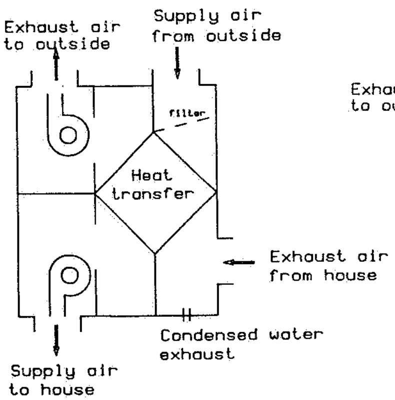

Figure 3: Unit A.

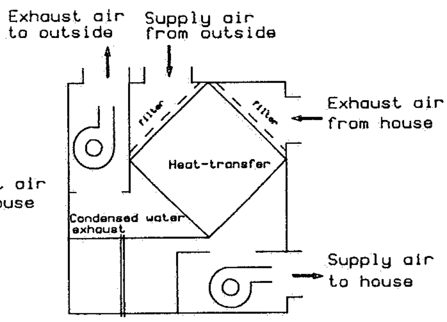

Figure 4: Unit B.

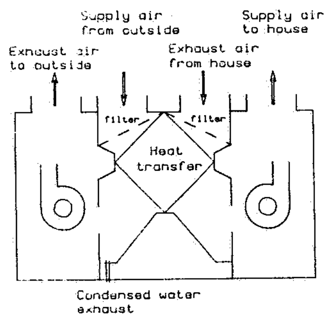

Figure 5: Unit C.

5. Proposal to standardization

From the measure results it appeared that the resulting leakage flow from exhaust to supply (I_{14}) can be reduced to less than 1% of the supplied airflow. As a provisional standard on the basis of the measurement results wil be used in [2]:

- the ventilation air supplied to the dwelling cannot consist of more than 1% exhausted dwelling air, as a result of **internal leakage** in the heat recovery unit.

From smell spreading and the loss of ventilator capacity the resulting internal leakage ($I_{14} + I_{32}$) is of importance. As a provisional standard is mentioned in [2]:
- the **total result internal leakage** among working condition is not allowed to be more than 2,5% of the total air volume flow. In case of a airflow of 2 x 225 m^3/h this is at most 11m^3/h.

6. Back flow heat recovery ventilator

6.1. Working principle and leakages.

Finally the application of leakage measurement with tracergas on the back flow recovery ventilator. The unit is concerning air capacity comparable with other heat recovery units for application in dwellings [3].
The air flow supplied by the unit to the measure dwelling was 149 m^3/h, the exhausted airflow was 184 m^3/h.

On the basis of the working principle (figure 7) of the unit 3 types of leakage can occur (see figure 6):
- leakage during the overturn of the shuttle valve ("short circuit").
- leakage through back flow of exhausted dwelling air from the canals and the accumulation mass.
- leakage between the shuttle valve in the final position ("steady" leakage).

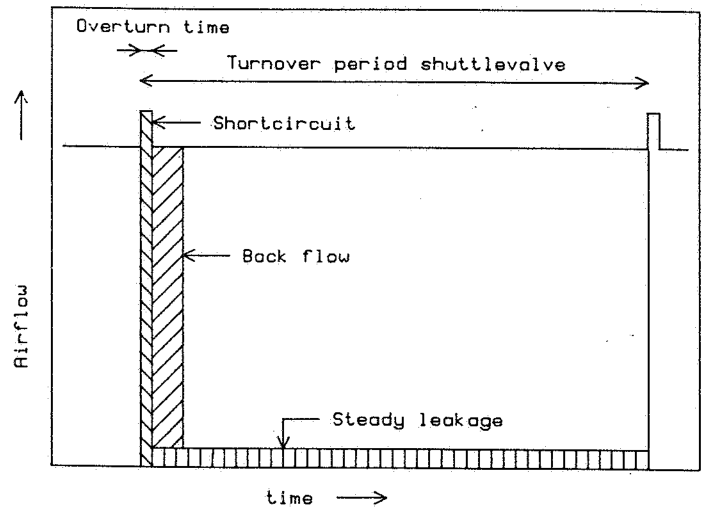

Figure 6: Possible occurring leakages.

The exhausted air from the dwelling will be blowed into the dwelling as a result of all 3 types of leakages. Except smell spreading, apparently these leakages also influence the efficiency of the unit.

6.2. Measurements

The occurring leakages are measured with the help of a tracergas. The tracergas (figure 7) is injected in one of the exhaust canals. The tracergasconcentration in the exhausted air is measured in the canal after the exhaust ventilation. From the relation of the injected quantity tracergas and the measured tracergasconcentration in the exhausted air, the exhausted quantity is determined. Also the short increasement of the exhausted air quantity during the overturn of the shuttle valve is measured on this manner. Herefrom the occurring leakage is determined.

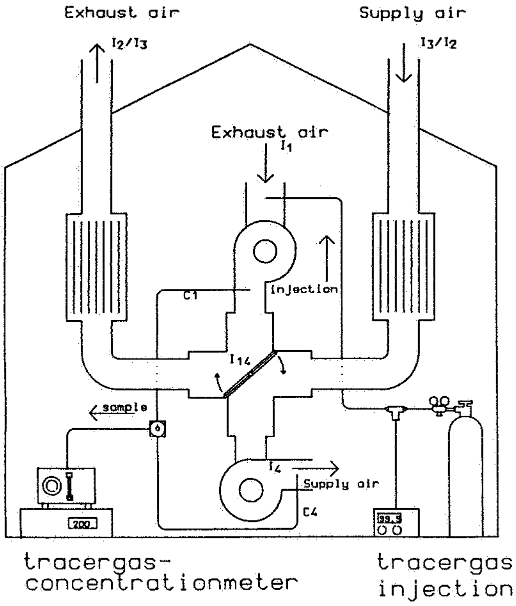

Figure 7: Measure set up.

The tracergasconcentrationmeter has a certain slowness. The rapid concentration changes during and after the turnover of the shuttle valve will be spread over a longer period. This has no influence on the average concentration which eventually is important for the determination of the leakage. Considering the minimal measure reach of the tracergasconcentrationmeter it appeared that less than 1% leakage along the shuttle valve takes place in the end position. The measured average leakage can be calculated back to the real leakage (table 2).

	time [s]	leakage flow [m^3/h]	average percentage [%]
leakage during the turnover of the shuttle valve	0,9	202	1,3 %
leakage through backflow of air from the canals	2,8	184	3,7 %
Stationary leakage via the shuttle valve in the end position	76	< 2	< 1 %

Table 2. The measured air leakage of exhausted inside air to supplied outside air, divided in time and quantity.

6.3. Efficiencies

The measured efficiencies of the heatrecovery unit can be corrected for the leakage. Herewith the following suggestions are made:

1. The measured efficiency can be corrected with the help of an average measured

leakage percentage.
2. The temperature of the leakage air is equal to the temperature of the exhausted inside air.

Both suggestions are justified [3]. Suggestion 2 means that it is assumed that these leakage takes place directly from the exhausted inside air to the supplied air of the dwelling. This is pointed out with the "worst case" situation because the influence of the leakage on the efficiency is at its maximum and therewith the correction on the measured efficiency is the highest.
The efficiency of the unit is measured during a period of 3 weeks. The measured average efficiency is a lineair equation (figure 8). Considering this efficiency as a function of the temperature difference ΔT between inside and outside air and corrected for the leakage and inequal supplied and exhausted volume flow.

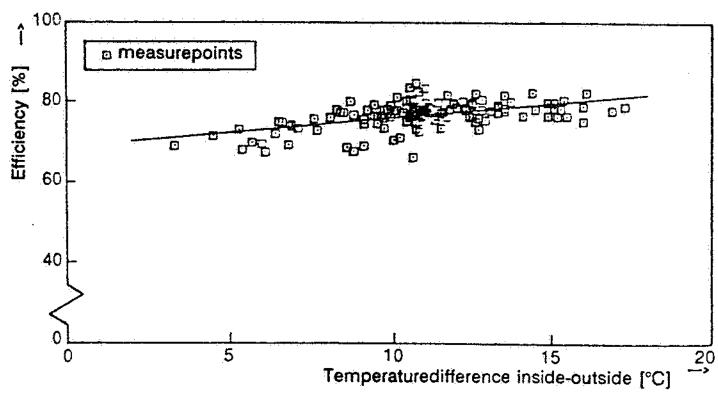

Figure 8: Measured efficiency (corrected for leakage).

6.4. Conclusions

From the measurements appears that the shuttle valve of the unit in the final position closes sufficiently to prevent leakage along this shuttle valve. The leakage during and short after the turn over of the shuttle valve is normal for the heat recovery principle and therewith unavoidable. The measurements have showed that these leakage can be estimated on the basis of the turnover time of the shuttle valve and the volume of the canals between the shuttle valve and outside. The unavoidable leakage percentage is about 2,4% in case of a minimal canal volume and dependent of the volume flows.

7. References

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[3] Gerwen, R. van: Leakage and efficiency measurement on a heat recovery exchanger based on accumulation and shuttle valve. Report 5860-1* Cauberg-Huygen Raadgevende Ingenieurs B.V., 1990 (in Dutch).

* Research reports by order of the Dutch Agency for Energy and the Environment (NOVEM).

Apendix A.

Definitions apply in this paper:

- **Resulting leakage flow** (I_{14}, I_{32})
  The nett volume flow which comes via several ways eventually from the exhausted inside air in the supplied outside air resp. from the exhausted outside air in the supplied inside air.
- **Leakage fraction** (F_1, F_2)
  The part of the supplied outside air, consisting of exhausted inside air resp. the part of the exhausted inside air consisting of exhausted outside air. If the leakage will be mentioned in percents there will be spoken of leakage percentage.
- **Efficiency** (η_a, η_b)
  With efficiently is undoubtedly meant the temperature efficiency. This is the relation of the reached temperature difference and the largest temperature difference. This reached temperature difference can be measured in the exhausted and supplied outside air (η_t) or in the exhausted and supplied inside air (η_a).
- **Measured efficiency**
  The temperature efficiency measured on the basis of the measured temperature of the airflows without the heat recovery unit.
- **Temperature corrected efficiency** (η'_a, η'_b).
  The temperature efficiency measured on the basis of the measured temperature inclusively the effect of heating up through the ventilators.
- **Corrected efficiency** ($\eta'_{a,c}$, $\eta_{t,c}$).
  The temperature efficiency inclusively the effect of heating up
  through ventilators and the effect of leakage.
- **Energy efficiency**
  The relation of the recycled sensible heat and the maximal to recycle sensible heat considering the fact that the maximal temperature difference can only be covered by the smallest volume flow.
- **Sensible heat recovery efficiency**
  The relation of the recycled sensible heat and the maximal to recycle sensible heat considering the fact that the maximal temperature difference can only be covered by the largest volume flow.