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EVALUATION OF VENTILATION SYSTEM IN VERY LOW ENERGY HOUSES

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0. Synopsis

Since 1985 more than 170 very low energy houses, all of the same type and structure, were built in the Flemish Region, Belgium. Because conduction losses are very low, mean U_m-value 0.30-0.35 $W/(m^2 \cdot K)$, ventilation losses become very important, up to 45% of the heat losses if no heat recovery is utilised. Three of the houses were monitored in detail for energy consumption, energy and ventilation efficiency.

All houses are equipped with the same ventilation system: balanced mechanical ventilation with heat recovery. Tracer gas measurements, pressurisation tests, multipoint temperature measurements and on site and laboratory tests of the heat recovery system, give us a complete scope of the ventilation system and its energy and ventilation efficiency.

Pressurisation and depressurisation tests revealed the main air leaks in the construction: the different connections wall-floor and wall-roof, the window perimeter, even the sockets. Extra care in construction practice changed the n_{50}-value from an average of 4.5 AC/h to 3.5 AC/h, still high for a house with controlled ventilation.

After testing the airtightness, we carried out tracer gas measurements in whole dwellings and between the different zones. Real ventilation rates and interzonal flows were derived. Questions like: Are the airflows in accordance with the design values? Do they match the requirements? How can we measure interzonal flows with one tracer? were answered. The paper gives a mathematical description of the tracer gas flow patterns (solution of the differential flow equations) and compares the results with the measured data.

To complete the evaluation we carried out laboratory tests and field measurements on the heat recovery system. In laboratory the flat plate cross-flow heat exchanger showed a thermal efficiency up to 65% under specific climate conditions. In the dwellings, insulation and airtightness of the ducts appeared to be very important. The temperature efficiency decreased to values less than 45%.

As a conclusion, one may stress that a global evaluation of the ventilation efficiency has to include different tests. The medium or poor airtightness has the greatest impact on the energy efficiency of heat recovery and on the ability to control the system. Detailed testing also showed some flaws in the ventilation system and in the building construction.

1. Introduction

All 70 low energy houses are of the same type and structure. They have high insulation levels, with a mean U_m-value of 0.30 - 0.35 $W/(m^2 \cdot K)$ (see Table 1).

	U-value	insulation thicknesses
cavity wall	0.19 $W/(m^2 \cdot K)$	15 cm EPS + 4 cm MW
sloped roof	0.18 $W/(m^2 \cdot K)$	min. 14.5 cm PUR
flat roof	0.16 $W/(m^2 \cdot K)$	min. 16 cm PUR
floor	0.5 $W/(m^2 \cdot K)$	7 cm EPS
glazing	1.8 or 1.3 $W/(m^2 \cdot K)$	

Table 1: Major U-values and insulation thicknesses of the low energy building [ref. [2]]

A survey of 42 of these dwellings revealed their very low energy use. The average measured total energy use is about 62 kWh/(m^2.a). The energy use for heating varied from 40 to 58 kWh/(m^2.a) with an average of 45 kWh/(m^2.a) in the Belgian climate (1987 degree days, base 15°C) [ref. [3]].

Because conduction losses are very low, ventilation losses become very important, up to 45% of the heat losses if no heat recovery is used. A heat exchanger is included in the balanced ventilation system.
The goal of this research work is to get a clear description of the ventilation and energy efficiency of the ventilation system in this type of low energy house. The strategy we used here is also applicable and useful for other well-insulated dwellings with a controlled ventilation system. First the ventilation and energy efficiency are discussed separately. Then, as a conclusion, they are coupled.

2. Ventilation efficiency

Following items are measured: the airtightness of the building envelope, the airtightness of the ventilation ducts, the supplied and extracted air flows. To derive the actual ventilation rates and the interzonal airflows, tracer gas measurements were performed.

2.1. Airtightness of the building envelope

The airtightness of the building envelope is accurately tested in six houses. The results in Table 2 show the overall airtightness. Differences between the different houses are clear. Firstly the more recent the house the more airtight it is. The values with pressurisation are higher than with depressurisation. Cellar and garage are not airtightly separated from the protected building envelope: houses with cellar and garage in the house are less airtight than the others.

	depressurisation	pressurisation	year of construction	cellar or crawl space	garage in house
1	4.3	6.3	1990	Yes	Yes
2	4.0	5.4	1991	Yes	No
3	4.4	5.3	1991	No	Yes
4	4.9	4.5	1992	Yes, with door	Yes
5	3.6	3.6	1995	No	No
6	3.8	3.8	1995	Yes	Yes

Table 2: Measured n_{50}-values for 6 low energy houses

By visualisation with smoke and by taping of some leaks, the air leaks are qualitatively identified. The major air leaks are a consequence of the building construction itself.
The construction is built up as follows: on the foundation walls and pillars, prefabricated 3.9 × 3.9 m large concrete slabs with EPS insulation are positioned. Then the main load bearing structure, a skeleton of steel profiles and laminated timber joists and trusses, is erected. Finally the lightweight wall, roof and window elements are filled in and the dwelling is finished with a brick outer leaf and a tiled roof surface.

The roof segments are large lightweight prefabricated elements. They just fit into the load bearing structure, but all the seams and junctions remain possible air leaks, especially the connection wall-roof and the connection at the top of the roofs.
The same problem is investigated with the built in lightweight wall elements. Formerly the EPS insulation plates were placed directly on the floor slab, nowadays a space is left to be filled with PUR-foam.
Another interesting air leak is the floor slab itself. Some airopen junctions between the concrete slabs make it possible that air flows from within the crawl space through the floor into the light weight double plated inner walls. Because of this defect in the building construction even the sockets in inner walls are possible air leaks. (In the worst case all interior walls are filled with crawl space air, because all inner walls are interconnected.)
The doors to the garage, the crawl space and cellar are not airtight enough and the window perimeter is an other air leak.
None of these air leaks is dominant but together they make the building envelope too airpermeable for an efficient mechanical ventilation with heat recovery.

2.2. Airtightness of the ventilation ducts

The ducts of the ventilation system consist of a combination of two materials, stiff PVC-tubes and flexible, insulated ducts (2 cm MW). Both the supply and extract ducts are tested by depressurisation with a small power controlled fan. Table 3 and Figure 1 show the results for a pressure difference of 50 Pa. These values are extremely and intolerably high. When the system is working on medium speed at 50 Pa, 33% of the air escapes through air leaks in the ductwork.

	airflow [m^3/h] at 50 Pa	
air leaks		
Supply circuit	57	50 Pa
Extract circuit	55	
ventilation fans		
low	79	
medium	151	?
high	265	
enhanced	320	

Table 3: Leakage airflows compared with the airflows through the ventilation system (different speed levels) at a pressure drop of 50 Pa

2.3. Measurement of the supplied and extracted air flows

Due to the great leakage flows in the ventilation system one can conclude in advance that the ventilation system will not supply the amounts of air it is dimensioned for. Nevertheless we did the measurement in 2 dwellings (dwelling 4 en 6). In both houses the airflows are measured in two conditions:

- all interior doors closed and the ventilation system on low level (worst scenario)
- all interior doors opened and the ventilation system on high level (most favourable)

The airflows were investigated with a rotor anemometer at the ventilation openings. In the worst scenario, almost none of the air inlet or extract openings delivers or extracts enough air according to the Belgian regulations. Even in the most favourable case some rooms are not provided well in one house.

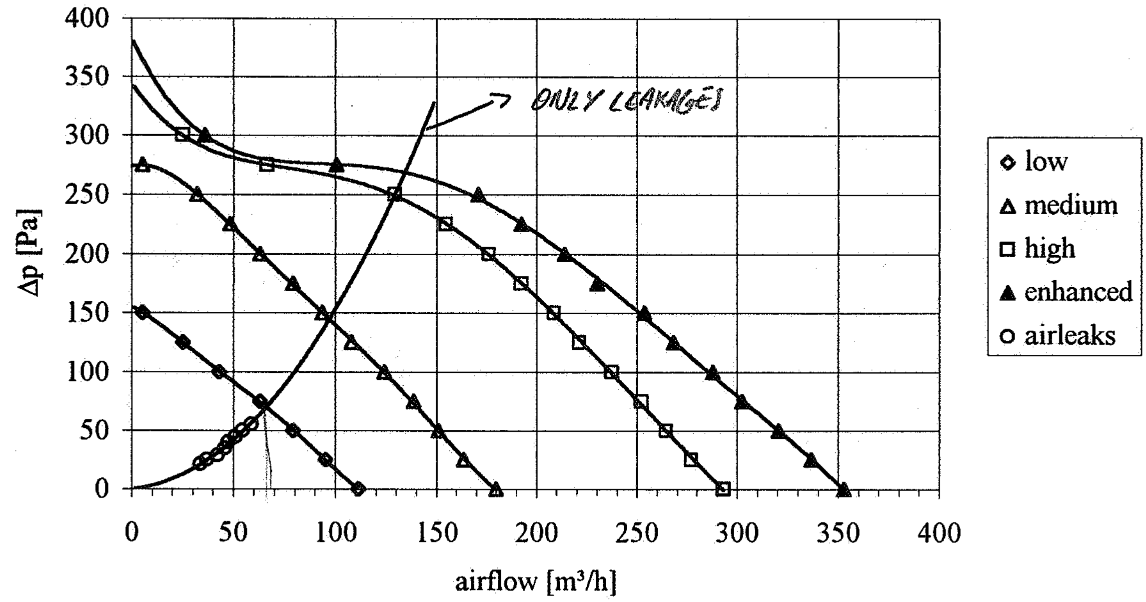

Figure 1: fan characteristics of the ventilation system compared with the duct leakage flows

2.4. Ventilation rates for each room

Instead of calculating mass balances between rooms, starting from the extracted and supplied airflows, one can measure real ventilation rates with tracer gas measurements. So for some of the rooms in the different houses the ventilation rates are measured using "the decay method". Ventilation rates from 0.35 AC/h (sleeping room house 1) up to 0.75 AC/h (bathroom house 2) are measured. In most of the cases there is no constant decay. This is obvious because of the lack of airtightness of the building envelope. The climate still plays an important role in the ventilation of the dwellings. But thanks to the lack of airtightness (high infiltration rates), most of the rooms receive a higher and sufficient ventilation rate.

2.5. Interzonal airflows

The ventilation rates calculated from the single zone measurements have been compared with the regulations. But one also has to examine if the airflows go from inlet to outlet and with the right amounts of fresh air. Therefor we tried to measure and calculate the interzonal airflows. The first and very important hypothesis, is the assumption that the ventilation rate is constant. Using this assumption, one can easily derive, from the mass balances, the differential equations describing the airflows between two different rooms and outside (in appendix).

Combining these equations and the tracer gas measurements, it is possible to calculate the interzonal airflows, so that the best fit is achieved between measured and calculated tracer gas concentrations.

Results for dwelling 1: The airflows were found by iteration of a two-zone model with the tracer gas measurements. Figure 3 shows the similarity of the measured and theoretical (best fitted) tracer gas concentrations.

from	→ to	airflow [m³/h]
living room	→ outside	95
living room	→ adjacent	17
outside	→ living room	109
adjacent	→ living room	3
outside	→ adjacent	62
adjacent	→ outside	76

Table 4: calculated interzonal airflows

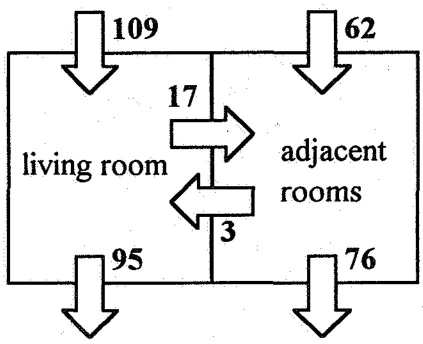

Figure 2: calculated interzonal airflows

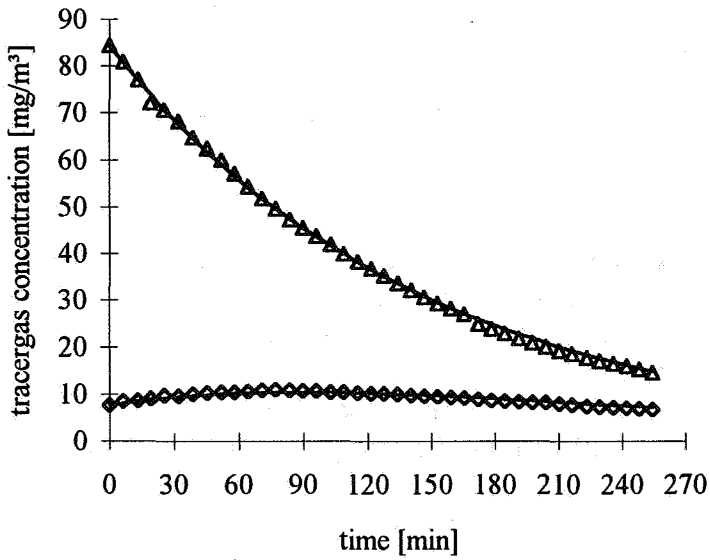

Figure 3: measured and theoretical (best fitted) tracer gas concentrations.

There are some remarks on this method. Some measuring cycles give insufficient results because of different reasons:

- the ventilation rate is not constant
- the measuring period is too short
- the tracer gas concentrations in the adjacent rooms are very low
- the tracer gas concentrations are supposed to be homogeneous in each room
- the tracer gas concentrations are not measured in the extract and supply ducts

Nevertheless the method gives information about the airflow patterns within the house. Some flaws in the ventilation system have been detected. For example: the bathroom in house 4 has a return flow through the hall to the toilet.

3. Energy efficiency of the heat recovery system

All the houses are equipped with a mechanical ventilation system with a static air-to-air heat exchanger. We will not proceed here with an economic analysis of this choice, we only look to the energy efficiency. First some results of the laboratory tests of the heat exchanger are given. Further the energy efficiency of the heat exchanger in the low energy houses is considered.

3.1. Laboratory tests of the air-to-air heat exchanger

The heat exchanger used is a flat plate air-to-air heat exchanger with cross-flow.
During several weeks the heat exchanger was tested under very different laboratory conditions in over 60 test-cycles (temperature, temperature difference, relative humidity, mass flow rates, pressure drops). The overall conclusion is that the tested heat exchanger retains a very constant temperature efficiency of about 65 to 67 % under different conditions of temperature difference and air flow rates.

3.2. On site testing of the air-to-air heat exchanger and the heat recovery system

In house 1 the efficiency of the heat exchanger was tested on site. The heat exchanger itself revealed a very high efficiency of about 73 %. However, the main problem is that, due to the lack of insulation and airleakage of the ducts, the temperature difference between outside and inside, is not active over the heat exchanger. As a consequence, temperature efficiency in situ decreases to 45 %.

4. Global evaluation of the mechanical ventilation system in the very low energy houses

The most important aspect for an efficient ventilation system for this type of houses is AIRTIGHTNESS of the envelope and the ducts, as well from the energetic point of view, as for ventilation efficiency. Lack of airtightness of the building envelope disturbs the ventilation balance and makes the airflows in the different rooms weather dependent. It also withdraws the energy efficiency of the heat recovery system. All air which infiltrates or exfiltrates through the envelope is lost for heat recovery. Lack of airtightness of the ductwork short-circuits the balanced ventilation system and, due to this, the efficiency of the heat recovery in the investigated dwellings decreases to less than 45 %.
Despite or sometimes thanks to the lack of airtightness most of the rooms are ventilated sufficiently.

5. Appendix

5.1. Calculation of interzonal flows with one tracer gas, using the decay method [ref. [1], [5]]

- conservation of mass: hypothesis: the air density is constant

$$\sum_j \left(-q_{ij} + q_{ji}\right) = 0 \qquad (1)$$

for $i = 1, n$ with n = number of zones
$j = 1, n$ + outside, $j \neq i$
q_{ij} and q_{ji} = airflows from i to j and from j to i, [m^3/h]

- conservation of mass of the tracer gas

$$V_i \frac{dc_i}{dt} = \sum_j \left(q_{ji} \cdot c_j - q_{ij} \cdot c_i \right) \quad (2)$$

for $i = 1, n$ with n = number of zones
$j = 1, n$ + outside, $j \neq i$
c_i = tracer gas concentration in zone i, [mg/m³]

The equations (2) form a system of n coupled linear first order differential equations with n independent variables c_i and with the airflows q_{ij} and q_{ji} and the volumes V_i as parameters. The solution of this system is a sum of n exponential functions of the form:

$$c_i(t) = A_{i1} e^{\lambda_{i1} \cdot t} + A_{i2} e^{\lambda_{i2} \cdot t} + \ \ldots \ + A_{in} e^{\lambda_{in} \cdot t} \quad (3)$$

with A_{ij} and λ_{ij} functions of the airflows q_{ij} and q_{ji}

The differential equations are solved numerically with the method of central differences. With the tracer gas concentrations at time t, the tracer gas concentrations at time $t+\Delta t$ are calculated, for a specific set of the parameters q_{ij} and q_{ji} and V_i.

$$c_{i,t+\Delta t} = c_{i,t} - \sum_j \left(q_{ji} \cdot c_{j,t} - q_{ij} \cdot c_{i,t} \right) \cdot \frac{\Delta t}{V_i} \quad (4)$$

By solving the minimisation problem between calculated and measured tracer gas concentrations the unknown airflows q_{ij} and q_{ji} are derived iteratively.

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