ACCURATE PERFORMANCE TESTING OF RESIDENTIAL HEAT RECOVERY UNITS

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ABSTRACT

The Norwegian Building Research Institute (NBI) has completed a study of the performance of balanced residential ventilation systems with heat recovery (HRVs) in Norway. The study involved both a national questionnaire survey and thorough laboratory tests of 10 HRVs on the market. The overall conclusion is that balanced ventilation with heat recovery provides very good air quality, and has a payback time of 4~6 years for the most profitable systems despite Norway's cheap hydropower (0.09 €/kWh in 2002). Today's European standards for HRV performance testing (EN 308:1997, prEN 13141-7:2003) do not explicitly define net recovery efficiency, i.e. how to account for system losses such as fan energy, air leakage, defrosting, etc., when calculating net annual energy savings or net air exchange rate. Furthermore, the specified test conditions are not entirely realistic, nor fair for different HRV types. NBI has therefore developed an improved new test method that has now been accepted as a Nordtest method in the Nordic countries. This paper describes some of the philosophy behind the new test method, focusing in particular on the definition of heat recovery efficiency, and issues related to total enthalpy and moisture recovery.

KEYWORDS

Heat recovery, Dwellings, LCC, Leakage, Enthalpy, Humidification

INTRODUCTION

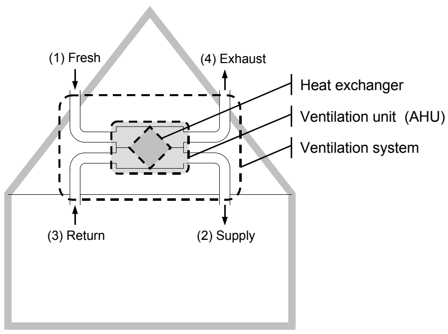
Balanced ventilation is now installed in half of all new detached houses in Norway. NBI has completed a two-year study to evaluate the performance of balanced residential ventilation with heat recovery in cold-climate conditions (Schild, 2003a, 2003b). The project consisted of a questionnaire survey among 250 homeowners and performance testing of 10 different ventilation units in the laboratory. The questionnaire had 29 questions about the installation, reliability, ease of maintenance/operation, and performance (comfort, noise, IAQ, humidity, energy consumption). The laboratory tests included: fan performance, air leakage, heat and moisture recovery, and noise level. This paper concentrates on the testing of heat recovery efficiency.

The study was primarily motivated by a lack of satisfactory documentation on heat recovery units. There is presently no satisfactory internationally harmonized standard for accurate performance testing of 'net heat recovery efficiency', 'annual net heat recovery efficiency', and 'net air exchange capacity' of heat recovery units. The main method presently in use in Europe, EN 308:1997, and similar methods such as Nordtest VVS 24:1983, are unclear on a number of points related to laboratory procedure and calculations. In particular they do not explicitly explain whether, or how, to account for system losses such as fan energy, air leakages, defrosting, etc, when calculating net air exchange, or annual net energy savings. Some manufacturers presently document only the apparent supply temperature ratio measured under steady state conditions of say +5°C outdoors, which can exceed 100% if the supply fan is particularly inefficient! (Equation 1a). This regrettable practice has been legitimised in a new European standard proposal for simplified testing of residential ventilation units (prEN 13141-7). Moreover, CEN standards prEN 13141-8 and EN 13053 give other inconsistent definitions. This situation makes it difficult for potential buyers to make a consistent and fair comparison between products, or to calculate LCC accurately, as technical data provided in different manufacturers' product catalogues is therefore not entirely reliable or compatible. NBI therefore developed an improved test method for this study. The new method has been accepted in the Nordic countries (Nordtest method, 2003). It is also hoped that the new approach to testing & documentation will eventually be incorporated in future CEN & EUROVENT performance testing of heat recovery units. The Canadian standard CAN/CSA-C439 was one of the sources of inspiration for the new Nordtest method, but numerous enhancements have been made relative to that standard too.

DEFINITIONS OF RECOVERY EFFICIENCY

The true efficiency of a heat recovery system depends on where one draws the system boundary, i.e. whether it is the heat exchanger itself, the whole air handling unit (AHU) or the entire ventilation system including ducts (Figure 1). Conventionally, the efficiency of the heat exchanger alone is documented. We have instead chosen to document the net heat recovery efficiency of the whole AHU. The AHU's net heat recovery efficiency, takes into account all system losses except for the unpredictable duct losses: heat loss and air leakage in the ducts. The system losses include: heat loss and leakage in the AHU casing, internal leakages & carry-over inside the unit, the fraction of fan energy and preheating that are lost to the exhaust air, and any infiltration in the building caused by imbalance between supply & return flow rates. However, the fraction of the unit's electrical (& hot water) consumption that ends up heating the supply air stream (e.g. supply fan energy) is assumed to be useful during the heating season. If the flow rates are balanced, there is no recirculation, and there is no condensation in the heat exchanger, then the AHU's net heat recovery efficiency can be measured very easily, as it is equal to the exhaust temperature ratio (Equation 1b). In the case of condensation, the net heat recovery efficiency can be by approx. 10% higher. The Nordtest method prescribes more accurate equations than (Equation 1b), which are valid in all cases.

Figure 1 Schematic showing nested system boundaries for a ventilation system with heat recovery



$$\eta_{\text{supply}} \approx \frac{T_2 - T_1}{T_3 - T_1} \qquad \eta_{\text{exhaust}} \approx \frac{T_3 - T_4}{T_3 - T_1} \qquad \textbf{(Equation 1)}$$

where

η Apparent temperature ratio for a heat exchanger or AHU or whole ventilation system, depending on the chosen system boundary where the temperatures are measured. Supply or exhaust side.

T Air temperature [°C]

$_{1,2,3,4}$ Reference to fresh, supply, return, and exhaust air streams respectively. See Figure 1

The AHU's net heat recovery efficiency is therefore a measure of the reduction in energy consumption for ventilation relative to the case of natural ventilation with the same net air exchange rate. When conducting calculations of annual energy savings, we need a degree-day weighed value of heat recovery efficiency, as it is affected by the changes in outdoor temperature and moisture. In very cold weather, the net heat recovery efficiency has to be reduced to prevent ice build-up in the heat exchanger. The need for frost protection is different for different types of heat exchanger (Figure 2). Recuperative heat exchangers (e.g. contra-flow plate heat exchanger) need to keep the exhaust air stream above 0°C (or higher because of non-uniform flow in the heat exchanger), by means of a preheat battery. Regenerative units can operate with exhaust air temperatures below 0°C (but above the dew-point) because the condensation is blown out at regular intervals. Regenerative units can therefore operate at -15°C without frost protection. When frost protection is not needed, heat recovery efficiency improves in colder weather due to increased condensation.

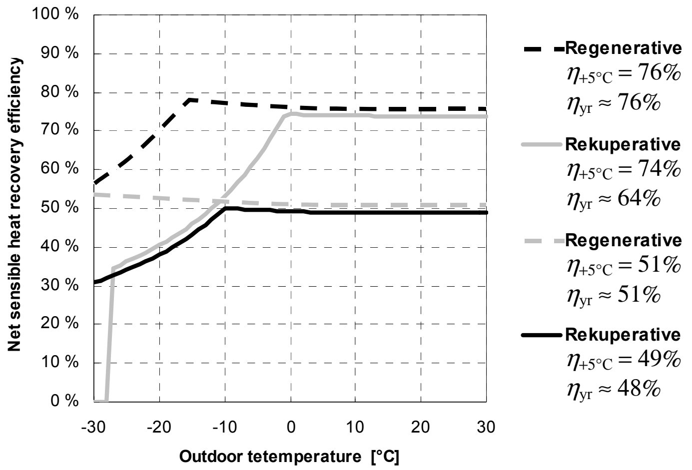


Figure 2 Net sensible heat recovery efficiency at different steady-state outdoor air temperatures for 4 different heat recovery units with good frost protection (the recuperative units have the same frost protection battery capacity limit; the regenerative units reduce their effective heat recovery efficiency without a heating battery). The annual net sensible heat recovery efficiency (η_{yr}) to the right applies to a modern house in Oslo, Norway.

Table 1 shows typical examples of values of net sensible heat recovery, both for steady state conditions at +5°C and the annual value (degree-day weighted during heating season, using room temperature as base). The calculation method is described in detail in Schild (2003a) and Nordtest (2003).

Table 1 Examples of measurements of residential heat recovery units conducted by NBI

Type of unit	Regenerative	Recuperative	Regenerative	Recuperative
Example	Reciprocating	Contra-flow plate	Rotary	Cross-flow plate
Supply temperature ratio, at +5°C outside	85%	90%	68%	59%
Net sensible heat recovery efficiency, at +5°C outside	72%	72%	49%	45%
Annual net sensible heat recovery efficiency, dwelling in Oslo	72%	66%	49%	45%

Conventional calculations of energy savings for heat recovery systems involve separate calculations for the heat exchanger itself and the fan energy. This can lead to errors if the calculation is based on the general assumption that all the supply fan energy ends up heating the supply air stream, and all the exhaust fan energy ends up heating the exhaust air stream. This is illustrated in Table 2 for two example AHUs (Figure 3) both with identical fans (70 W) and heat exchangers with 80% efficiency (when no defrost). The net sensible heat recovery efficiency is different in both cases. Moreover, neither of the two example systems has 70 W effective heating in both air streams in summer & winter, as does the conventional assumption. The reason for this is that System A has a defrost battery with 2 kW capacity, and System B has its exhaust fan located before the heat exchanger instead of just before the exhaust duct. In conclusion, the main advantage of our proposed definition of AHU 'net heat recovery efficiency' is that it is an 'all-in-one' performance measure that realistically reflects true overall performance, enabling fair and convenient comparison of different products. Moreover, this definition of heat recovery efficiency also simplifies both the laboratory measurements and the energy savings calculations without sacrificing accuracy.

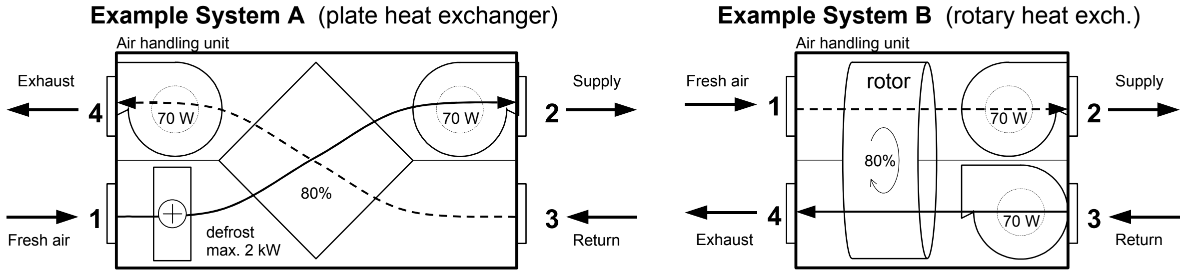


Figure 3 Schematic of component positions inside two example AHUs

Table 2 Component of the AHU's electrical power consumption that heats the supply & exhaust air streams respectively, for two example systems with identical capacity fans & heat exchanger (Figure 3).

		System A True values	**System B** True values	Conventional assumption
Portion of AHU's electricity consumption that leads to heating of supply air (for a house in Oslo)	Heating season	147 W	126 W	70 W
	Summer season	70 W	126 W	70 W
Portion of AHU's electricity consumption that leads to heating of exhaust air (for a house in Oslo)	Heating season	377 W	14 W	70 W
	Summer season	70 W	14 W	70 W
AHU's net sensible heat recovery efficiency	At steady-state +5°C outdoors	70.3%	78.8%	80.0%
	Heating season average (house in Oslo)	53.7%	79.0%	80.0%

In this study, NBI measured recovery efficiencies for both sensible heat [i.e. sensible enthalpy: $T \times (1006 + 1805\ w)$ J/kg $_{\text{dry air}}$, where T is dry-bulb air temperature in Kelvin, and w is humidity ratio, $0 \le w \le 1$] and moisture (latent heat), and thus also total enthalpy recovery efficiency. Irrespective of whether a building has central humidification or not, simplified calculations using total enthalpy recovery efficiency can easily lead to incorrect overestimation of cost savings. It is most rigorous to conduct separate calculations of sensible heat and latent heat. The latent heat calculations need only be done if the building has a central humidifier (or equivalent) that has a lower running cost as a result of moisture recovery in the heat exchanger. An example of such a calculation is given in Case1 in Table 3, for a 200 m² building with a total-enthalpy recovery efficiency of 50%. The simplified calculation based on total enthalpy efficiency leads to an overestimation of savings (6771 kWh) because of a number of simplifying assumptions implicit in the calculation. Alternatively, by conducting separate calculations of sensible and latent heat (5810 kWh), periods of excess moisture or sensible heat in the building are more accurately taken into account.

Table 3 Energy savings with a heat recovery unit (with 50% net sensible heat recovery efficiency and 50% net moisture recovery efficiency relative to natural ventilation) with and without humidification.

Case1: Energy savings for a building with central humid-ification up to 30%RH	Accurate separate calculations of sensible enthalpy (net sensible heat recovery efficiency) and latent heat (net moisture recovery efficiency)	**5810 kWh**
	Simplified calculation based on total enthalpy (net enthalpy recovery efficiency). Heating season assumed when $h_{inside} > h_{outside}$	*6771 kWh*
Case2: Energy savings for a normal dwelling, irrespective of AHU's moisture recovery efficiency.		**4878 kWh**

For normal dwellings (for which central humidification is strictly not recommended), energy cost savings should be calculated using the ventilation system's net sensible heat recovery efficiency only (Case2 in Table 3), even if the ventilation unit has moisture recovery. Units with moisture recovery have slightly higher sensible heat recovery efficiency because of the slightly higher indoor relative humidity and thus more condensation in the heat exchanger. Moreover, less energy is lost to frost protection. However, the recovered latent energy cannot be equated directly as a cost saving itself, as it does not lead to a reduction in vapour production in the dwelling. Activities that cost and generate vapour, including showering, drying clothes and buying food & drinks, continue unabated by the ventilation unit's moisture recovery efficiency. Nevertheless, the recovered moisture leads to a higher indoor humidity (approx. 10% higher at 50% moisture recovery efficiency), which can have beneficial health/comfort effects due to dry indoor air in cold-climates. It is nigh impossible to estimate these benefits in terms of cost savings. Indoor relative humidity below 25% can cause symptoms such as dry skin and mucus membranes.

A deeper discussion of the pros and cons of the improvements proposed in new Nordtest method is given by Schild & Ruud (2002).

LABORATORY SETUP & RESULTS

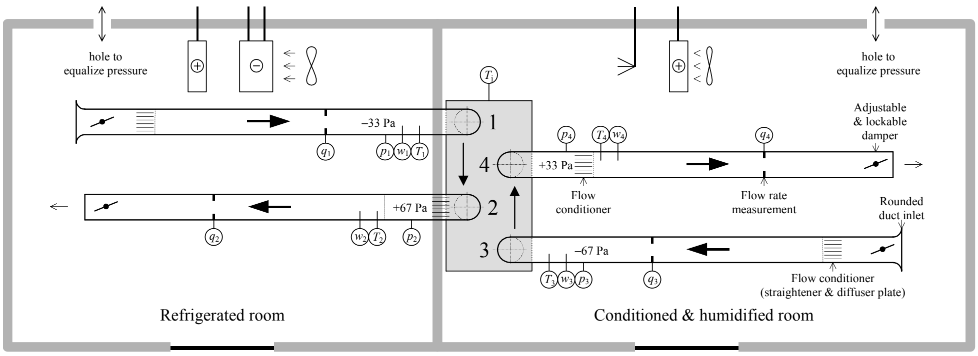


Figure 4 Schematic of "2-closed-loops" test configuration for ducted AHUs. This configuration gives the lowest humidification load in the indoor climate chamber, and slows the accumulation of ice in the chiller battery in the outdoor climate chamber. Ducts are insulated.

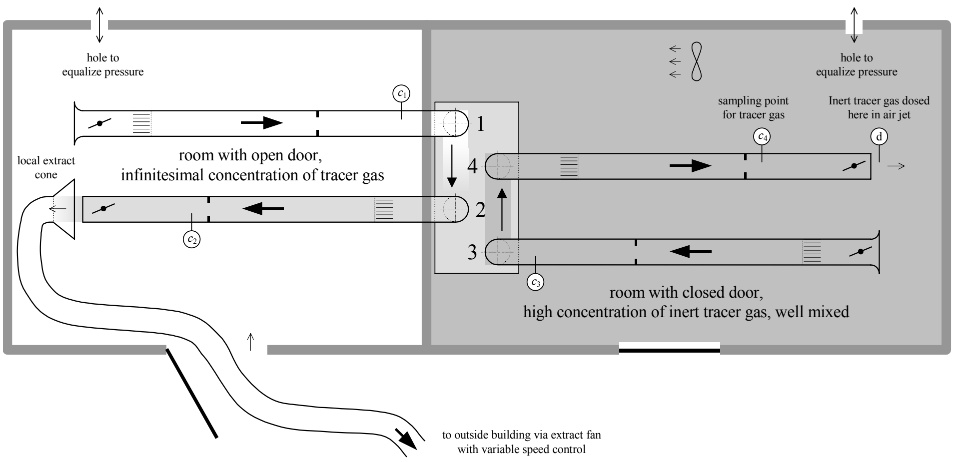


Figure 5 Schematic of set-up for tracer gas test for ducted AHUs, to find the fraction of recirculated indoor air in the supply air stream, R_s. The door to the outdoors chamber is left open. A duct with a sufficiently large opening diameter (or an inlet cone) catches the supply jet discharged from the end of the supply duct.

Figure 4 shows the general experimental set-up for measuring heat recovery efficiency in the new Nordtest method. The method also describes testing of non-ducted units and reciprocating units. The tracer gas test, for measuring recirculation, uses virtually the same set-up (Figure 5). To ensure more realistic test conditions with respect to internal leakage, the ducts leading from the AHU to the building are given twice the pressure drop of the ducts between the AHU and the outside air, e.g. 33 Pa & 67 Pa respectively. Table 1 shows measured efficiencies for four of the 10 tested ventilation units. Annual net sensible heat recovery efficiencies were calculated for three different locations (climates) in Norway: Oslo, Bergen and Tromsø. The results are documented in detail in Schild (2003a).

CONCLUSIONS

- The study's main conclusion is that balanced ventilation is a mature technology that is recommended as standard for new housing. It gives benefits in terms of both air quality and energy conservation. All the tested units had lower LCC than mechanical exhaust ventilation, which is the predominant type of residential ventilation in Norway today. Payback time was at best 4 to 6 years, despite Norway's cheap hydropower (0.09 €/kWh in 2002). IAQ in dwellings with balanced ventilation is better than for dwellings with natural or mechanical exhaust ventilation. This is especially true in the winter season — due to controlled supply of draught-free filtered air. Moreover, moisture recovery can reduce the risk of discomfort due to dry air. All these factors have a positive effect on the residents' health and perception of air quality.

- Existing test standards in Europe are too simplistic and are not harmonized. An improved test standard has been developed for use by Nordic countries

- The AHU's annual net heat recovery efficiency is a useful 'all-in-one' performance measure that realistically reflects true overall performance, enabling fair and simple comparison of different heat recovery products. Recovery efficiency is documented at the actual 'net air exchange rate', i.e. correcting for infiltration and unwanted recirculation.

- For normal dwellings (for which central humidification is not recommended) energy savings can be calculated using the AHU's net sensible heat recovery efficiency. For buildings with central humidification, it is more accurate to calculate cost savings using separate calculations for sensible and latent heat, than calculations using net total enthalpy recovery efficiency.

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