Energy analysis for balanced ventilation units from field studies

Bart Cremers

Zehnder Group Zwolle
Lingenstraat 2
8028 PM Zwolle, The Netherlands
bart.cremers@zehndergroup.com

ABSTRACT

Balanced ventilation units are well known to provide a sufficient amount of fresh air in residential buildings in a controlled way, without relying on ever-changing naturally driven forces. During colder periods, heat recovery ensures a reduction of the ventilation heating load. Outside the colder periods, recovery is reduced or shut off automatically, providing mechanical ventilative cooling. During warmer periods, the recovery is used again to provide a comfortably cool supply of fresh air. The combination of a balanced ventilation unit with ground heat exchange, provides precooling in the hot season, so that the ventilative cooling is taking place for the entire hot season, and not only during cool summer nights.

Field studies are used in this research, to explain the automatic control between recovery and no recovery. Six projects in Western to Central Europe are monitored with balanced ventilation units, and two of these units are combined with ground heat exchange. For an entire year, the relevant parameters are recorded in each project, and hourly average values are analysed. The heat recovered, the ventilative cooling, and the cold recovered have been evaluated and given as a function of outdoor air temperature. The values are summed into annual heating recovered, annual ventilative cooling and annual cold recovered. The sums are compared to the electrical consumption in the respective period.

The yearly averaged ventilation rates range from 95 to 250 m^3/h. From the results it is clear that recovery is dependent on flow rate and temperature difference outdoor-indoor. The values for annual heat recovered range from 1850 to 4570 kWh. When ventilative cooling takes place, the amount of cooling with respect to the indoor temperature is also a function of flow rate and temperature difference outdoor-indoor. Without precooling by ground heat exchange, the annual ventilative cooling with respect to indoor temperature range from 393 kWh to 657 kWh. When precooling is used, it is shown that the annual ventilative cooling is increased to 1480 kWh because the period for ventilative cooling is extended. The annual cold recovered by the units range from 27 kWh to 61 kWh .

The annual electric consumption of the fans has been evaluated using measured values of fan rotational speed and air flow rate, and an average fan efficiency for the relevant fans in the units. The energy benefit can be expressed in terms of the seasonal performance factor SPF, which is the energy gain (heat recovered, ventilative cooling and cold recovered) divided by the electrical consumption of the fans in the respective period. In the heat recovery period, the SPF is evaluated to range between 16 and 23 with a positive outlier of 47 in a project with low average air flow rate. In the ventilative cooling season, the SPF is evaluated to range between 3.7 and 4.9, and a value as high as 9.8 for the project with low average air flow rate. In the cold recovery season the SPF ranges from 2.0 to a value of 4.5 as maximum.

KEYWORDS

Residential ventilation, heat recovery, ventilative cooling, cold recovery, monitoring

1 INTRODUCTION

Balanced ventilation systems are generally known for providing fresh air in dwellings. The focus of laboratory tests is on heat recovery but there are no standardized tests for ventilative cooling. Long term measurements (at least one year) in houses are significantly less reported.
The growing use of computers to store huge amounts of data makes it possible to analyse field studies over longer periods. This study aims to evaluate how much heat and cold is recovered annually in real-life circumstances, compared to the electricity consumption of the fans.
As opposed to heat and cold recovery, ventilative cooling is often described by natural means, because in favourable conditions (driven by wind and stack effect), the amount of ventilation and cooling can be quite large. The amount of ventilative cooling that mechanical systems bring into dwellings has not been measured often. This study explains with monitored data under which circumstances ventilative cooling is brought into the dwelling, and evaluates the annual amount of ventilative cooling compared to the electrical input.

2 MONITORING SET-UP

Balanced ventilation units are monitored in six field studies, located in The Netherlands (labelled NL01 and "Nulwoning"), Germany (DE01, DE02 and DE03) and Austria (WE01). The ventilation units are similar in construction and in control, although the fans varied in three sizes to accommodate for various maximum flow rates. Three units (NL01, DE02 and DE03) are equipped with a standard heat exchanger and the rest of the units is equipped with an enthalpy exchanger. In two particular units (DE01 and "Nulwoning"), ground heat exchange was used to precondition the incoming fresh air (preheating during colder periods and precooling during warmer periods).

a) b)

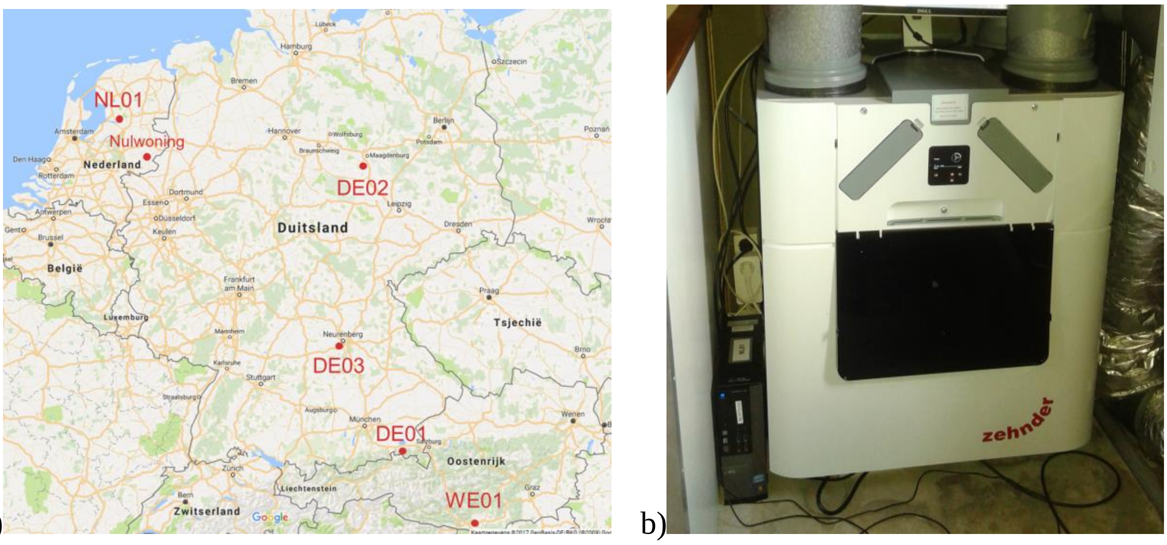

Figure 1: a) Geographical locations of the field studies and b) Photograph of an example ventilation unit (NL01).

From September 2016 until August 2017, various parameters were monitored on a 5-minute interval, an later analysed using the hourly averaged values of the parameter. Temperature is measured using built-in sensors in the supply air (SUP), the extract air (ETA) and the outdoor air (ODA). For the two ventilation installations with ground heat exchange, the outdoor air is measured before it is preconditioned (that is, the true outdoor temperature). The rotational speed of both fans (supply and extract) and the produced flow rates are also monitored. Outdoor temperatures vary from a minimum of -13°C in winter to a maximum of 35°C in summer.

3 RESULTS AND ANALYSIS

3.1 Functional description of balanced ventilation unit

A balanced ventilation unit has the primary goal to provide the dwelling with a sufficient amount of fresh air. During the cold season (hereafter referred to as the heat recovery season), the heat is recovered from the extract air to the supply air providing a comfortably warm supply temperature which is close to the extract temperature.

During the seasons with intermediate temperatures, the heat recovery is automatically reduced or totally switched off by activating a bypass functionality (referred to as ventilative cooling). By doing this, the supply temperature is reduced and therefore comfortably cool. The bypass functionality is only activated when all of the following conditions are true:

- Central heating is inactive in the dwelling [no waste of energy],
- No risk of too cold supply air [no draught and/or condensation on uninsulated supply ducts],
- Outdoor air (possibly precooled) air is colder than extract air [ventilative cooling possible],
- Extract air is warmer than comfortable [ventilative cooling is required].

During the warmer season, when the outdoor air is warmer than the extract air, recovery takes place again, so the supply air is cooled by the extract air leaving the supply air comfortably cool (referred to as cold recovery season).

Figure 2a shows the hourly averaged extract and supply temperatures for the entire year in the field study DE03. During heat recovery season and cold recovery season the supply temperatures are close to the extract temperature and during ventilative cooling the supply temperature is close to the outdoor temperature.

Monitored temperatures for the entire year in a project with ground heat exchange ("Nulwoning") are given in figure 2b. The heat recovery season can also be observed but the preheating of the outdoor air by the ground gives an even higher recovery efficiency resulting in supply temperatures even closer to the extract temperature. When the outdoor temperature is lower than the extract temperature, there is ventilative cooling similar to figure 2a. The difference appears when the fresh air is precooled by the ground, to a level which is below the extract temperature. In this case, the ventilative cooling is extended to the entire summer season, with even lower supply temperatures than without ground heat exchange.

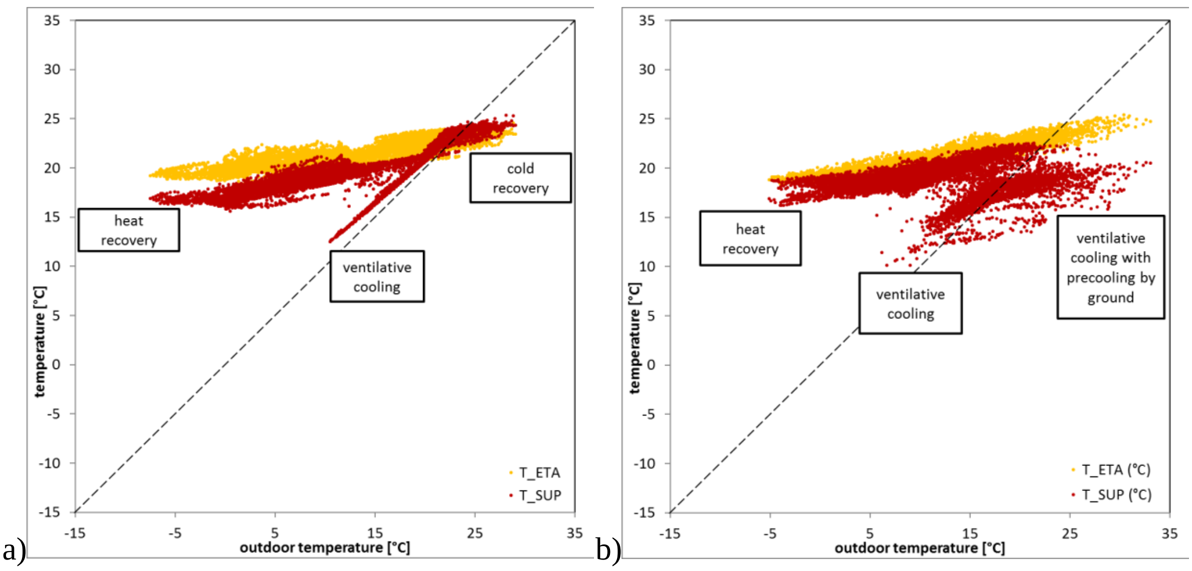

Figure 2: Extract temperature (yellow) and supply temperature (red) as a function of outdoor temperature for field test DE03 (a) and field test "Nulwoning" (b).

3.2 Heat recovered, ventilative cooling and cold recovered

During the heat recovery season, the supply temperature is increased and therefore the heating load for the dwelling is reduced with a considerable amount. The avoided heating load (heat recovered) is evaluated from the monitored recordings using the fresh air flow rate and the difference between supply temperature and outdoor temperature. The heat recovery in project DE03 during this season can be observed in figure 3 by the positive values during colder periods. The hourly values appear as two distinct lines corresponding with the frequently used fan positions by the occupant of the dwelling. The lower the outdoor temperature, and the higher the flow rate, the more heating load is saved.

During the periods with ventilative cooling, the amount of cooling delivered by the fresh air is evaluated using the fresh air flow rate and the difference between supply temperature and extract temperature (negative values to reflect the cooling effect). In figure 3 it can be observed that the ventilative cooling is around 700 W at a flow rate of 220-240 m^3/h for an outdoor temperature around 10°C. When outdoor temperatures increase, the amount of ventilative cooling decreases until zero when outdoor and extract temperatures are equal (22°C).

During the cold recovery season, temperature outdoors is higher than extract temperature, so that ventilative cooling cannot be used anymore. However, the cold recovery ensures a reduction on the cooling load of the dwelling. The amount of cold recovered has been evaluated using the fresh air flow rate and the difference between supply temperature and outdoor temperature (negative values to reflect the cooling effect with respect to no recovery). For an example flow rate of 220-240 m^3/h the cold recovered is up to 300 W at outdoor temperature of 29°C. Note that only the sensible part of the cold recovered has been assessed; the latent part has not been evaluated in this study.

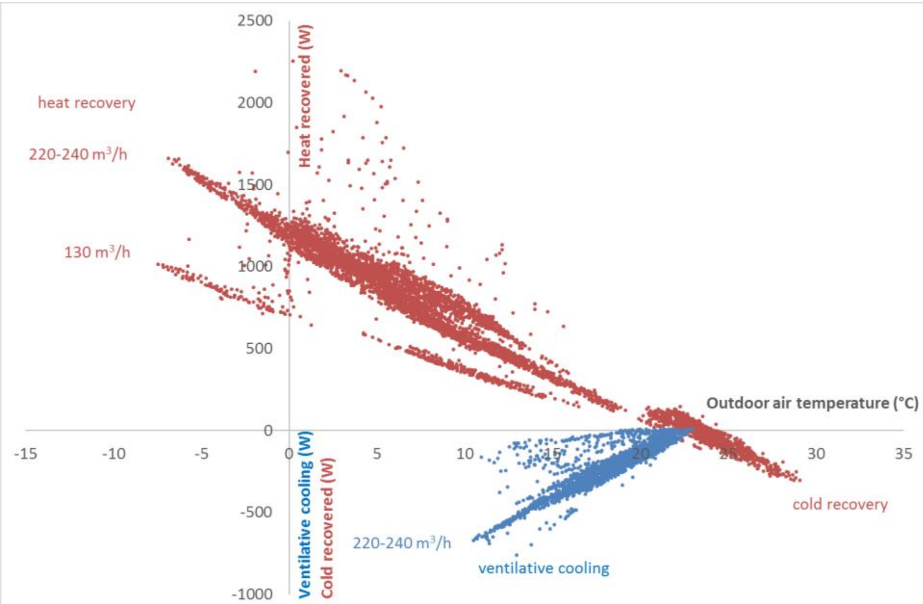

Figure 3: Heat recovered (red dots above horizontal axis), ventilative cooling (blue dots) and cold recovered (red dots below horizontal axis) as a function of outdoor temperature for field test DE03.

For the project with ground heat exchange ("Nulwoning") in figure 4, the heat recovered is shown as four lines for the corresponding fan positions absent, low, middle and high. The ground heat exchange ensures good precooling effect on the incoming fresh air. In this case, for outdoor temperatures below 15°C, the outdoor air is cooler than the ground and ground heat exchange is not used. This is observed in figure 4 by the diagonal branch in the blue dots. For outdoor temperatures above 15°C, precooling by the ground is used and therefore ventilative cooling is used for the entire summer. Because both extract air and ground temperatures rise in the same pace with increasing outdoor air (see figure 2b), the ventilative cooling with ground heat exchange is fairly constant during the summer (here: around 700 W at 330 m^3/h).

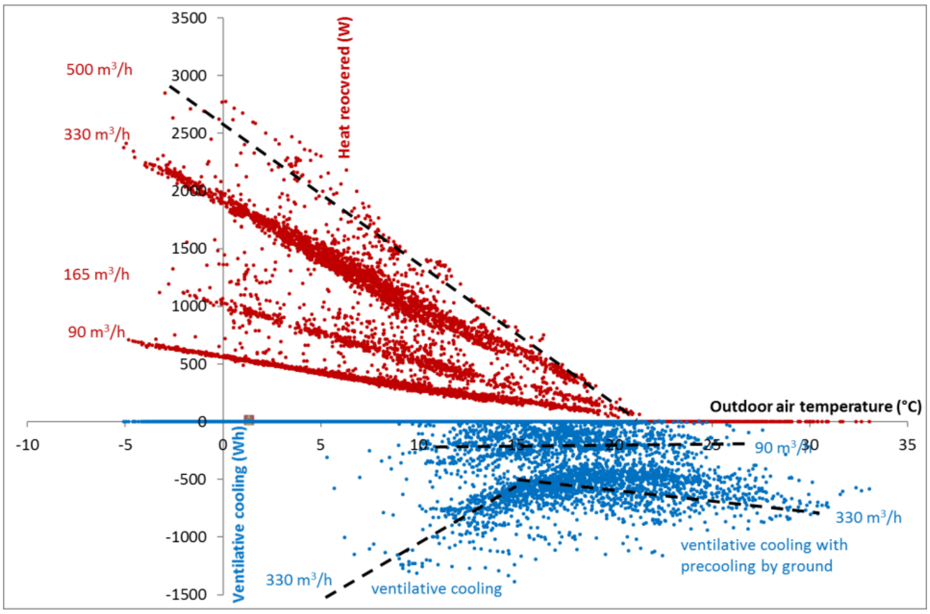

Figure 4: Heat recovered (red dots) and ventilative cooling (blue dots) as a function of outdoor temperature for field test “Nulwoning”.

3.3 Seasonal performance factors

The energy gains from the balanced ventilation unit have been assessed in the last paragraph. The energy needed for these gains is given by the electrical consumption of the two fans in the ventilation unit. The electrical consumption for the project “Nulwoning” has been recorded directly, but for the other projects it has been calculated from the fan rotational speed, the air flow rate and an average fan efficiency. For the associated fans in the field tests, this method has been developed from extensive laboratory measurements.
The total pressure p at a certain rotational speed n is calculated from:

$$p = p_{ref} * \left(\frac{n}{n_{ref}}\right)^2$$

with reference pressure p_{ref} = 1040 Pa at a reference rotational speed n_{ref} = 4100 rpm.
In the relevant operation range of the fans the efficiency η_{fan} is about 50% with which the electrical consumption P_{el} can be calculated using the air flow rate Φ_v:

$$P_{el} = (p * \phi_v)/\eta_{fan}$$

The hourly values for the heat recovery, for the ventilative cooling and for the cold recovery are summed up into annual total values of heat recovered, ventilative cooling and cold recovered respectively. The electrical consumption by the fans have also been summed into different periods: heat recovery season, ventilative cooling period and cold recovery season.

The annual amount of heat recovered has been evaluated to be in the range from 1850 kWh to 4570 kWh (see table 1). Depending on the central heating system, this saves heating costs for the dwelling. Moreover, the maximum necessary heating power is reduced and therefore suitable for a combination with a heat pump, which can be smaller than without heat recovery. The Seasonal Performance Factor SPF in the heat recovery season (ratio between heat recovered and electrical input) ranges from 16 to 47. This value is largest with low air flow rate because electrical input varies quadratically and heat recovered varies linearly with air flow rate. The values indicate that heat recovery is a very efficient way of maintaining low heating cost during colder periods of the year.
The ventilative cooling that is brought by the mechanical ventilation system and the Seasonal Performance Factor in this season (ratio between ventilative cooling and electrical input) are also given in table 1. Field study NL01 and DE01 are excluded from further analysis because of technical failures *in this particular period*, and resultingly lower values for the ventilative cooling. The ventilative cooling is dependent on average air flow rate, but also the comfort temperature profile as set by the occupant, which influences the frequency of use of ventilative cooling. The ventilative cooling in field study "Nulwoning" is exceptionally high, because in this project ground heat exchange is used. Therefore ventilative cooling is used during the entire summer, because of the precooling effect of the ground. The SPF values for ventilative cooling range from 3.7 to 9.8 with the highest value for the lowest ventilation air flow rate.

Table 1: Annual values of heat recovery and ventilative cooling in six field studies.

		Heat recovery			Ventilative cooling		
	Av. flow rate [m3/h]	Fan consumption [kWh el]	Heat recovered [kWh th]	SPF HR [-]	Fan consumption [kWh el]	Ventilative cooling [kWh th]	SPF cooling [-]
NL01 (HRV)	150	130	2824	22	~~45~~	~~126~~	~~2.8~~
DE02 (HRV)	160	150	3404	23	145	657	4.5
DE03 (HRV)	210	251	4117	16	133	497	3.7
WE01 (ERV)	95	39	1850	47	40	393	9.8
DE01 (ERV)	220	262	4449	17	~~181~~	~~695~~	~~3.8~~
Nulwoning (ERV)	250	290	4570	16	300	1480	4.9

When outdoor air is warmer than extract air, the cold from the extract air is recovered to the supply air. Besides the better comfort of the supply temperature, this provides a reduction of the cooling load. Field study NL01 and DE01 are excluded again for the reasons stated above. In table 2 it is shown that 27 kWh to 61 kWh are recovered, giving rise to SPF in the cold recovery season values (ratio between cold recovery and electrical input) from 2.0 to 4.5. In field study "Nulwoning", cold recovery does not take place because the precooled air is always lower than the extract air.

Table 2: Annual values of cold recovery in six field studies.

	Cold recovery		
	Fan consumption [kWh el]	Cold recovered [kWh th]	SPF CR [-]
NL01 (HRV)	~~13~~	~~31~~	~~2.4~~
DE02 (HRV)	24	61	2.5
DE03 (HRV)	27	53	2.0
WE01 (ERV)	6	27	4.5
DE01 (ERV)	~~7~~	~~10~~	~~1.4~~
Nulwoning (ERV)	0	0	-

4 CONCLUSIONS

This study shows an energy analysis of balanced ventilation system during a full year. Monitored parameters from six field studies are used to evaluate Seasonal Performance Factors. Values for the heat recovery season indicate that a large amount of heating is recovered by the ventilation unit, resulting in a considerably lower heating load for the dwelling. Compared to efficiency values for heating by heat pumps, the SPF values prove that it is energy efficient to use heat recovery (for reduction of required heat) in combination with a heat pump (for production of heat). The size of the heat pump can be significantly reduced when using heat recovery.

Values for the ventilative cooling indicate efficient performance of cooling with the mechanical supply of fresh air. Using ground heat exchange, the period where ventilative cooling is used is extended from only during cool summer nights to the entire summer period.

When outdoor is warmer than extract air, ventilative cooling by natural means is not preferable. The cold recovery by a balanced ventilation system reduces the cooling load of a dwelling to some extent, besides the comfort increase by reduction of the supply temperature.