HEAT RECOVERY EFFICIENCY:

MEASUREMENT AND CALCULATION METHODS

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ABSTRACT

The efficiency of air-to-air heat recovery ventilation units is of great importance for EP calculations (energy performance of buildings) throughout Europe. Efficiencies compared on a reliable basis are also crucial for contractors and installers of such systems.
Different determination methods are in use across Europe (EN 308, EN 13141-7, NEN 5138 in The Netherland, Eurovent, Passive House Institute (PHI), Dibt in Germany, etc.). Heat recovery determination involves 2 main steps: (1) a measurement (test conditions, etc.) and (2) a further calculation of the result (definition of efficiency, possible corrections, etc.). The differences between the above mentioned methods concern the measurement conditions (air temperature and humidity, etc.) as well as the result calculation. In Belgium a determination method was recently developed in the context of the EP-regulation based upon measurement conditions of EN 308, but with some modifications of the measurement conditions as well as of the result calculation.

This paper gathers test data from more than 160 measurement points on real series products available on the European market. The aim was to compare and discuss the different ways of heat recovery measurement and calculation in order to identify the key points to improve the heat recovery determination methods, let's dream, towards a convergent and unique method across Europe.

Based on the temperatures measured in the 4 flows (outdoor, supply, extract and exhaust air), two different efficiencies (temperature ratios) can be calculated: on the supply side or on the exhaust side. The gap between both is directly related to the thermal balance, as defined in EN 308. This gap varies greatly from one product to another. Several hypotheses can explain this gap, such as: transmission heat fluxes through the casing, air leakages, unbalance of the flow rates during the test, heat from the fans (if not corrected), etc. Most of these effects lead to an overestimation of the supply efficiency and underestimation of the exhaust efficiency. To our knowledge, the Belgian calculation method is the only method which takes this effect into consideration (by using the average of supply and exhaust efficiencies).
The efficiency of a heat exchanger as a separate component is surely not enough to identify the performance of a whole AHU. The average efficiency determined on a whole AHU is always lower and depends on the quality of the AHU itself (internal thermal bridges, for example). The operation of the fan during the test seems playing also an important role. In real life, the efficiency of the whole AHU is the most relevant result.
Finally, the paper discusses also the impact of the different test conditions on the measured efficiency.

KEYWORDS

EN 308, EN 13141-7, NEN 5138, Dibt, balanced ventilation, supply efficiency, exhaust efficiency, thermal balance, flow balance, air leakages, fan heat, transmission heat losses.

INTRODUCTION

Ventilation systems with heat recovery are promising to reduce the energy use for building ventilation. Very high values of heat recovery efficiency up to 90% and higher are claimed by some manufacturers and popular information papers. However, these figures are often considered as overestimated. Reliable efficiency values are obviously necessary for

EP-calculations (energy performance of buildings) throughout Europe as well as for contractors, installers and users of such systems.
Different determination methods are in use across Europe (EN 308, EN 13141-7, NEN 5138 in The Netherland, Eurovent, Passive House Institute (PHI) [1], Dibt in Germany, etc.). Heat recovery determination involves 2 main steps: (1) a measurement (test conditions, etc.) and (2) a further calculation of the result (definition of efficiency, possible corrections, etc.). The differences between the above mentioned methods concern the measurement conditions (air temperature and humidity, etc.) as well as the result calculation. The EN 308 is a European standard with a large scope (heat exchanger (Hx) as a component or Air Handling Unit (AHU) as a whole; both residential and non-residential applications). But the EN 308 is not very clear and is often used out of its range of validity (leakages, thermal balance, etc.). In Belgium a determination method was recently developed in the context of the EP-regulation based upon measurement conditions of EN 308, but with some modifications of the measurement conditions as well as of the result calculation [2].

Moreover, there are different ways of calculating heat recovery efficiencies:
- "supply efficiency" based on the temperature measured on the supply side;
- "exhaust efficiency" based on the temperature measured on the exhaust side.

Previous studies [3] suggested that this "supply efficiency" can be largely overestimated due to uncontrolled heat fluxes. The standard EN 308 requires normally a thermal balance deviation lower than 5% but this requirement is very rarely fulfilled for most of tests carried out on the whole AHU. Most of the above mentioned methods use the "supply efficiency", which is probably overestimated. On the other hand, the exhaust efficiency is probably underestimated. In the new method in force in Belgium, the efficiency used in the EP-regulation is calculated with the average between the supply and the exhaust efficiency to take into account as much as possible these uncontrolled heat fluxes responsible for these large deviations of the thermal balance.

This paper gathers test data from more than 160 measurement points on real products available on the European market. The aim is to compare and discuss the different ways of heat recovery determination and calculation in order to identify the key points to improve heat recovery determination methods, let's dream, towards a convergent and unique method across Europe.

MATERIAL, METHODS AND DEFINITIONS

Test data of heat recovery units were obtained from different manufacturers present on the European market (38 different heat recovery units from 17 different manufacturers). The raw data were collected in the test reports from different well-known test laboratories across Europe (10 different test laboratories). For most of the heat recovery units, the test was carried out for different flow rates, giving more than 160 measurement points in total.
For most of the cases, the tests were carried out on the whole AHU with fans in operation. In a few cases only, the tests were carried on the whole AHU but with fans off, or on the heat exchanger as a separate component. All the tests were carried out according to one of the following test methods or standards: EN 308, EN 13141-7, Dibt, NEN 5138 or Passive House.

Based on the temperatures measured in the 4 flows (outdoor, supply, extract and exhaust air), two different efficiencies can be calculated: on the supply side, i.e. the heat which is added to the supply air, or on the exhaust side, i.e. the heat which is extracted from the extract air. The raw data from the test reports (temperatures in the 4 flows, flow rates, absorbed electrical power) were used to calculate the different parameters according to the definitions as follows.

Supply efficiency, not corrected: $\eta_{t,\sup} = \dfrac{t_{22} - t_{21}}{t_{11} - t_{21}}$ (1)

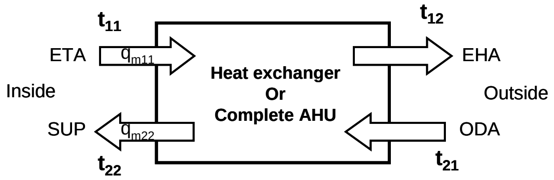
Exhaust efficiency, not corrected: $\eta_{t,eha} = \dfrac{t_{11} - t_{12}}{t_{11} - t_{21}}$ (2)

Supply efficiency, corrected for fan heat: $\eta_{t,\sup,corr} = \dfrac{t_{22} - \Delta t_{22} - t_{21} - \Delta t_{21}}{t_{11} + \Delta t_{11} - t_{21} - \Delta t_{21}}$ (3)

Exhaust efficiency, corrected for fan heat: $\eta_{t,eha,corr} = \dfrac{t_{11} + \Delta t_{11} - t_{12} + \Delta t_{12}}{t_{11} + \Delta t_{11} - t_{21} - \Delta t_{21}}$ (4)

Average efficiency used in EP-regulation in Belgium: $\eta_{t,average} = \dfrac{(\eta_{t,\sup,corr} + \eta_{t,eha,corr})}{2}$ (5)

where t are the temperatures of the air flows, as follows:



11: extract air (ETA);
12: exhaust air (EHA);
21: outdoor air (ODA);
22: supply air (SUP);

and Δt are calculated according to the position of the fan, by convention, as follows:

		Fan for extract air	
		In position 11 (ETA)	In position 12 (EHA)
Fan for supply air	In position 21 (ODA)	$\Delta t_{11} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v11}}$ $\Delta t_{21} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v22}}$ $\Delta t_{22} = \Delta t_{12} = 0$	$\Delta t_{12} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v11}}$ $\Delta t_{21} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v22}}$ $\Delta t_{22} = \Delta t_{11} = 0$
	In position 22 (SUP)	$\Delta t_{11} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v11}}$ $\Delta t_{22} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v22}}$ $\Delta t_{21} = \Delta t_{12} = 0$	$\Delta t_{12} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v11}}$ $\Delta t_{22} = \dfrac{0.5 \cdot P_{elec,ahu,test}}{0.34 \cdot q_{v22}}$ $\Delta t_{21} = \Delta t_{11} = 0$

Each efficiency is given at one or more test flow rates. The test flow rate is defined as the lowest of the measured flow rates for supply and for exhaust.
Note that the term "efficiency" is used for simplicity rather than "temperature ratio". These temperature ratios are not exactly efficiencies from the physical viewpoint, because the physical heat recovery efficiency can only be simplified in the form of temperature ratio if (1) mass flow rates are in balance; (2) there is only exchange of sensible heat, no condensation occurs.

RESULTS

For all the tests carried out on the whole AHU with the fans in operation (Figure 1, Top), the calculated supply efficiency (not corrected) was always slightly (or even largely) higher than

the calculated exhaust efficiency (not corrected). The gap between the supply and the exhaust efficiencies decreased when these supply and exhaust efficiencies are corrected for fan heat as described above (Figure 1, Middle). However, even with correction for fan heat, this gap did not completely disappear at least for some tested products.
For the tests carried out on the heat exchanger alone or on the AHU with fans off (Figure 1, Bottom, no correction needed for fan heat), this gap was significantly lower than for tests carried out on the AHU with fans in operation. For 15 of these tests, the supply and exhaust efficiencies were very close from each other; the flow unbalance for these 15 tests was quite limited, lower than 1.5%. For the 5 other tests, this gap was slightly higher; but the flow unbalance for these 5 tests was higher than 5%.
This gap between the supply and the exhaust efficiency is directly related to the deviation to the thermal balance calculated as defined in EN 308. For the tests carried out on the AHU with the fans in operation, 84% of the tests showed a thermal balance deviation higher than 5%; the thermal balance deviation for all these tests was 13% on average. If the thermal balance is corrected for fan heat, 55% of the tests showed a thermal balance deviation higher than 5%, with a value of 7.5% on average. For the tests carried out according to the Dibt method or to the NEN 5138 standard, this average value of thermal balance deviation was significantly higher with more than 10% while it was lower for tests carried out according to EN 308 with less than 5% (only for tests carried out on the whole AHU with fans in operation).

Interesting observations can also be drawn from series of several tests carried out on the same individual product. Figure 2, top, middle and bottom, shows such comparisons for 3 different individual products.
For the first example (Figure 2, Top), comparing tests carried out on a same product, either on the heat exchanger alone or on the AHU with fans in operation, the calculated efficiencies (supply, exhaust and average) were higher for the heat exchanger alone than for the AHU with fans in operation. The gap between the supply and exhaust efficiency was also very low for the tests carried out on the heat exchanger alone and largely lower than for those carried out on the AHU with fans in operation.
For the second example (Figure 2, Middle), comparing tests carried out on a same product, either on the AHU with fans in operation or on the AHU with fans off, the gap between the supply and exhaust efficiency was largely lower for the AHU with fans off than for the AHU with fans in operation (with a thermal balance deviation of around 20%). The calculated average efficiency was also higher for the tests with fans off than for those with fans in operation. A similar effect was also observed for 3 other individual products for which the test data with fans off were available (data not shown).
The third example (Figure 2, Bottom) compared the results of several tests carried out on a AHU with fans in operation, obtained from different laboratories, according to different standards and on different product samples. The average efficiency (Figure 2, bottom left) from these different tests on the same product varied from 79% to 84% in the tested flow range, while the supply or the exhaust efficiencies (Figure 2, bottom right) vary to a larger extent. The average efficiency determined on the heat exchanger alone from the same product reached a higher value of 91%.

Finally, the influence of the flow rate on the heat recovery efficiency was also evaluated (data not shown). For all the tests with data available for several flow rates, the slope of the average efficiency as a function of the test flow rate ranged from a negative slope of -0.06%/(m^3/h) to a positive slope of 0.04%/(m^3/h) and was -0.02%/(m^3/h) on average. In more than 70% of the cases, this slope was negative and ranged between 0.00 and -0.04%/(m^3/h).

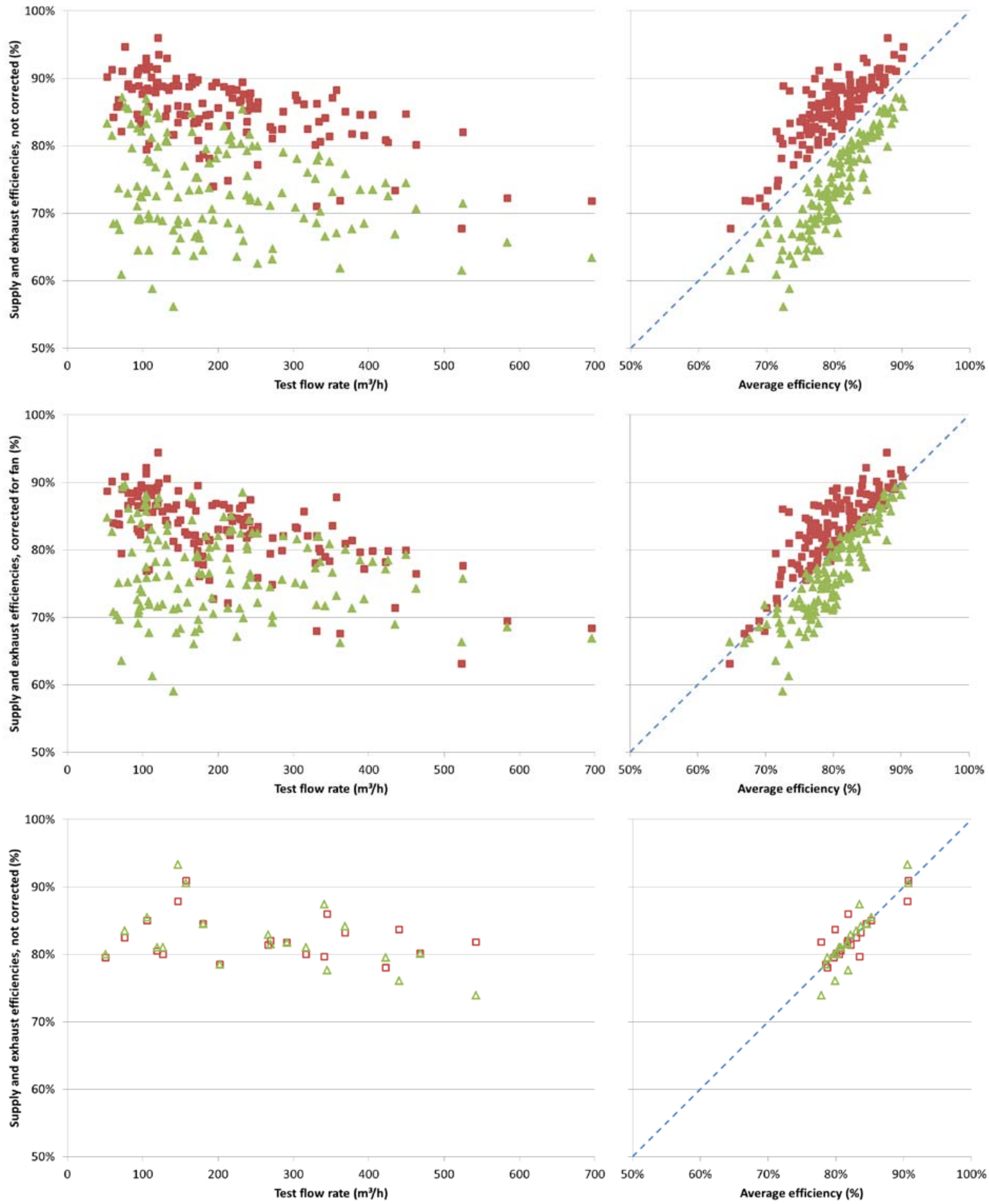


Figure 1. Supply efficiency (squares) and exhaust efficiency (triangles), as a function of the test flow rate (left) or as a function of the average efficiency calculated in the Belgian regulation (right): tests carried out on AHU with fans in operation (closed symbols), or testes carried out on the heat exchanger alone or the AHU with fans off (open symbols); not corrected values (Top), values corrected for fan heat (Middle), values without correction needed (no fan heat, Bottom).

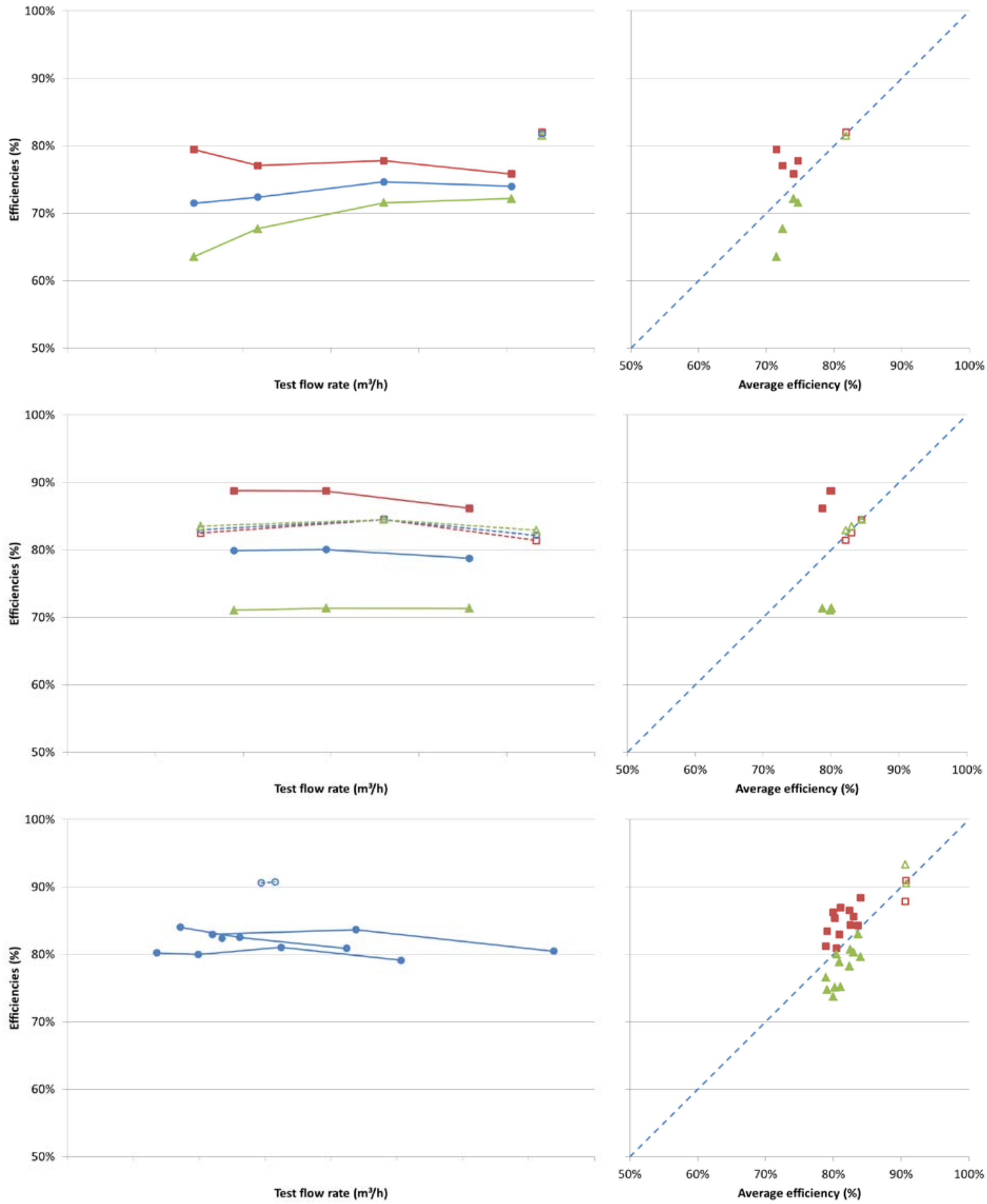


Figure 2. Supply efficiency (squares), exhaust efficiency (triangles) and average efficiency calculated according to the Belgian regulation (circles), as a function of the test flow rate (left) or as a function of the average efficiency (right), for 3 individual products (Top, Middle and Bottom): tests carried out on the AHU with fans in operation (closed symbols), or tests carried out on the heat exchanger alone or on the AHU with fans off (open symbols); supply and exhaust efficiencies were corrected for fan heat if applicable; for the product 3 (Bottom), several tests results were available from different laboratories (and according to different standards).

DISCUSSION

Thermal balance

In theory, the supply efficiency and the exhaust efficiency (if corrected for fan heat) should be equal (because no energy is created or lost in the system). However, the results demonstrated that these two efficiencies are nearly never equal! In most cases, the supply efficiency is higher than the exhaust efficiency. This means that apparently we win more energy in the supply air than we recovered from the exhaust air. This gap between the supply efficiency and the exhaust efficiency is directly related to the thermal balance, as defined in EN 308. The very high gap between the supply and exhaust efficiency observed for most of the tested AHU explains why the requirement of EN 308 for the deviation of the thermal balance (maximum 5%) is not satisfied for most of the products. Several uncontrolled heat fluxes in the system can be hypothetized to explain this gap, as follows.

Fan heat. First of all, the heat released from any fan will increase the temperature of the supply air, causing an apparent higher supply efficiency; and increase the temperature of the exhaust air, causing an apparent lower exhaust efficiency. A fan with a class SFP3 (according to EN 13779) will, for example, increase the temperature of the air of around 1 K (if all electricity is dissipated into the air flow). However, this effect can be easily corrected using the absorbed electrical power measured during the test. As shown in the results, such a correction decreases significantly this gap, leading to nearly equal supply and exhaust efficiencies for some products, while this correction is not enough to explain this gap for some other products.

Flow rate unbalance. Unbalance of the flow rates during the test is responsible for a deviation between the supply and the exhaust efficiencies. For example, if the extract flow rate is higher than the supply flow rate, the supply efficiency will apparently increase while the exhaust efficiency will apparently decrease: more heat is available to pre-heat the supply air. In theorie, the effect of flow unbalance could be corrected by calculation. However, it should be preferably to avoid such flow unbalance during the test itself.

Transmission heat fluxes from or to the surrounding (through the casing). With all the above mentioned methods, the efficiency test is carried out in a warm surrounding (between 18 and 25°C depending on the method used). In such conditions, the exhaust air can be warmed up due to heat transfer and can cause a lower exhaust efficiency. An increase of the supply efficiency can also occur to a lesser extent (smaller temperature difference). In real conditions, these transmission heat transfers correspond to real heat losses for the building if the AHU is placed inside the building for example.

Leakages. The effect of internal and external leakages is difficult to predict because not only the temperature can change, but also the mass flow rates in the 4 flows. For example in case of internal leakages from the extract flow to the supply flow, the supply efficiency will increase and the exhaust efficiency will decrease.

As a summary for the thermal balance deviation, there are several uncontrolled heat fluxes, possibly leading to an increase, apparent or not, of the supply efficiency and to a decrease, apparent or not, of the exhaust efficiency, as summarized in Table 1.

The supply efficiency, as used in most of the above mentioned methods such as EN 308, EN 13141-7, NEN 5138, etc., is thus highly probably overestimated for most of the tested heat recovery devices.

Note that the Passive House method is the only method using the exhaust efficiency (with additional calculation for the fan heat); this is specific to the conventions used in the EP-calculation method for Passive Houses (PHPP) and this will not be discussed further in this article [3].

Possible causes of deviation between the supply and the exhaust efficiencies		Estimated impact on the	
		Supply efficiency	Exhaust efficiency
Fan heat	(depends on fan position)	↗	↘
Unbalanced flows:	Supply > extract	↘	↗
	Extract > supply	↗	↘
Leakages	Internal, extract to supply	↗	↘
	External	?	?
Transmission heat fluxes:	Test in warm surrounding	~ or ↗	↘↘

Table 1. Possible causes for deviation between the supply and the exhaust efficiencies and their qualitatively estimated impact on both the supply and the exhaust efficiencies.

To our knowledge, the new method in the Belgian regulation is the only method which takes both supply and exhaust efficiency into consideration, by using the average between the supply and the exhaust efficiency, in combination with the correction for fan heat. This average calculation assumes that the apparent overestimation of the supply efficiency and apparent underestimation of the exhaust efficiency are roughly symmetric. For the moment, this assumption is surely more reasonable than looking only at the supply efficiency, without any requirement on the deviation of the thermal balance. For some individual products on which several tests have been carried out, the variation of this average efficiency is also lower than the variation of the supply or exhaust efficiency between these different tests [3].

Test on the AHU or on the heat exchanger

It's clear from the results that the efficiency of a heat exchanger alone can be higher than the efficiency of a whole AHU equipped with the same heat exchanger.
The heat recovery efficiency of the whole AHU depends surely on the architecture and design of the heat exchanger itself (type of exchanger, e.g. counter flow vs. cross flow, size of exchange area, local exchange effectiveness, etc.) but depends also on the quality of the whole AHU, such as insulation, air leakages, thermal bridges, etc. The effect of the AHU can strongly degrade the whole efficiency even if the exchanger itself is very good. For example, certain thermal bridges will cool down the supply air because of contact with the colder exhaust air.
The bigger gap between the supply and the exhaust efficiency observed for tests carried out on the whole AHU than this for tests carried out on the heat exchanger alone could also be related to the possible uncontrolled heat fluxes described above. Air leakages as well as transmission heat fluxes from or to the surrounding can be largely higher for the whole casing of an AHU than for a heat exchanger as component.
It should therefor be advised to test the efficiency on a whole AHU only, as done in most of the above mentioned methods.

The effect observed for the tests carried out on the AHU with fans in operation or with fan switched off is however more surprising. While the gap between the supply and the exhaust efficiency was very low with fans off, it was largley higher with fans in operation. Among the hypothetic uncontrolled heat fluxes decribed above, the operation of the fan can affect the air leakages but not the transmission heat fluxes through the AHU casing. It should then be advised to test the whole AHU with fans in operation. Moreover, if the air leakages are well involved in this effect, it could be possible that not only the fan operation as such, but also the pressure difference across the AHU during the test could play a significant role. Pressure difference as close as possible to the real working pressure of the AHU should then be used during the test.

Influence of the flow rate

It is also usually known that the heat recovery efficiency of a given product decreases slightly as the test flow rate increases. As shown in the results, the slope of this decrease can vary largely from one test data to another, with even an increase of the efficiency with the flow rate in a few cases. E.g.: a negative slope of -0.02 %/(m^3/h), as average of the entire data, results in an efficiency drop of 3 % when doubling the flow from 150 to 300 m^3/h. For the determination of efficiency in the context of EP-regulation, it should be advised to carry out the test at least at a flow rate as close as possible to the maximum flow rate of the AHU, with eventually additional measurement points at lower flow rates.

Other divergences in test conditions

The other conditions of the test, such as the required temperature and the relative humidity for the outdoor air and for the extract air, play probably also a role in the result of the test. Fortunately, the divergences between the above mentioned methods are maybe not the most crucial point from the scientific point of view.
Among important differences in the test methods, the following can be underlined.
Temperature difference. For example in the new EN 13141-7 published in 2010, the temperature difference between outdoor and extract air has been lowered to 13 K instead of 20 K in the previous version of this standard (referring to EN 308). Nevertheless one can expect that more reliable results could be obtained using a higher temperature difference.
Relative humidity. In the Dibt method in Germany or the NEN 5138 standard in The Netherlands, the required relative humidity of the extract air is quite high leading to condensation in most of the cases. The higher thermal balance deviation observed with these methods compared EN 308 and EN 13141-7 might be possibly related to this condensation.

Proposal for future approach

Although European standards exist for quite a long time, a lot of member states still use their own test methods for heat recovery efficiency. This is maybe partly initiated by the fact that the EN 308 standard is not always very clear and partly due to different EP-calculation methods, using different efficiency figures. Having different test methods and different test conditions in each European country, for such very expensive tests (10 000 to 20 000 EUR), is not acceptable for the manufacturers in such an international and competitive market. Test methods should therefore converge towards a common approach as soon as possible, at least at European level. The test methods should result in the availability of relevant raw data that can be recalculated towards the required efficiency expression, adapted to the EP-calculation of each member state or to the requirements of the upcoming Ecodesign directive. We can hope that current development works in CEN standardisation (EN 308 revision) as well as in the context of the Ecodesign directive will help to facilitate this needed convergence.

Other challenges for the future

The last example product (Figure 2, Bottom) revealed also a certain variability of the results for different tests carried out on the same product. Besides the possible role of the test conditions (test method) and the possible variability between different test laboratories, the variability of the AHU production and the procedure of selection of the sample to be tested could be an important point of attention in the future.
Another important challenge concerns the custom products, used for example in large ventilation systems such as in commercial buildings. The high costs of the tests which can be

distributed over a high sales number for products in series are probably not acceptable for custom products. Another approach could be studied, such as the interpolation of calculated efficiencies for a range of custom products between 2 extreme products being effectively tested in the laboratory.
Finally, the heat recovery efficiency is not the only point of attention of ventilation AHU. More attention could also be drawn to other performances of AHU such as the electrical consumption of the fans, the automatic balancing of flow rates, the acoustical performances, IAQ related performances such as air leakages, type of materials, etc.

CONCLUSION

While ventilation with heat recovery is promising to decrease the energy use for building ventilation, more reliable and comparable values of heat recovery efficiency are needed in the context of EP-regulation as well as for contractors and users of these systems.
The presented results emphasized some attention points for the heat recovery efficiency measurement as well as calculation. The measurements should be carried out on the whole AHU with fan operating at a pressure condition as close as possible to the real conditions. Given the large divergence between the supply and the exhaust efficiency for most of products, alternative ways of calculation should be examined to avoid using overestimated values of supply efficiency. The recently developed method in the Belgian regulation, using the average between the supply efficiency and the exhaust efficiency, presents several advantages on this point.
Moreover, this paper pointed out also the need for convergence toward a unique and coherent test method across Europe. It is not acceptable for the manufacturers to have so many different test methods and test conditions in the different European countries for such international and competitive market. It can be expected that current works at the level of CEN standardisation and of the Ecodesign Directive will help to facilitate this need convergence.

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