Air to air heat recovery: assessment of temperature efficiency

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ABSTRACT

For the assessment of air to air heat recovery systems in ventilation systems, efficiency seems to be the major evaluation parameter, although other parameters such as pressure drop, frost behavior and power consumption of fans can play an important role. Efficiency of a heat exchanger can be expressed in many forms; temperature efficiency, moisture efficiency, enthalpy efficiency, primary energy rate, etc. When speaking of temperature efficiency, an important difference should be made between the efficiencies at the supply and exhaust sides respectively. Supply side efficiency will increase with increasing supply temperature due to inefficient fans and/or heat gains through a badly insulated casing. In case of these parasitic energy flows one can't speak of real energy recovery; the supply efficiency can be used to evaluate comfort at the air supply openings. Exhaust side efficiency accounts for these parasitic energy flows more correctly and is a better expression to evaluate energy performance of the AHU with heat recovery.
Worldwide, many different efficiency measuring methods exist, according to various standards. The conditions at which to measure efficiency vary; flow – moisture – temperature conditions, acceptable leaks, etc; all leading to hardly comparable results. There is a strong need for more uniform testing conditions, as well as a clear understanding of what efficiency means and how to use it in system evaluation.
Apart from instantaneous performance, some standards also include a seasonal system performance, including effects of varying flow rates en temperatures, moisture conditions and defrosting. This approach will help to assess the global energy performance of the system, as a part of a real building.

1. HEAT EXCHANGER

Basically, an air to air heat recovery system brings together two air flows at a different temperature and enables the transfer of heat from the hottest to the coldest side. Two air flows can be identified as well as 4 temperatures (figure 1), at locations 11, 12, 21 and 22. The thermal effectiveness ε of the heat exchanger is expressed as the ratio between the gained heat (HX) and the available heat between extract air and outdoor air. When latent heat isn't considered, the effectiveness can be defined as a temperature ratio. Equation 1 is valid on the condition that both mass flows are in perfect balance, no condensation occurs and no other heat transfers are assumed. In its simplest form, the transferred heat is proportional to the temperature difference between supply air and outdoor air (the gained heat), but also to the temperature difference between extract air and exhaust air (the heat that isn't rejected):

$$\varepsilon_t = \frac{gain}{available} = \frac{HX}{ETA - ODA} = \frac{\theta_{22} - \theta_{21}}{\theta_{11} - \theta_{21}} = \frac{\theta_{11} - \theta_{12}}{\theta_{11} - \theta_{21}} \qquad (1)$$

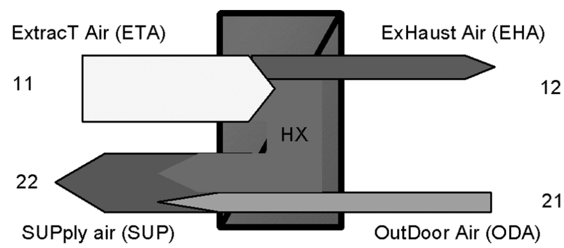

Figure 1: Heat exchanger

We can see that the effectiveness ε_t can be written as a supply temperature ratio as well as an exhaust temperature ratio. When used in a building, an air to air heat exchanger (HX) is placed into an air handling unit (AHU). Therefore 3 levels of heat recovery systems should be addressed (figure 2):
1. The heat exchanger as a separate component
2. The heat exchanger in an air handling unit. In dwellings it often comprises the fans and the regulator as well as filters, heating battery and by-pass provisions. Especially in non residential applications, the AHU can be completed with cooling and/or moistening devices.
3. The air handling unit used in a building, placed inside or outside the heated zone, with air ducts interconnecting the unit to the outdoor air at one side and to the air distribution system at the other side.

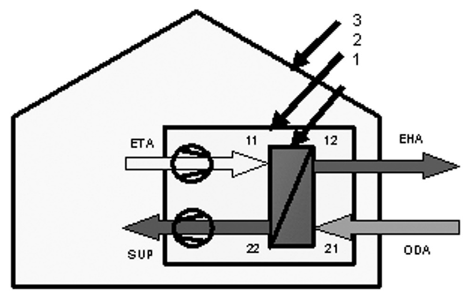

Figure 2: levels of approach

The performance approach will differ depending on the heat recovery level that is considered.

2. AIR HANDLING UNIT

Considering the AHU-level, following observations are of importance:

2.1 Mass flow balance

Usually, an air handling unit is evaluated with supply and exhaust (mass) flow rates in balance. When the supply flow rate increases at a constant exhaust flow rate, the supply temperature, as well as its ratio will decrease. When the exhaust flow rate is higher than the supply flow rate, more heat is available to heat the supply flow and the supply temperature ratio will increase. As will be explained, the performance is only apparently better.

2.2 Flow rate

When the flow rate increases, the convective heat transfer coefficient will increase as well as the heat to be transferred. Generally, temperature ratios tend to reduce by 5 to 15 % when the flow rate is doubled. Nevertheless, the flow rate at which the performance is measured is an important criterion.

2.3 Temperature and humidity

Basically, the outdoor temperature is of relatively low importance to the temperature ratio. However, when moisture contained in the exhaust air condenses or even freezes, the operation temperature might have a huge influence on the performance. With relatively dry air in dwellings in winter situation, condensation of moisture is not likely to occur very frequently, so testing conditions are normally set at non-condensing conditions, although moisture recovering heat exchangers (rotary wheels, reciprocating HX or semi permeable HX) will act at slightly higher moisture conditions. Due to the moisture recovery, the humidity in the building remains higher.

2.4 Parasitic heat transfer

In an air handling unit, besides the heat flux from the warmer to the cooler part of the HX, many other energy fluxes can be identified:

• Air leaks in the AHU due to small leaks (internal leaks, external leaks, recirculation leaks or cross-over in rotary wheels) depend on the pressure difference in the unit. This pressure difference as well as the direction of the leak flow depends on the position of the fans, the design pressure drop in the ducting system and the actual flow rate. A leak from extract air towards supply air mostly increases the supply air temperature (and the supply temperature ratio) but reduces the supply air quality and should therefore be minimized.

• Heat fluxes by heat transmission between air handled in the unit and the room of the installation depend on the thermal insulation of the AHU(including thermal bridges) and on the temperature of the room of the installation (with an important difference between rooms inside or outside the conditioned volume of the building) and can be positive or negative. When placed inside of the insulated and heated building zone, heat transfer will be a loss for the building heat balance and a gain for the AHU, although it might be rejected outwards directly with exhaust air. When placed outside the heated building zone, transmitted heat is a loss of energy.

• Heat brought into (removed from) the AHU from outside, intentionally by heating (or cooling) batteries or unintentionally. The latter is the case with e.g. fans, all the electrical energy supplied to electrical consuming devices will be converted to heat. With fan-motor combinations, placed directly into the air flow, the generated heat will be dissipated directly into the air and raise the supply air temperature to some extent. The heat dissipated in the AHU casing (e.g. belt driven fans and external control devices) can be transferred indirectly to the air or will be lost to the surrounding room.

• Various methods exist to prevent the unit from freezing: supply flow rate reduction, by-pass, recirculation, electrical heaters,…Strongly depending on the climate, the influence on the overall seasonal performance can't be neglected.

All these parasitic heat fluxes are added to or subtracted from the main HX heat flux and will influence the temperature ratios. E.g.:

• heat from a fan placed in the supply air of the AHU will increase the supply air temperature, and as a consequence, the supply temperature ratio. Inefficient fans will lead to an apparent high supply temperature efficiency. Fan heat in the extract flow will be either recovered in the HX or will be lost through the exhaust; this loss will be accounted for in the exhaust temperature ratio.

• heat entering the AHU by transmission through the casing to raise the temperature in the exhaust air is a loss for the building and will lower the exhaust temperature ratio.

As a result from these parasitic heat fluxes the supply and exhaust temperature ratio won't be equal anymore in a real AHU.

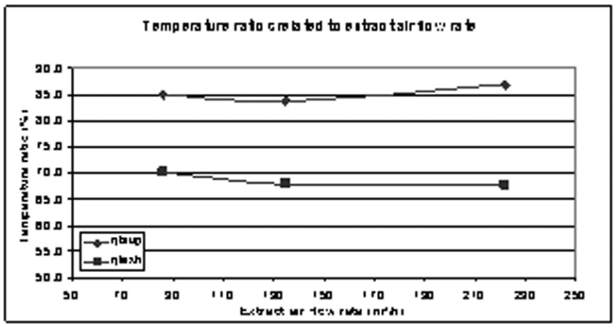

Figure 3: example of supply and extract temperature ratios (mass flow balance).

Figure 3 shows the obtained temperature ratios for a typical AHU for dwellings. In this particular case, supply and exhaust temperature ratios differ a lot. For other products, the difference is sometimes limited to 5 %.
For cooling applications, not in the scope of this paper, similar ratios should be addressed, but in very different temperature conditions. Parasitic heat gains in the supply air might be unwanted.

3. BUILDING

When an AHU is placed in the building, other effects should be addressed.

3.1Balance

When an AHU is out of mass flow balance, this will be corrected in the building by in- or exfiltration. Heat from air leaving the building through cracks won't be recovered. The loss in effectiveness due to low exhaust flow rates will not be compensated. On the other hand, too low supply flow rates will be compensated by unheated infiltration air and despite an apparent high temperature efficiency the overall effectiveness at the building level will be lower compared to the perfect balance situation. Balancing the system is of utmost importance.

3.2 Air leakage of ducts

In most cases ducted units are used (non ducted units can be used for ventilation of a single room). Experience indicates that air ducts might not be airtight (at all) with leakage rates up to 20 of the nominal flow rate. Untight ducts might lead to contamination of the supply air or to loss of preheated air into non heated building areas. It increases the need for fresh air to compensate the losses, as a result of which the total energy demand in the building will increase.

3.3 Heat transfer through ducts

A temperature difference between the air being transported and the surrounded area leads to loss or gain of heat. An air flow rate of 300 m³/h at 20 °C represents a heating power of +/- 1300 W at a heating season mean temperature of 7 °C. With non-insulated duct, additional losses can be important. Heat transfer from warm air through a non insulated metal duct (diameter 160 mm, length 10 m) in a non heated zone might represent, in this example, an additional loss of more than 300 W.

3.4 Evaluation

Which temperature ratio to choose to evaluate an AHU isn't a question of what is right or wrong but depends on what to evaluate. When evaluating the indoor climate and comfort, the supplied air temperature is of major concern and will be used, based on the supply temperature ratio. When there is a need to heat up or to cool down the supply air leaving the AHU, again the supply temperature ratio enables this power calculation. However, when assessing the energy performance of the whole building, losses by leaks, heat transfer, fan heat should be accounted for in the heat balance. Hence, the exhaust temperature ratio is a much better energy balance evaluating tool, since it indicates the part of the heat that isn't rejected to the environment (on condition of mass flow balance and similar air composition).
When comparing air handling units as a product, it is difficult to account for the building effects on the unit performance when the application is not known (yet). Once applied in a building, available data can be used to perform an energy performance calculation. Because various calculation methods exist, the AHU performance data should be available in basic format (different ratios, leaks, fan power, freezing effects,…) and preferably not as one figure that combines all effects. The same is valid for moisture recovery; in stead of using an enthalpy ratio, address sensible heat recovery and moisture recovery separately. Using basic AHU performance data, seasonal performance can be evaluated using local weather data as well as building characteristics and user profile data.

4. VARIOUS STANDARDS

Throughout the world many different standards and test methods are used. Although they are intended to be used for the same equipment, the purpose, the approach and test conditions might be different. Table 1 gives an overview of the approach of a number of methods used in Europe. Mostly, supply temperature ratios are used, sometimes exhaust temperature ratios are used or even both. Most standards require a mass flow balance and test also for leaks, heat transfer and electrical power. However, the way in which these secondary energy fluxes are treated may be very different. Some standards require a minimum level of mass balance and a

Approach level →	HX	AHU (Air Handling Unit)						
Method →	EN 308:1999	EN 13141-7:2004	EN 13141-7: draft revision	NEN 5138:1999	NEN 5138:2004	DIBt	NT VSS 130/ Nordtest	PH
Mass flow balance		**<3%**	**<3%**	**cor ηtsup**	**cor ηtsup**		**Cor η**	<
Internal leaks	**<3%**	**classes**	**<class**	**<2%**	**<2%**	**<5% Cor η’**	**Cor η**	**<3%**
External leaks	**<3%**	**classes**	**<class**	**<5%**	**<5%**	**<5% Cor η’**	**Cor η**	**<3%**
Reciculation leaks	**<3%**		**<class**				**Cor η**	
Casing heat transfer	**<5% Heat balance**	**?**	**in η_{texh}**			**Cor η’**	**<5% Heat balance**	
Fan power	**cor η_{tsup}**	**?**	**in η_{texh}**				**Cor η**	**Cal +**
ηtsup	**η_{tsup}**	**η_{tsup}**	**η_{tsup}**	**η_{tsup}**	**η_{tsup}**	**η’ WRG uncor**	**η_{hsen}**	
ηtexh		**?**	**η_{texh}**				**$\eta_{simplified}$**	**η_{teff}**
Frost protection	**Indicate effects**				**cor η_{tsup}**	**Cor η’**		
Duct insulation								

table 1: comparison of methods
legend: cor: correction to
<: limit for validity
Cal + (PH): added to η_{texh}

maximum level of leaks in order to validate the calculated ratios but don’t correct the ratios. Other standards even correct for the parasitic fluxes through correction factors in the used formulas.
With different measuring and calculation base, the temperature ratios obtained from different standards can’t be compared.
Figure 4 compares the obtained results according to various methods for a typical unit. It will be clear that these results aren’t interchangeable between different countries. Most results shown are well above the exhaust

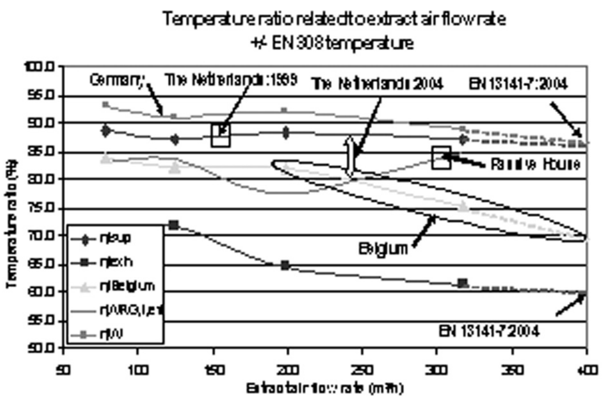

Figure 4: results for a typical unit (nominal flow +/- 400 m³/h)

temperature ratio, indicating an indoor climate performance rather than an energy performance.

5. A FUTURE APPROACH

There is a strong need for correct heat recovery product data to evaluate both indoor climate and energy performance of buildings. Mainly due to historic reasons many methods exist although there is, generally speaking, a common agreement of what is needed. Actually, the manufacturers are obliged to follow different test procedures when market introduction is envisaged. This has become an expensive exercise. It is however not realistic to switch to a new method at once, because all local calculations in each country might have to be adapted too, as well as governmental support actions. This could be solved when a unique testing method is introduced that:
• is based on common mandatory and optional testing conditions (temperature, humidity, flow rates,…),
• reports the results as separate data, and not combined into one single figure
This standard should enable to:
• calculate derived AHU characteristics based on the reported raw data, adapted to local requirements and applications.
• present a compatibility with the existing methods: the test results enable, using a relatively simple calculation method, to calculate performance data according to present requirements (EN 308, NEN 5138, DIBt, …).

A problem might be that test conditions (flow, temperature, humidity,...) differ sometimes. If no solution is found for this compatibility, transition to new general test methods becomes unlikely.
Actually, the European EN 13141-7 (single dwellings) is in the process to being adapted to fulfil the abovementioned requirements to a great extent.

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