Impact of ductwork airtightness and conduction losses on heat recovery efficiency

F.R. Carrié(1) and V. Leprince(2)

1 INIVE
Lozenberg 7
BE-1932 Sint-Stevens-Woluwe, Belgium
info@inive.org

2 Centre d'Etudes Techniques de Lyon
46 rue Saint Théobald
F – 38081 L'Isle d'Abeau Cedex, France

ABSTRACT

We have developed a simple model to estimate ductwork leakage and heat conduction losses in steady-state conditions for a balanced ventilation system. Implemented in a spreadsheet, it allows us to calculate their impact on heat recovery efficiency consistently with EN 15241 without the need for a dynamic simulation tool. One case study shows that the global heat recovery of a balanced ventilation system with a nominal heat recovery of 80% can be reduced to less than 50% if the ductwork leakage and thermal resistance are poor. These large energy impacts and today's field data suggest that these aspects should be considered in energy performance calculations and that building professionals will have to pay particular attention to duct leakage and thermal resistance with the trend towards nearly zero-energy buildings.

KEYWORDS

ductwork, airtightness, leakage, heat conduction, heat recovery, low-energy buildings

INTRODUCTION

The EPBD recast [4] sets ambitious targets for year 2020 including the obligation for EU countries to implement regulations to increase the number of nearly zero-energy buildings (NZEB) in the next few years, and to generalize nearly zero-energy targets in new buildings and major renovations.

Previous studies (see for instance, [1][2][3][10][11][12][13]) have shown that ductwork airtightness and conduction losses are key in these types of buildings; however, to our knowledge, these losses are rarely taken into account in regulatory energy performance calculation. Probably the most detailed approach in such tools would be to fully integrate EN 15241 and 15242 ([8][9]) iterative methods for the calculation of the airflow rates taking into account envelope and ductwork leakage as well as heat conduction through duct walls. As achieved in the French energy performance regulation RT 2012, those methods can be integrated in an hourly energy calculation that includes primary energy use for heating, cooling, domestic hot water, auxiliary equipment, and lighting given specific occupation scenarios and weather conditions.

The objective of this paper is to give an overview of the underlying calculation principles for ductwork leakage and conduction losses as well as to give estimates of the subsequent energy losses in the light of today's objectives to generalize very-low energy buildings.

BACKGROUND

The objective of this paragraph is not to give a detailed explanation of standards EN 15241/15242, but rather to give an overview of the calculation principles.

EN 15242 allows one to calculate the airflow rates including infiltration assuming that the building or part of the building modelled can be represented by one pressure node. It takes into account the mechanical ventilation airflow rates (including ductwork leakage), opened windows, natural ventilation openings, and cracks in the envelope. The airflow rates corresponding to the two last items are characterized by a pressure difference across the components; windows opening airflow rates are calculated with the opened area, wind velocity and temperature difference. The internal pressure is solved for to reach mass equilibrium between flows entering and leaving the zone.

EN 15241 gives the characteristics of the air passing through an air treatment plant as well as the power involved for its treatment. It takes into account duct heat and leakage losses, fan power demand and the part released to the air, heat exchangers, mixing boxes, pre-heating/cooling/(de)humidification.

Two basic equations describe the physical phenomena that take place. It is possible to assess the leakage flow rate escaping through the duct walls with equation (1):

$$q_{vl} = K\, A\, \Delta p^{0.65} \qquad (1)$$

where K ($m^3\, s^{-1}\, m^{-2}$ at 1 Pa) is the leakage coefficient normalized by the duct surface area (EN 12237 or EN 1507, [5][7]) and the duct surface area A (m^2) can be obtained and through EN 14239 [6].

As for conduction losses, equation (2) gives the heat flux passing through a duct:

$$T_f - T_b = (T_i - T_b)\exp\left(-\frac{U\,A}{Q_{ma}\,c_p}\right) = B\,(T_i - T_b) \qquad (2)$$

where:

T_f is the air temperature at the duct end (K);
T_i is the air temperature at the duct entrance (K) ;
T_b is the air temperature of the duct surroundings (K) ;
U is the U-value (thermal transmittance) of the duct ($W\, m^{-2}\, K^{-1}$) ;
B is the transmission losses fraction (-).

and the other symbols are defined in the nomenclature.

APPROACH

It is of course of interest to perform sensitivity analyses of the impact of duct leakage class or U-value on the global performance of a given building, but since it is difficult for other professionals to use these results in different contexts, the analyses would have to be reproduced with a similar software e.g. with different climates conditions, occupation scenarios, or ventilation system types. Therefore, it requires access and sometimes customization of these software programmes, which is uneasy.

For a more generic understanding of the issues, we have developed a simplified model for a balanced ventilation system with heat recovery. The system modelled is represented schematically in Figure 1 where the symbols used are described in the nomenclature. The model assumes that the leaks are located at the air terminal devices. The objective of our development was to obtain an analytical relationship between the global efficiency of the system as a function of the leakage and conduction characteristics. For this, we assumed that the anti-freeze system, as well as the fans did not change the air temperature, i.e., $T_{af} \approx T_{ext}$, $T_{s,exch} \approx T_{s,AHU}$, *and* $T_{r,exch} \approx T_{r,AHU}$. The global efficiency of the system is defined by:

$$\varepsilon_{glo} = \frac{Q_{ma,s} - Q_{ma,ls}}{Q_{ma,r} - Q_{ma,lr}} \frac{T_s - T_{ext}}{T_i - T_{ext}} \tag{3}$$

$$T_s - T_{ext} = T_s - T_b + T_b - T_{ext} = B_s \left(T_{s,exch} - T_b\right) + \left(T_b - T_{ext}\right) \tag{4}$$

$$\begin{aligned} T_{s,exch} - T_{ext} &= \varepsilon_T \left(T_{r,AHU} - T_{ext}\right) \\ &= \varepsilon_T \left(T_{r,AHU} - T_b + T_b - T_{ext}\right) \\ &= \varepsilon_T \left(B_r \left(\frac{Q_{ma,lr} T_b + \left(Q_{ma,r} - Q_{ma,lr}\right) T_i}{Q_{ma,r}} - T_b\right) + T_b - T_{ext}\right) \\ &= \varepsilon_T \left(B_r \left(1 - \alpha_r\right)\left(T_i - T_b\right) + T_b - T_{ext}\right) \end{aligned} \tag{5}$$

$$\begin{aligned} T_s - T_{ext} &= B_s \left(\varepsilon_T \left(B_r \left(1-\alpha_r\right)\left(T_i - T_b\right) + T_b - T_{ext}\right) + T_{ext} - T_b\right) + T_b - T_{ext} \\ &= B_s \left(\varepsilon_T \left(B_r \left(1-\alpha_r\right) \beta \left(T_i - T_{ext}\right) + \left(1-\beta\right)\left(T_i - T_{ext}\right)\right) + \left(\beta - 1\right)\left(T_i - T_{ext}\right)\right) + \left(1-\beta\right)\left(T_i - T_{ext}\right) \end{aligned} \tag{6}$$

Therefore,

$$\begin{aligned} \varepsilon_{glo} &= \frac{Q_{ma,s}}{Q_{ma,r}} \frac{1-\alpha_s}{1-\alpha_r} \left(B_s \left(\varepsilon_T \left(B_r \left(1-\alpha_r\right) \beta + \left(1-\beta\right)\right) + \left(\beta - 1\right)\right) + \left(1-\beta\right)\right) \\ &= \frac{Q_{ma,s}}{Q_{ma,r}} \frac{1-\alpha_s}{1-\alpha_r} \left(B_s B_r \varepsilon_T \left(1-\alpha_r\right) + \left(1-\beta\right)\left(1 + \varepsilon_T B_s - B_s - \varepsilon_T B_s B_r \left(1-\alpha_r\right)\right)\right) \end{aligned} \tag{7}$$

In the case of ducts running in unconditioned spaces well-insulated from the inside, b is close to 1 and then the ratio of the global efficiency to the nominal temperature efficiency of the heat exchanger reduces to:

$$\frac{\varepsilon_{glo}}{\varepsilon_T} = \frac{Q_{ma,s} - Q_{ma,ls}}{Q_{ma,r}} B_s B_r \tag{8}$$

This simple model does not provide an assessment of the global heat recovery efficiency for the building, which would need to take into account envelope leakage. However, it gives a simple equation for the system efficiency including the ductwork, which is useful to compare to the nominal efficiency of the heat exchanger. The results shown below are based on the values given in Table 1.

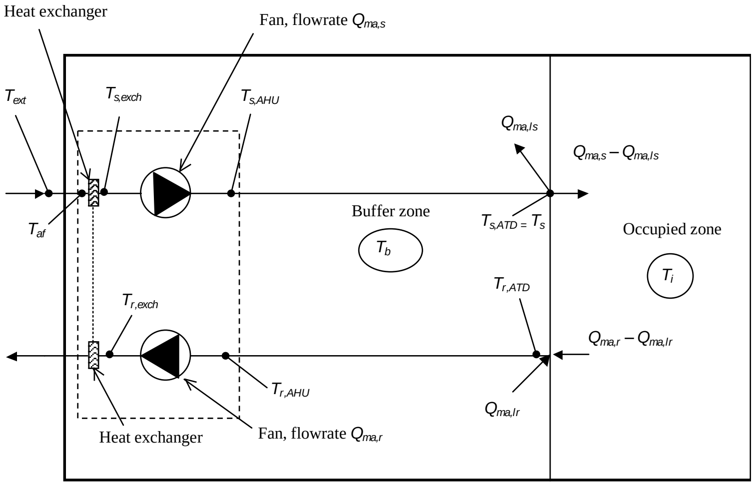

Figure 1. Schematic diagram of a balanced ventilation system with heat recovery. Representation is consistent with EN 15241.

Table 1. Input values used in simplified model described in Figure 1.

Description	Value
Temperature reduction factor	1
Duct thermal resistance	Variable (1.2 or 5.0 m^2 K W^{-1}) (i.e., about 5 or 20 cm of insulation)
Duct leakage class	Variable (3 *A, A, B, C, D)
Supply duct surface area	12 m^2 (e.g. about 30 m of 125-mm ducts)
Return duct surface area	8 m^2
Pressure difference across duct wall	100 Pa
Global extract and supply airflow rate in building	120 m^3/h
Nominal efficiency of the heat exchanger	80%

RESULTS

Figure 2 shows the variation of the global energy use expressed as the ratio of the global efficiency (Equation (7)) divided by the temperature efficiency of the heat exchanger for the system described in Figure 1 and Table 1. While the nominal efficiency of the heat exchanger is 80%, the global efficiency of the system falls down to:

- 73% for a Class C system (for airtightness) with a resistance of 5 m^2 K / W;
- 54% for a Class C system with a resistance of 1.2 m^2 K / W;
- 65% for a Class A system with a resistance of 5 m^2 K / W;
- 50% for a Class A system with a resistance of 1.2 m^2 K / W;
- 53% for a system 3 times leakier than Class A with a resistance of 5 m^2 K / W;
- 43% for a system 3 times leakier than Class A system with a resistance of 1.2 m^2 K / W.

The results of the SAVE-DUCT project [1] suggest that the latest case is common in France and Belgium in terms of ductwork airtightness, and probably in many other European countries except for the Nordic region.

If the ducts are placed inside the building (*b* = 0), there is little effect on the heat recovery efficiency. In that case, leaky ducts are detrimental to fan energy use only (which is not analyzed here) if the flow rate complies with the flows required at the air terminal devices.

This simple analysis shows the significance of the losses when a heat recovery system and the ductwork are located in an unconditioned space. When implemented in a global energy calculation method, preliminary analyses have shown that the impact can easily reach 15% of the global energy use (excluding appliances) of a very-low energy building.

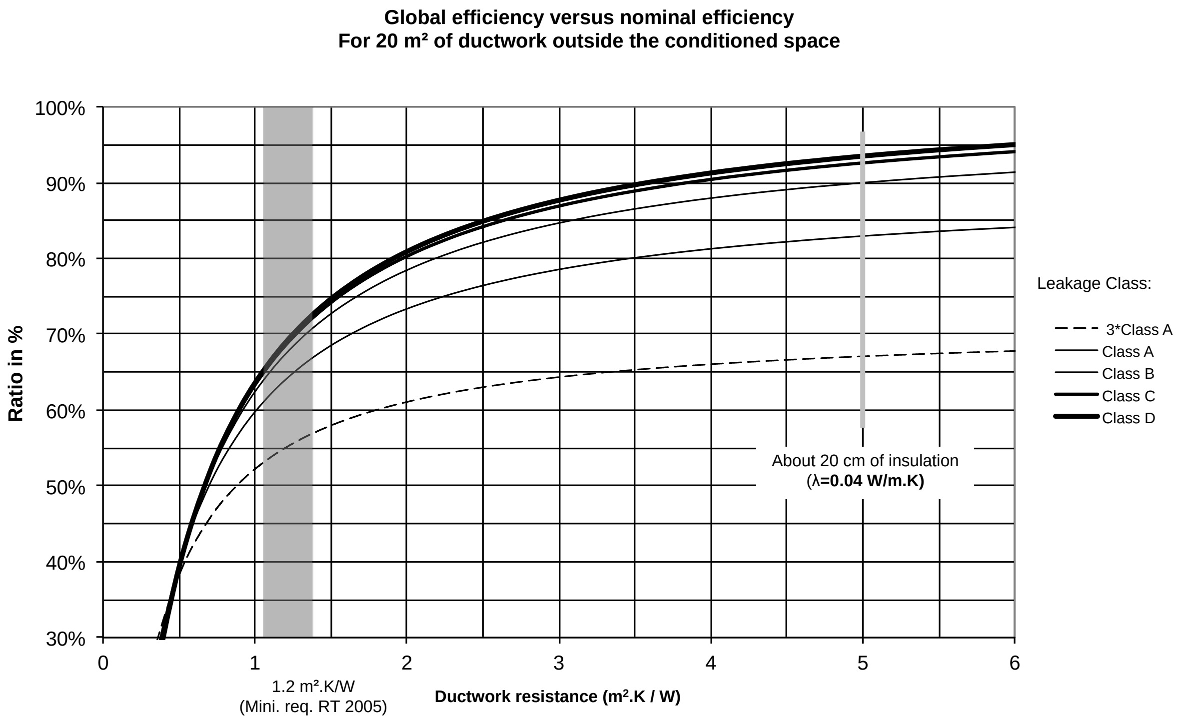

Figure 2 : Global efficiency versus nominal efficiency for various leakage classes and ductwork thermal resistance

CONCLUSION

Our analyses have shown that the impact of ductwork leakage and transmission losses are quite significant on the heat recovery of a whole ductwork system, as the nominal efficiency has dropped almost by a factor of 2 (from 80% to 44%) with leaky and poorly insulated ducts located in an unconditioned space. This translates into significant energy wastage that is clearly incompatible with nearly zero-energy targets. Of course, the energy use impact would be radically different with ducts inside the conditioned space or with an exhaust-only system. However, because balanced ventilation systems with ducts outside the conditioned space represent in several countries a significant market share in these types of buildings, these issues must be addressed to generalize nearly zero-energy buildings. Today's measured field data and market knowledge on ductwork leakage and heat resistance show that for most countries, these aspects will be a major challenge for the building industry and building professionals.

NOMENCLATURE

Symbol	Description	Units
a	Ratio of leakage air flow rate to fan airflow rate, e.g. $a_s = \frac{Q_{ma,ls}}{Q_{ma,s}}$	-
b	Temperature reduction factor of buffer zone	-
c_p	Specific heat capacity of air	J/(kg K)
B	Ratio of transmission losses	-
q_v	Flow rate	$m^3\ s^{-1}$
q_{vl}	Leakage flow rate	$m^3\ s^{-1}$
Q_{ma}	Mass airflow rate	$kg\ s^{-1}$
T	Temperature	K
□	Efficiency	-
□□	Temperature efficiency of heat exchanger	-
□	Air density	$kg\ m^{-3}$

Subscripts and superscripts

af	Antifreeze
ATD	At air terminal device
b	Pertaining to buffer zone
ext	Pertaining to exterior
i	Pertaining to indoor
lr	Leakage on return side
ls	Leakage on supply side
r	Pertaining to return side
r,AHU	Before fan on return side
r,exch	Before heat exchanger on return side
s	Pertaining to supply side
s,AHU	After fan on supply side
s,exch	After heat exchanger on supply side
glo	Global

REFERENCES

[1] Carrié, F.R., Andersson, J., and Wouters, P. 1999. Improving Ductwork - A Time for Tighter Air Distribution Systems, Report, EU Project SAVE-DUCT, Brussels 1999. ISBN 1902177104.

[2] Carrié, F.R., Rosenthal, B. 2008. An overview of national trends in envelope and ductwork airtightness, AIVC Information Paper VIP 29, August 2008, 6 pp., http://www.aivc.org/medias/pdf/Free_VIPs/VIP29_Airtightness.pdf, http://www.asiepi.eu/wp-5-airtightness/information-papers.html

[3] Carrié, F.R., Wouters, P., Heijmans, N., Rosenthal, B., Aurlien, T., Guyot, G., 2008. Ways to stimulate a market transformation of envelope airtightness. Analysis of on-going developments and success stories in 4 European countries, Web event, 12th December 2008, http://www.asiepi.eu/wp-5-airtightness/web-events/web-event-1.html

[4] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union. 18 June 2010. L 153/13-34.
[5] European Standard EN 12237 (2003). Ventilation for buildings - Ductwork - Strength and leakage of circular sheet metal ducts.
[6] European Standard EN 14239 (2004). Ventilation for buildings - Ductwork - Measurement of ductwork surface area.
[7] European Standard EN 1507 (2006). Ventilation for buildings - Sheet metal air ducts with rectangular section - Requirements for strength and leakage.
[8] European Standard EN 15241 (2007). Ventilation for buildings—Calculation methods for energy losses due to ventilation and infiltration in commercial buildings.
[9] European Standard EN 15242 (2007). Ventilation for buildings—Calculation methods for the determination of air flow rates in buildings including ventilation.
[10] Malmström, T.G., Andersson, J., Carrié, F.R., Wouters, P., and Demotte, C. 2002. Source Book for Efficient Ductwork in Europe. Report, EU Project SAVE-AIRWAYS, Contract n° 4.1031/Z/99-158. 2002.
[11] Publications and activities of the ASIEPI project. http://www.asiepi.eu/wp-5-airtightness.html, EU Project IEE-SAVE, Contract n° EIE/07/169/SI2.466278.
[12] Schild, P., Caillou, S., Millet, J-R., Mattsson, L. Å., Railio, J., Carrié, F.R. 2009. How to improve ductwork airtightness - Ongoing developments and success stories in Europe, Web event, 16th December 2009, http://www.asiepi.eu/wp-5-airtightness/web-events.html
[13] Schild, P.G., and Mysen, M. 2009. Recommendations on Specific Fan Power and Fan System Efficiency, AIVC Technical Note 65, 42 pp. Available at www.aivc.org.