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IMPACT OF DUCTWORK LEAKAGE ON THE FAN ENERGY USE OF CENTRAL MECHANICAL VENTILATION UNITS WITH HEAT RECOVERY USED IN HOUSES

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2 ABSTRACT

Various studies demonstrate a significant impact of ductwork leakage on the fan power consumption of ventilation systems. They have shown that the total energy used by fans can be reduced by 30-50% by improving the airtightness of the ductwork system. However, most of those studies focused on non-residential and multi-family buildings. This study focuses on single-family dwellings; specifically houses.

This paper first explains why fan energy use increases with ductwork leakage and then presents a model, which is based upon (Leprince & Carrié, 2018), that is used to estimate the impact of ductwork leakage on the fan energy use of central mechanical ventilation units with heat recovery in three houses.

The calculations have shown that fans connected to leaky ductwork (3*Class A) in the three houses use 57-169% more energy than fans connected to very airtight ductwork (Class D), if they ventilate to provide the hygienic flowrate at Air Terminal Devices.

3 INTRODUCTION

There are a number of studies that demonstrate a significant impact of ductwork leakage on fan energy use (Soenens & Pattijn, 2011) (Stroo, 2011) (Berthault, Boithias, & Leprince, 2014) (D.F., 2011) (Bailly, Duboscq, & Jobert, 2014) (Levinson, Delp, Dickerhoff, & Modera, 2000) (Carrié, Bossaer, Andersson, Wouters, & Liddament, 2000) (Krishnamoorthy & Modera, 2016) (Leprince & Carrié, 2018). (Soenens & Pattijn, 2011) concluded that more than 30% of the energy used by the fans in the ventilation systems in a hospital wing, care home and office building could be saved using airtight ventilation systems (Soenens & Pattijn, 2011). Those results are consistent with (Stroo, 2011) and with the experimental study of Berthault in a multi-family building (Berthault, Boithias, & Leprince, 2014), which concluded up to 50% energy savings with class C airtight ductwork compared to 1.5*class A.

However, recent measurements performed in France in the context of the Effinergie + label (Moujalled, Leprince, & Mélois, 2018) have shown that almost 50% of the ductwork systems in the tested houses have ductwork airtightness 2.5*class A or worse. This stresses the need to change construction habits because the ductwork in most of the tested buildings was designed to achieve at least class A (required by the Effinergie + label), but missed the target.

Unfortunately, the negative impact of ductwork leakage on fan energy use and sound production is still neglected in most countries (Leprince, Carrié, & Kapsalaki, 2017), particularly in residential buildings.

This paper aims to:

- explain the impact of ductwork leakage on flowrate and pressure drop;
- calculate the impact of ductwork leakage on the fan energy use of central mechanical ventilation units with heat recovery in 3 houses with different ductwork systems, hygienic flow rates and pressures drops.

4 DUCTWORK LEAKAGES AND FAN ENERGY USE

4.1 FAN ENERGY USE

The fan power consumption depends upon the flowrate produced by the fan and the pressure difference on either side of the fan.

The nominal efficiency of the fan is defined by the following equation:

$$\eta = \frac{\Delta P * Q}{P_{el} * 3600}$$

η	-	Efficiency of the fan
ΔP	Pa	Pressure difference at fan
Q	m^3/h	Flowrate at fan
P_{el}	W	Electrical power of the fan

This efficiency may not be constant according to the pressure difference and flow rate.

The higher the pressure drop (resistance) in the ductwork, the higher the pressure difference the fan needs to produce to overcome this resistance and achieve the hygienic flow rate.

Generally, axial fans are able to produce high flowrates, but cannot generate enough large pressure difference to overcome any resistance without running at higher speeds and producing more sound. On the other hand, centrifugal fans are able to generate large pressure differences, but their flowrates are limited.

4.2 PRESSURE LOSSES

Pressure drop in ductwork systems is due to the irreversible transformation of mechanical energy into heat (ASHRAE, 2013). There are two types of losses:

- friction losses (occurring along the ductwork)
- and dynamic losses (occurring at bends and junctions)

4.2.1 FRICTION LOSSES

Friction losses occur along the entire length of duct. They are due to fluid viscosity. Friction loss can be calculated using the Darcy equation (ASHRAE, 2013)

$$\Delta p_f = \frac{1000 f L}{D_h} * \frac{\rho V^2}{2}$$

Δp_f	Pa	Friction losses in terms of total pressure
f	-	Friction factor
L	m	duct length
D_h	m	hydraulic diameter
V	m/s	velocity
ρ	kg/m^3	air density

Friction losses are proportional to the flow velocity to the power of 2 so also to the square of the flowrate.

4.2.2 DYNAMIC LOSSES

Dynamic losses result from flow disturbance caused by duct accessories, which change the direction of the flow (bends) and of the hydraulic diameter (adaptors) and at converging/diverging junctions.

Dynamic loss can be calculated using the following equation (ASHRAE, 2013):

$$\Delta p_t = \frac{C \rho V^2}{2}$$

C	-	Total loss coefficient

Δp_t	Pa	Total pressure loss
V	m/s	velocity
ρ	kg/m^3	air density

4.2.3 TOTAL PRESSURE LOSS IN THE DUCTWORK

Total pressure loss in a duct section is calculated by combining friction and dynamic losses.

$$\Delta p = \left(\frac{1000f}{D_h} + \sum C\right)\left(\frac{\rho V^2}{2}\right)$$

Therefore, the pressure loss in the ductwork system is proportional to the square of the flowrate and the higher the flowrate to overcome ductwork leakage, the higher resistance in the ductwork.

4.3 FAN AND PRESSURE LOSSES

The fan needs to compensate for the additional flowrate due to ductwork leakage and also the additional pressure drop to maintain the hygienic flowrate. Therefore, both the flowrate and the pressure at the fan needs to be increased.

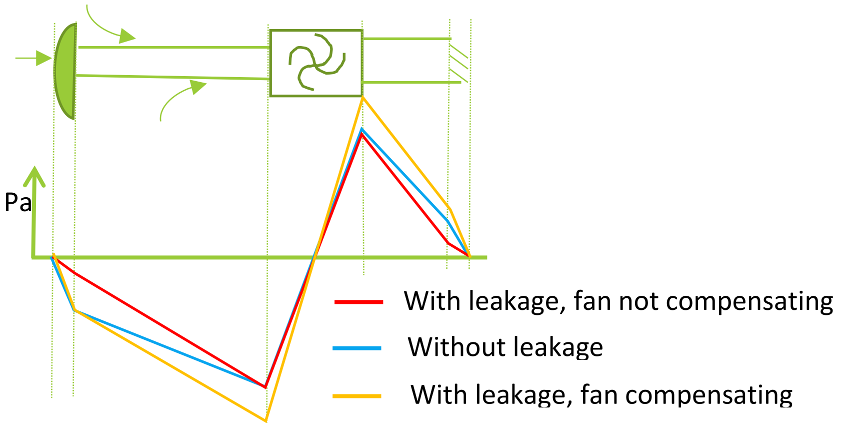

Figure 1: Pressure profile within the system with and without leakages according to the fan pressure drop

The flowrate (Q) at the Air Terminal Devices (ATD) depends upon the pressure at the ATD according to a power law.

$$Q = C\,\Delta P^n$$

C and n depend upon the air terminal device (n is close to 0.5).

Therefore, the lower the pressure drop at ATD’s, the lower the flowrate.

Therefore, as shown in Figure 1, if the fan is not compensating for the additional pressure drop due to ductwork leakage, the pressure drop and flowrate at ATD’s will decrease.

Generally, the pressure drop at a fixed ATD providing the hygienic flowrate is around 10 Pa. Self-adjusting ATD’s generally need 50-70 PA to function properly.

4.4 EQUATIONS

To estimate the additional energy used to overcome ductwork leakage the additional flowrate and the additional pressure drop shall be calculated using the calculation model developed by (Leprince & Carrié, 2018), which is based upon EN 16798-5-1 (CEN, 2016).

If the fan compensates for leakages the flowrate at the fan shall be

$$q_{v;ahu} = q_{v;dis;req} + q_{lea}$$

$$q_{lea} = A_{du} * c_{lea} * \Delta P_{du}^{ep} * 3600$$

With

$q_{v;ahu}$	m^3/h	Required flowrate at Air Handling Unit
$q_{v;dis;req}$	m^3/h	Sum of required flowrates at Air Terminal Devices
q_{lea}	m^3/h	Flowrate through leakages
A_{du}	m^2	Area of the ductwork
c_{lea}	$m^3/s/m^2$ at 1Pa	Airtightness factor of the ductwork
ep	-	pressure difference exponent, default value: 0.65
ΔP_{du}	Pa	Average pressure difference between inside and outside the ductwork

Leakage only creates an additional pressure drop in the ductwork (not at the ATD), so to estimate the additional pressure drop due to ductwork leakage the pressure drop at the ATD's shall be deduced from the total pressure drop.

$$\Delta P_{fan} = \Delta P_{ATD;req} + \left(\frac{q_{v;dis;req} + q_{lea}}{q_{v;dis;req}}\right)^2 * \Delta P_{du;noleak}$$

ΔP_{fan}	Pa	Required pressure at fan to provide required pressure at ATD
$\Delta P_{ATD;req}$	Pa	Required pressure at ATD to provide required flowrate
$\Delta P_{du;noleak}$	Pa	Pressure drop in the ductwork when there are no leakages (when flowrate in the ductwork is the hygienic flowrate). This pressure drop does not include pressure drop at ATD.

To simplify the calculation and avoid cross-references, it can be assumed that ΔP_{du} is constant whatever the leakage is and equal to:

$$\Delta P_{du} = \Delta P_{ATD;req} + \frac{\Delta P_{du;noleak}}{2}$$

In this study, any leakage inside the AHU itself and the heat exchanger have been neglected to only show the impact of leakage in the ductwork system.

5 CASE STUDY

5.1 HYPOTHESIS

The following three scenarios have been simulated:

House 1 is a medium-sized house with a central mechanical ventilation system with heat recovery. The ductwork system is a radial air distribution system using semi-rigid plastic ductwork. The diameter of the ductwork is 75mm and the total length is 125m. It is assumed that the ductwork is equally split between supply and extract.

House 2 is also a medium sized house a central mechanical ventilation system with heat recovery. The ductwork system is a trunk and branch air distribution system using metal or rigid plastic ductwork with 6m of ductwork DN160mm and 40m of ductwork DN125mm. It is assumed that the ductwork is equally split between supply and extract.

House 3 is a large house with a central mechanical ventilation system with heat recovery. The ductwork system is a radial air distribution system using semi-rigid plastic ductwork. The diameter of the ductwork is 75 mm and the total length is 200 m. It is assumed that the ductwork is equally split between supply and extract.

Table 1 summarises the hypothesis of the ventilation system in each house used for the calculation.

	House 1	House 2	House 3
Hygienic flowrate (m^3/h)	225	225	300
Required pressure at ATD's (Pa)	10	10	10
Ductwork area of each airflow m²	14.72	9.36	23.6
Pressure drop in ductwork (without leakages) (Pa) for each airflow	100	100	150

Table 1: Hypothesis for cases studies

5.2 RESULTS

Table 2 shows the required flowrate and pressure of ***each*** airflow and fan in each house and for the various airtightness classes. The required pressure at the fan includes the pressure drop in the ductwork plus the required pressure at the ATD's.

Required flowrate of each fan (m^3/h)			
	House 1	**House 2**	**House 3**
3*Class A	286	264	424
1.5*Class A	256	245	362
Class A	245	238	341
Class B	232	229	314
Class C	227	226	305
Class D	226	225	302
No leakage	225	225	300

Required pressure at each fan (Pa)			
3*Class A	172	148	309
1.5*Class A	139	128	228
Class A	129	122	204
Class B	116	114	174
Class C	112	111	165
Class D	111	110	162
No leakage	110	110	160

Table 2: Required pressure and flowrate for each fan according to the ductwork leakages for the 3 houses tested

The fan power consumed to produce this pressure and flowrate can either be calculated by assuming a constant efficiency or read in the fan curves provided by the ventilation unit manufacturer.

The annual fan energy use shall be estimated assuming that the fans in both airflows work 8,760 hours per year.

Table 3 shows the annual energy use of both fans assuming a constant fan efficiency of 0.27.

Annual energy use of both fans (kWh)			
	House 1	**House 2**	**House 3**
3*Class A	888	703	2359
1.5*Class A	641	565	1488
Class A	571	523	1255
Class B	485	471	984
Class C	459	454	904
Class D	450	449	878
No leakage	446	446	865

Table 3 : Annual energy use of both fan per year (kWh) assuming an efficiency of 0.27

Figure 2 and Figure 3 compare the annual energy use of both fans in the 3 houses according to the various airtightness classes.

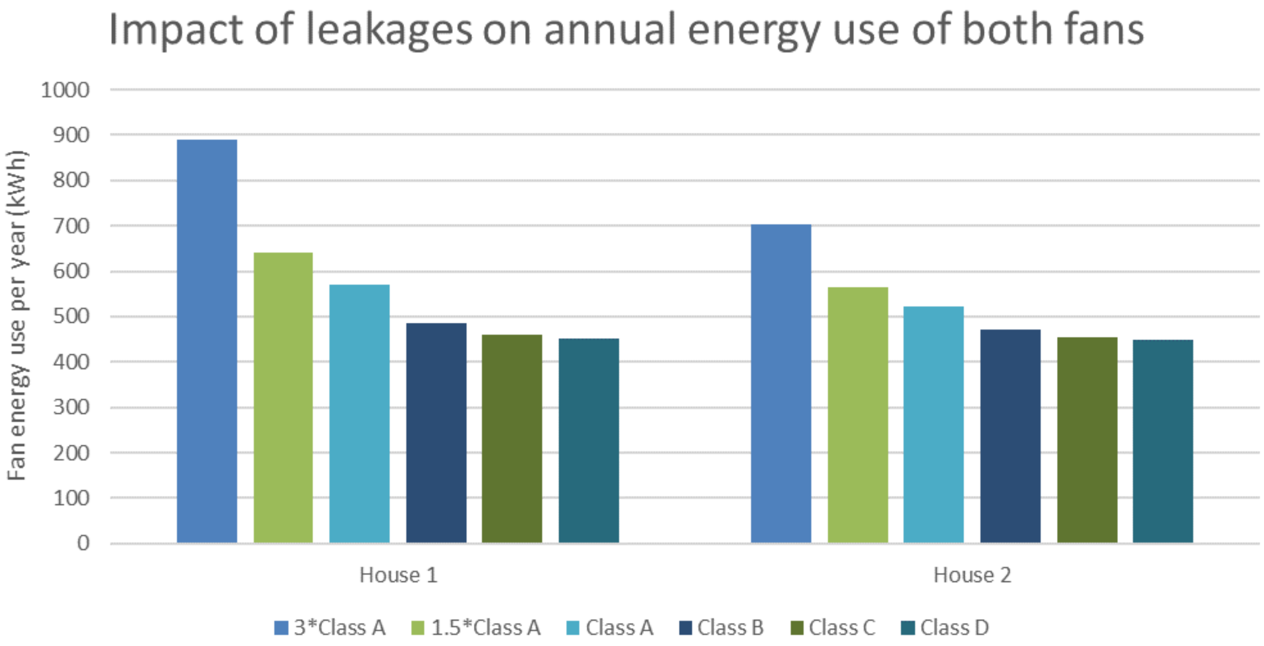

Figure 2: Annual energy use of both fans in houses 1 and 2 (estimated assuming a fixed fan efficiency of 0.27)

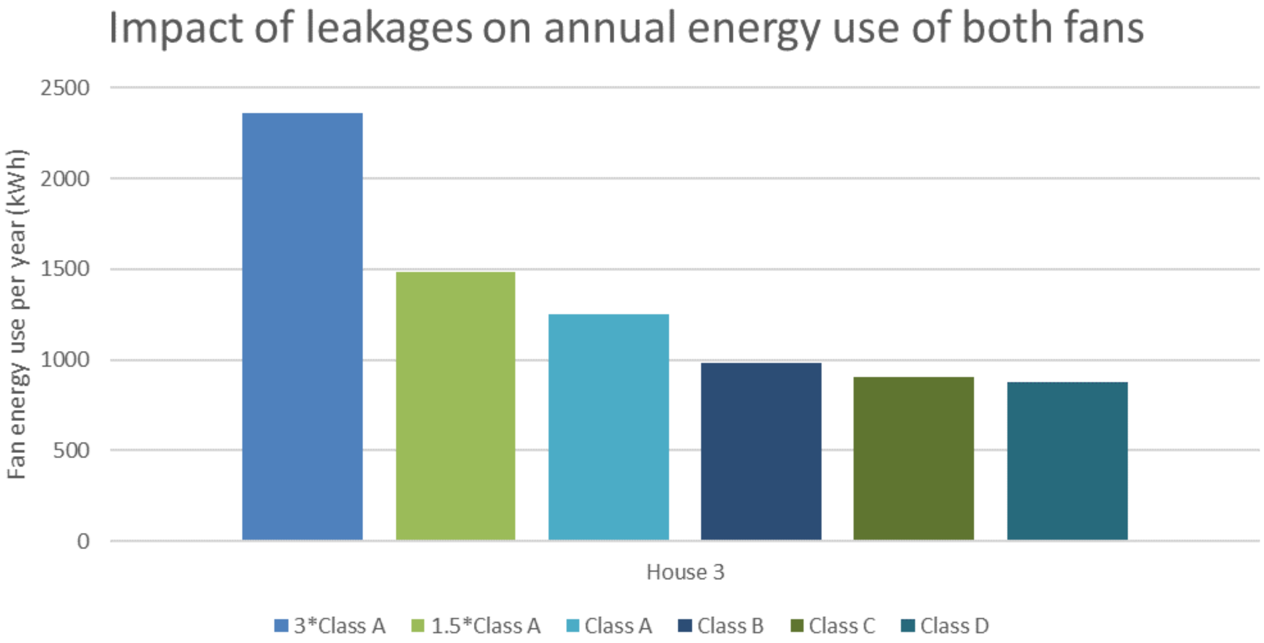

Figure 3: Annual energy use of both fans in house 3 (estimated assuming a fixed fan efficiency of 0.27)

6 CONCLUSION

The first part of this study has demonstrated the impact of ductwork leakage on both the flowrate and pressure drop at the fan. It has provided equations to calculate the impact according to

- the required hygienic flowrate
- the required pressure at ATD
- ductwork properties (surface area, leakage coefficients and pressure drop without leakage).

The second part of this study has applied those equations on central mechanical ventilation systems with heat recovery in three houses. It has shown that fans connected to leaky ductwork (3*Class A) can use 57-169% more energy than fans connected to very tight ductwork (Class D) to produce the required hygienic flowrate.

If the fans have to work harder to produce the required hygienic flow rate, then one can assume that they will produce more sound through the casing and in the ductwork and possibly noise hindrance. Further research is needed to determine the impact of ductwork leakage on the sound pressure level in the habitable rooms due to mechanical ventilation.

7 FUNDING AND DISCLAIMER

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8 REFERENCES

ASHRAE. (2013). *2013 ASHRAE Handbook: Fundamentals.*

Bailly, A., Duboscq, F., & Jobert, R. (2014). Impact of a poor quality of ventilation systems on the energy efficiency for energy-efficient houses. *35th AIVC Conference " Ventilation and airtightness in t* (pp. 108-118). Poznań, Poland, 24-25 Septembe: AIVC.

Berthault, S., Boithias, F., & Leprince, V. (2014). Ductwork airtightness: reliability of measurements and impact on ventilation flowrate and fan energy consumption. *35 TH AIVC-4 TH TIGHTVENT & 2 ND VENTICOOL CONFERENCE , 2014* (pp. 478-487). Poznań, Poland, 24-25 September: AIVC.

Carrié, F., Bossaer, A., Andersson, J., Wouters, P., & Liddament, M. (2000). Duct leakage in European buildings: Status and perspectives. *Energy and Buildings, 32*(3), 235-243.

CEN. (2016). *EN 16798-5-1:2016 Energy performance of buildings - Ventilation of buildings - Part 5-1: Calculation methods for energy requirements of ventilation and air conditioning systems.*

D.F., D. (2011). Case study: effect of excessive duct leakage in a large pharmaceutical plant. *32th AIVC Conference. Towards Optimal Airtightness Performance* (pp. 55-56). Brussels, Belgium: AIVC.

Krishnamoorthy, S., & Modera, M. (2016). Impacts of duct leakage on central outdoor-air conditioning for commercial-building VAV systems. *Energy and Buildings, 119*, 340-351.

Leprince, V., & Carrié, F. (2018). Impact of ductwork airtightness on fan energy use: Calculation model and test case. *Energy and Buildings, 176*, 287-295.

Leprince, V., Carrié, F., & Kapsalaki, M. (2017). Building and ductwork airtightness requirements in Europe – Comparison of 10 European countries. *38th AIVC Conference. Ventilating healthy Low-energy buildings* (pp. 192-201). Nottingham, UK: AIVC.

Levinson, R., Delp, W., Dickerhoff, D., & Modera, M. (2000). Effects of airflow infiltration on the thermal performance of internally insulated ducts. *Energy and Buildings, 32*(3), 345-354.

Moujalled, B., Leprince, V., & Mélois, A. (2018). Statistical analysis of about 1300 ductwork airtightness measurement in new French buildings: impact of the type of ducts and ventilation systems. *39th AIVC conference.* Juan les pins.

Soenens, J., & Pattijn, P. (2011). Feasibility study of ventilation system air-tightness. *32th AIVC Conference. Towards Optimal Airtightness Performance* (pp. 51-54). Brussels, Belgium: AIVC.

Stroo, P. (2011). Class C air-tightness: Proven roi in black and white. *32th AIVC Conference. Towards Optimal Airtightness Performance2* (pp. 96-97). Brussels, Belgium: AIVC.