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Impacts of air distribution system leakage in Europe: the SAVE-DUCT project

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CEN TC 156 "Ductwork"
Class A (lowest)
f_A = 1,32 l/s m2 @ 400Pa
ELA = 0,34 cm²/ft² @ 25 Pa
Class C -- f_A = 0,15 l/s m2 @ 400 Pa

SWEDEN
Lindab
Good
Round system
Cost + 25 à 50 %
MAAR installé vite [illegible]

Françoise

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Synopsis

This paper gives an overview of duct leakage issues in Europe. A literature review indicates a lack of ductwork air tightness measurement data in the member states. However, based on a few papers and above all on a field study on 22 duct systems in France, we conclude that the ventilation and energy use implications of leaky ducts are large and merit further examination. To this end, we have started the SAVE-DUCT project (1997-1998) aiming at studying the potential implications of a tight air duct policy at the European level. Our work entails an overview of existing codes and standards, a review of available information on ductwork air tightness, and a field measurement campaign. On this basis, data analyses and simulations will be performed. In addition, a two-day workshop will be held in Brussels (June 10-11, 1998) so as to better interact with manufacturers, installers and consultant engineers as well as standardisation and governmental bodies.

List of symbols

A	(tested) duct surface area (m^2)
ELA	effective leakage area (m^2)
f	leakage factor ($m^3 s^{-1} m^{-2}$)
K	leakage coefficient per m^2 of duct surface area ($m\ s^{-1}\ Pa^{-0.65}$)
n	flow exponent (-)
Q	(leakage) flow rate ($m^3 s^{-1}$)
Q^*	Q divided by regulation airflow rate (-)
ΔP	pressure drop across the leaks (Pa)
ΔP_{ref}	reference pressure differential (Pa)
ρ	density of air ($kg\ m^{-3}$)

Introduction

Mechanical ventilation systems are widely used in European buildings to provide fresh air to the occupants and also to avoid an accelerated deterioration of materials. However, many unanswered questions remain about the performance of these systems. One aspect of particular interest regards the leakiness of the ductwork which has been identified as a major way of wasting energy in US residences (Modera, 1989; 1993). According to Modera, a typical California house with ducts located in the attic or crawl-space wastes approximately 20% of heating or cooling energy through duct leaks and draws approximately 0.5 kW more electricity during peak cooling periods.

Based on a literature review and mainly on a field study conducted in France, this paper presents how duct leaks can impact on the performance of commonly used ventilation systems in Europe, and briefly describes the SAVE-DUCT project.

Literature review

It is commonly accepted that the ductwork air tightness is not a major issue for proper functioning of duct systems and thus leakage tests are viewed as an unnecessary expense. However, as stated in Eurovent Guidelines 2/2 a limited ductwork air tightness may be required to minimise the cost and the energy penalty due to an over-sized or inefficient plant, and/or to ease the flow balancing process, and/or to have control over the leakage noise (see Laine (1990)). Other impacts such as the entry or release of pollutants through leaks[1] or the in/ex filtration to unconditioned spaces can be foreseen. To provide a general (however simplified) picture, we have represented schematically duct leakage implications in Figure 1.

Among the member states, Sweden is probably the most advanced on this issue. Nearly every duct system is leak-tested, and air tightness class C (see Eurovent 2/2) is commonly required and fulfilled in new installations. The situation appears to be quite different in the other European countries. Tests are very seldom performed in standard buildings, and thus the knowledge on the ductwork air tightness mainly relies on a few studies.
In the UK, Babawale *et al.* (1993) have investigated one forced air-heating system and have come to worrying conclusions in terms of energy use and comfort conditions. They recommend a research effort to ascertain the extent and impact of duct leakage in new and old building stock in the UK, especially when the ducts run through unconditioned spaces. However, such installations are not very much used in European countries in general.
In Belgium, Ducarme *et al.* (1995) monitored a demand controlled ventilation (DCV) system recently installed in an office building. It was shown that the ductwork air tightness is a key aspect for fully benefiting from the energy savings offered by the DCV. In this specific case, the initial ductwork air tightness was so poor that no savings at all could be achieved: whatever the demand was, the same air flow rate was supplied the building, either to the occupied offices or to the corridor through the leaks. Afterwards, it proved to be very difficult and time consuming to improve the ductwork air tightness so as to meet Eurovent Class A.

[1] To our knowledge this issue has not been examined in the European context.

Pittomvils *et al.* (1996) investigated in detail the balanced ventilation system used in more than 170 very low energy houses built in the Flemish Region of Belgium by field and laboratory testing. They showed that the ductwork was so leaky that about one third of the air supplied by the fan at medium speed escapes through leaks before reaching the ventilated room.
In France, Riberon *et al.* (1992) found "insignificant" duct leakage in 19 new single-family houses. However, Carrié *et al.* (1996) measured very large leakage rates in 9 duct systems of multi-family buildings, 8 of schools, 2 of a day-care centre, and 3 of office buildings. Their analyses show that potentially large indoor air quality and energy use impacts at a national level.

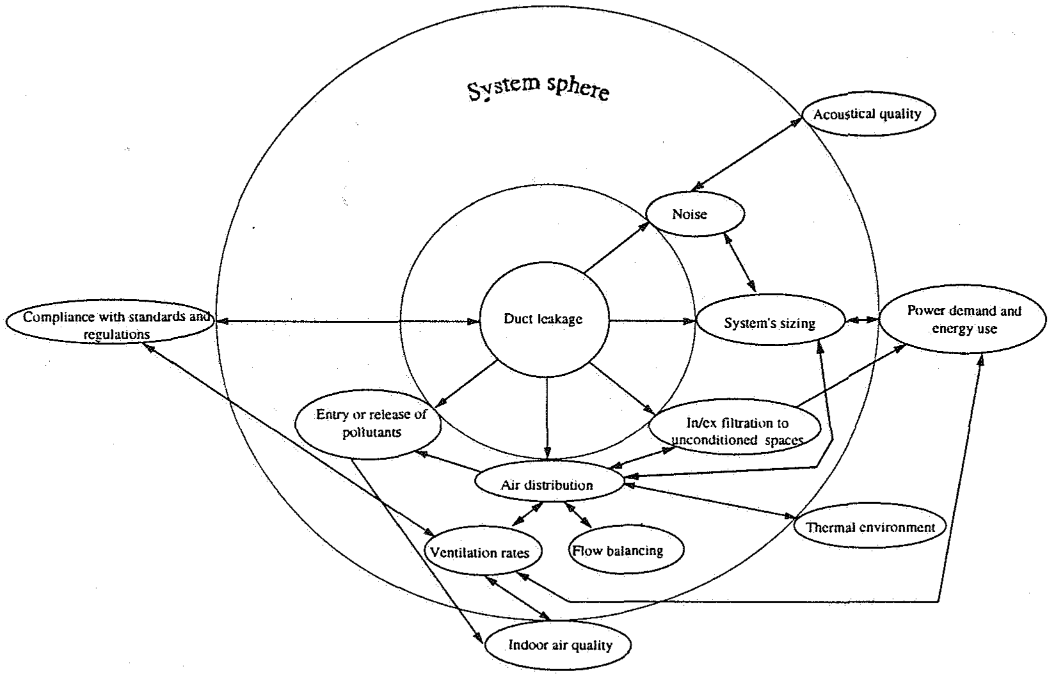


Figure 1: Schematic diagram of duct leakage implications.

Field measurements on 22 duct systems in France

To provide a more detailed picture of ductwork air tightness issues, we propose to focus the field study reported by Carrié *et al.* (1996) that was funded in part by Ademe, and which is the basis of the SAVE-DUCT project described hereafter.

Measurement method

In Europe, most ductwork air tightness standards propose a one-point measurement of the leakage flow rate at a given pressure differential and classify the installations similarly to Eurovent 2/2, i.e. in terms of the leakage coefficient per square meter of duct surface area defined in Equation 1:

$$\frac{Q}{A} = f = K\,\Delta P^{0.65} \qquad \text{(Equation 1)}$$

It is noteworthy that this classification relies on an arbitrary flow exponent of 0.65 which according to DW/143 (HVCA, 1986) is justified by Swedish tests performed on a variety of constructions. As this assumption may not hold in other countries, Carrié *et al.* performed the leakage measurement at several pressure stations which enabled them to assess K as well as the Effective Leakage Area (ELA) and the flow exponent defined as follows:

$$Q = ELA\sqrt{\frac{2\,\Delta P_{ref}}{\rho}}\left(\frac{\Delta P}{\Delta P_{ref}}\right)^{n} \qquad \text{(Equation 2)}$$

Results

The sample included 9 duct systems of multi-family buildings (4 to 5 levels), 8 of schools, 2 of a day-care centre, and 3 of office buildings. All of the buildings were located in the vicinity of L'Isle d'Abeau. Significant flaws were observed as shown in Figure 2.

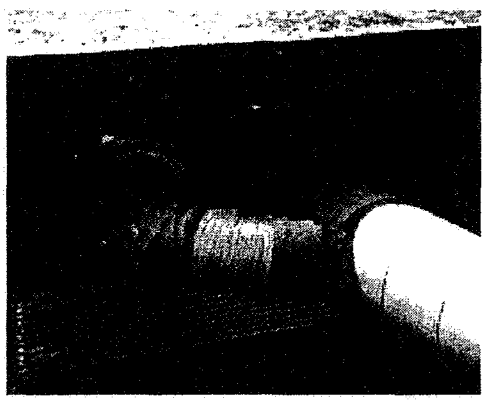


Figure 2: Photograph of poorly installed duct connections.

The results are represented Figure 3, and summarised in Table 1. It appears that the flow exponent has an average value considerably different from 0.65. Furthermore, it is found that except for one system, none can be classified according to the Eurovent 2/2 air tightness classes. K is in average well above that of class A ($K < 0.027\ 10^{-3}$ m s^{-1} Pa$^{-0.65}$).

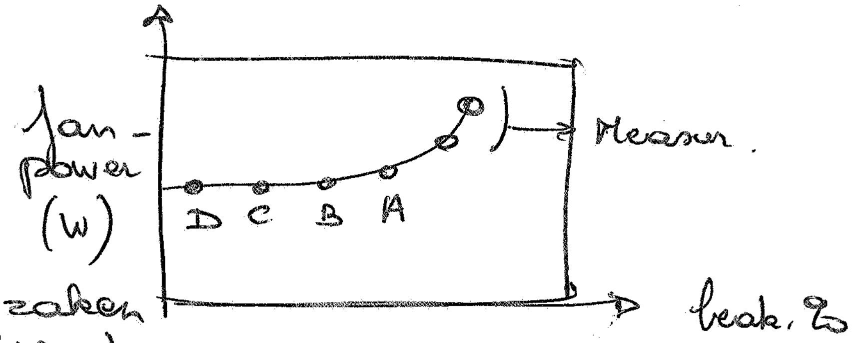
	Flow exponent n (-)	K (m s^{-1} Pa$^{-0.65}$)	ELA/A (cm^2/m^2)
Multi-family buildings	0.59 (0.05)	0.125 (0.050)	1.9 (0.8)
Non-residential buildings	0.57 (0.04)	0.066 (0.035)	1.0 (0.5)

Table 1: Duct leakage field measurements results (Carrié *et al.*, 1996). Average values of *n*, *K*, *ELA/A*. The standard deviations are shown in parenthesis.

invloed op power installé; fan-power (W)

dus voor power A of D niet zo veel, wel voor andere zaken consumpt, quality (iAQ), ...

cost effective! (class C)



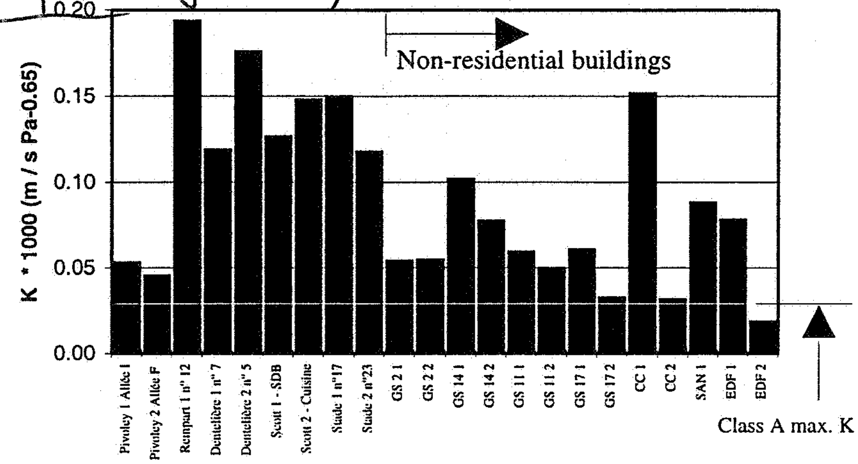


Figure 3: Duct leakage field measurements (Carrié *et al.*, 1996) - Leakage coefficients.

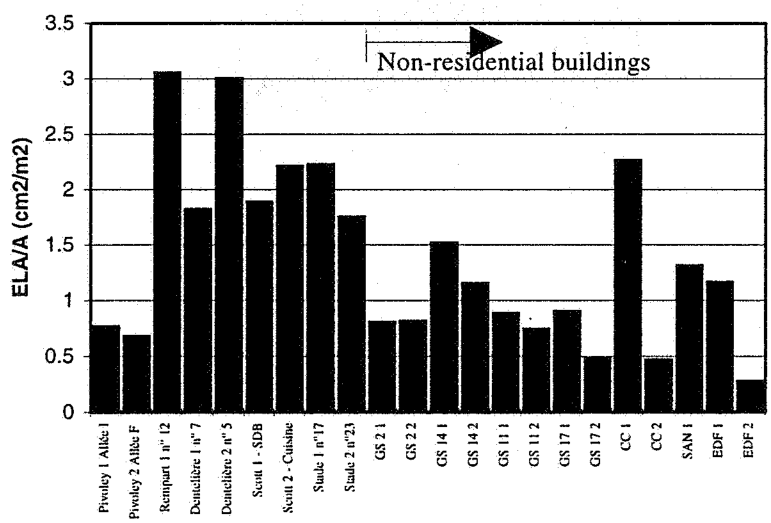


Figure 4: Duct leakage field measurements (Carrié *et al.*, 1996) - ELA at 80 Pa normalised by the (tested) duct surface area.

The leakage airflow rate divided by the regulation airflow rate (Q^*) is in average of 13% for residential buildings (Figure 5). These leakage rates result in a significant additional fan energy use at a national level given that in France 1 600 000 multi-family housings have been equipped with a mechanical ventilation system between 1981 and 1994 to comply with the regulation airflows. Thus, based on a mean (fan) power consumption estimate of 33 W per housing (see Barles *et al.* (1995)), the additional electricity energy consumption due to duct leakage would be of about 140 millions of kWh per year (16 MW during peak and off-peak periods alike). These energy implications are expected to be even greater as leaky ducts impact on the ventilation rates in a building, which in turn modifies the energy used for heating or cooling.

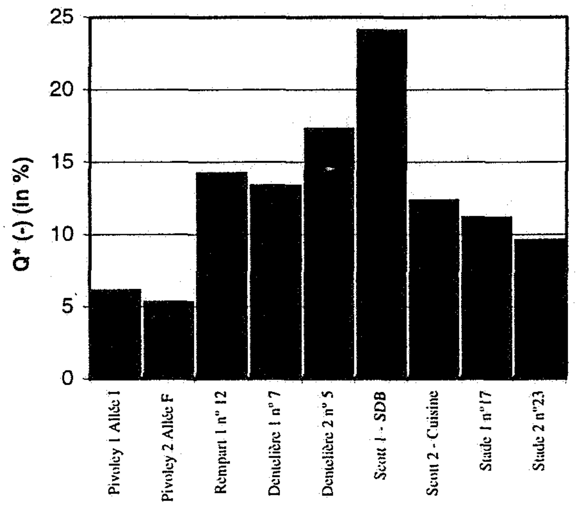


Figure 5: Leakage airflow rate at 80 Pa divided by regulation airflow rate (Q^*) (from (Carrié *et al.*, 1996)).

Scope of the SAVE-DUCT project

All of this calls into question the applicability of ductwork air tightness standards and also the quality of the installation of ventilation systems in the member states. On this basis, we have started the SAVE-DUCT project (1997-1998) whose objectives may be summarised as follows:

1. Quantify duct leakage impacts
2. Identify and analyse ductwork deficiencies
3. Propose and quantify improvements
4. Propose modifications to existing standards

This programme is funded in part by the SAVE programme of Commission of the European Communities - Directorate-General for Energy (DG XVII). It is divided in 4 phases:

1. State of the art
   - 1.1 Existing codes and standards (Task 1)
   - 1.2 Existing duct leakage in Europe (Task 2)
   - 1.3 Survey of HVAC manufacturers and contractors (Task 3)

There exists a number of designs of air duct systems, commercially-available ventilation products, and traditions in practice that can potentially affect the leakiness of these systems. This phase is aimed at giving better knowledge about all of those aspects.
A survey of HVAC manufacturers will be done in Sweden, Belgium and France so as to know what types of systems are most used and what could be their air tightness weaknesses. This information will be cross-examined with a survey of HVAC contractors.

2. Field measurements (Task 4)
   Leakage data should be obtained from different states according to a well-defined protocol so as to quantify the impact of different practice traditions and policies. Our sample will include 60 buildings split between Sweden, Belgium and France.
   Existing rehabilitation techniques such as that developed by Modera and Carrié (1996) shall be tested on a few buildings.

3. Data analysis and simulation work (Task 5)
   The data collected in phases 1 and 2 will be analysed to back out estimates of energy use and ventilation rates implications of duct leakage.
   We will also analyse the origins of ductwork permeability. Particular attention will be given to the quality of the installation and that of the commercially-available products. The issue of the compliance with existing standard will also be addressed.

4. Implementing the results
   - 4.1 Workshop in Brussels (Task 6)
   - 4.2 Publication (Task 7)

Existing standards will be analysed by quantifying their impacts similarly to what will be done in phase 3. Several improvements will be proposed to manufacturers, HVAC designers and contractors, and standardisation committees.
A workshop will be held in Brussels on the 10th and 11th of June 1998. It is intended to implement the results of the SAVE-DUCT project and allow an exchange of views with the practice (producers, installers, consultant engineers, etc.) and the standardisation bodies. Also, a book reporting the major findings of this project shall be published.

Conclusion

From this review, there appears an evident lack duct leakage measurement data in Europe (except for Sweden). Impact studies are also very limited. Still, based on a few studies, we can conclude that the ventilation and energy use implications of leaky ducts are large and merit further examination. To this end, we have started the SAVE-DUCT project (1997-1998) whose main objective is to better quantify the potential impacts of a tight air duct policy at the European level. It includes a field study on about 60 buildings to provide a more accurate picture of the ductwork air tightness status. The interaction with manufacturers, installers and standardisation bodies appears to be key to the success of this project. As for this, much is expected from the two-day workshop that will be held in Brussels (June 10-11, 1998).

Acknowledgements

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