Field experience with ductwork airtightness improvement after installation in Europe

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ABSTRACT

For years, ventilation and air-conditioning systems have played an increasingly important role in ensuring sufficient air exchange in buildings. With time buildings are becoming more and more airtight to avoid energy losses through uncontrolled air leakage and mechanical ventilation systems are installed to ensure a good indoor air quality. What is a good approach in theory can fail in practice due to leaky ductwork. Various studies have shown a low awareness on this issue in most European countries [1], with leaky ductworks impacting the energy use, the indoor air quality or generating noise [2].

One solution applicable both to new ductwork systems not meeting the expected air tightness class and existing leaky ductwork, is a sealing through aerosols injection. This technique explained in [3] and patented as the Aeroseal process, allows to seal air duct systems from the inside within a short time and without having to search for leaks beforehand. Leakages with gaps of up to 15 mm are permanently eliminated by using a sealant that is certified according to VDI 6022. In Europe almost 700 sealing projects have been carried out using this method since 2015.

This paper presents the results of 7 ductwork sealing projects performed during the year 2021 on existing (mostly non-residential) buildings located in 7 different European countries: Germany, France, Ireland, Czech Republic, the Netherlands, Poland and Switzerland. The ductwork leakages were reduced from 87% up to 98% with an average of 93%. The impact on the energy consumption is quantified for these 7 buildings. The highest savings are for the approximately 30 000 m² building in Ireland, reaching 36k€ per year for about 2/3 of the ductwork sealed, which allows a return on investment in about 2 years.

Each sealing project being performed by a different service company, feedback from 6 operators were collected giving information on:

- Possible ductwork airtightness issues encountered on-site in the various European countries: poor workmanship; failed manual sealing; lack of air duct clamps; holes made by air tightness testing devices and flexible connections that opened up.
- Possible technical sealing issues such as leakage flowrate measurement problems below 1L/s
- Feedback from costumers: decreased energy consumption; improved IAQ; less leakage of toxic gasses and odor disappearance
- Some trends regarding the market of ductwork sealing in their country, for example in Ireland more stringent criteria for pressure testing of systems result in more duct tightening work.

KEYWORDS

Ductwork leakage, sealing, aerosol, field experience

1 INTRODUCTION

For years, ventilation and air-conditioning systems have played an increasingly important role in ensuring sufficient air exchange in buildings. With time buildings are becoming more and

more airtight to avoid energy losses through uncontrolled air leakage and mechanical ventilation systems are installed to ensure a good indoor air quality. What is a good approach in theory can fail in practice due to leaky ductwork. Various studies have shown a low awareness on this issue in most European countries [1], with leaky ductworks impacting the energy use, the indoor air quality or generating noise [2].
One solution applicable both to new ductwork systems not meeting the expected air tightness class and existing leaky ductwork, is a sealing through aerosols injection. This technique explained in [3] and patented as the Aeroseal process, allows to seal air duct systems from the inside within a short time and without having to search for leaks beforehand. Leakages with gaps of up to 15 mm are permanently eliminated by using a sealant that is certified according to VDI 6022. According to European resellers, more than 650 sealing projects have been carried out using this method since 2015 in Europe.
This paper presents the results of 7 ductwork sealing projects performed during the year 2021 on existing (mostly non-residential) buildings located in 7 different European countries: Germany, France, Ireland, Czech Republic, the Netherlands, Poland and Switzerland.
A survey was sent to the sealing operators to collect both:

- Technical data on the building, ventilation system and ductwork sealing used in particular for the calculation of the leakage reduction and the fan energy use savings;
- Experience from on-site sealing: airtightness problems and sealing difficulties encountered; feedback from customer and return-on-investment times.

2 METHODOLOGY

2.1 Aeroseal air duct sealing technique

The aerosol-based sealing process was developed in the 1990s at the University of Berkeley, USA [4], [5], and was patented as the Aeroseal process (see Figure 1). The innovation consists in sealing ductwork from the inside, within a short time and without having to search for leaks beforehand. Chemically speaking, this technique is based on an emulsion of water and vinyl acetate polymer, a stable, non-toxic and non-flammable mixture, that is aerosolized into 4-10 micron-sized particles [6].

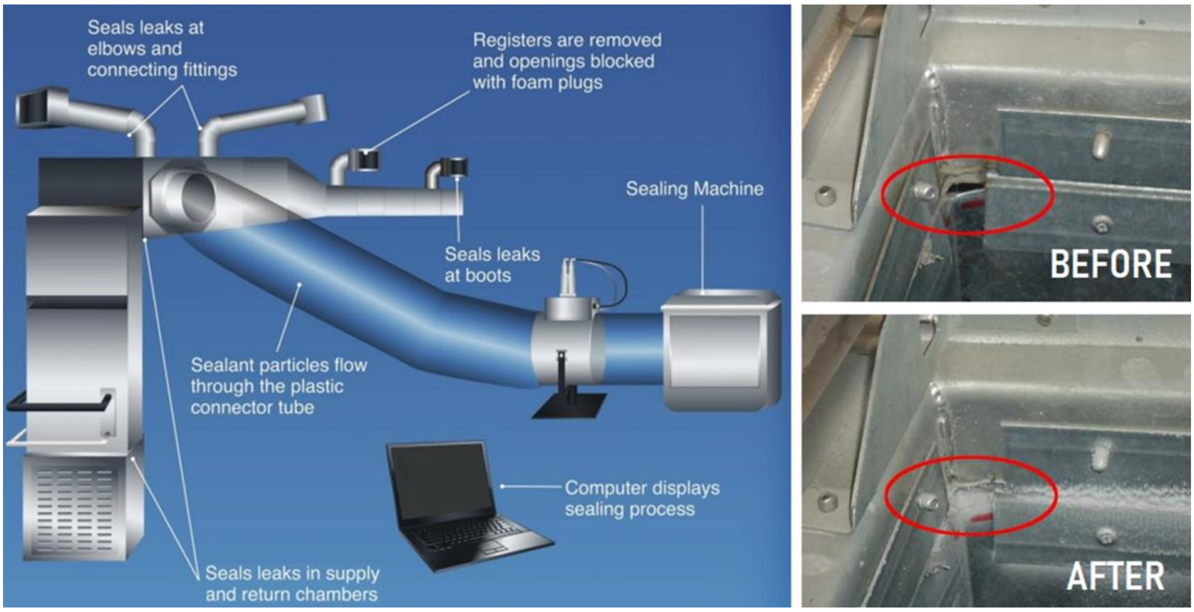

Figure 1 - Aeroseal sealant technology (Image courtesy of Aeroseal LLC)

The resulting aerosol is distributed under pressure inside the ventilation ductwork system. As explained by Modera [3]: “By temporarily blocking the diffusers, the sealant-laden air is forced to the leaks. Maintaining mild turbulence keeps the sealant particles suspended until they reach the leaks. The pressure maintained within the duct system causes the air to accelerate as it exits through the leaks, causing the particles to be flung against the walls of the leaks when they cannot turn as sharply as the accelerating air.” As a result, the particles seal little by little leaks with gaps of up to 15 mm forming a robust air sealing that will last for years while staying pliable and flexible and remains effective over a wide range of operating pressures, temperatures and humidity levels found in residential, commercial and industrial air duct systems [6]. Contrary to a coating process, the particles deposit only at the leaks and not elsewhere in the ductwork.
Until today the Aeroseal process has been applied in more than 125 000 ductwork systems of both residential and non-residential buildings, mostly in the USA. In Europe the product was introduced in the market in 2015 by Mez-Technik located in Germany and since then there have been almost 700 sealing projects in over 20 countries thanks to Aeroseal partners companies from 18 countries.

2.2 Case study: selected 7 buildings across Europe

In order to evaluate the performance of this aerosol-based sealing technique, a survey was sent to 7 Aeroseal partners across Europe to collect detailed data on ductwork sealing projects performed in 2021.
Table 1 presents the buildings’ characteristics of the selected sealing projects and the reasons why a sealing was requested. The building selection was made in order to cover a wide range of parameters with various locations (7 countries); building types (residential, educational, commercial, industrial); years of construction (from 1980 to new); surfaces (up to 42 000 m²). The sealing reasons also differ from one building to the other but almost always includes a necessity to improve the airtightness class to meet the national regulation or a contractual value.

Table 1 – Details on the studied buildings and reasons for ductwork sealing

Ref	Location (Country)	Building type	Year of constr.	Approx. surface (m²)	Reason(s) for ductwork sealing
CH	Zurich (Switzerland)	Office building	New	29 045	- Airtightness class not reached - Odor nuisance - Performance optimization
CZ	Praha (Czech Republic)	Multifamily housing	2016	12 714	- Odor nuisance
DE	Leinfelden-Echterdingen (Germany)	Office Building	New	42 000	- Airtightness class not reached - Problems with air distribution - Concrete shafts not built properly
FR	Saint Denis (France)	High school	2017	15 500	- Airtightness class not reached
IE	Tipperary (Ireland)	Medical Device Manufacturer – Cleanroom	1980	30 000	- Fulfill airtight ductwork - Hygienic problems in cleanrooms
NL	(The Netherlands)	Factory (truck manufacturer)	2006	30 000	- Airtightness class not reached - Hygienic problems - Odor nuisance
PL	Krakow (Poland)	Office building	2008	5 000	- Airtightness class not reached - Hygienic problems - Noise problems - Odor nuisance

Details provided by the survey respondents on the ventilation systems are given in Table 2. Once again, the project selection allows to cover a wide range of parameters:

- There is a factor of 50 between the lowest flowrate capacity (6000 m^3/h for the CZ project) and the highest (301407 m^3/h for the IE project)
- Most ventilation systems have 2 to 5 air handling units (AHU), but there are 52 for the FR project
- Exhaust, supply and double (with heat recovery) ventilation systems are all represented
- All ductworks are rigid, mostly rectangular but some include circular sections, about half are double-walled, and various dimensions are encountered up to about 1 m high.

Table 2 - Ventilation systems details of the studied buildings

Project reference	**CH**	**CZ**	**DE**	**FR**	**IE**	**NL**	**PL**
Flowrate capacity							
Total capacity (m^3/h)	127000	6000	12370	23251	301407	270000	66750
Number of air handling units impacted by sealing	5	4	8	52	5	2	2
Percentage of sealed ductwork (approx.)	N/A	N/A	N/A	30%	66%	N/A	N/A
Type of ventilation system							
Supply/exhaust/double	Double/ Exh.	Exh.	Double	Double	Supply	Supply	Double
Heat recovery?	Yes	No	Yes	Yes	No	No	Yes
Type of ductwork							
Circular/rectangular/both	Rect.	Rect.	Rect.	Both	Both	Rect.	Both
Flexible/semi/rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid
Double-walled, e.g. insulation?	Yes	Yes	Yes	No	No	No	Yes
Average diameter/height (min – max) (mm)	600 - 1100	500*250	800	125 - 500	315	1000	

Table 3 gives the ductwork sealing details, including the airtightness classes before the sealing, targeted, and after the sealing. As they are calculated from the ductwork area, the percentage of flowrate compared to the flowrate capacity is also indicated. One can note that some sealings were performed on very leaky ductworks (worse than 2.5 class A and up to 36% of the total flowrate capacity), others on already rather tight ductworks (especially for the NL project, initially class B).

Table 3 - Ductwork sealing details of the studied buildings

Project reference	**CH**	**CZ**	**DE**	**FR**	**IE**	**NL**	**PL**
Airtightness test **before** the sealing							
Airtightness class (on av.)	A	> 2.5 class A	2.5 class A	> 2.5 class A	2.5 class A	B	2.5 class A
Test pressure (Pa)	400	300	375	250	500	500	500
Total leakage rate (l/s)	493	421	1814	2547	7743	326	4550
% leakage / capacity	1,4%	21,4%	36,1%	30,4%	9,2%	0,4%	20,7%
Target							
Targeted class after sealing	-	A	C-D	C	- 90% of leakage	As tight as poss.	B
Airtightness test **after** the sealing							
Airtightness class (on av.)	C	B	C	C	B	< class D	B
Test pressure (Pa)	400	200	375	250	500	500	500
Total leakage rate (l/s)	28,0	14,7	127	56,8	992	13,8	485
% leakage / AHU flowrate	0,08%	0,88%	3,69%	1,04%	1,18%	0,02%	2,61%

The survey also includes questions on feedback from the operators about the sealing projects studied in this paper and more generally about their on-site experience with this sealing process (see paragraph 3.3).

2.3 Data Analysis: energy savings calculation

The energy savings on the fan power are estimated in this study considering that fans fully compensate for ductwork leakage. When the fan cannot, or only partially, compensate for leakage, it is the environmental air quality that is impacted [7].
Ductwork sealing can also induce significant heating/cooling savings [8] [2], when conditioned air leaks in a non-conditioned area. They were not calculated in this study as it would require detailed data that were not available (ductwork area located in non-conditioned spaces; duct location compared to the insulation layer; etc.) [7].

Fan power calculation
Apart from the IE project, the fan powers before/after sealing were not known by the survey respondents, and were therefore calculated as follows:

$$P_{AHU,i} = \frac{\Delta p_{AHU,i} \times Q_{AHU,i}}{\eta_{AHU,i} \times 3600} \tag{1}$$

With :

- i= bef/aft: ductwork state: before / after the sealing
- P_{AHU}: the power of the air handling unit (AHU) (W)
- Δp_{AHU}: the pressure difference at the AHU (Pa)
- Q_{AHU}: the air flowrate at the AHU (m^3/h)
- η_{AHU}: the AHU efficiency (-)

Air flowrates calculation
The AHU flowrate after the sealing was considered to be the flowrate capacity provided:

$$Q_{AHU,aft} = Q_{AHU,nom} \tag{2}$$

For the FR project, the capacity was not known for all AHU and was roughly estimated where necessary from the ductwork area (A_{duct}) with a formula from the FD of RT 2012:

$$Q_{AHU,nom}\,(m^3/s) \approx \frac{A_{duct}(m^2)}{180\,(m^2/s.m^3)} \tag{3}$$

The flowrate before the sealing is deduced from the value after and from the leakage flowrates (Q_{leak}) measured before and after the sealing:

$$Q_{AHU,bef} = Q_{AHU,aft} + Q_{leak,bef} - Q_{leak,aft} \tag{4}$$

Fan efficiency
The fan efficiency varies with its flowrate. After sealing it was calculated with formula (1) when the flowrate and pressure where known. Otherwise, a default value of 0.4 was taken.
The fan efficiency before the sealing was estimated using a formula from the support Excel sheet of standard EN 16798-5-1:

$$\eta_{AHU,bef} \approx \sqrt{\frac{Q_{AHU,bef}}{Q_{AHU,aft}}} \times \eta_{AHU,aft} \tag{5}$$

3 RESULTS

3.1 Leakage reduction

All sealing projects allowed significant leakage reductions in percentages, as illustrated in Figure 2. On average the leakage flowrates were indeed reduced by 93.4%, with a minimum of 87.2% for the IE project and a maximum of 97.6% for the FR project. This is done in a rather short time with cumulated aerosol injection times for the whole projects ranging from about 1 and a half hour (for the CZ project with the smallest ductwork area) to 62 hours (for the FR project with a very high number of different AHU units).

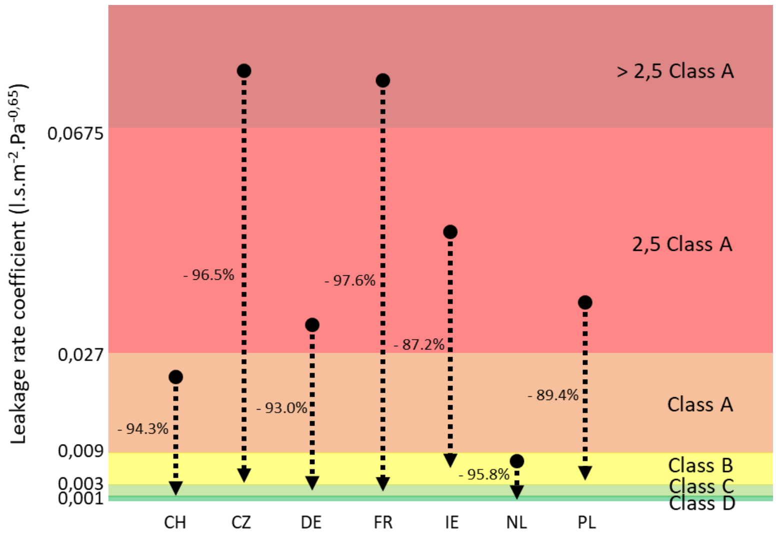

Figure 2 – Ductwork leakage rate decreases with the Aeroseal sealing process

3.2 Impact of ductwork leakage on energy savings

The fan power savings by ductwork sealing with the Aeroseal process are calculated for all projects according to the methodology described in paragraph 2.3 and presented in Table 4. A color code allows to distinguish the input data given directly by the survey respondents (in green), calculated (in orange), and corresponding to default values (in red).

The absolute fan power savings vary a lot depending on the sealing project (between 0.6 and 38 kW) due to the wide range of fan powers and initial leakage rates. In percentage of the initial total fan power, the savings represent from 1% (for NL project with the tightest initial ductwork) to 65% (for the FR project with the worst initial airtightness class).

The energy and cost savings are also calculated with the annual operating times and national electricity prices. As the annual operating time was not known by most respondents, and to ease sealing impact comparison between projects, these savings are also given assuming a fan operating full time. It was anyway the case for the IE project which has the highest savings (about 331 000 kWh/year corresponding to about 36 000 €/year) since it is the project with the largest ductwork, one of the highest initial fan power and leakage rates. On the other hand, the CZ project has the lowest savings as (about 5 000 kWh/year corresponding to about 900€/year) despite having the highest initial leakage coefficient, as it is the project with the smallest ductwork area and initially lower fan power.

The return-on-investment (ROI) times depend on various factors including the operating time, the leakage rates, the system size and the regional energy cost. In case of fans operating full time, the ROI times are estimated to be between 1 and 3 years for all projects except the NL one that had a ductwork already quite tight initially (class B).

One can note that in the current context of global increase in energy prices, the ROI time is expected to become even lower in the near future.

Table 4 – Calculation of fan power, energy and cost savings by ductwork sealing (green: values given; orange: values calculated; red: default values; black: results (calculated values for all sealing projects))

Project reference	**CH**	**CZ**	**DE1**	**FR**	**IE**	**NL**	**PL**
Total ductwork area (m²)	440	131	1202	844,24	2750	800	2210
Aerosol injection time (h)	36,1	1,4	21,1	61,5	49,6	2,1	35,9
Annual operating time of the fan (h/yr)	2190-8760	8760	2940	2405	8760	4800	2940
Electricity price (€/kWh)	0,204	0,180	0,228	0,110	0,110	0,178	0,150
Fan parameters **before** sealing							
Average AHU pressure before sealing (Pa)	444	310	846	1156		1008	592
Total AHU flowrate before sealing (10^3 m^3/h)	128,7	7,1	10,9	28,0	299,9	271,8	79,0
Average fan efficiency before sealing (-)	0,231	0,43	0,475	0,499		0,544	0,435
Total required fan electrical power BEFORE sealing (kW)	149,1	1,405	5,089	15,72	139,3	140,0	29,99
Fan parameters **after** sealing							
Average AHU pressure after sealing (Pa)	432	200	375	400	246	1000	400
Total AHU flowrate after sealing (10^3 m^3/h)	127,0	6,0	7,7	19,7	266,0	270,0	66,8
Average fan efficiency after sealing (-)	0,108	0,400	0,400	0,400	0.179	0,542	0,400
Total required fan electrical power AFTER sealing (kW)	145,2	0,8	2,0	5,4	101,5	138,4	18,5
Fan power savings							
Total saved fan power (kW)	3,9	0,57	3,08	10,3	37,8	1,6	11,5
Percentage of initial total fan power saved (-)	2,6%	41%	60%	65%	27%	1,1%	38%
Energy and cost savings							
Results for **real / estimated** operating time of the fan							
Total saved energy (10^3 kWh/yr)	25,4	5,0	9,0	24,7	331,0	7,7	33,7
Total cost savings (€/yr)	5 176	902	2 062	2 718	36 414	1 365	5 051
Results for fan operating **full time** (8760 h/year)							
Total saved energy (10^3 kWh/yr)	34,1	5,0	26,9	90,0	331,0	14,0	100,3
Total cost savings (€/yr)	6 956	902	6 144	9 901	36 414	2 490	15 049

As illustrated by Figure 3 and Figure 4, the percentage of initial fan power saved by ductwork sealing is not directly proportional to the initial leakage rate coefficient but rather on the initial percentage of leakage compared to the flowrate capacity. The linear regression shows indeed a good correlation between these two parameters, with a coefficient of determination R^2 of 0.987. As a result, it seems that for a given ductwork, the percentage of initial fan power that can be saved by an Aeroseal sealing process is about twice the percentage of leakage compared to the flowrate capacity:

$$\frac{(P_{AHU,bef} - P_{AHU,aft})}{P_{AHU,bef}} \approx 2 \times \frac{Q_{leak,bef}}{Q_{AHU,bef}} \tag{6}$$

The annual cost savings can therefore be roughly estimated as follows:

$$savings(€) \approx 2 \times P_{AHU,bef}(kW) \times \frac{Q_{leak,bef}}{Q_{AHU,bef}} \times t_{AHU,annual}(h) \times price_{elec}(€/kWh) \quad (7)$$

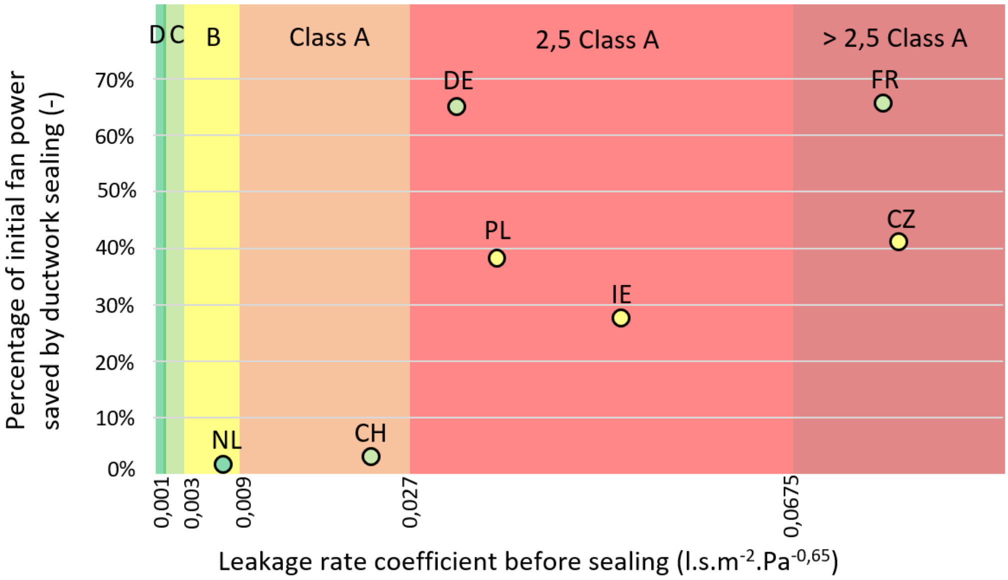

Figure 3 – Percentage of initial fan power saved by sealing the ductwork according to the leakage rate coefficient before the sealing (the points' color corresponds to the airtightness class after sealing)

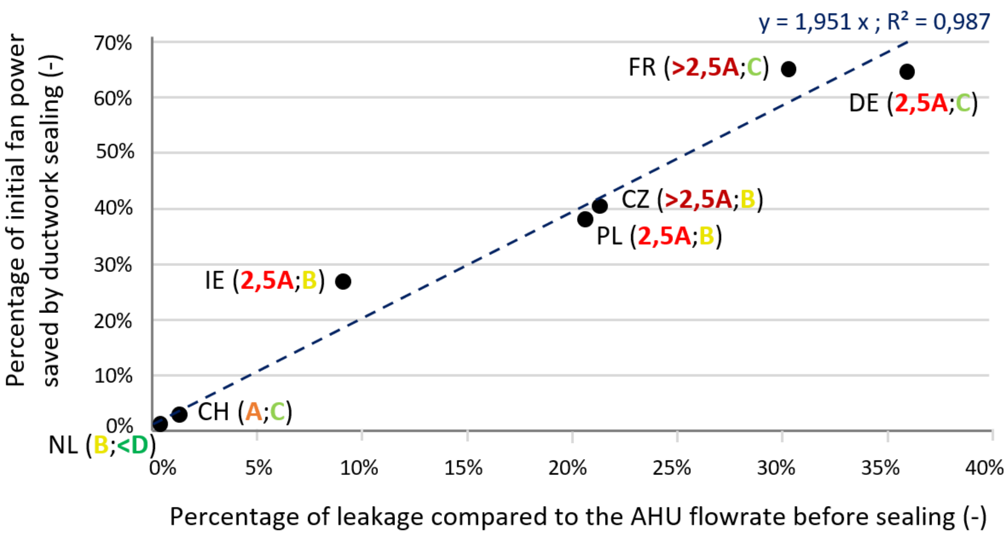

Figure 4 - Percentage of initial fan power saved by sealing the ductwork according to the initial percentage of leakage compared to the AHU flowrate (airtightness classes before and after the sealing given into the brackets)

3.3 On-site experience from the sealing operators

In complement to the technical details, feedback from the sealing operators (of 7 different companies and European countries) was also collected with the survey. They shared on-site experience regarding specific points, both for the selected projects and more generally for all ductwork sealings they performed.

The operators have observed on-site the following reasons behind poor ductwork airtightness:

- workmanship issues: poor workmanship; failed manual sealing; lack of air duct clamps; bad duct frame connection on ceiling for insulated ductworks; holes made by air tightness testing devices; flexible connections that opened up
- product issues: poor products quality; damaged components;

They reported the following feedback from customers after the ductwork sealings:

- decreased energy consumption;
- improved IAQ, in particular less leakage of toxic gasses
- odor disappearance
- reduced fan rotational speed

The estimated return on investment time for the selected projects was answered by only two operators to be respectively 1.5 and 2 years, which is in line with our calculations (see paragraph 3.2).

When questioned about the technical difficulties encountered during the Aeroseal sealing process, some operators mentioned issues:

- with the installed ductwork: installing sheet steel blocks to build up injection sections;
- with the equipment: leakage flowrate measurement problems below 1L/s; difficulties to carry the sealing machine (including compressor) to the upper floors; overheating of the sealing machine.

Despite obvious benefits of good ductwork airtightness, there is a low awareness on this topic in Europe. Aeroseal operators foresee the following trends regarding ductwork sealing in their country:

- in Ireland: more stringent criteria for pressure testing of systems results in more duct tightening work;
- in the Netherlands: extended life of ducting systems: no disassembly, but refurbishment;
- in Poland: phenomenon observed: testing only the main channels in selected sections, e.g. 30% of the system.

4 CONCLUSIONS

The Aeroseal process, already widely used worldwide, allows to seal ductworks from the inside after their installation. Technical details from 7 sealing projects performed in 2021 across Europe, on a large variety of buildings and ventilation systems, were collected through a survey and analyzed in this paper. It allows to conclude that the Aeroseal ductwork sealing process:

- is **efficient**: ductwork leakages reduced on average by 93% (from 87% up to 98%);
- is **rather fast**: the cumulated injection time for the whole project varies from about 1 to 60 hours depending on the ventilation system's size and complexity (usually less than 1h per injection point);
- **saves fan energy use and money**: from 5 000 to 331 000 kWh per year leading respectively to about 900 € and 36 000€ of savings each year, depending on the initial fan consumption and airtightness level;
- has a **low return-on-investment time**: estimated to be between 1 and 3 years for all projects but the NL one with an initially already rather tight ductwork (in case of fans operating full time).

Moreover, it is observed with a linear correlation that the percentage of initial fan power that can be saved by an Aeroseal sealing process is about twice the percentage of leakage compared to the flowrate capacity. This allows to roughly estimate of the savings before sealing the ductwork with formula (7):

$$savings(€) \approx 2 \times P_{AHU,bef}(kW) \times \frac{Q_{leak,bef}}{Q_{AHU,bef}} \times t_{AHU,annual}(h) \times price_{elec}(€/kWh)$$

These findings rely on only 7 sealing projects but a future study on a large number of projects is expected as more technical details will now be systematically filled in by the operators for each sealed ductwork.

On-site experience from the sealing operators were also collected giving information on:

- Possible ductwork airtightness issues encountered on-site in the various European countries: poor workmanship; failed manual sealing; lack of air duct clamps; holes made by air tightness testing devices and flexible connections that opened up.
- Possible technical sealing issues such as leakage flowrate measurement problems below 1L/s
- Feedback from costumers: decreased energy consumption; improved IAQ; less leakage of toxic gasses and odor disappearance
- Some trends regarding the market of ductwork sealing in their country, for example in Ireland more stringent criteria for pressure testing of systems result in more duct tightening work.

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