Airtightness measurements on calcium silicate ductwork

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ABSTRACT

Calcium Silicate fire protection boards can be used to construct fireproof ductwork for smoke extraction and/or HVAC services. In this paper, the airtightness of the duct system is evaluated.
Air leakage tests are performed on smaller duct samples as well as a larger duct network. Using identical smaller duct samples, the repeatability of the building methodology is evaluated. Multiple samples with varying parameters are built, allowing us to evaluate the impact of ductwork size, board thickness and building methodology. The main leakage points are identified and related to the building methodology. Measurements on the larger duct network result in a reliable air leakage value for in-situ built ductworks. On average, an ATC leakage class 4 is obtained, which is in line with recent literature values for classical metallic ductwork.

KEYWORDS

Ventilation, Ductwork, Airtightness, Fireproof, Smoke extraction

1 INTRODUCTION

Ghent University and N.V. Promat Research and Technology Centre are collaborating on the research project SEDS (Smoke Extraction Duct Systems). The airtightness of the ducts is evaluated to gain insight in the performance of the duct system. The ducts are constructed from Promat boards.

Air leakage tests are performed on smaller duct samples as well as a larger duct network. Achieving a good airtightness is an important factor to minimize fan energy use and reduce fan noise. As less ventilation air is lost during distribution, a smaller sized ventilator can be installed. When ventilation air is used for heating or cooling, avoiding air leakages in ventilation ductwork is important to minimize heating or cooling energy losses.

2 AIR LEAKAGE TESTS

2.1 Measurement procedure

Air leakage tests are performed according to EN 1507:2006. For positive pressure, the air leakage at a pressure differences of 400 – 800 – 1200 – 1600 – 2000 Pa was tested. For negative pressure, pressure differences of 150 – 300 – 450 – 600 – 750 Pa were used.

In EN 1507:2006, four airtightness classes are defined. The normative document EN 16798-3:2017 introduced a new classification system in which additional airtightness classes are defined and new class names are adopted. Both classification systems are listed in Table 1.

Table 1: Airtightness classes according to EN 1507:2006 and EN 16798-3:2017

Airtightness class		**Air leakage limit (fmax)**
old	**new**	**(m^3.s-1.m-2)**
	ATC 7	not classified
	ATC 6	$0.06750 \cdot p^{0.65} \cdot 10^{-3}$
A	ATC 5	$0.02700 \cdot p^{0.65} \cdot 10^{-3}$
B	ATC 4	$0.00900 \cdot p^{0.65} \cdot 10^{-3}$
C	ATC 3	$0.00300 \cdot p^{0.65} \cdot 10^{-3}$
D	ATC 2	$0.00100 \cdot p^{0.65} \cdot 10^{-3}$
	ATC 1	$0.00033 \cdot p^{0.65} \cdot 10^{-3}$

Air leakage measurements are performed using a Lindab LT600 / Wöhler DP700, which is specifically designed to measure the air leakage of ventilation ductwork. According to the technical data of the device, the pressure is measured with an accuracy of 0.5 Pa or 2.5% of the measurement. The air flow is measured with an accuracy of 0.0009 l/s or 5.0% of the measurement.

The measurement device is set to the desired pressure difference step. Measurements are conducted for 2 minutes, and an average value is calculated to achieve reliable measurements.

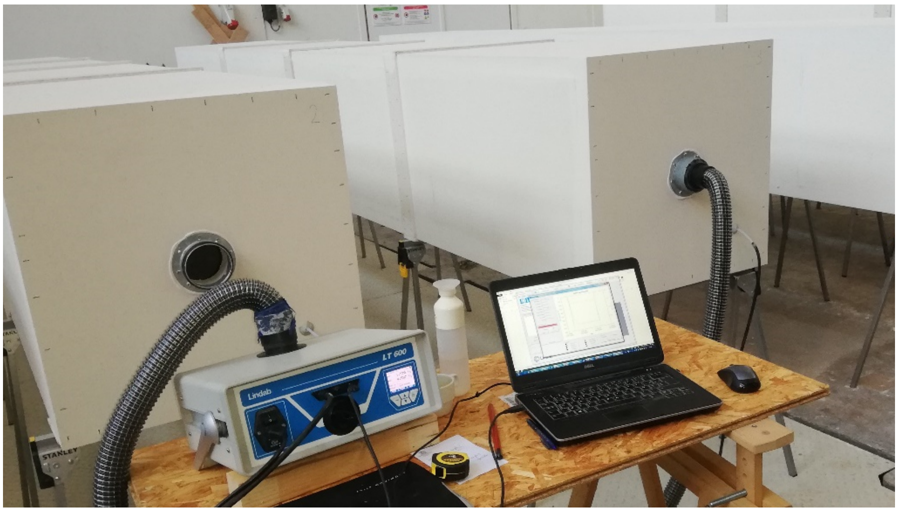

Figure 1: Measurement setup

Table 2: Test matrix

sample	**dimension**	**sample variation**	**contractor**	**construction**	**board type**
1	60x60x480	sample 1	contractor 1	Method A	L500 (50 mm)
2	60x60x480	sample 2	contractor 1	Method A	L500 (50 mm)
3	60x60x480	sample 3	contractor 1	Method A	L500 (50 mm)
4	60x60x480	sample 1	contractor 2	Method A	L500 (50 mm)
5	60x60x480	sample 1	contractor 3	Method A	L500 (50 mm)
6	100x125x360	sample 1	contractor 1	Method A	L500 (50 mm)
7	60x60x480	sample 1	contractor 1	Method B	L500 (50 mm)
8	60x60x480	sample 1	contractor 1	Method A	LS (35 mm)
9	2x Y-split	sample 1	contractor 1	Method A, 22.5°	L500 (50 mm)

2.2 Test specimen

Samples

Multiple small samples were built to check the influence of different properties of the ductwork. Table 2 shows the test matrix with the different characteristics of the samples.

Sample 1, 2 and 3 are identical samples to check the influence of workmanship reproducibility. All samples are built by the same contractor at the same time. The samples have internal dimensions of 60 x 60 cm, and consist of four segments of each 120 cm length. All samples, except sample 7, are built using 'Method A', where every duct segment is prepared individually, and connected to each other using Promatect H cover plates. The samples are built using the Promatect L500 board, with a thickness of 50 mm.

Sample 4 and 5 were intended to be built by different contractors to check the impact of workmanship repeatability. As the air leakage results of the sample 1, 2 and 3 showed a significant variation, it was concluded that the building of additional samples by a different contractor would not lead to valuable results, so this part of the research was not executed.

Sample 6 was built with dimensions of 100 x 125 x 360 and consists of three segments of 120 cm length. As we assume most air leakages are located at the joints, and not through the boards itself, we expect a higher air leakage for ducts with a larger joint to area ratio. As sample 6 has a lower joint to area ratio compared to sample 1, we expect a lower air leakage per area.

Sample 7 has the same dimensions as sample 1, but is built using 'Method B'. In this methodology, the duct is constructed in place, by alternately mounting top, side and bottom panels to each other in staggered positions. As such, the duct is not constructed with different duct segments and no cover plates are used.

Sample 8 is built using Promatect LS boards with a board thickness of 35 mm.

Sample 9 consists of two Y-split ducts which are connected. Different parts of the boards are cut to an 22.5° angle and glued together.

All samples are shown in Figure 2.

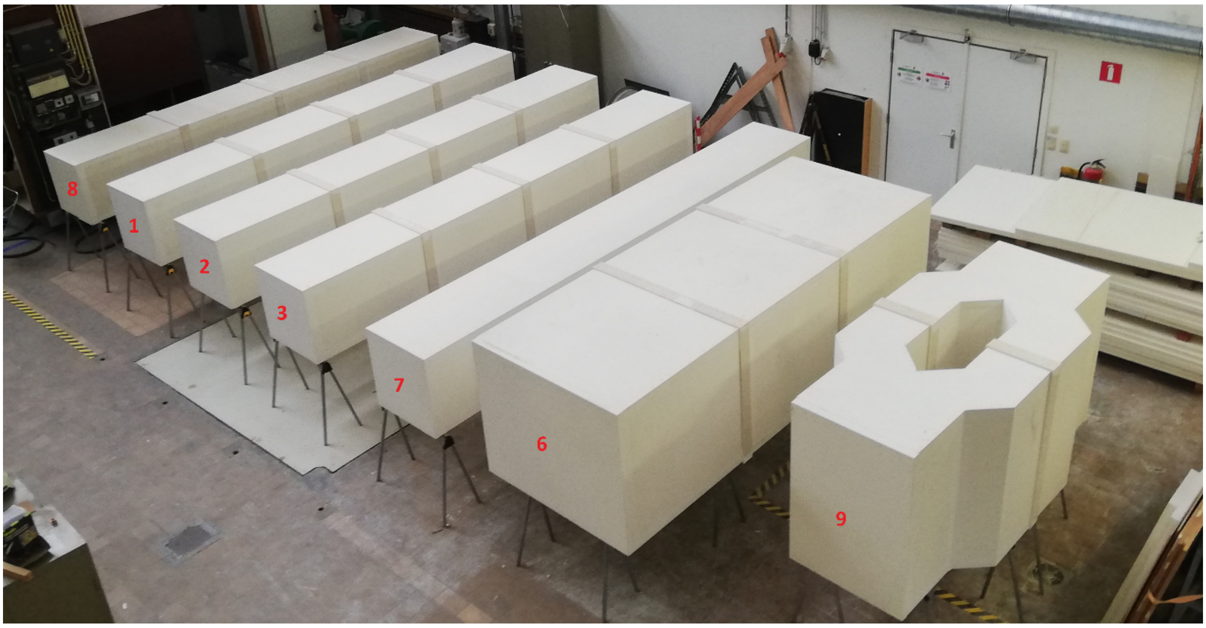

Figure 2: Samples in the lab

Network

A larger network is designed to measure the airtightness of a more realistic ventilation duct, as it could be installed in a building. The network consists of one main branch and six side branches. The main branch starts with interior dimensions of 50 x 100 cm, but the dimensions are gradually reduced to 30 x 60 cm. Side branch dimensions vary from 35 x 70 cm to 30 x 50 cm. Different components and connections are integrated such as horizontal reductions, vertical reductions, corners, segmented corners and level changes.

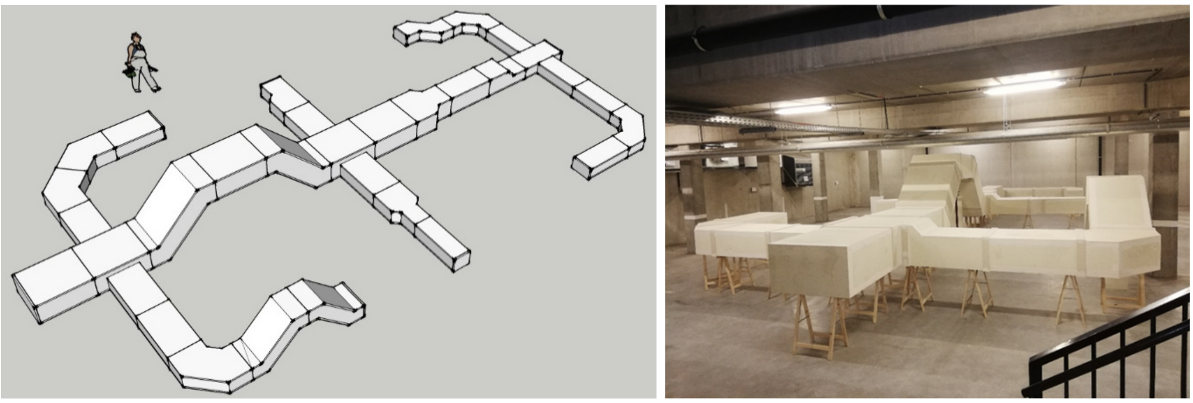

Figure 3: Duct network

2.3 Construction methodology

Method A

The following steps are performed to build a straight duct:

1. Boards are cut to the right dimensions using a circular saw with a conductor.
2. The longitudinal joints of the boards are wetted with water and glue (Promat Promacol K84) is applied and spread out with a brush.
3. The boards of the first compartment are glued together and stapled for additional strength.
4. Glue is applied at the end of the first compartment.
5. Promatect H cover strips are glued and stapled to the end of the first compartment
6. The first compartment is installed in place, glue is applied at the board edges
7. Glue is applied to the interior side of the Promatect H cover plates and spread out using a brush.
8. A second compartment is inserted in the cover plates of the first compartment.
9. Staples in the cover plates assure the connection between the compartments.
10. Interior joints are smoothed to remove excess glue.

Figure 4: Method A

Method B

In the second methodology ducts are built in place. The top and bottom boards are staggered 600 mm compared to the side boards, as illustrated in the following pictures. No Promatect H cover plates are used.

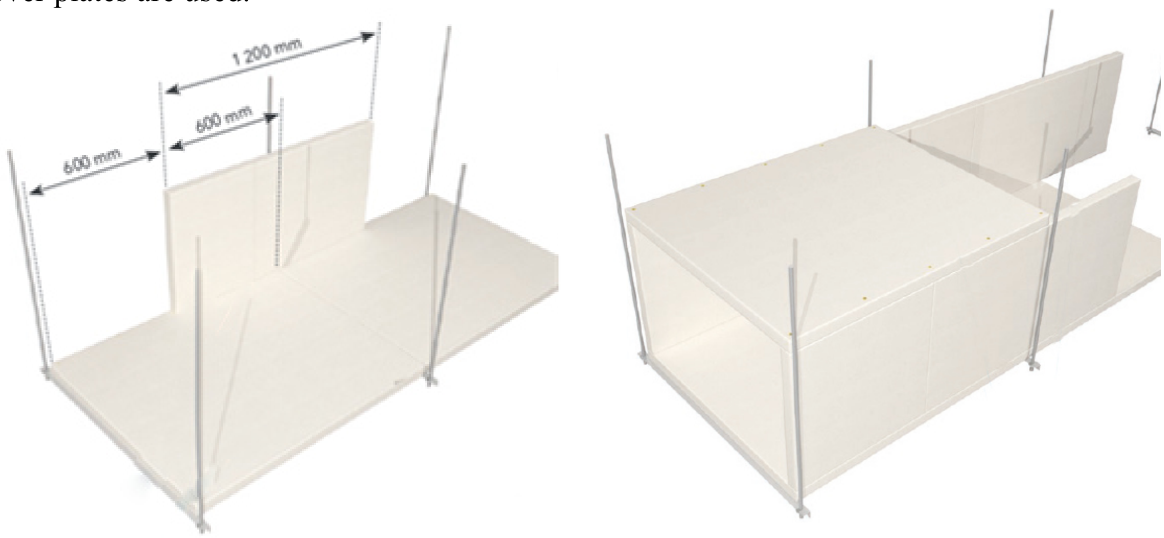

Figure 5: Method B

2.4 Measurement results

The measurement results for both positive and negative pressure are presented in Tables 3-4.

Table 3: Results positive pressure

sample	400 Pa [m³/s/m²]	800 Pa [m³/s/m²]	1200 Pa [m³/s/m²]	1600 Pa [m³/s/m²]	2000 Pa [m³/s/m²]	ATC	old class
1	0.00024	0.00039	0.00050	0.00058	0.00067	4	B
2	0.00017	0.00027	0.00036	0.00043	0.00050	4	B
3	0.00008	0.00013	0.00018	0.00022	0.00026	3	C
6	0.00103	0.00153	0.00193	0.00229	0.00261	5	A
7	0.00004	0.00007	0.00009	0.00012	0.00014	2	D
8	0.00007	0.00011	0.00015	0.00019	0.00022	3	C
9	0.00128	0.00187	0.00235	0.00274	0.00309	5	A
network	0.00027	0.00042	0.00055	0.00066	-	4	B

Table 4: Results negative pressure

sample	150 Pa [m³/s/m²]	300 Pa [m³/s/m²]	450 Pa [m³/s/m²]	600 Pa [m³/s/m²]	750 Pa [m³/s/m²]	ATC	old class
1	0.00012	0.00020	0.00027	0.00033	0.00038	4	B
2	0.00008	0.00014	0.00018	0.00023	0.00027	4	B
3	0.00004	0.00006	0.00008	0.00010	0.00013	3	C
6	0.00063	0.00095	0.00120	0.00142	0.00162	5	A
7	0.00002	0.00004	0.00005	0.00006	0.00007	2	D
8	0.00003	0.00005	0.00007	0.00009	0.00011	3	C
9	0.00070	0.00106	0.00134	0.00157	0.00179	5	A
network	0.00013	0.00022	0.00029	0.00035	0.00041	4	B

2.5 Typical leakage paths

During the air leakage tests, the ducts were checked to locate leakages. A few leakage paths were encountered resulting from small imperfections of cutting the boards and assembling them. The impact may be variable as shown by the performance measured in identical samples 1-3 to check the influence of workmanship reproducibility by the same installer. Imperfections might be avoided by more systematically using machine cutting tools.
Some attention points are noted at the cover plate connections and end plates, see Figure 6, where small leaks can be found. Imperfections of cutting can lead to joints that are filled with excessive glue, or in some cases the glue is forgotten, see Figure 7.
In sample 6 and 9 local problems were detected as a result of difficulties to reach some joints by installers, leading to a lower than expected airtightness class. Given the small scale of the samples such local defects have a relatively large influence.

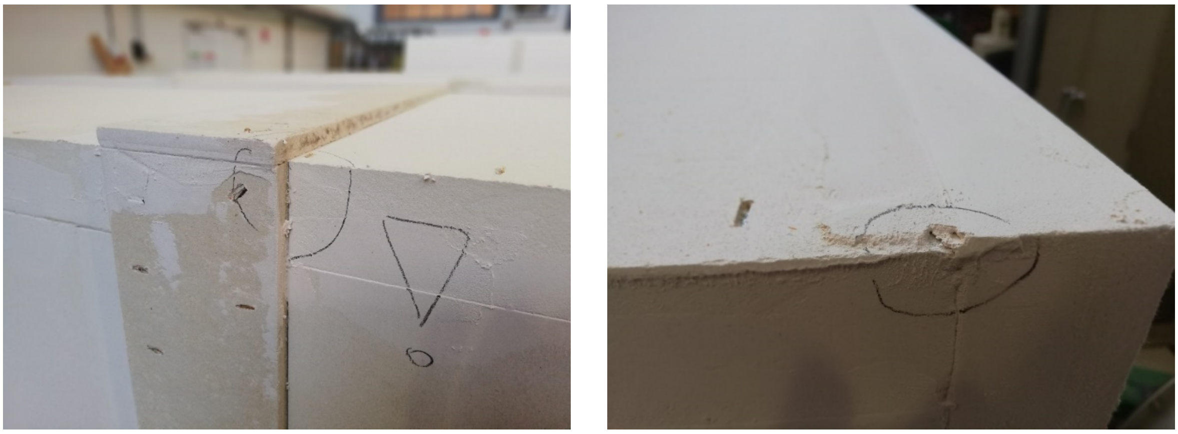

Figure 6: Leakage around cover plates and end plates

Figure 7: Leakage at board connections due to cutting imperfections

2.6 Additional tests

Sealing of end plates
Some leakages were observed at the joints and corners of end plates. As the samples consist of two end plates for a relatively short duct, the effect of these leakages might be relatively large compared to an average duct as it would be applied in a building.

To exclude the effect of leakages around the end plates, four samples were sealed airtight at the end plates. A paste was applied with a brush, which forms an airtight membrane when dry.
Ten weeks after the initial tests, new air leakage tests were performed. Surprisingly, most samples showed a higher air leakage with the sealed end plates. However, this did not result in a change in leakage class.
The leakage at the end plates cannot be quantified, but based on the airflow detected at the leakages under large positive pressure, this was relatively small compared to leakages around the cover plates.

Aeroseal
To reduce the air leakage in the large duct network, an aerosol-based sealing technique called Aeroseal (Mez 2018) was executed by the Belgian company Stokjes nv. This technique consists of sealing the ductwork by blowing in a polyvinyl acetate using a fan and a spray nozzle. During sealing a 400 Pa positive pressure was applied.
The sealing was executed after the execution of pressure loss testing, for which the results are not reported in this paper. As a result of the test procedure, the duct network was opened and resealed multiple times, and holes were drilled in the network to install pressure taps. As a result, the initial air leakage at the start of the test differs from the original air leakage as reported above (ATC 4).
At the applied pressure difference of 400 Pa, the initial leakage was 0.00032 $m^3/s/m^3$ which dropped to 0.00003 $m^3/s/m^3$ when the sealing procedure was stopped after 45 minutes. The ATC leakage class decreased from class 4 to class 2. According to the old classification system, class D is achieved starting from class B.
After the sealing procedure is stopped, the Aeroseal nozzle needs to be flushed by spraying pure water. Doing so, the fan keeps blowing air, containing the sprayed polyvinyl acetate in the ventilation duct. This way, the air leakage is further reduced, even though these results are not incorporated in the reported air leakages.

3 DISCUSSION

On average, ATC leakage class 4 is obtained for the construction method A (class B according to old classification). This is the case for the large duct network which is representative for a duct network built in a building. Most lab samples achieved class 4 as well, although two samples achieved class 3 and one sample achieved class 5. These results are in line with the measured performance of typical metal plate ductwork in recent French non-residential buildings, where the leakage class is found to be mostly class B or better (Leprince, 2020).
Sample 7, built according to construction method B, showed a significant lower air leakage and achieved leakage class 2. Although the result for method B only applies to a single sample, it suggests that it may be easier to achieve good workmanship quality using method B.
Sample 8, built with Promatect LS (35 mm) achieved leakage class 3, which is better than the average sample built with Promatect L500 (50 mm). This result also applies to a single sample only, but it suggests that boards with a lower thickness do not necessarily lead to lower airtightness performance.
Sample 1, 2 and 3, which have identical characteristics and were built at the same time by the same contractor, showed relatively large variations in air leakage. Sample 2 showed double the air leakage of sample 3, while sample 1 showed three times the air leakage of sample 3. Sample 1 and 2 achieved leakage class 4, while sample 3 has leakage class 3. It can be concluded that local leakages have a very high impact on the overall leakage of ductwork, and this is even more pronounced in tests on small samples. This however stresses the importance of workmanship quality.

Sample 6 showed a very large local imperfection causing a high leakage. As the boards are airtight, all leakage is expected to occur at the joints. As sample 6 had a lower joint to surface area, a lower leakage was expected, as this is expressed per unit of area. This assumption could not be demonstrated due to the local imperfection, but the analysis of leakage paths confirms that all leakages occur at the joints. As a result, ducts with larger dimensions and lower joint to surface ratios will have a relatively lower air leakage.

Sample 9 was built to check the air leakage around mitred joints, with the boards cut to an 22.5° angle. Some leakage was detected in wider joints which were filled, causing small cracks as a result of shrinking of the drying glue. This phenomenon was also observed in regular joints, where irregularities of the board dimensions resulted in wider joints which were filled with glue.

The initial air leakage tests were performed one week after construction. Air leakage tests performed 10 weeks later, showed a small increase in air leakage, even though the end plates were sealed to exclude leakages.

The large ductwork was further sealed using an aerosol-based sealing technique. As a result the leakage class improved from class 4 to class 2, showing that Promat ducts can be sealed to high performance airtightness classes, if necessary in combination with aerosol sealing.

4 REFERENCES

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