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AIRTIGHTNESS /AIRBORNE SOUND INSULATION STUDY IN ACCREDITED SOUND INSULATION FILITIES

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ABSTRACT

The potential relation between airtightness and acoustic performance of constructive solutions is not yet well known and described, although it has been widely proved that both phenomena have strong links.

The objective of this research is to provide additional experimental knowledge in this field of research, working in a controlled environment, thus reducing the number of variables affecting both acoustic performance and airtightness.

The test specimen is a hollow tongue and groove brick with mortar rendering wall. The acoustic performance of the original test specimen has already been tested in AUDIOTEC´s accredited sound transmission facilities. The research consists in gradually making holes on the test sample and evaluating airtightness and airborne sound insulation as the amount of "leaks" increases. Airtightness has been measured with a blower door test and the sound insulation has been measured using AUDIOTEC´s instruments and facilities.

Palabras Clave— airtightness and sound insulation, air leakage, indoor comfort, air infiltration

1. INTRODUCTION

There are four basic aspects related to the comfort inside a building: acoustic, lighting, hydrothermal, and air quality. Three of these aspects are undoubtedly affected by air leakages in the building: the acoustic, the hydrothermal and the air quality performance of the building.

The most common method for measuring the airtightness of buildings is the pressurization test, also called Blower Door test[1] This test is based on the air permeability law of flow through an orifice which is given by:

$$Q = C.\Delta p^{n} \tag{1}$$

Where Q is the measured air flow in m^3/h, Δp is the pressure difference measured between both sides of the envelope, C is the air leakage coefficient and *n* are related to the shape of the hole or kind of airflow (laminar or turbulent) and ranges between 0.5 to 1.

By using the blower door device Δp and Q are measured simultaneously under different pressure differences ranging from 4 Pa to 80 Pa. After that, by plotting both parameters, C and *n* can be calculated from the graph. Finally, the air leakage can be normalized using either the entire building volume, that is, the air change rate (n50), or by the envelope area, that is, the specific leakage rate (Q50).

Despite this method's popularity, it has some disadvantages that make it more complicated to implement in some situations. For instance, for testing airtightness in large buildings several fans shall be used and/or the building shall be divided into zones to be studied independently. Also, it is very sensitive to weather conditions such as wind speed and temperature difference, although there are ISO guidelines on how to avoid the temperature influence. Furthermore, it cannot detect the leak's location and only allows quantifying the airtightness of the envelope. To overcome this drawback, there are different methods which are usually combined with

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pressurization tests, such as IR thermography or fog generators.

One of the motivations of this study is to investigate alternative methods to locate and possibly quantify air leaks using acoustic measurements. Since acoustic measurements are performed under natural conditions, no external circumstance (forced pressure difference) would alter the configuration of the envelope elements, thus introducing less sources of error related to this. Besides, the pressurization tests do not include the airtightness of the door where the Blower Door is placed and for the acoustic tests the door would also remain unaltered.

In spite of the fact that it is very intuitive that there must be a relation between air infiltration/airtightness in buildings and the corresponding sound insulation, there are very few studies focused on the relation between both phenomena. Some researchers have aimed at identifying or even quantifying the air leakage size using different acoustic methods, but although it is agreed that both phenomena are related, the subject is not simple and further research is required.

Kölsch B[2] introduces an acoustic beamforming method for detecting leakage locations using microphone arrays using a white noise source with a frequency range of 1-25 kHz. It is observed that sufficiently large leaks are detected over the full frequency range whereas, as the size of the leak decreases, it becomes detectable only at higher frequencies. In this paper it is shown that the acoustic camera in the form of an acoustic beamforming method can be used for detecting and making a very rough estimation of leaks' sizes in the building envelope. Aiming at improving the detection and quantification of air leakages by acoustics measurements, Kölsch B [3] designed a perfectly sealed scale model transmission chamber where different material configurations and openings could be installed between the two spaces. For the acoustic measurements, the author used an ultrasonic dynamic sound source and ¼ inch microphones and the airflow was measured with a Venturi meter installed between and external blower and the chamber. The pressure difference between both chambers was also measured. With this set up, and based on 26 different wall conditions, it was concluded that an estimate of the magnitude of the airflow could be obtained, but again, further research was found necessary.

Other relevant research on this field was performed by Iordache et al, [4]– [6] both under laboratory and in field conditions. The first research on windows in field conditions [4] found, for specific sound pressure levels, differences between in and out and for a specific type of double wood-frame window, that an empirical equation can be used to estimate the air change rate at 4 Pa. The studies they performed under laboratory conditions [5] comparing eight different types of openings on nine different types of windows, concluded again that both phenomena are correlated and that, in certain cases, the infiltrated airflow could be determined as a function of the global weighted noise level difference ΔLA. Their last study [6] was performed in the same in situ scenario as the first one [4] but with single wood-frame windows and with some refurbishment in the inside of the room. In this case, a different empirical equation was found, which could be used to estimate the air change rate. The very good results found are limited to the specific cases of study, that is, double wood-frame and single wood-frame respectively.

It is thus clear that there is some kind of correlation between airtightness, airflow rate, estimated leakage area and the acoustic performance of a wall, but there are so many potential variables affecting this relation that much more theoretical and experimental research is required to enlighten this field of research. Some of the aspects to study can be related to the shape and size of the leaks, to the material where leaks are located, to the cumulative size or position of the leaks within the wall… And bearing in mind the limitations of acoustic measurements to one single façade or test wall which will be difficult to translate into a full building.

In this context, this study aims at further investigating the relationship between airtightness and airborne sound insulation under a controlled environment where only one variable (opening size) will be modified gradually. The objective of this study is to evaluate the airtightness and acoustic performance of a solid and sealed wall by making successive controlled holes under laboratory conditions.

This is considered the first of a series of experimental studies which will be programmed according to the results of this study.

2. METHODOLOGY

In order to study airtightness and acoustic performance under the same conditions, a sample wall has been mounted in an accredited airborne sound insulation laboratory, that is between two acoustically independent rooms. The sample wall has then been gradually drilled as explained hereinafter. Acoustic and airtightness tests have been performed according to the corresponding standards.

2.1. Laboratory, equipment, and sample description

All measurements were carried out at AUDIOTEC's airborne sound insulation accredited laboratory.

For the acoustic measurements, AUDIOTEC's equipment was used, and measurements were made according to ISO 10140-2 [7] using two different source positions in the source room and a rotating boom both in the source and receiving room. Besides the standardized descriptors found in the literature (R_w, C, C_{tr}, R_A), the A-weighted sound pressure level difference will be calculated according to equation (2)

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$$\Delta LA = L1A - L2A \qquad (2)$$

where L1A and L2A are the average A-weighted sound pressure level values in the source and receiving room respectively.

The airtightness tests have been carried out by the fan pressurization method, commonly known as Blower Door, according to ISO 9972: 2015 [8]. The equipment used was the Minneapolis Blower Door MiniFan (5 m³/h - 2,300 m³/h), with serial number DB-CE2336. Pressure gauge DG-1000, with serial number 12547, was also used.

In this case, the airtightness test was done by generating a controlled pressure difference by placing a fan (blower door) at the door opening in the receiving room and leaving the door open in the source room. Each airtightness test consists of a set of seven semi-automatic measurements at different overpressures, 12, 20, 28, 36, 44, 52, and 60 Pa. Before each airtightness test, the fan opening was temporarily covered to measure the pressure difference between the inside and outside, recording zero-flow pressure difference values.

The measured sample is a wall separating the source and receiving room and previously placed on a mobile sample holder. The wall dimensions are 2.8 m in height and 3.6 m in width. The wall is built with extra big format hollow bricks plastered with 15 mm mortar on one side and 5 mm mortar on the other side. The bricks are joined together by tongue and groove joint, and rows are joined by a cementitious adhesive. The sides and the lower part of the sample are finished with cement mortar, while the upper one is with plaster as shown in Figure.1.

Figure 1. The wall in its original state before drilling any holes.

2.2. Measurement protocol

Since, as previously mentioned, the purpose of this research is to study the potential correlation between airtightness and sound insulation, all the acoustic and airtightness measurements will be performed under the same conditions described in the previous section but with different wall openings (drilled holes or controlled holes) situations. Hereinafter the different phases of the experimental work are described:

PHASE 0 or REFERENCE PHASE: Acoustic and airtightness measurement of the original wall without any artificial opening.

PHASE 1: Twenty-four holes are drilled sequentially. The size of the holes is 14 mm diameter, corresponding to 1,54 cm^2. Airtightness and sound insulation are measured after each new hole is made. The order in which the holes are drilled is duly numbered. When the 24 holes are drilled the calculated opening area (OA) is 37 cm^2 (Figure 2).

PHASE 2: All the holes are covered by a previously selected “plastic tap” (see Figure 3) which can be opened and closed on demand. In order to avoid potential leaks around the “taps”, the joints were properly sealed with an ad hoc putty. The diameter of the controlled holes in these taps is 6,7 mm, corresponding to 0,35 cm^2 calculated opening area. Starting from the situation “all tabs closed”, the tabs are opened following the same sequence as in PHASE 1 and airtightness and sound insulation are measured each time a new tap is opened. When the 24 controlled openings are open, the equivalent opening area (OA) is 8,5 cm^2.

PHASES 3 and 4: Two different opening patterns were selected in order to study if the position and total surface of the openings could provide additional information.

The results of PHASES 3 and 4 are not shown in detail in this study but have been used to elaborate Table 2.

Figure 2. The 24 drilled holes for PHASE 1 measurements

Figure 3. The 24 holes covered by a plastic controlled tap

3. AIRTIGHTNESS MEASUREMENTS RESULTS

Figures 4 and 5 represent the permeability curves corresponding to the tests performed in PHASE 0 (no holes), PHASE 1 (with 4, 8, 16, 20 and 24 holes) and PHASE 2 (with 0, 4, 8, 16 20 and 24 taps open). The quantitative differences between both figures are due to the different size of the holes and the taps-controlled openings as mentioned in the previous section. In both figures the trend is as expected with increasing air leakage both as the pressure difference increases and as the number of holes (opening area) increases. The air leakage values are lower in PHASE 2 due to the smaller size of the taps-controlled openings.

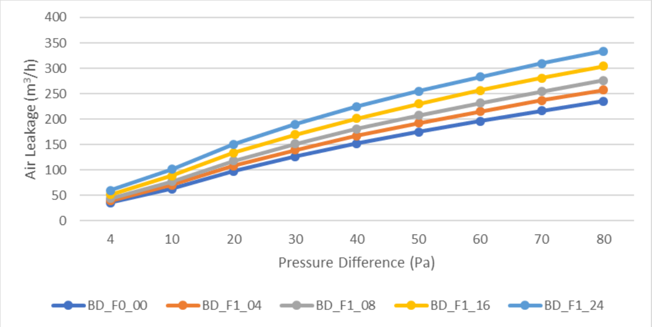

Figure 4. Permeability Curves for Phases 0 and 1

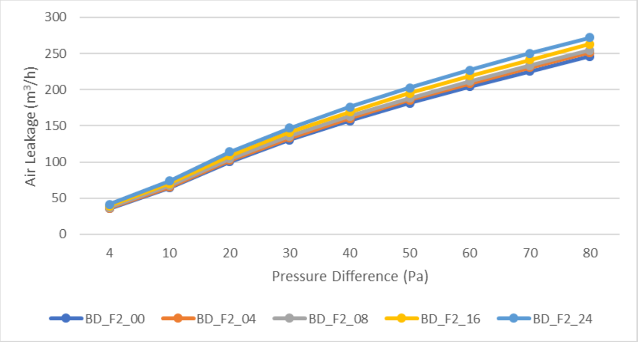

Figure 5. Permeability Curves for Phase 2

Figures 6 to 9 show the relation of Q50 (specific leakage rate under 50 Pa pressure difference) and n50 (air change rate under 50 Pa pressure difference) with the calculated opening area.

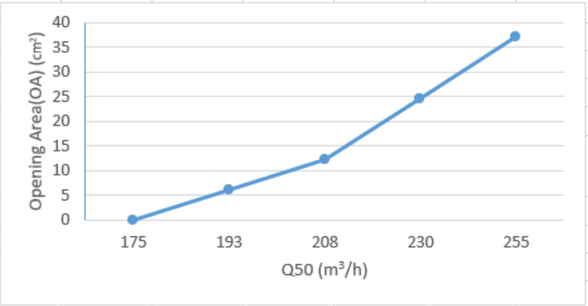

Figure 6. OAQ50 for 0, 4, 8 16, 20 and 24 drilled holes

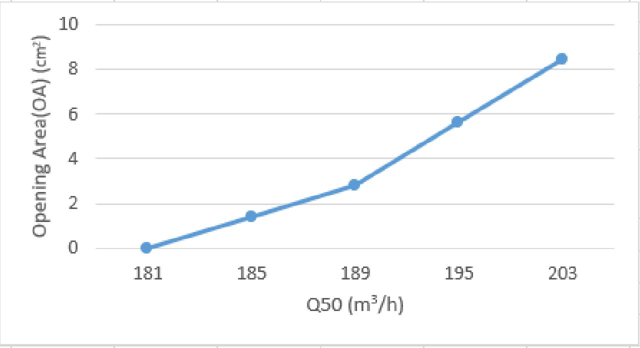

Figure 7. OA/Q50 for 0, 4, 8 16, 20 and 24 tap-controlled openings.

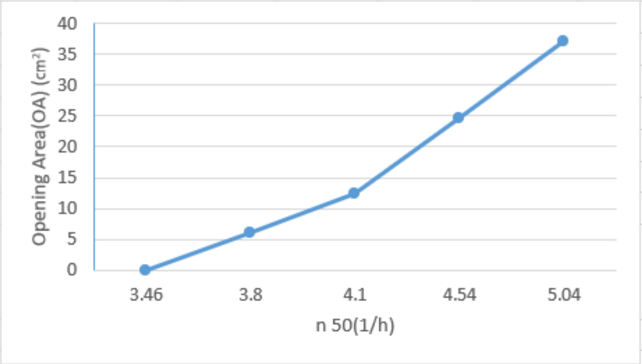

Figure 8. OA/n50 for 0, 4, 8 16, 20 and 24 drilled holes

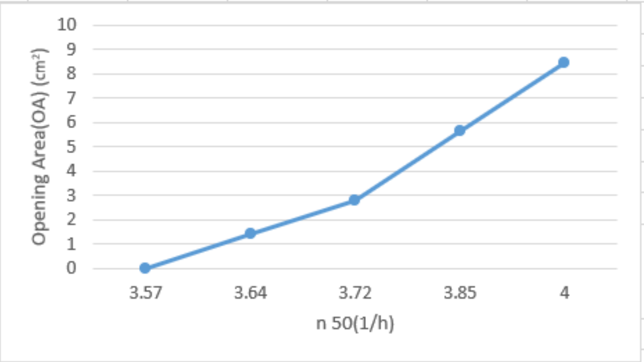

Figure 9. OA/n50 for 0, 4, 8 16, 20 and 24 tap-controlled openings.

For PHASE 1 (figures 6 and 8), when all the 24 holes are drilled, the air leakage value is Q50=255 m^3/h, which corresponds to n50 approximately equal to 5, that is all the air inside the room is changed 5 times per hour.

For PHASE 2 (figures 7 and 9), when all the 24 tap-controlled openings are open, the air leakage value is Q50=203 m^3/h.

It is interesting to point out that if the "completely sealed conditions" in both phases are compared (0 openings) the corresponding Q50 and n50 values are approximately similar (175 m^3/h and 3,46 h^{-1} for PHASE 1 and 181 m^3/h and 3,57 h^{-1} for PHASE 2). This small difference confirms the successful installation of the plastic taps as far as airtightness is concerned and the possibility of performing tests with the taps closed as if no drill had been performed. The small difference is possibly due to very small leaks around the taps.

Concerning the exponent “n” in equation 1, if all the PHASES are considered, it has been found to vary between 0,57 and 0,67. Figure 10 shows the “n” values obtained for PHASE 1 with increasing number of holes. In this case “n” decreases from 0,63 to 0,57 as the number of holes increases from 0 to 24.

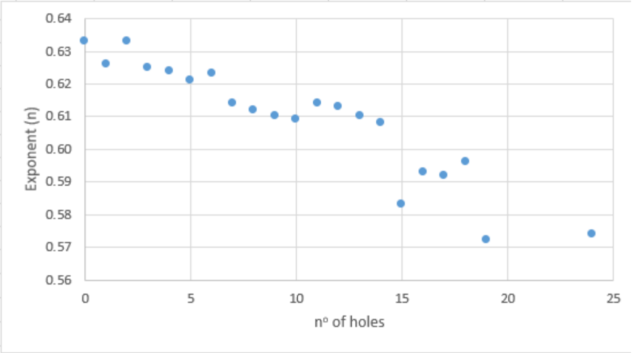

Figure 10. Variation of the Exponent n with the number of holes in PHASE 1.

4. ACOUSTIC MEASUREMENTS RESULTS

Prior to making the acoustic measurements it was expected to observe a decrease in airborne sound insulation as the number of openings was increased, just as an increase in airflow was clearly observed in the previous section.

Unfortunately, the acoustic experimental results have not shown the expected trend, as it is shown hereinafter.

As it can be seen in Tables 1 and 2, no significant difference has been found neither in R_w and other sound typical sound insulation descriptors nor in ΔLA, as the number of holes was increased. This was a surprising result because all acoustic descriptors remained almost invariable as the number of openings was increased. If a tendency was observed, it was in the opposite direction as expected (increasing R_w and ΔLA)! These results are puzzling and need a deeper analysis which will be undertaken in the future.

Table 1: Airborne sound insulation descriptors as a function of nº holes

nº holes	Rw	C	Ctr	RA	RA,tr
4	39	-1	-3	38,6	35,8
8	39	-1	-3	39	36,3
12	39	-1	-2	39,3	36,7
16	39	-1	-2	39,2	36,5
20	39	0	-2	39,5	36,9
24	39	0	-2	39,5	37

Table 2: ΔLA as a function of nº holes and OA

nº holes	OA (cm^2)	ΔL_A(dBA)
0	0	36.6
4	1.4	36.8
4	1.4	36.6
8	2.8	36.9
8	2.8	36.7
11	3.9	36.9
12	4.2	36.8
12	4.6	36.8
12	4.6	36.8
16	5.6	36.8
16	5.6	36.8
20	7.1	36.9
24	8.46	36.9

5. CONCLUSIONS AND FUTURE WORK

Airtightness and acoustic measurements have been performed in a controlled environment over a sample test wall. The sample wall has been gradually modified by making artificial leaks on the wall in the form of successive controlled openings (drills).

The airtightness measurements results are consistent to what is expected, resulting in higher Q50 and n50 values as the total leak area was increased (increased number of holes).

On the other hand, the acoustic results have turned out to be inconclusive, probably due to diverse factors which need to be analysed further in upcoming tests. Some of the future ideas to investigate are the following (but not limited to them):

- Can many very small-size individual leaks have a very different acoustic effect than one bigger leak with a similar equivalent leakage area?
- Can it be possible that although single number quantities do not present a significant variation, these variations would be observed in the spectral results?
- How does the shape of the leak affect acoustic performance of the wall?
- Could an acoustic camera have detected the very small leaks?
- Is there a limit in the leak size that can be properly detected using building acoustics frequency range?

The objective of the research is ambitious and requires much experimental and theoretical input in order to obtain a result which could be properly scaled and exported as an alternative “air leakage” location and quantification system.

6. AKNOWLEDGMENTS

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7. REFERENCES

[1] G. Raman, M. Prakash, R. C. Ramachandran, H. Patel, and K. Chelliah, “Remote Detection of Building Air Infiltration Using A Compact Microphone Array And Advanced Beamforming Methods.”

[2] B. Kölsch, A. Tiddens, J. Estevam Schmiedt, B. Schiricke, and B. Hoffschmidt, “Detection of Air Leakage in Building Envelopes Using Ultrasound Technology,” in *Symposium on Whole Building Air Leakage: Testing and Building Performance Impacts*, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International, 2019, pp. 160–183. doi: 10.1520/STP161520180022.

[3] B. Kolsch, I. Walker, W. Delp, B. Schiricke, and B. Hoffschmidt, “Comparison of Airflow and Acoustic Measurements for Evaluation of Building Air Leakage Paths in a Laboratory Test Apparatus,” 2022. [Online]. Available: https://escholarship.org/uc/item/6r69f93b

[4] V. Iordache and T. Catalina, “Acoustic approach for building air permeability estimation,” *Build Environ*, vol. 57, pp. 18–27, Nov. 2012, doi: 10.1016/j.buildenv.2012.04.008.

[5] V. Iordache and M. Zaharia, “Correlation Analysis of Air Transfer and Sound Wave Transfer,” *Romanian Journal of Acoustics and Vibration*, vol. 16, no. 1, pp. 84–90, 2019, [Online]. Available: http://rjav.sra.ro/index.php/rjav/article/view/124

[6] T. Catalina, V. Iordache, and F. Iordache, “Correlation between air and sound propagation to determine air permeability of buildings for single/double wood pane windows,” *Energy Build*, vol. 224, p. 110253, 2020, doi: 10.1016/j.enbuild.2020.110253.

[7] “ISO 10140-2:2010 - Acoustics — Laboratory measurement of sound insulation of building elements — Part 2: Measurement of airborne sound insulation.” Accessed: Sep. 25, 2023. [Online]. Available: https://www.iso.org/standard/42088.html

[8] ISO, “ISO 9972. Thermal performance of buildings. Determination of air permeability of buildings. Fan pressurization method (ISO 9972:2015).” 2015. [Online]. Available: https://www.iso.org/standard/55718.html

[9] “HORIZON – MSCA – 2021 – DN, No. 101072598 – Acoustic and Thermal Retrofit of Office Building Stock in EU.” Accessed: Sep. 26, 2023. [Online]. Available: https://actarebuild.eu/