TÉCNICO LISBOA

Extended Abstract

Compatibility between Ventilation and Sound Isolation

Sound Damping in Ventilation Openings

André Tomás Madruga

Abstract

In order to comply with the human requirements in the habitation, the need arises to guarantee the acoustic comfort and the purity of the interior air. These requirements are currently regulated in the Portuguese state, but not in a very precise way.

One way of introducing clean air into a compartment is through the provision of openings in the outer walls, which are considered to have zero noise reduction at the design stage. This simplification can be excessively conservative, making it necessary to increase the sound insulation on the walls to compensate for this low noise reduction.

The objective of this dissertation is to study the sound reduction phenomenon that occurs in these openings in order to develop a more accurate simplified forecasting method.

In order to reach this goal, 1440 case studies were analyzed, with variations of area and volume, as well as classes of frames and shapes of openings. These case studies were analyzed in terms of their sound insulation performance based on the predictive methods of EN 12354-1 and, where this was insufficient, the Sharp method, which were combined with the Wilson and Soroka and Gomperts models for the particular analysis of openings.

Finally, it was created an envelope for the difference between the results obtained through the method detailed in this dissertation and the traditional method, in order to propose corrections to apply to the traditional calculation method currently used in the design phase, and much more expeditious.

Key-words: Ventilation, Sound proofing, Openings

1 Introduction

1.1 Motivation and objectives

In order to comply with the functional requirements of buildings, mainly to meet the requirements of indoor air hygiene, watertightness and thermo-hygrometric comfort, there is a need to make openings on the walls of buildings, which negatively affect the capacity of the building to satisfy

the demands of acoustic comfort, which ensure that the building has sufficient insulation to external or internal sounds. Considering this incompatibility of constructive solutions, the need arises to evaluate the acoustic behavior of these openings in order to minimize costs and thus satisfy the requirements of economy.
The aim of this study is to study the effect of sound reduction on the ventilation openings by making the association between the size and shape of the aperture and the frequency of the incident sound wave. For this purpose, several case studies will be analyzed, corresponding to current situations in residential and service buildings, making an analysis of space, ventilation and later acoustic comfort requirements. In this analysis will be studied several constructive solutions of walls and openings.
Finally, corrections will be proposed to apply to the simplified calculation method, usually applied in design and more expeditious.

2 Functional Requirements and Regulation

2.1 Introduction

Building is to solve the problem posed by the satisfaction of the demands of the users in the performance of the functions for which the building is designed. This solution must be carried out on a scientific basis, specifying correctly the qualities for the building, and these must be validated by scientific processes.
The user of the building is the human being, animal, merchandise or equipment for which, or taking into account the necessity of whose intervention, the building is conceived. In this way, it is necessary to define the requirements according to each type of user and with each type of activity that each user will perform in the building.
Considering the scope of this dissertation, the only focus is the needs of the human being in housing, which have been enumerated in several lists by several authors, for example the human requirements in buildings proposed by D'Havé [1]. From these requirements, it is possible to extrapolate the functional requirements, considered as requirements that human requirements place on the use of all or part of the building. There are also several lists of functional requirements applicable to buildings, highlighting in this dissertation, the functional requirements proposed by R. Gomes [2].
These requirements can be grouped into three main groups: safety requirements (which guarantee life protection), habitability requirements (which guarantee the performance of various activities without detriment to health and a certain level of comfort) and economic requirements (which condition others, especially in quantifying the conservation of formulated quality levels). Of these three large groups will only address the requirements of habitability and economy.

2.2 Habitability requirements

The habitability requirements, considered in the present dissertation, in the context of climate and exposure to noise and air pollution in which the building is inserted, lead to the definition of specifications of in-service behavior in function of performance indicators. These specifications shall describe the requirement to be met, the mode of expression of the requirement and the form of verification or evaluation in service (or at the design stage).

2.3 Hygiene requirements

Hygiene requirements relate to the building's ability to ensure hygienic conditions in the course of the functions for which it was designed. These conditions translate into personal hygiene (drinking water supply, evacuation of waste water and rainwater and other debris), purity of the ambient air and possibility of disinfection and cleaning of each place that compose it. In the scope of this dissertation, the purity of the ambient air plays a fundamental role, since the removal of pollutants requires an exchange of polluted indoor air for clean outdoor air, usually through openings.

In fact, indoor air must be maintained in a condition satisfactory to the health of users, not containing excessive proportions of toxic gases, dust, harmful aerosols, etc., and it should be possible to rapidly evacuate them.

These requirements could be fulfilled through high renewal flows, but due to the existence of requirements for watertightness, hygrometric comfort and economy, the flow rates should be the minimums that guarantee conditions that are not harmful to health.

Through the law of energy conservation, Bernoulli's Theorem and the continuity equation we arrive at the equation (1), which allows to determine the flow through an opening.

$$Q = S\sqrt{\frac{2\Delta p}{\rho}}, \tag{1}$$

where:

Q: air flow under renovation ($m^3 \cdot s^{-1}$);

S: air passage opening area (m^2);

p: pressure (Pa);

ρ: fluid density (≈ 1,2 $kg \cdot m^{-3}$ for air around 15 to 20ºC).

2.4 Watertightness requirements

The watertightness requirements relate to the building's ability to block the entry of air, gases, water, dust, and other solid materials.

The presence of moisture in buildings seriously affects its functionality, reducing material durability and habitability conditions. Humidity can have several origins, and can be grouped in work humidity, capilar, hygroscopic, infiltration, condensation, and due to fortuitous causes.

2.5 Thermo-hygrometric comfort requirements

The requirements of thermo-hygrometric comfort ensure that there are no exaggerated heat exchanges between the interior of the building and the exterior and between compartments, while

ensuring comfort in summer and winter. That said, there are three forms of heat transmission: conduction, convection and radiation.
In order to regulate this requirement, the REH (Regulamento de Desempenho Energético dos Edifícios de Habitação) [3] imposes restrictions of thermal resistance, heat flow, air renewal, among others. A minimum value of 0.6 air renovations per hour is set in the cooling season, and in the case of a ventilation project according to standard NP1037-1 [4] or NP1037-2 the value to be used shall be that obtained through this standard.
Taking into account that NP1037-1 is more conditioning than the REH, his procedure will be adopted in this dissertation.

2.6 Acoustic comfort requirements

The requirements for acoustic comfort are intended to ensure that the building envelope or compartment separation elements provide sufficient sound insulation in such a way that the internal sound level does not exceed the permissible limits for carrying out the functions for which the building was designed.
Sound is the result of vibrations caused by pressure variations and is transmitted in the medium of solid or aerial propagation through mechanical waves in which the amplitude corresponds to the intensity and the frequency to the tone. In this way, pressure fields are obtained in the compartments, which can have several spatial distributions, with emphasis on the diffuse field, which presents the same sound intensity at all points of the interior space, or, on the outside, the free field , with sound intensity reducing as the distance to the sound source increases.
Since the sound pressure values range from 20 µPa (threshold of audibility) to 200 Pa (threshold of pain), with a variation between these two limits of 10^7, it is necessary to use a logarithmic scale such as the decibel scale (dB). On this scale, the sound pressure levels are given by

$$L_p = 10\log_{10}\frac{p^2}{p_{ref}^2}, \tag{2}$$

where:
L_p: sound pressure level (dB);
p: sound pressure (Pa);
p_{ref}: reference sound pressure (= $2\cdot10^{-5}$ Pa).

3 Case studies

3.1 Definition of case studies

The case studies were defined respecting the requirements of the RGEU (Regulamento Geral das Edificações Urbanas) [5], namely in the definition of the volumetric dimensions of the compartments. Length-width ratios between 1 and 2 were adopted, complying with the minimum stipulated dimensions. In relation to the height, were adopted 2,4 (minimum regulatory), 2,7 and 3,0 meters, since these are the most common values in our country.

Thus, taking into account the various compartment sizes and the various permeability classes, a total of 1440 case studies were created, which parameters are presented in Table 1.

Table 1: Parameters considered in the definition of the case studies.

	Length-width ratio	Length (m)	Width (m)	Height (m)	Permeability class of spans
Minimum value	1	2,1	2,1	2,4	1
Maximum value	2	10,8	7	3	4
Increment	0,1	n. a.	0,3 until 3 m; 0,5 in the remaining	0,3	1
Stop criterion	Maximum value	n. a.	Length ≥ 10 or Width ≥ 7	Maximum value	Maximum value

3.2 Calculation of ventilation flows

The mean value of (Hourly Air Renovation) RPH was calculated according to norm NP 1037-1, averaging the weighted averages of RPH values for each typology of buildings. These averages were obtained considering the minimum areas of the compartments and the dwellings stipulated in the RGEU and applying the values of RPH of 1 to the main compartments and 4 to the service compartments.

In order to validate these values, the spreadsheet provided by LNEC (Laboratório Nacional de Engenharia Civil) [6] was used to calculate hourly renewals under the energy certification procedure. In order to obtain results in this calculation sheet, it was assumed that the buildings were isolated, located in zone A of the national territory at an altitude of 90 m and a height of 17 m. It was also assumed that the glazing area corresponded to 10% of the useful area of the compartments, being the window frames of class 1.

Table 2 shows a summary of the calculation of the mean RPH values.

Table 2: Average hourly air renovation.

Typology	Bedrooms (m^2)	Living room (m^2)	Kitchen (m^2)	WC (m^2)	A_u (m^2)	$A_{principal}$ (m^2)	$A_{services}$ (m^2)	$RPH_{NP1037-1}$ (h^{-1})	RPH_{LNEC} (h^{-1})
T0	0,0	10,0	12,0	3,5	29,8	14,3	15,5	2,56	1,66
T1	10,5	10,0	10,0	3,5	44,2	30,7	13,5	1,92	1,59
T2	19,5	12,0	12,0	3,5	61,2	45,7	15,5	1,76	1,54
T3	28,5	12,0	14,0	4,5	77,4	58,9	18,5	1,72	1,51
T4	35,0	12,0	14,0	4,5	89,3	70,8	18,5	1,62	1,49
T5	44,0	16,0	14,0	6,0	103,7	83,7	20,0	1,58	1,48
T6	53,0	16,0	16,0	6,0	113,9	91,9	22,0	1,58	1,47
							Average:	1,82	1,53

The ventilation flow rate was then calculated by multiplying the volume of the compartments by the mean value of RPH. Because it was more conservative, the value obtained through standard NP1037-1 was used.

3.3 Ventilation openings

In the design of the ventilation openings, four permeability classes of the sills were considered, and the permeability factor values of 8, 4, 1 and 0,5 $m^3 \cdot h^{-1} \cdot m^{-2}$ were assigned to classes 1, 2, 3 and 4 respectively, for a pressure difference of 10 Pa.

The areas of the glazed spans were calculated assuming 10% of the compartment area with a minimum value of 1,08 m^2, according to the RGEU [5].

The flow rate due to the permeability of this through the spans was calculated by multiplying the areas of the spans by the permeability factors for the pressure difference considered.

The flow rate for the design of the openings was then estimated by discounting the through flow rate due to the permeability of the openings.

The area of the openings was calculated considering a contraction coefficient of 0.5 and an air density of 1,205 $kg \cdot m^{-3}$, using equation (1).

To obtain more realistic results, it was considered the possibility to perform only one opening per compartment, being this square, with the dimensions of the edges rounded to the centimeter or circular, with the radius rounded to 5 mm, as well as the possibility of executing multiple apertures per compartment, which could be rectangular, with 1,5 x 5,0 cm^2, or circular, with a radius of 10 mm.

3.4 Sound reduction of apertures

The sound reduction of the openings can be estimated based on the Wilson and Soroka equation [7]. According to the authors, this expression allows approximate results with an error of less than 1 dB.

According to Soroka, this formula is also valid for rectangular openings as long as the length / width ratio is less than 8.

Gomperts [8] defined particularities of the sound transmission of apertures defined by two equations for circular and rectangular apertures.

3.5 Sound reduction of the façade elements

The calculation of the sound reduction of the façade elements was carried out for three different constructive solutions, described in Figures 1 to 3 and for a double glass window of elevated acoustic performance 6-12-10+ mm, being the outer panel 10 mm thick and made of laminated glass. The weighted sound reduction of the glazing is 37 dB [9].

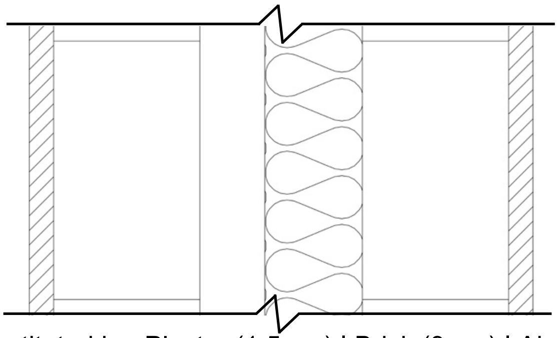

Figure 1: Double wall constituted by: Plaster (1,5 cm) | Brick (9 cm) | Air box (4 cm) | XPS (6 cm) | Brick (9 cm) | Plaster (1,5 cm).

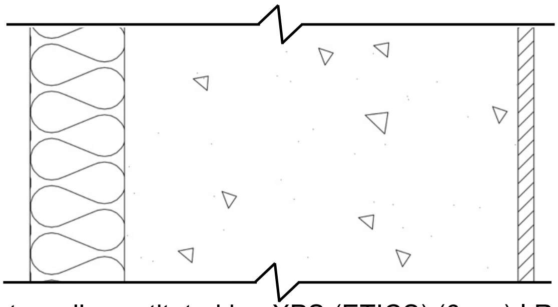

Figure 2: Reinforced concrete wall constituted by: XPS (ETICS) (6 cm) | Reinforced concrete (25 cm) | Plaster (1 cm).

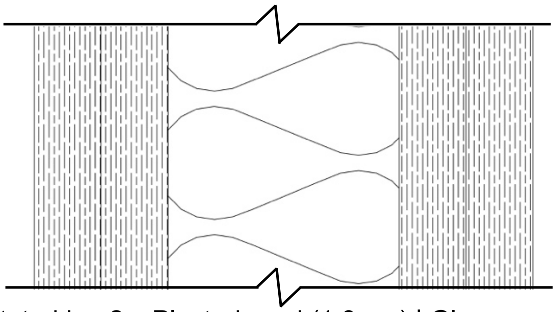

Figure 3: Wood Wall constituted by: 2 x Plasterboard (1,3 cm) | Glass wool (4,5 cm) | 2 x Plasterboard (1,3 cm).

The calculation of the sound reduction of solutions involving more than one panel (Figures 1 and 3) was performed according to Sharp's model [10] and [11], having the double wall a $R_{w,wall}$ = 54 dB and the wood wall a $R_{w,wal}$ = 55 dB.

The calculation of the sound reduction of solutions involving only one panel (Figure 2) was performed according to EN12354-1 [12], resulting in a $R_{w,wall}$ = 56 dB.

After determining the sound reduction by frequency of each constructive element (opaque zone, glazed window and ventilation aperture), the sound reduction value of the heterogeneous element was obtained. For this, it was considered that the aperture was located in the smaller wall, since this hypothesis is the most unfavorable in terms of sound insulation. In relation to glazed spans, it was considered that its area was 15% of the compartment area with a minimum of 1,08 m^2. This consideration is more unfavorable, since the sound reduction of the spans is less than the noise reduction of the opaque zone, so the greater the area of the voids, the less the noise reduction.

4 Analysis of the results of the case studies

4.1 Corrections to the simplified method

The conclusions of the previous sections allow to estimate, in a stage of the acoustic conditioning project in which natural ventilation openings are not known, their effect on the overall sound reduction as a function of the degree of permeability of the vents used.

$$R_w = 10\log_{10}\left(\frac{A_{wall} + A_{glazing} + A_{opening}}{A_{wall}\cdot 10^{-\frac{R_{w,wall}}{10}} + A_{glazing}\cdot 10^{-\frac{R_{w,glazing}}{10}} + A_{opening}}\right) - \Delta R_w \qquad (3)$$

$$A_{openning} = (see \text{ Table 3})$$

$$\Delta R_w = \begin{cases} \blacksquare\ one\ opening, regardless\ of\ its\ shape: \\ \quad 0{,}246\ln A - 1{,}4962 \\ \blacksquare\ mutiple\ circular\ openings: \\ \quad -0{,}067\ln A + 2{,}7587 \\ \blacksquare\ multiple\ retangular\ openings: \\ \quad -0{,}049\ln A - 0{,}7621 \end{cases}$$

Where A (m^2) is the ventilation opening area.

Table 3: Approximations obtained by linear regression for the ventilation opening area (cm^2) as a function of volume (m^3) ($A = aV + b$).

Permeability class	a	b	Correlation coeficient
4	3,4782	-0,1816	1
3	3,4474	-0,3632	1
2	3,2629	-1,4529	0,99997
1	3,0169	-2,9059	0,99986

5 Conclusions

In the present dissertation, the requirements of ventilation and acoustic comfort of buildings were analyzed, translated by quality rules related to the areas of ventilation openings in façades and to the sound insulation of the same façades.

Methods were presented to estimate the areas of ventilation opening and airborne insulation of façades and their constituent elements, such as glazing.

Methods of estimating sound insulation of ventilation openings were also presented, which were proposed by Gomperts, and Wilson and Soroka.

Based on these tools, a study of 1440 cases was developed, where the dimensions of the compartments, façade and glazing, as well as the type of wall and opening were varied.

For each type of opening, their contributions were analyzed for the overall sound insulation of the façades, and a comparison was made with a simplified calculation method. Such a comparison made it possible to obtain simplified method correction functions that can be used by acoustics designers to consider the loss of insulation introduced by ventilation openings, which are often overlooked in acoustics projects.

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