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Is Thermal Resistance Correlated With Sound Insulation?

Jacek Nurzyński*

Building Research Institute ITB, ul. Filtrowa 1, Warsaw 00-611, Poland

Abstract

An implementation of the sustainable development idea in the building sector stimulates search for materials and structures providing better heat insulation. Because the acoustical expectations and requirements also rise, a need for harmonization of both parameters increases. The article demonstrates differences between thermal and acoustical behavior of various building elements. The analysis of measurement results obtained for different structures demonstrates that finding a simple relationship between acoustical and thermal insulations is quite difficult. Tendencies observed in each case are rather opposite than parallel and materials or technical solutions that improve thermal resistance of a building partition often deteriorate its acoustic performance.

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Keywords: Building acoustics; sound insulation; thermal resistance; energy conservation

1. Introduction

As a consequence of current trends in energy efficiency in the buildings sector thermal issues quite often entirely dominate and overshadow the question of a building acoustic performance. Sound insulation is frequently perceived as a simple thermal resistance analogy and a belief that providing good thermal insulation is enough to ensure proper acoustic performance is fairly common, not only among architects. However the analysis of sound insulation results shows that establishing simple relationship between acoustical and thermal insulations is difficult. For traditional building partitions tendencies in thermal and acoustical behavior are rather opposite than parallel, technical measures and solutions that improve their thermal resistance often reduce the sound insulation. Massive homogeneous partitions need sufficient surface mass to obtain good acoustic performance when high porosity is

* Corresponding author. Tel.: +48-225-664-271; fax: +48-228-430-707.
E-mail address: j.nurzynski@itb.pl

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necessary for good thermal resistance. In the case of ceramic hollow bricks a pattern of hollows brings about different and conflicting results in terms of acoustic and heat insulation.

Sound reduction index of a partition is frequency dependent and influenced by different resonance effects which in no way affect thermal performance. For example lightweight sandwich panels, consisting of low density insulated core and two metal sheet facings, show strong coincidence in middle frequency bands. In effect the sound insulation expressed by single number indicator values practically does not depend on the panel thickness or even decreases when the thickness is increased. Such a behavior is typical for all kinds of sandwich panels regardless of their core; mineral wool, EPS or PUR/PIR foams show the same trends. Other building elements behave in another different way and possible relationships between thermal and acoustic properties are not the same for all of them. The article demonstrates specific problems for chosen building elements, key points when working on a rational compromise between acoustic and thermal performances.

Nomenclature

f_0	resonance frequency, Hz
m_1' , m_2'	surface mass of a basic wall (m_1') and a lining (m_2'), kg/m^2
s'	dynamic stiffness, MN/m^3
λ	thermal conductivity, W/(m·K)
ρ	density, kg/m^3
C, C_{tr}	spectrum adaptation terms, dB
R	thermal resistance, (m^2·K)/W
R_W	sound reduction index, dB
R_{A2}	$R_{A2} = R_W + C_{tr}$, dB
$\Delta R_{W,direct}$	direct difference of the weighted sound reduction indices R_W with and without lining, dB
$\Delta(R_W+C)_{,direct}$	direct difference of the weighted sound reduction indices (R_W+C) with and without lining, dB
$\Delta(R_W+C_{tr})_{,direct}$	direct difference of the weighted sound reduction indices (R_W+C_{tr}) with and without lining, dB

2. Traditional massive partitions

2.1. Homogeneous basic walls

Massive homogeneous walls made of concrete, ceramic bricks or calcium silicate blocks usually have good sound insulation and poor thermal resistance. Generally an increase of material density results in thermal performance deterioration, except for lightweight insulating materials as e.g. EPS [1]. The acoustical tendency is just opposite; an increase in surface mass brings about better sound insulation. The results of measurements reported in table 1 show that, if any correlation between sound insulation and thermal resistance exists, it is negative. Different parameters may be considered when searching for the correlation; material density or its porosity, thickness of the partition, mass per unit area, thermal resistance or thermal transmittance and different acoustical single number indicators. In the case of external homogeneous walls the most appropriate for an analysis are thermal resistance R and the sound reduction index R_{A2}, both related in some way to the material density.

Table 1. Thermal and acoustical performances of 240mm homogenous partitions made of materials with different density.

Partition structure	ρ (*kg/m³*)	m₁' (*kg/m²*)	λ (*W/(m·K)*)	R ((*m²·K)/W*)	R_A2 (*dB*)
Concrete	2400	576	2,00	0,12	58
Calcium silicate brick	1600	384	0,90	0,27	51
Lightweight concrete (keramzite)	760	183	0,39	0,62	44
Cellular concrete (500)	500	120	0,18	1,33	43

There are different models for evaluation of thermal conductivity for porous materials [2, 3]. Previous findings based on measurements taken for various building elements show that some exponential dependency between thermal conductivity and material density or porosity may be derived [1, 4]. Thermal conductivity depends on a particular phase and component configuration, bounding matrix, aggregate, pore structure, moisture, etc, so the dependencies are not general, but only refer to a specific type of building materials. On the other hand an empirical mass law expresses the relationship between sound insulation of a homogenous partition and its surface mass, doubling the mass cause an increase of R_{A2} index by about 8,6dB. However the precision of a general mass law is limited, real measured values may be different than calculated by -4dB till +8dB [5]. To increase the precision various local mass laws have been developed for specific local materials.

As the sound reduction index is frequency dependent searching for any general rules for estimation of single number indicators is tricky even for homogeneous structures. For relatively thin walls a weighted sound reduction index is affected by coincidence frequency, when thickness resonance influences behavior of thick partitions. Correlation between thermal resistance and sound insulation is possible for monolithic, homogenous and relatively thick walls of similar structure [6, 7]. But thermal transmittance of such walls is so high that if they are used for an exterior shell they need additional insulation. Massive walls with additional lining behave in acoustic terms different than bare homogeneous structures. Therefore any correlation derived for heavy bare walls is of little practical use, when for multilayer and more complex partitions finding any correlation appears unlikely.

2.2. Ceramic hollow bricks

In the case of ceramic hollow bricks the situation is even more complex. Beside surface mass, wall thickness and material density also the holes pattern plays a pivotal role in working on good sound or thermal insulation. External wall is usually made of elements with rectangular or undulated hollows arranged parallel to the wall surface, which is profitable for thermal resistance. The values of thermal conductivity coefficient usually lie within a range of 0,15 W/(m· K) till 0,20 W/(m· K). However the parallel arrangement of hollows brings about resonance effects and causes significant decrease of sound insulation at middle and high frequencies [8]. This may be suppressed by rearranging the holes by forming them perpendicular to the wall surface. An example is show in a Fig. 1a. Three different walls with different thickness and different hollow pattern were tested. The thickest wall (380mm) with undulated hollows has the lowest value of the sound reduction index; R_{A2}=43dB. The best result was obtained for the thinnest one (250mm) with holes perpendicular to the wall surface, R_{A2}=49dB. That solution is profitable in terms of acoustic but barely acceptable from an energy conservation view point due to thermal bridges created inside the block. The recommendations on hollow patterns seem to be different in terms of acoustic and thermal insulation; finding one solution satisfying both is still a challenge.

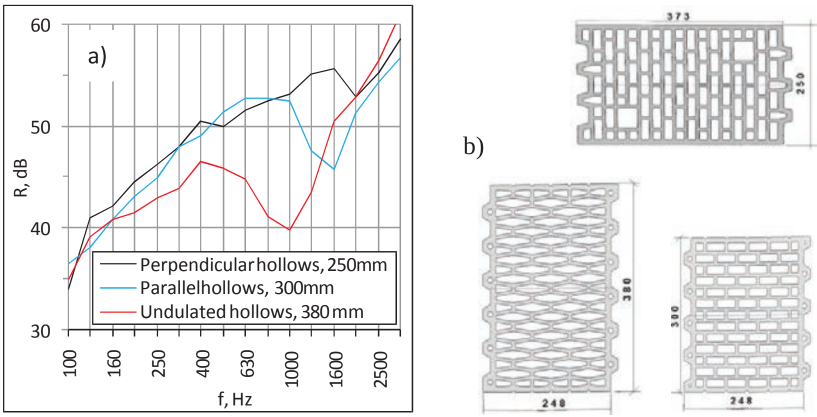

Fig. 1. (a) Sound insulation of walls made of ceramic hollow bricks, laboratory measurements results [8]; (b) Hollows pattern; undulated, parallel and perpendicular to the wall surface.

2.3. External thermal insulation composite systems ETICS

Thermal insulation materials, as mineral wool or expanded polystyrene, have poor sound insulation and shouldn't be used alone as a separating acoustic barrier. Instead, mineral wool is profitable when applied as absorption inside the cavities of lightweight frame partitions. EPS is not appropriate for this purpose due to its poor sound absorption. Both, mineral wool and expanded polystyrene are also used for additional thermal insulation of an external wall. Lightweight composite systems (ETICS) are commonly used for new buildings as well as for thermo-retrofitting of traditional old buildings and block of flats from the Sixties and Seventies. ETICS usually brings about significant reduction of sound insulation in a certain frequency range due to resonance. The sound reduction improvement index of a lining should be tested and declared by the manufacturer. The word *improvement* is misleading as for ETICS the values are usually negative [9]. According to an empirical rule developed from previous experiences the value of ΔR_W depends mostly on a resonance frequency; the lower resonance, the better acoustical performance of a wall. Mass-spring-mass resonance may be calculated:

$$f_0 = 160\sqrt{s'\left(\frac{1}{m_1'} + \frac{1}{m_2'}\right)} \tag{1}$$

Then the resonance frequency of ETICS depends on the surface mass of a rendering and the dynamic stiffness of a resilient insulating layer. The mass of rendering is more or less the same so in practice the resonance may be shifted down by reducing dynamic stiffness of the insulation. An example that demonstrates the effect is shown in Fig. 2. Three different ETICSs were tested when applied on the same basic wall made of ceramic hollow bricks, 380 mm thick, one side plastered. Linings were made of expanded polystyrene (EPS), lamella-type mineral wool (LMW), and special soft mineral wool (MW), each of them 100mm thick. Soft mineral wool was used to move the resonance frequency down as much as possible; it was fastened directly to the wall without any studs or supporting frame. In each case application of ETICS causes significant reduction of sound insulation around resonance frequency and considerable improvement at middle and high frequencies (Fig. 2a). The use of soft mineral wool (MW) results in the resonance lowering and substantial extension of the frequency range when the sound insulation improves (Fig. 2a). Single number quantities are reported in table 2. When ΔR_W is considered the tendency observed is obvious; profitable are solutions with low resonance frequency and the MW lining is very promising. However, when $\Delta(R_W+C_{tr})$ index is taken into account, which is the basic criterion for an exterior shell assessment, the tendencies and conclusions are not so clear.

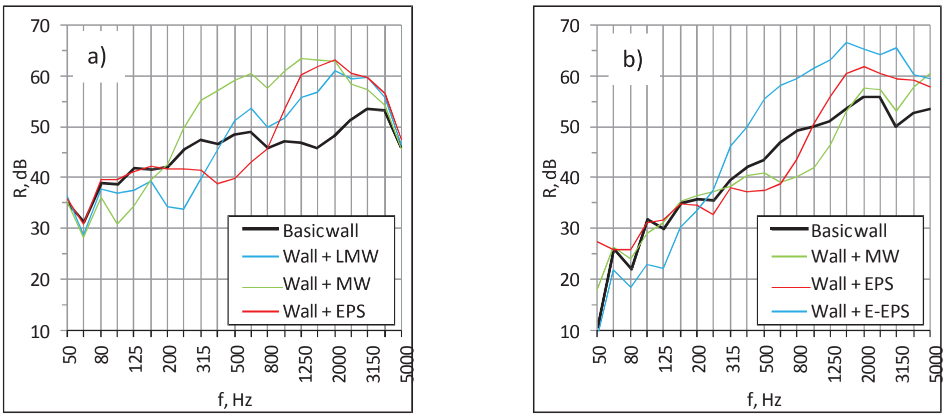

Fig. 2. (a) Sound insulation of a basic wall made of hollow ceramic bricks, 380mm, and the wall with different ETICS; (b) Sound insulation of a basic wall made of cellular concrete, 250mm, and the wall with different ETICS.

The $\Delta(R_W + C_{tr})$ index is strongly influenced by low frequency behavior so empirical rules developed previously for ΔR_W do not apply. The effect of inappropriately low resonance may be the opposite of what is expected. This is seen in Fig. 2b. Three different ETICS of another type were tested when applied on a basic wall made of cellular concrete. The wall was 250 mm thick, one side plastered. Linings were made of mineral wool (MW100 mm), expanded polystyrene (EPS100 mm) and elastic expanded polystyrene (E-EPS150 mm), which is basically intended for reducing impact noise of floating floor and in general is not used for thermal linings [10]. In the case it was applied to lower the resonance frequency as much as possible. The values of respective single number indicators obtained for expanded polystyrene (EPS) and mineral wool (MW) were nearly the same; -2dB till -4dB. The use of elastic expanded polystyrene (E-EPS) gives the best value of R_W index, $\Delta R_{W,direct}$ = 0dB, but badly affects R_{A2}, $\Delta(R_w+C_{tr})_{,direct}$= -5dB which is the worst result of the three ETICSs tested.

Table 2. Sound reduction improvement of an ETICS, measurements results. Basic wall made of ceramic hollow bricks.

Lining	f_0 (*Hz*)	$\Delta R_{W,direct}$ (*dB*)	$\Delta(R_W+C)_{,direct}$ (*dB*)	$\Delta(R_W+C_{tr})_{,direct}$ (*dB*)
Expanded polystyrene, EPS	400	0	-1	-1
Lamella mineral wool, LMW	250	2	0	-2
Soft mineral wool, MW	100	8	6	2

3. Windows and curtain walls

Windows are usually weak points in a building shell in terms of sound insulation as well as energy conservation. Acoustical performance of a window depends mostly on the glazing. A thermal insulating double glass unit is a resonant system. The sound insulation of a symmetrical unit, consisting of two panes having the same thickness, at specific low frequencies is lower than obtained by its single pane. Also the value of R_{A2} index is usually lower for a complete symmetrical unit than for single panes that it consists of. High sound insulation of a unit maybe achieved by using different combination of panes, laminated glass, enlarged distances between panels, gas filling etc. However at some point the window frame starts contributing so greatly to the total sound insulation that the effect caused by glazing improvement is restricted, particularly when aluminum windows and curtain walls are considered. As an example the results of laboratory measurements taken for aluminum curtain wall equipped with highly insulating glass are shown in a Fig. 3. Two cases were investigated; the wall was supported with a frame made of original profiles, then the same frame equipped with the profiles filled with strips of plasterboard, the same glazing was used in both cases. The application of profile fillers significantly improved the total sound insulation of the wall, R_{A2} index increased by 3dB. The frame used in the study constitutes only about 10% of the total wall area, in practice in windows or walls with operable parts the contribution of a frame is bigger and the acoustical effect is stronger. But from thermal view point this method of sound insulation improvement is unacceptable.

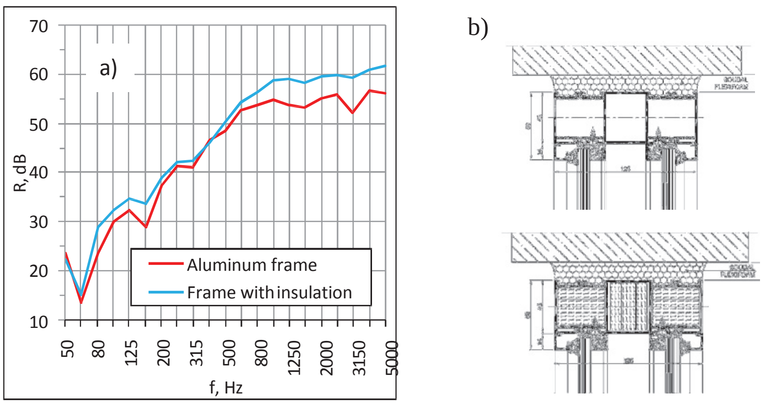

Fig. 3. (a) Sound reduction index of an aluminum curtain wall, an effect of the frame insulation; (b) The frame profiles with and without a filler.

4. Internal partitions, acoustical and thermal requirements

A highly insulating exterior shell is of key importance to an energy-efficient building but also internal partitions plays a role in the whole heat protection system. In Poland thermal requirements for floors between garages and dwellings and also walls between staircases and rooms are already in force. Besides, regulations on required thermal resistance for separating partitions between flats are being considered to prevent energy flow when a certain dwelling is temporary not occupied, possible energy gains have been estimated. However the problem is that traditional internal massive walls are not good enough in terms of heat resistance, when ceramic hollow blocks or autoclaved aerated concrete etc. are not satisfying in terms of sound insulation. Acoustic requirements for internal separating partitions are usually much higher than for external walls. Initially the attention was turned towards possible adaptation of lightweight composite insulation systems, but the use of a lining which significantly reduces sound insulation is unacceptable for internal partitions. In that case linings that improve both thermal and sound insulation should be precisely selected, as even simple cladding made of lamella-type mineral wool alone, used for floor slabs between a garage and flats, reduces sound insulation in the resonance area at low frequencies [9].

5. Conclusions

As there is no analogy between thermal and acoustical behavior, developing any general dependency relating both parameters is not possible and deducing sound insulation from thermal resistance is very tricky. Any correlation may be derived for well defined groups of homogeneous solid partitions with similar structure, but such dependencies are of little practical use.

Different building materials, structural arrangements and technical solutions may bring about the opposite effects in terms of acoustics and heat resistance. Then a holistic approach is necessary to provide a comfortable, tailor made buildings meeting all requirements and expectations. It also refers to a ventilation system as its various elements (slot ventilators, cracks, air inlet devices etc.) greatly affect both thermal and acoustical performance [11]. Consequently all requirements and recommendations within the area of building physics should be coordinated to avoid incoherence making different requirements conflicting and hardly applicable in practice.

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