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Possible correlation between acoustic and thermal performances of building structures

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Most European standards required today high level performances for both sound and thermal insulation of building structures, according to Directive EEC 89/106. Building structures have different acoustic and thermal physical properties, with global performance parameters not directly correlated each others. Due to lot of technical solution for solving separately both problem, many technicians required simple rules in order to guaranties good performances.
In this work are presented some results of possible correlation between sound transmission and thermal performances values depending on simple physical properties like density or surface mass of different building components.

1 Introduction

The improvement of thermal insulation performances of buildings structures is one of the objectives to reach for a more correct use of the energy, following the acknowledge of the Directive 2002/91/CE regarding the energetic efficiency in buildings. In this direction the "correct" choice of building components is become very difficult now being tied up to the satisfaction of different performance parameters, relative not only to the energetic saving aspects and the protection against the noise from internal and external sources but also to the structural aspects, the internal illumination, the ventilation. In order to a correct planning the *conditio sine qua non* is to have an ample knowledge of the physical properties and the performance parameters of the building and the building components in order to respect limits of national standards. The aim of this study is the comparison of the thermal and acoustics performances of 40 vertical walls used in Italian constructions.

2 Sound insulation

The acoustic performance of a building structure excited by an airborne sound source can be defined by different parameters all depending on the value of the sound transmission factor *t*, ratio of the sound power transmitted to the sound power incident the partition. The adopted national parameter is the sound reduction index R:

$$R = 10 \cdot log \cdot \left(\frac{1}{t}\right) = 10 \cdot log \cdot \left(\frac{W_i}{W_t}\right) \quad [dB] \qquad (1)$$

The value of R depend on geometric and physics properties of the wall and varies with the frequency and the direction of the incident sound. Nevertheless a single number index (the weighted sound reduction Rw) is usually evaluated for a global performances of the partition where the frequency values are weighted by a reference curve according to EN ISO 717-1 standard.

Acoustic performances of a partition can be different from laboratory and "in situ" measurements, due to airborne and structural flanking transmission. To compare acoustic and thermal performances we refers to laboratory data in order to avoid any external influence not depending on material properties.

3 Thermal insulation

Thermal performances of a building component can be evaluated by different parameters describing the steady-state behaviour, or the dynamic state, [2]. In steady-state condition, the parameter that better describes the thermal behavior is the thermal resistance (or the thermal transmittance) calculated according to ISO 6946 [1]. In dynamic state condition there are instead many parameters that, besides account of the characteristic trasmissives of the component, they also consider the thermal inertia through the property of storage and loss of heat flow. The ISO 13786/2007 standard [2] defines an admittance calculation method for dynamic thermal properties of a building component with the hypothesis of external periodic sinusoidal perturbations of the temperature and the heat flow.

Dynamic heat balance relationships can be defined by a simple matricial equation where, for a single layer wall, is expressed the following:

$$\begin{bmatrix} \hat{\vartheta}_e \\ \hat{q}_e \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \cdot \begin{bmatrix} \hat{\vartheta}_i \\ \hat{q}_i \end{bmatrix} \qquad (2)$$

where variations of temperature and heat flow, related to stationary values, are represented by the complex amplitude, respectively $\hat{\vartheta}$ and $\hat{q}$. If some boundary conditions are defined, as for example constant temperature of the inside environment, the element Z_{22} of the matrix represents the ratio between the two variations of external and inside heat flow:

$$Z_{22} = \left.\frac{\hat{q}_e}{\hat{q}_i}\right|_{\hat{\vartheta}_i=0} \qquad (3)$$

In analogy to the sound transmission factor *t* , the Z_{22} term can be considered the expression of the ratio among the thermal energy transmitted to the energy thermal incident. Further these considerations, among the parameters that represent the dynamic behaviour of the wall, we can define also the "thermal lag" t_Y and the "thermal capacity" κ. The thermal lag of the thermal wave is evaluated by the temporal variation of the periodic thermal transmittance [2], represented by the element Z_{12} of the thermal transfer matrix. From the Z_{11}, Z_{12} and Z_{22} elements is possible to evaluated the thermal capacities of the wall, different for internal or external side of the component. In order to compare results with the weight sound reduction index, we evaluate, in logarithmic terms, the module of the element Z_{22}. Besides it will also be considered the thermal lag t_Y, the thermal capacity κ and the thermal resistance Rt. Calculation of the thermal resistance in steady-state condition and of the thermal lag in dynamic-state, we have been considered the thermal surface resistances according to [1], while for the thermal capacity the thermal surface resistances were been excluded.

4 Comparison test

For a technical evaluation of the acoustic and thermal performances of vertical building components we have been analyzed different structures described in UNI TR 11175 standard [3] where the weighted sound reduction index Rw are reported, measured in different Italian laboratories. In this section a summary description of the layers composing the structure and its physical characteristics will be given , while a detailed description is presented in [3]. Four different kind of structures have been analyzed:

- "light walls" with gypsum plasterboards and internal insulating material (mineral wool, mineral fiber, wood fiber); total thickness between the 7,6 and the 21,5 cm with mass per unit area variable between 23 and 66 Kg/m^2.

- "single-layer heavy walls", composed by typical hollow bricks plastered on both sides and concrete hollow blocks with expanded clay; total thickness between 13,5 and 38 cm, with mass per unit area variable between 141 and 407 Kg/m^2.

- "walls with external insulation", composed by typical hollow bricks with the insulation (expanded polystyrene foam, mineral wool, mineral fiber, wood fiber, glass wool) only on the external side and plaster on the internal side; total thickness between 20 and 37 cm with mass per unit area variable between 144 and 301 Kg/m^2.

.- "multi-layer heavy walls", or double walls composed by typical hollow bricks with insulation (expanded polystyrene foam, mineral fiber, wood fiber, glass wool) into the cavity wall; total thickness between 24 and 32,5 cm with mass per unit area variable between 195 and 255 Kg/m^2.

For each structure all the thermal parameters have been calculated according to [1] and [2]. Thermal characteristics related to single layers of the components have been evaluated according to UNI 10355/1994 and UNI 10351/1994 standards and also from product data give by different manufacturing of building materials: in case of typical hollow brick, values of the equivalent thermal conductivity conforming to the standard UNI EN 1745, have been used. The total surface mass of the structural component has been evaluated by taking in account also the mortar of horizontal and vertical joints between different blocks.

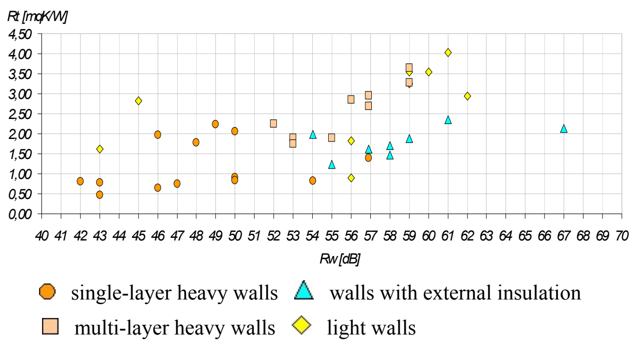

Fig.1 - comparison between the weighted sound reduction index Rw and the thermal resistance Rt.

In all graphs, all the component parameters have been divided in homogeneous groups ordered according the growing surface mass. A first comparison (fig. 1) between the thermal resistance and the weighted sound reduction index don't give any important correlation among these two parameters: it's only remarkable that high values of acoustic isolation correspond to high values of thermal isolation (fig. 2).

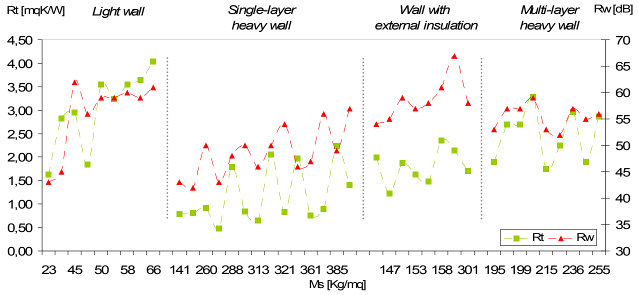

Fig.2 - Comparison between the weighted sound reduction index Rw and the thermal resistance Rt.

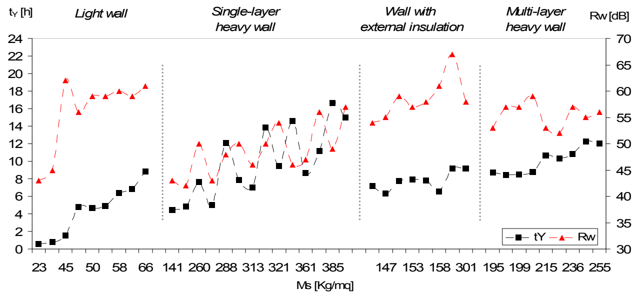

Fig.3 - Comparison between the weighted sound reduction index Rw and the thermal lag t_Y.

In dynamic-state condition, we analyzed 3 different cases, where thermal lag, thermal capacity and the element Z_{22} expressed in dB are compared to the sound reduction index. Fig. 3 shows that, there is a very low correlation between the thermal lag, t_Y and the weighted sound reduction index Rw, except for the case of single-layer walls.

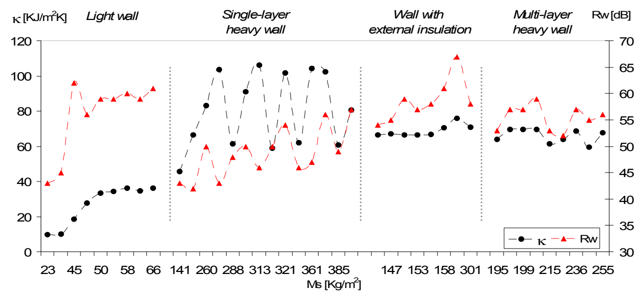

Fig.4 - Comparison between the weighted sound reduction index Rw and the thermal capacity κ (external-side).

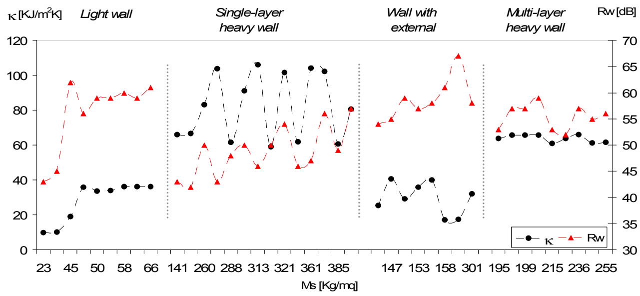

Fig.5 - Comparison between the weighted sound reduction index Rw and the thermal capacity κ (internal-side).

Comparing the thermal capacity and the weighted sound reduction index for every component (figure 4 and 5) we can notice similar trends. Both that for light walls, walls with external insulation and heavy multilayer walls. High values of thermal capacity correspond to high values of the weighted sound reduction index and vice versa.

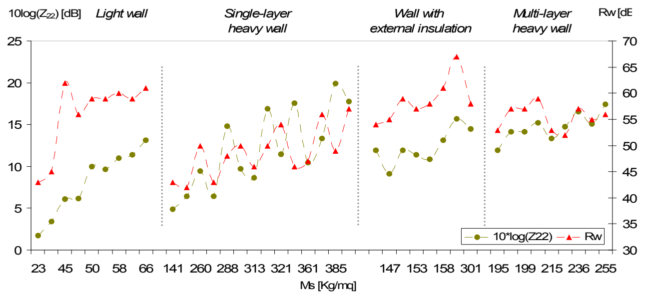

Fig.6 - Comparison between the weighted sound reduction index Rw and $10\log(Z_{22})$.

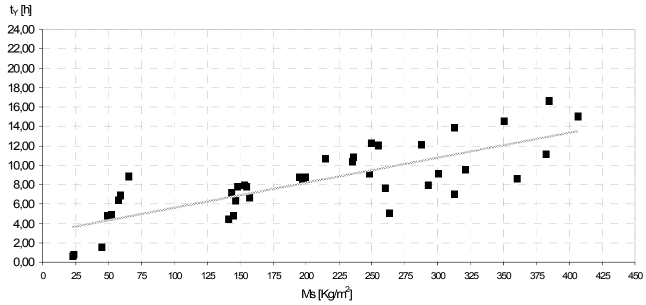

Fig.7 – Trend of the thermal lag t_Y depending on the surface mass M_s .

Figure 6 shows the trend of values of Z_{22} element of the thermal matrix correlated to the index Rw. it notices a similar trend as for the thermal capacity, for many component.

5 Analysis

Performances of single groups of structures will be analyzed to evaluate some simple correlations. All thermal parameters have been correlated to the logarithm value of the surface mass in order to verify any kind of "law of mass" as for the sound insulation index. Extended evaluations are presented according to previous results [4].

5.1 Single-layer heavy walls

Figure 8 shows that, increasing the surface mass, the value of the weighted sound reduction index grows, as theoretical models and also confirmed by the line of tendency that present a slope similar to the mass-law, even if results are quite spread. Also trends of the thermal lag values presents similar slopes as shown in figure 9. We can notice that the two lines of tendency present very similar inclinations.

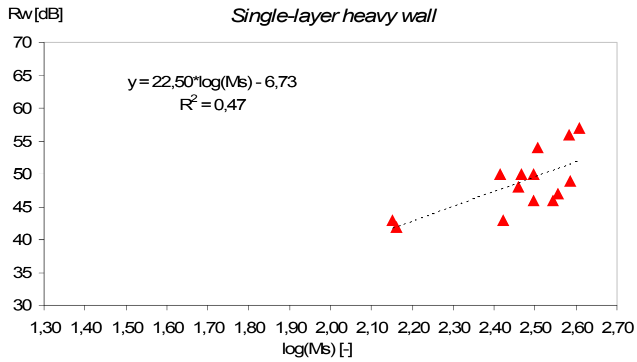

Fig.8 - Trend of the weighted sound reduction index Rw depending on the surface mass Ms.

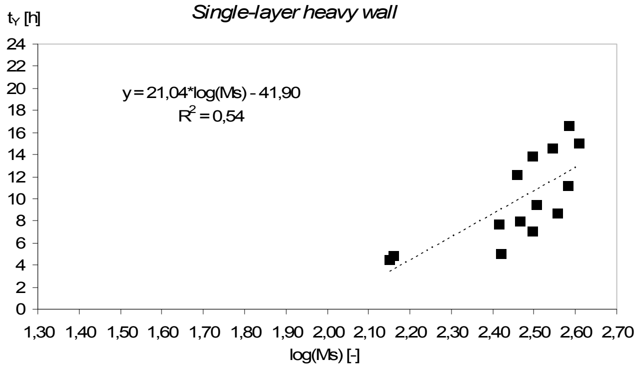

Fig.9 – Trend of the thermal lag t_Y depending on the surface mass Ms.

5.2 Multi-layer heavy walls

For the multy-layer heavy walls we can notice as the weighted sound reduction index Rw doesn't follow the same trend of single-layer the walls: increasing the surface mass, the tendency line to decrease (fig. 10). This is probably due to the isolation layer inside the wall: some walls, also having a low surface mass, present an high weighted sound reduction due to an adequate thickness of the insulating material.

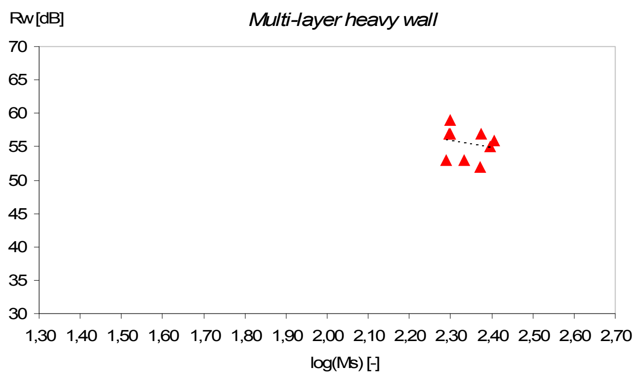

Fig.10 - Trend of the weighted sound reduction Rw depending on the superficial mass Ms.

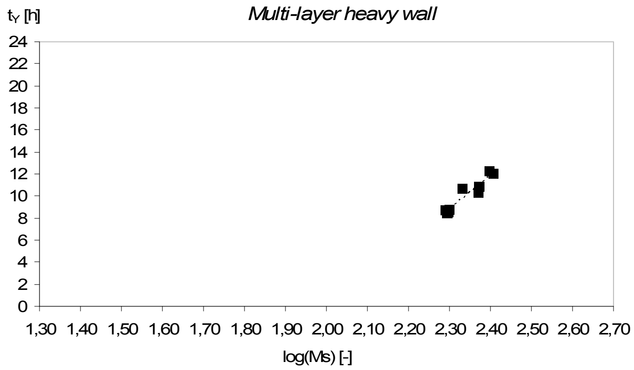

Fig.11 - Trend of the thermal lag t_Y depending on the surface mass Ms.

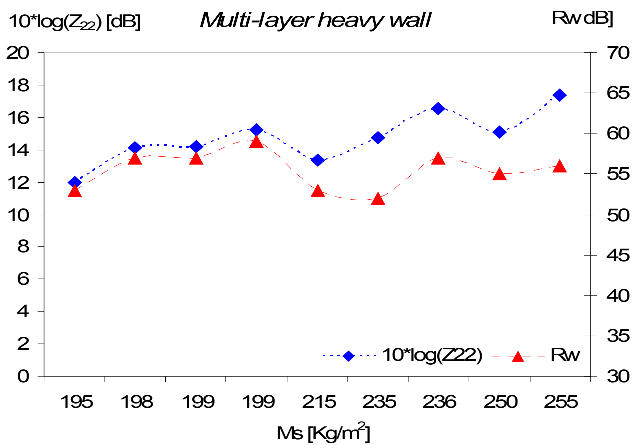

Fig.12 - Trend of the weighted sound reduction index Rw and $10\log(Z_{22})$.

If figure 11 we observe instead, as for the single-layer walls, that the thermal lag grows generally increasing the surface mass of components. In figure 12 a correlation is noticed instead between the values of Z_{22} and those of the weighted sound reduction index Rw.

5.3 Light walls

For light walls we have an evident influence of the surface mass on both thermal and acoustic performances.

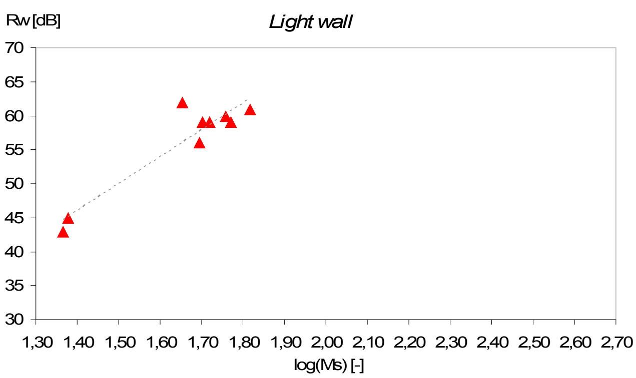

Fig.13 - Trend of the weighted sound reduction index Rw depending on the surface mass Ms.

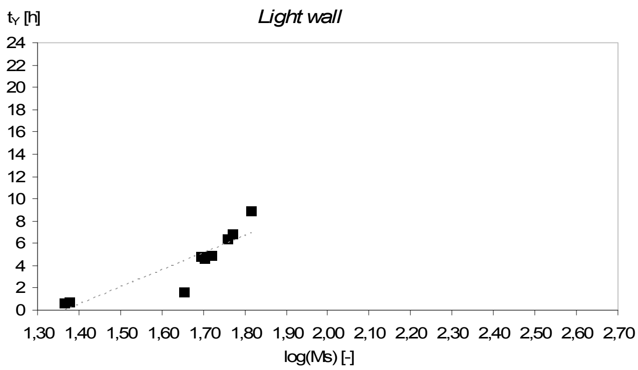

Fig.14 - Trend of the thermal lag t_Y depending on the surface mass Ms.

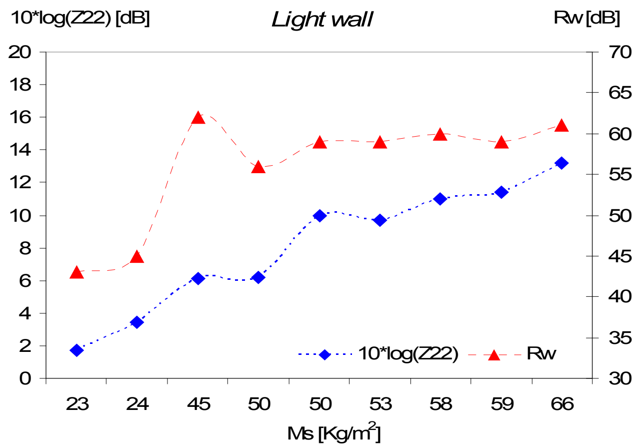

Fig.15 - Trend of the weighted sound reduction index Rw and $10\log(Z_{22})$.

5.4 Walls with external insulation

Figure 16 show as the weighted sound reduction index grows increasing the surface mass of the wall. Since it mainly deals with walls composed from high density layer (brick) and one of low density (insulation material), the trend is similar to that of some single-layer walls, as for the thermal lag.

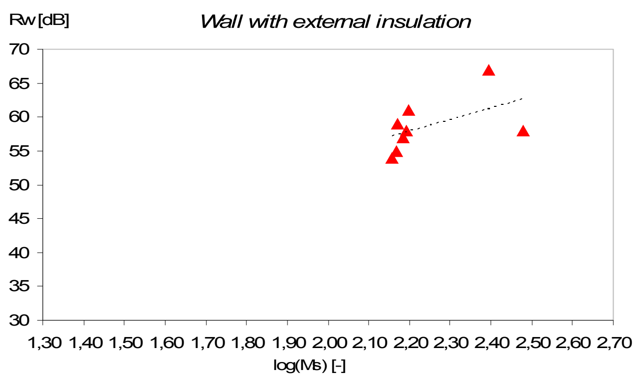

Fig.16 - Trend of the thermal lag t_Y depending on the surface mass Ms.

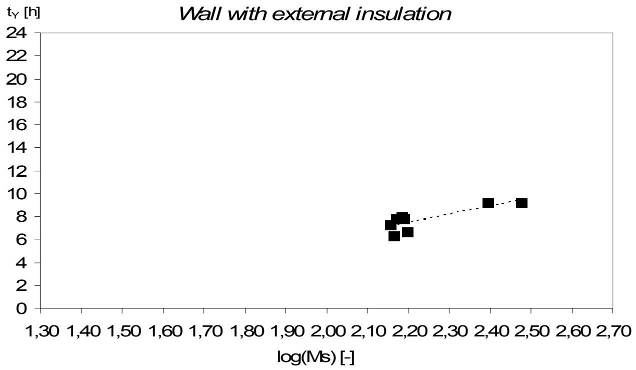

Fig.17 - Trend of the thermal lag t_Y depending on the surface mass Ms.

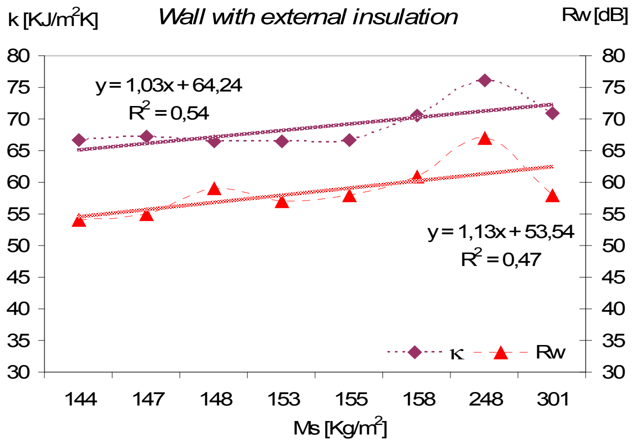

Fig.18 - Comparison between the weighted sound reduction Rw and the thermal capacity. (opposite side to insulation).

Figure 18 shows the comparison between values of Rw and with those of the thermal capacity related to the opposite side to insulation. It is evident a certain similitude of the two trend, also confirmed by the lines of tendency. The presence of the insulation on a the external side increases the thermal capacity of the component on the internal side as the acoustic performances, confirming the importance of the contribution of the surface mass.

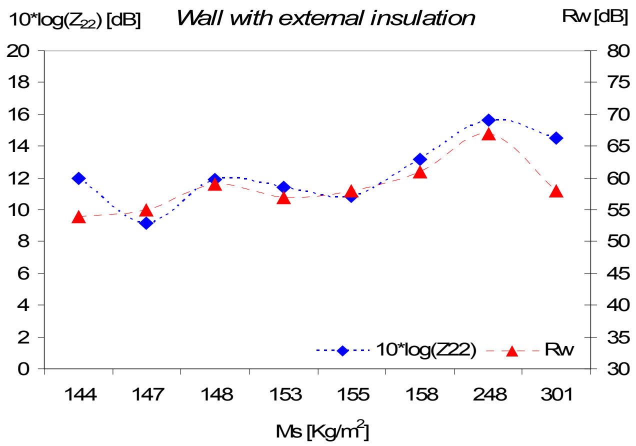

Fig.19 – Comparison between weighted sound reduction Rw and $10\log(Z_{22})$.

This analogy is also present in the figure 19, where are represented the values of Z_{22} correlated to those of Rw.

5 Conclusions

The comparison of performances of this components (even if in a limited number), underlining that Rw values are laboratory measurements [3] while all the thermal parameters are calculated values, shows in some cases some correlations between the acoustic and thermal performances.

For all the walls (figure 2) the thermal resistance increase with the surface mass as the acoustic insulation. For single-layer heavy walls the surface mass has a fundamental role in the above-said performances as confirmed by the figures 8 and 9. In this particular case, for the values of Rw and those of t_Y, the lines of tendency have similar slope. For the multi-layer walls and light walls there are not any coherent correlations among acoustic and thermal parameters. However for components with one-side insulation, the influence of the "insulating" layer together with the surface mass of the brick, gives important increasing of performances under certain conditions.

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