

# ANALYSIS OF THERMAL AND ACOUSTIC PERFORMANCE IN RESIDENTIAL BUILDINGS WITH ONE WAY SLAB DEPENDING ON THE RIB WIDTH AND COMPRESSION LAYER

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## ABSTRACT

Slabs are horizontal or inclined structural elements which directly receive and transmit loads to the columns, either directly as in bidirectional slabs, or through beams like in unidirectional slabs. They have great repercussion on sustainability, since they guarantee the optimal exploitation and utilization of resources, leading to lower costs and lower environmental repercussions. The Spanish Technical Building Code (CTE in Spanish), through the Basic Document of Noise Protection (DB-HR) covers two main areas: an acoustic overview of the building and the imposition of verification of in situ measures as a new method, and thermal conditioning, directly related to energy efficiency in present day. Energy consumption, and especially its waste or misuse, is one of the main environmental issues in Western societies. The consequence of this excessive consumption is the increased emissions of CO<sub>2</sub> into the atmosphere; and reducing these emissions to "reasonable" levels is one of the main challenges for the continuation of life on Earth. Very often, it is considered that the industrial and transport sectors are solely responsible for the excessive energy consumption: however, in practice, in advanced societies energy consumption is divided approximately in even parts between the industry, transport and building sectors. This work analyzes and evaluates the impact on housing performances (acoustic and thermal) with unidirectional slabs. With that purpose, the variables rib width, compression layer, slab depth, and material used for the lightening element are modified. The graphical representation of the results reflects the performance of the different modeling processes. Remarkable is the need of incorporating metadata for the correct modeling, simulation, and selection of structural alternatives.

Keywords: thermal performance, acoustic performance, residential buildings, one-way slabs

## 1. INTRODUCTION

Slabs are horizontal or inclined structural elements which directly receive and transmit loads to the

columns, either directly as in bidirectional slabs, or through beams like in unidirectional slabs.

The functions of the slabs can be divided into:

- Structural: They receive and transmit loads to beams and/or columns so that they do it in turn to the foundations and the ground. They provide transversal stiffness to the beams (monolithic). They link and brace the horizontal and vertical resistant elements of the building structure. Enough stiffness is necessary to prevent perceptible oscillations, and a limited deformation which is based on the type of load to bear. Structurally, the slab must have stability, resistance, stiffness and durability.

- Architectural: Their function is to support the divisions between floors. They support facilities, floors, ceilings and layouts for interiors and facades.

- Habitability: They provide thermal insulation, acoustic insulation, protection against fire, air tightness and water.

- Sustainability: They guarantee the optimal exploitation and utilization of resources; they also lead to lower costs and lower environmental repercussions.

This research focuses on the analysis of the variation in thermal and acoustic performances (Habitability) of unidirectional slabs.

Modern day society, in general, inhabits earth surrounded by sources of noise caused by human activities of all kind, be it leisure, industrial, facilities that make lives more pleasant and comfortable, transportation, etc. Some possible discomforts users feel, as buildings inhabitants are vibrations and incoming noises.

Researching the possible issues of soundproofing a building can lead us to draw conclusions, solutions not only a posteriori, but also many other preventive measures in the design and execution of a new construction work.

On the other hand, it is necessary to obtain a good acoustic design of buildings, with that purpose, the acoustic properties of walls, doors, windows... is studied, but inside the building.

It is therefore convenient to differentiate basic concepts in the field of architectural acoustics or

building acoustics, such as soundproofing and acoustic conditioning. The objectives of each one, though related, are different but must be used together to unite and complement its potential.

The Technical Building Code (CTE in Spanish), through the Basic Document of Noise Protection (DB-HR) covers two main areas: an acoustic overview of the building and the imposition of verification of in situ measures as a new method.

The CTE considers the finished building as a product, considering the acoustic performances of the building as a whole, contrary to what was required so far by the NBE CA-88, which applied it to each of the construction elements. The DB-HR treats the elements, in a way that the soundproofing values are not solved by providing thicknesses to the materials, but by changing building systems.

The other important aspect for habitability is the thermal conditioning, directly related to energy efficiency in present day.

Energy consumption, and especially its waste or misuse, is one of the main environmental issues in Western societies.

The consequence of this excessive consumption is the increased emissions of CO<sub>2</sub> into the atmosphere; and reducing these emissions to "reasonable" levels is one of the main challenges for the continuation of life on Earth.

Very often, it is considered that the industrial and transport sectors are solely responsible for the excessive energy consumption: however, in practice, in advanced societies energy consumption is divided approximately in even parts between the industry, transport and building sectors.

In the building sector, mainly determined by the volume of residential buildings (housing), power consumption is split between different points. See as an example the data presented in the EURIMA Congress in 2002:

- Buildings are responsible for a third of the total energy consumption.
- Within Europe, Spain is the second largest energy consumer in houses despite the alleged mild climate.
- Among European countries, Spain is the second largest source of CO<sub>2</sub> emissions originated in housing.
- Spain is largest source of CO<sub>2</sub> emissions per capita originated in housing.

This research analyzes and evaluates the impact on housing performances (acoustic and thermal) with unidirectional slabs. With that purpose, the variables rib width, compression layer, slab depth, and material used for the lightening element are modified. The graphical representation of the results reflects the performance of the different modeling processes. Remarkable is the need of incorporating metadata for the correct modeling, simulation and selection of structural alternatives.

## 2. METHODOLOGY

The methodology of this research focuses on the analysis of the acoustic and thermal performance for the case of unidirectional slabs.

The solutions are studied by varying the geometric arrangements of the slab depth and rib width. The study cases are shown in a summary in Table 1 and Figure 2.

Table 1. Cases of slabs keeping lightening and cladding at fixed rates.

Lightening (cm)	Rib (cm)	HA (f <sub>ck</sub> )	Compres. Layer (cm)	Designation
15- 20- 25- 30	12	25	5	15+5 - 20+5 25+5 - 30+5
			10	15+10 - 20+10 25+10 - 30+10
	14	25	5	15+5 - 20+5 25+5 - 30+5
			10	15+10 - 20+10 25+10 - 30+10
	16	25	5	15+5 - 20+5 25+5 - 30+5
			10	15+10 - 20+10 25+10 - 30+10

These 24 cases are modeled using two different lightening elements: vibro-compressed concrete and expanded polystyrene, Figure 1.



Figure 1. Modeled Materials for lightening elements.

For the correct identification of the modeled cases the following encoding is performed. A letter identifies the material used in the lightening element (H: vibro-compressed concrete, P: expanded polystyrene); below, two digits identify the structural depth of the lightening element and the thickness of the compression layer resulting from their addition the overall depth of the slab, ending with the letter "n" followed by a digit expressing rib width in centimeters. As an example, a case identified H20+10 n14, corresponds to a slab of total depth of 30 centimeters (20+10) in which a lightening element of vibro-compressed concrete with depth 20 is used, a compression layer 10 centimeters thick and resistant ribs 14 centimeters width.

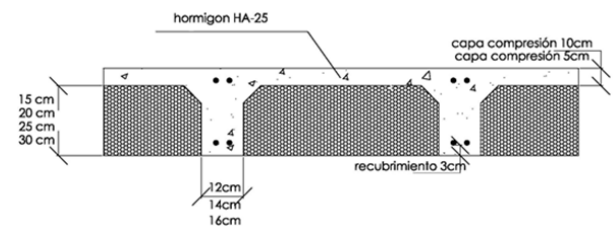


Figure 2 Sections of the floor.

The modeling of four discrete cases 4, 5, 6 and 7 meters of intercolumn with the usual loads in buildings and a beam width (primary structural element) of 60 centimeters is evaluated.

The next step was the thermal analysis of the different alternatives. The simulation is performed using the THERM software, developed at the Lawrence Berkeley National Laboratory. It is a software tool based on the finite element method for solving the two-dimensional equation of heat transmission.

This software tool has been properly tested by the examples of calculation proposed by different standard regulations such as ISO 10077- 2: 2003 "Thermal performance of windows, doors and shutters- Calculation of thermal transmittance" or UNE EN 1745: 2002 "Factory of masonry and factory components. Methods for determining the thermal values of a project. "

The calculation is performed by importing to THERM the corresponding section and creating over the template the model to be simulated using combinations of polygons. It is then necessary to define the properties of the materials involved and the outline conditions to be applied, Figure 3.

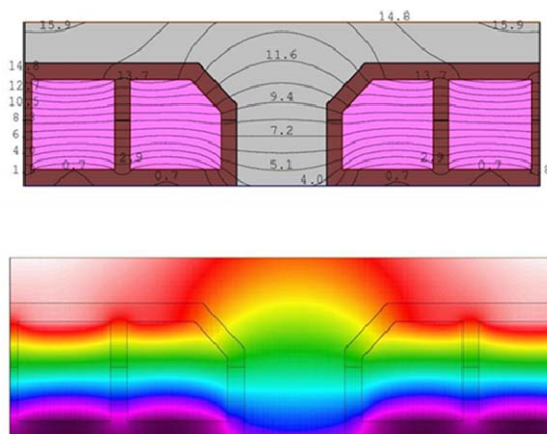


Figure 3 Modelling of the thermal analysis of the slab

With the above mentioned information, THERM executes the meshing for finite element analysis and the calculation of heat transfer in the simulated system.

To model the different slabs, the authors started from its sections, the different materials and properties and the implementation norms for calculating performances, based on the value of thermal transmittance U (W/m2K).

The assessment of the acoustic performance is complex. In the case of this study, the strategy is, given the technical and economic difficulties, to make trials in a laboratory to characterize the acoustic performances of the various slabs by the specific regulation of unidirectional slabs UNE-EN 15037-1 "Precast Concrete Products. Secondary beam and Vault Slab Systems."

The evaluation of acoustic performance is reflected by: the soundproofing against airborne noise  $R_w$  (dB) and the acoustic pressure transmitted by impact noise  $L_{n,w}$  (dB).

Once recorded the data of thermal transmittance, soundproofing to airborne noises and transmittance of acoustic pressure, the next step was to develop the graphical representations shown in the results section.

### 3. RESULTS

The presentation of the results is made by means of graphics. Each slab length presents a graph in which the X axis indicates the soundproofing of the proposed solution and in the Y-axis the information of the thermal performances of the analyzed proposal. To simplify the representations, the solution is characterized by the soundproofing.

The disappearance of cases with increased slab length is due to the fact that they are cases that are not technically feasible because of the excess of deformation.

In this case, the 48 alternatives studied are feasible. If expanded polystyrene (P) is used, better results are obtained by varying thermal transmittance between 1.44 and 2.16 W/m2K. Conversely, if vibro-compressed concrete (H) is used, the oscillation occurs in the range of 1.82 to 2.75 W/m2K.

In the acoustic performance, the soundproofing achieved by means of H solutions ranges from a 52.72 dB minimum and a 63.46 dB maximum, being the range lower for P solutions, ranging from 45.40 dB to 58, 39 dB.

In this case, 43 out of 48 alternatives studied are feasible. An increase of the lightened area occurs. In this way, the (P) solutions improve their thermal results varying transmittance between 1.36 and 2.07 W/m2K. In the (H) solutions there is a higher improvement due to a variation of the range of 1.76 to 2.54 W/m2K. This improvement comes from discarding the solutions with structural depth of 20 centimeters.

In the acoustic performance, the soundproofing achieved by means of H solutions ranges from a 54.28 dB minimum and a 62.97 dB maximum, being the range for the P solutions lower, ranging from 45.95 dB to 57, 64 dB.

This last increase of the lightened area narrows the feasible solutions to the ones with 20 and 25 centimeters of structural depth. In this way, the (P) solutions have a lower transmittance ranging between 1.31 and 1.73 W/m2K. The solutions (H) have a higher transmittance in the range of 1.72 to 2.22 W/m2K. The difference in the maximums of transmittance is of 29%.

In the sound performance, the soundproofing achieved by using the H solutions ranges between a 55.71 dB minimum and a 62.63 dB maximum, being the range lower for P solutions ranging from 47.66 dB to 57.13 dB. In this case, the worst acoustic solution in H is close to the best option in P.

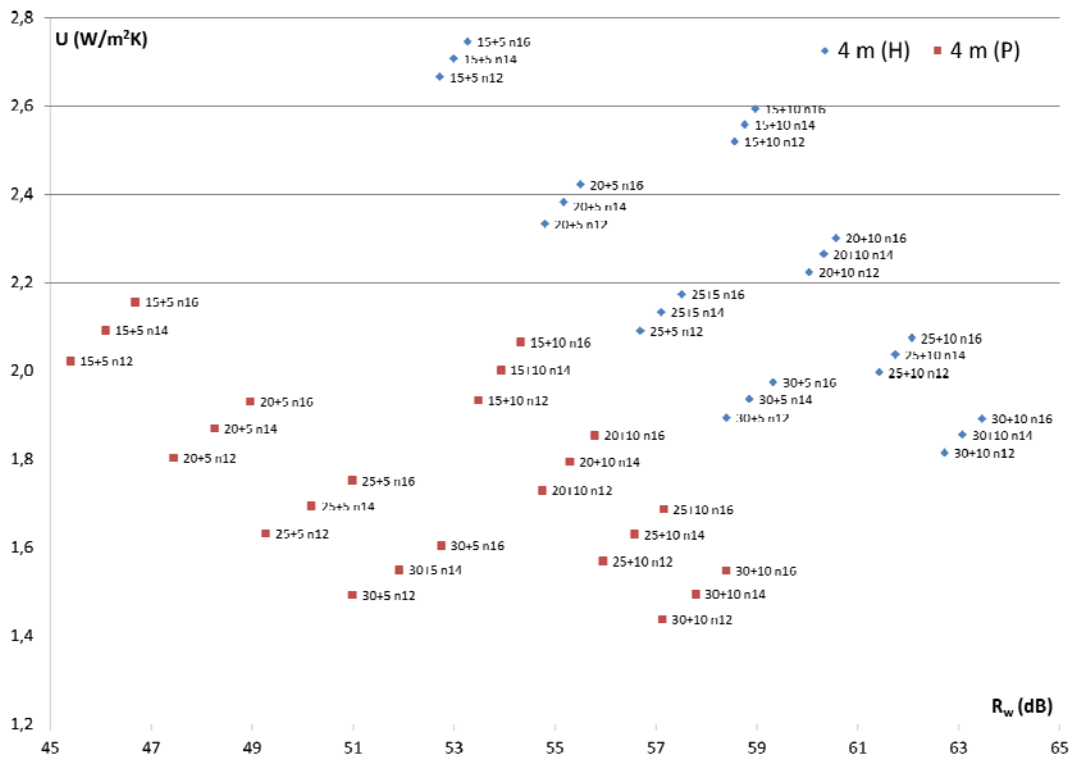


Figure 4. Acoustic/Thermal Results (Slab intercolumn 4 meters).

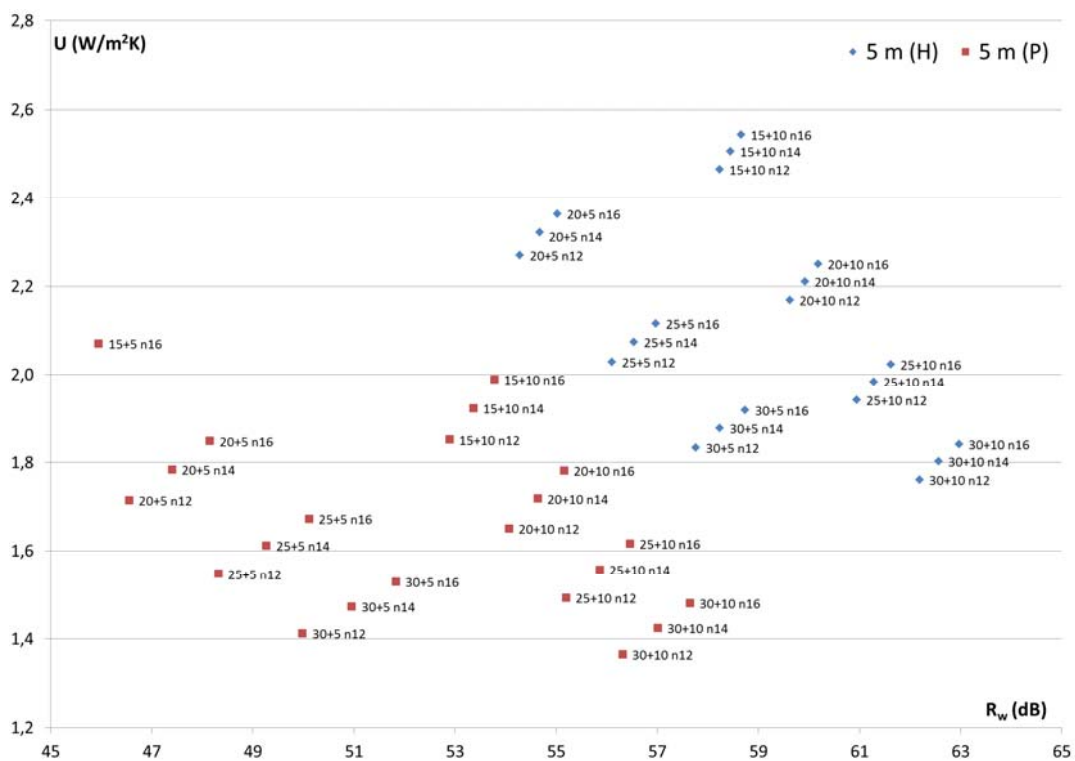


Figure 5. Acoustic/Thermal Results (Slab intercolumn 5 meters)

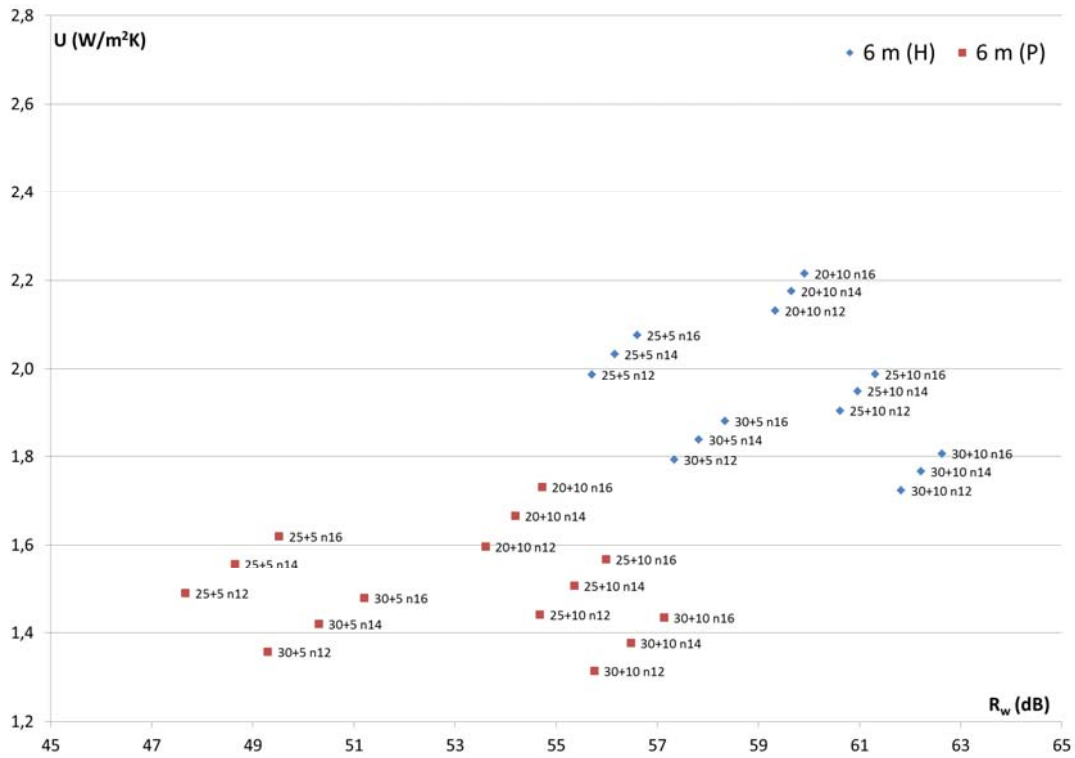


Figure 6. Acoustic/Thermal Results (Slab intercolumn 6 meters)

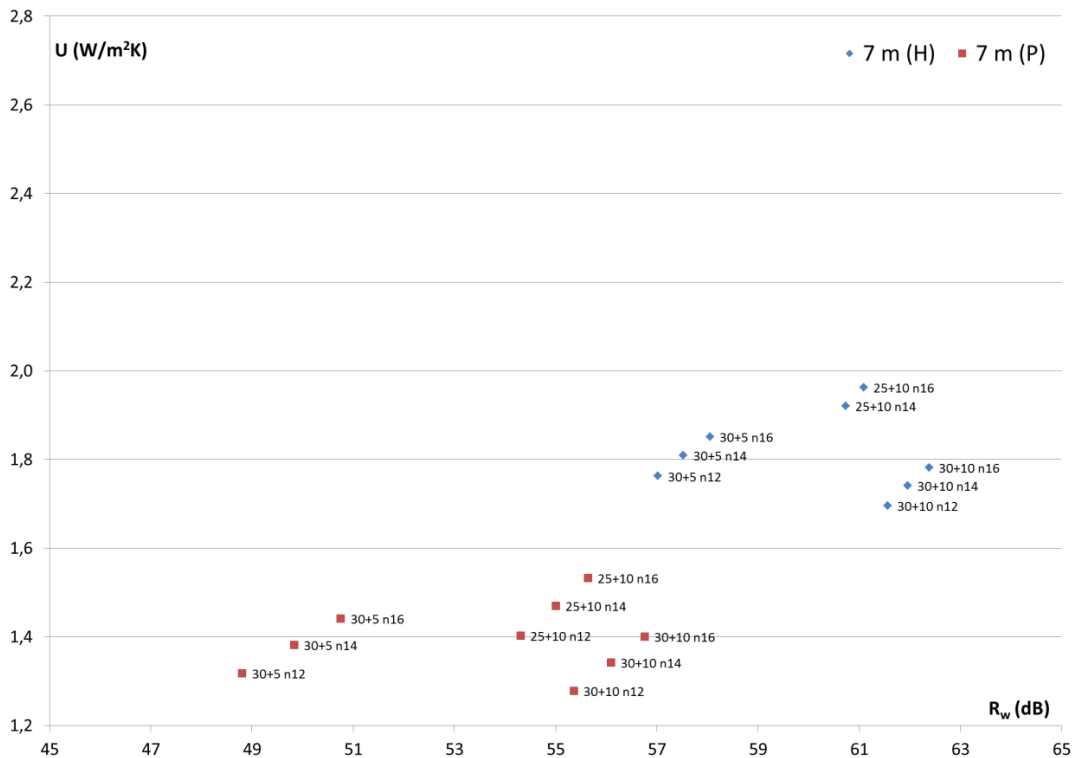


Figure 7. Results/Thermal Acoustic (Slab intercolumn 7 meters).

This last increase in the lightened area reduces the feasible solutions to the ones with a structural depth of 35 and 40 centimeters. In this way, the (P) solutions

have a lower transmittance ranging between 1.28 and 1.53 W/m<sup>2</sup>K. The solutions (H) have a higher transmittance in the range of 1.70 to 1.96 W/m<sup>2</sup>K. The



difference in the maximums of transmittance remains of 29% and the worst P solution has a lower transmittance than that of the best H solution.

In the sound performance, the soundproofing achieved by using H solutions ranges between a 57.02 dB minimum and a 62.38 dB maximum, being lower the range for P solutions ranging from 48.80 dB to 56.76 dB. In this case, the best acoustic solution comes from H cases, resulting in substantially lower soundproofing for the cases with the P option.

#### 4. CONCLUSIONS

This research presents relevant information on in situ unidirectional slabs alternatives for concrete structures. It reflects and quantifies the impact on comfort and living conditions of the modification of geometric parameters of the slab.

The increase in rib width brings improvements for the acoustic performance assuming a loss in thermal performance. These variations are higher in P solutions than in H ones.

The increase in structural depth caused by the variation of the depth of the vault, slightly improves both acoustic and thermal performances, with higher impact in the thermal ones.

If the depth variation is caused by increasing the compression layer, then the acoustic performance is substantially improved and the thermal performance is worsened.

If the slab intercolumn is over six meters, and high structural depths are imposed, an important difference between the thermal performances of the P solutions occurs compared to the H ones. On the other hand, the acoustic performances of H solutions are substantially better than those of P solutions.

The evolution of national and European standards clearly leads to a tendency where the products incorporated to the construction should present a declaration of their performance. It is important that manufacturers inform the technicians about the properties of the products they commercialize, which should be supported by trials or tests that mark the corresponding harmonized standards.

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