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NOISE CONTROL AND NATURAL VENTILATION IN DWELLINGS IN HUMID HOT COUNTRIES

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ABSTRACT
In this work, the study of sound propagation and noise control in buildings in humid tropical climate is considered and some results are discussed. In these conditions, sound propagates into the build space and from one room to another trough large openings used to allow natural ventilation. Some considerations considering the use of absorptive intermediary spaces as barriers for noise propagation are presented. A simplified model based on SEA (Statistical Energy Analysis) is used to describe the propagation in those spaces and to optimize its absorptive properties.

1 - INTRODUCTION
Mainly, the knowledge regarding sound pollution and noise control concerns the temperate climate countries, where the winter is taken into account to determine comfort conditions in buildings. The transposition of this knowledge for hot climate countries, as well as the harmonisation with the climatic design, is not immediate for some reasons. Among them, the typologies of the devices used in passive systems for environmental conditioning, the global cost, the feasibility and the socio-cultural aspects.
Attempts to conciliate the design solutions in humid tropical climate regarding the acoustic comfort with others aspects of this field, e.g. thermal and visual comfort, present some difficulties, normally refereed as "acoustic restrictions". A clear example is the kind of facades for this type of climate: little thermal inertia and generous openings to provide permanent natural ventilation; in this case, the law of the mass used for the acoustic isolation becomes totally useless.
The study of design solutions that take advantage from the acoustic absorption for noise propagation reduction in the inward of the built environment remains as an alternative. Among the possible solutions, the transposition of air-conditioning noise reduction techniques for the natural ventilation devices.

2 - THE URBAN NOISE PROBLEM IN RIO
A general approach for the urban noise control problem can be done through a systemic model where it is considered the acoustic energy propagation from the source to the receptor. The elements of this system are: the localization of the source, the region near the source, the urban layout, the region near the receptor building, the facade of the same building and the receptor placement. The noise, during in its propagation, will be attenuated due to various reasons. The most important one is the attenuation produced by the receptor's building facade. The facade quality will determine the acoustic quality of the place where the receptor is localized.
In a hot humid climate the conditions are different from that of the temperate and cold regions. The residential building's facades must have a little thermal inertia, as well as openings for the natural ventilation. In this way, the facade have also some acoustic-insulating codes. This restrictions cause serious consequences to the acoustic comfort. The city population, in a general way, is submitted to very high noise levels inside its dwellings.

In the city of Rio de Janeiro, Brazil, this problem happens in a critical level. Every day the environment authorities receive a great number of complaints due to the urban noise; several suits related to this problem happened over the last years. In a general way, the conception of the buildings do not consider the climatic principles. In a simple observation of the facades in the busy streets of the city of Rio de Janeiro, it is verified that the windows rest open the most part of the time. We may also observe that the public transportation is mainly based on urban buses, which use very noisy diesel engines. The traffic in the main streets of the city stands as the main source of the urban noise.

3 - POSSIBLE SOLUTIONS

The need of a reduction on the exposition to the noise inside dwellings has lead to some solution proposals. However, not all of them are applicable to the climatic and socio-cultural context of a city like Rio de Janeiro. The thermoacoustical insulation of the residential units, through the installation of soundproof windows and air conditioning systems, could solve the problems related to the thermal and acoustical comfort. However, such solution is completely unfeasible. Besides the enormous cost of this installation, it is totally out of all energy efficiency parameters, under the point of view of the sustainable development. The purpose of this work is, therefore, to consider one solution to be applied to projects of new buildings as well as, in some cases, to the existent old ones. It consists in the study of architectural devices for noise control inspired in the air conditioning noise control technology. These devices are in general used to attenuate the noise made by the fans in its propagation within the distribution ducts of these installations. Thus we have the round and the rectangular silencers which use chicanes, plenums, louvres and other systems. The transposition of these devices to the architectural scale, however, may not be immediate. It's necessary to identify the appropriate place to install such device on the plant of the building, as well as the verification of the deformations needed to fit the whole ensemble. Besides, the calculus methodology proposed by ASHRAE may not be always applied due to the greater dimensions of the devices.

4 - PROPOSED MODEL

The sound propagates through the architectural spaces with different proportions and it is interconnected by large openings for the natural ventilation. To study this propagation we will use a model based on the Statistical Energy Analysis. This model works based on a thermal analogy. To each architectural space −called subsystem− a vibratory temperature is associated, calculated from the sound pressure level. The sound propagates from the highest temperatures to the lower ones. The stream of sound energy between two subsystems is proportional to the difference of the vibratory temperatures of the subsystems. The proportionality factor is called coupling loss factor. The energy dissipated in each subsystem is proportional to the vibratory temperature of the subsystem.
Thus, considering that as an effect of propagation in a dwelling, the sound penetrates in one room and reaches the other room through an opening, we can assemble the model showed in Figure 1. In this simplified model where the walls are rigid and the transmission is done by large opening between rooms, we consider two subsystems. The subsystem 1 is a dwelling room and the subsystem 2 refers to another. With this model we can study the various influences due to the dimensions of each room, the size of the openings, as well as the influence of each room absorption coefficient. Thus, this model allows to optimize the acoustical properties of the intermediary spaces disposed between the noisy spaces and the acoustically sensitive ones, so that the sound transmission between them can be reduced.
From this model we have the following classical equations:

$$\mathrm{P}_1^{\mathrm{in}} = \mathrm{P}_1^{\mathrm{diss}} + \mathrm{P}_{12}$$
$$\mathrm{P}_{12} = \mathrm{P}_2^{\mathrm{diss}}$$

Where:

- $\mathrm{P}_1^{\mathrm{in}}$ − sound energy input in room 1,
- P_{12} − energy flow from the room 1 to the room 2 through the opening,
- $\mathrm{P}_1^{\mathrm{diss}}$ − dissipated energy in the room 1 due to the wall absorption.

To the model via SEA may be considered as the following:

$$\mathrm{P}_1^{\mathrm{diss}} = \eta_1 \omega \mathrm{E}_1$$
$$\mathrm{P}_{12} = \eta_{12} \omega \mathrm{E}_1 - \eta_{21} \omega \mathrm{E}_2$$

Where:

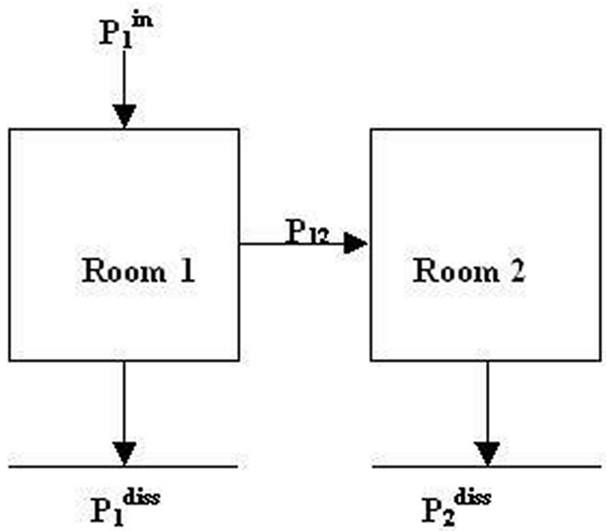

Figure 1: Architectural subsystems sound propagation model.

- E_1 and E_2 mean respectively the amount of sound energy of the systems 1 and 2 in a frequency range centralized in ω,
- η_1 − absorption loss factor in the subsystem 1,
- η_{12} − coupling factor loss between the systems 1 and 2 due to openings.

Note: These loss factors can be easily determined from room acoustics considering only reverberant fields.
Developing these equations we found the following classical results:

$$\frac{E_1}{E_2} = \frac{\eta_2 + \eta_{21}}{\eta_{12}}$$

The above equation represents the relation between the amount of the sound energy in both rooms.

$$P_1^{in} = \left[\frac{\eta_1\eta_2 + \eta_1\eta_{21} + \eta_2\eta_{12}}{\eta_{12}}\right]\omega E_2$$

The above equation represents the relation between the power input in the room 1 and the sound energy in the room 2. This equation allows to study the influence of the various system parameters to the noise level in the room 2.
The development of these equations leads to the following result:

$$L_{\rho 2} = L_{W\ 1} + 10\log_{10}\left(\frac{4S_{ab}}{A_1^2 + (A_1 + A_2\ )\,S_{ab}}\right) + 10\log_{10}\left(\frac{1}{V_2}\right)$$

Where:

- L_{p2} − sound pressure level in the room 2
- L_{W1} − sound power level input in the room 1
- S_{ab} − opening area between rooms 1 and 2
- A_1 − absorption area in room 1 without considering S_{ab}
- A_2 − absorption area in room 2 without considering S_{ab}
- V_2 − Volume of the room 2

This result shows the preponderant influence of the natural ventilation opening area between rooms 1 and room 2. One may also verify the influence of the acoustic absorption of the room 1 on the noise level in room 2. We may observe that A_1 and A_2 have upper values than S_{ab}. Thus the magnification of the absorption coefficient in room 1 can reduce the noise level in room 2.

5 - CONCLUSION

In this work it was presented an example of the utilization of a classical but powerful tool for the study of sound propagation between typical architectural subsystems in hot humid climates. The analysis of the sound energy propagation between two subsystems allows putting in evidence the importance of the intermediate spaces. These spaces may be carefully used as a sound barrier. The increase of the absorption coefficient in room 1 allows to diminish the noise level in room 2. The simplified model presented in this work can be extended to study a more complex situation of the propagation of sound in buildings.

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