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ANALYSIS OF ENERGY "TRAFFIC" IN ROOM AND ITS IMPLICATION ON SOUND INSULATION AND ABSORPTION OF MATERIALS

Dragana Šumarac Pavlović, Srdjan Bojčić, Ivana Ristanović, Filip Pantelić, Miodrag Stanojević

School of Electrical Engineering, University of Belgrade, Serbia (dsumarac@etf.rs)

Abstract: *Sound fields in regular rooms are not ideally homogeneous and diffuse, which leads to the non-homogeneous "traffic" of sound energy in their volumes. As a consequence, distribution of angles of incidence and intensity of the incident sound vary between room surfaces. Ray tracing method estimates the flow of energy in a sound field, also allowing the analysis of distribution of angles of incidence, angular incident energy distribution and incident energy density on different surface. Thus, effective absorption coefficients of the materials can be analysed, for different macro and micro geometrical characteristics of the rooms.*

Key words: absorption coefficient, incident energy density, ray tracing

1. INTRODUCTION

Sound field in real rooms does not meet the theoretical conditions for diffusivity. Ideal diffuse field presumes an even distribution of angles of incidence, i.e. equal distribution of incident energy for all angles and equal density of incident energy at all interior surfaces. Absorption properties of the material placed at an interior surface, as well as in situ sound insulation properties of a partition, depends on the angular distribution of incident energy and the statistics of the energy that hits all interior surfaces in the room. Calculation of the acoustic characteristics of the room and also the calculation of the surface's properties (absorption coefficient and sound reduction index) are based on assumption that the conditions in the room correspond to a diffuse field and therefore the distribution of incident energy is known [1].

In different rooms the difference appears between expected absorption properties of the material with the laboratory approved absorption characteristics and absorption manifested in reality. That difference goes in both directions (plus or minus) relative to the value expected for a diffuse sound field. What will be the manifested absorption characteristics of material exposed in a room depends on room's macro and micro geometric features and their mutual relationship. In the same way the insulating properties of partitions would, to some extent, vary depending on the conditions in the source room sound field [2, 3].

Several experiments were organized to test the limits in which absorption properties of a material can be expected as a function of actual diffusivity of a room. The experiments were performed by software simulation of sound field with different room's micro and macro geometrical configurations. The simulation was performed with a specifically developed software tool that uses ray tracing analysis [3]. It makes available the analysis of the incidence angles and energy density distribution at room's interior surfaces. A set of experiments were also performed with commercial software for ray tracing analysis in various models of real rooms.

2. EXPERIMENTAL SETUP FOR AN ANALYSIS OF ANGLES OF INCIDENCE AND INTENSITY OF THE INCIDENT SOUND

Sound field properties are determined by the macro and micro geometrical characteristics of the room:

- Macro characteristics - global shape and proportions
- Micro characteristics – relief of the inner surfaces

Macro geometrical characteristics have the predominant impact on the state of the sound field diffuseness, while Micro geometrical characteristics to some extend can change characteristic of the sound energy flow in the room.

To determine the possible variations of the material's absorption characteristics as a function of macro and micro geometrical characteristics of the room two models of parallelepiped rooms of different size were made. Macro geometrical characteristics were varied by changing their global configuration, while micro geometrical characteristics were changed using three different value of interior surface scattering coefficient. Figure 1 shows the form and dimensions of selected room models. In all simulations a uniform absorption coefficient was assumed for all interior surfaces, and its value was 0.1.

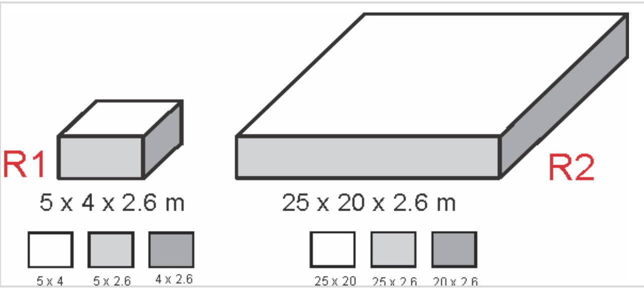

Fig.1. Two parallelepiped rooms used in simulation

3. ANGLE OF INCIDENCE DISTRIBUTION IN ANALYSED ROOMS

Ray tracing simulations were done in both rooms for three values of scattering coefficient. Simulation outputs are the parameters which describe the characteristics of the sound field which have some influence on apparent sound absorption property of the inner surfaces:

- Angular distribution of sound at interior surfaces
- Angular distribution of incident energy
- Density of incident sound energy

Presented on fig 2, 3 and 4 shows the distribution of angle of incidence on three surfaces of different size and for three values of scattering coefficient for the room R1, as well as the distribution of angles of incidence that is expected in a diffuse field. Surfaces are encoded with gray background according to fig 1.

In the case of proportional room differences in the distribution of angles of incidence are not much bigger compared with the diffuse field, except for very small values of scattering coefficient.

In the case of room with disproportional dimensions, differences in the distribution of angles of incidence are significantly higher, especially in the case of the largest surface area, the ceiling.

Figures 5, 6 and 7 show the results of simulations for the room R2. Deviations from the diffuse field distribution are manifested n many different ways.

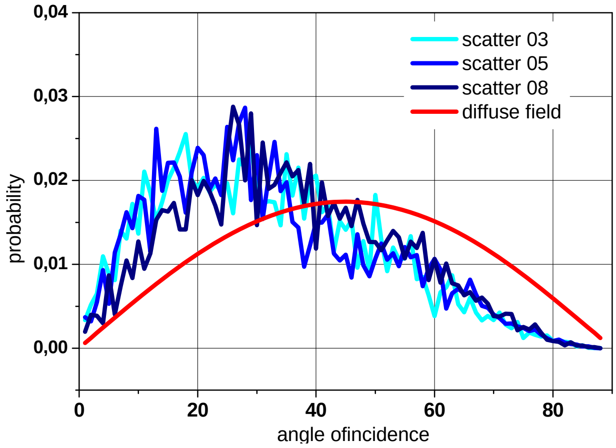

Fig.2. Calculated angle of incidence distribution at surface with dimensions 5 x 4 m in room R1 for three values of scattering coefficient

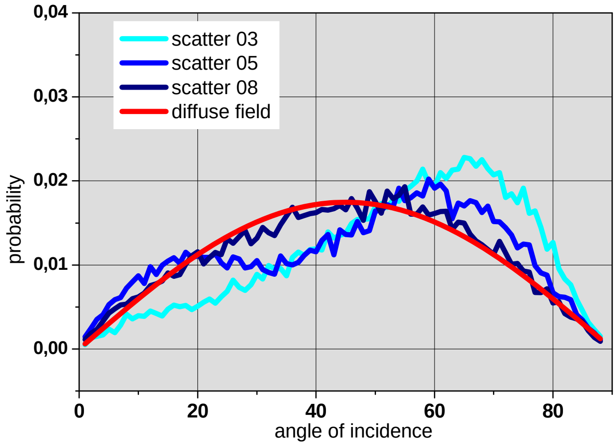

Fig.3. Calculated angle of incidence distribution at surface with dimensions 5 x 2.6 m in room R1 for three values of scattering coefficient

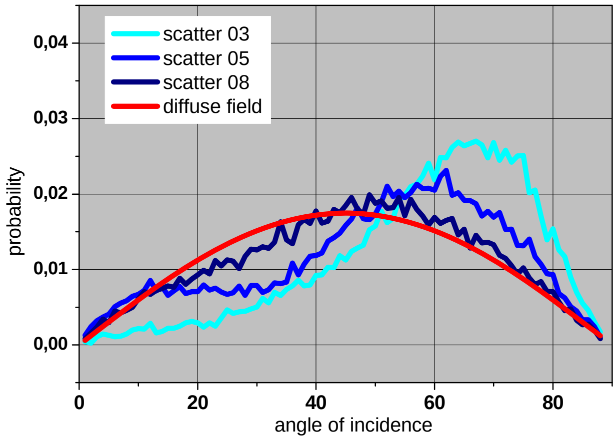

Fig.4. Calculated angle of incidence distribution at surface with dimensions 4 x 2.6 m in room R1 for three values of scattering coefficient

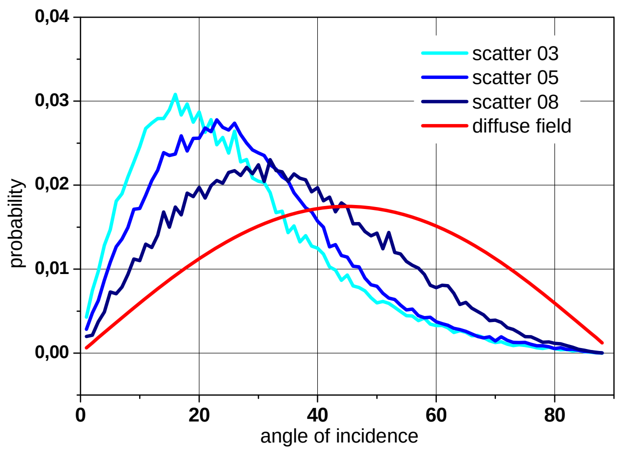

Fig.5. Calculated angle of incidence distribution at surface with dimensions 25 x 20 m in room R2 for three values of scattering coefficient

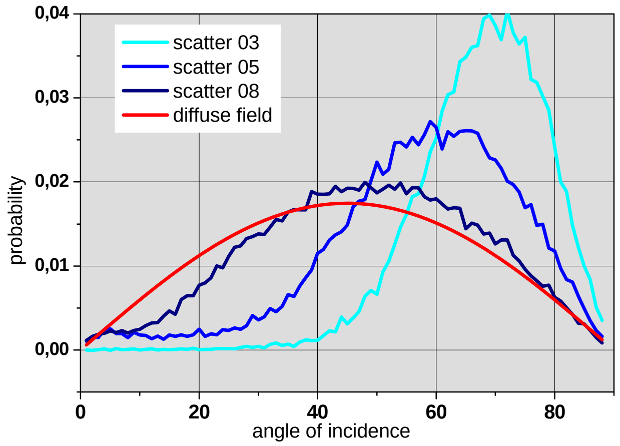

Fig.6. Calculated angle of incidence distribution at surface with dimensions 25 x 2.6 m in room R2 for three values of scattering coefficient

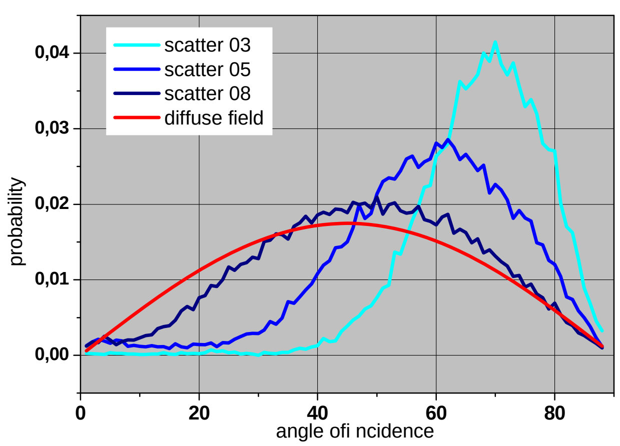

Fig.7. Calculated angle of incidence distribution at surface with dimensions 20 x 2.6 m in room R2 for three values of scattering coefficient

4. ANGLE OF INCIDENCE DISTRIBUTION IN ANALYSED ROOMS

Calculations of the sound field, in addition with ray incidence angles, may also track ray's intensity. Such analysis shows the angular distribution of incident energy on the interior surfaces. For room R1 the angular distribution of incident energy at its largest surface is shown in Figs. 8, 9 and 10, and for the smallest surface in Figs.11 and 12 and 13.

Angular distribution of incident energy for room R2 largest surface as well as distribution of angle of incidence for three values of scattering coefficient is present on the figures 14, 15 and 16. Calculated distributions for smallest surface in R2 are present on figures 17, 18 and 19.

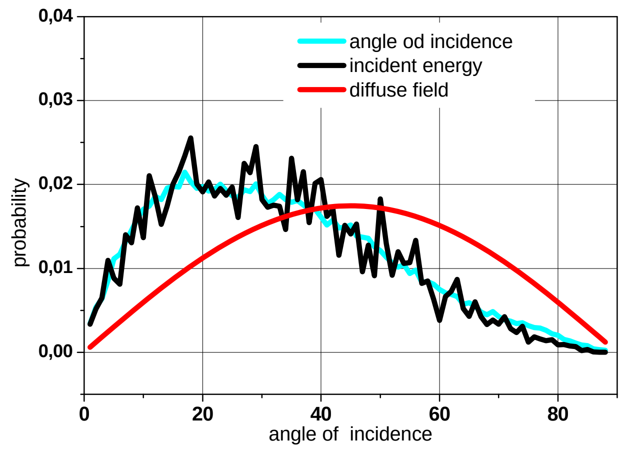

Fig.8. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 5 x 4 m in room R1 and for scattering coefficient 0.3

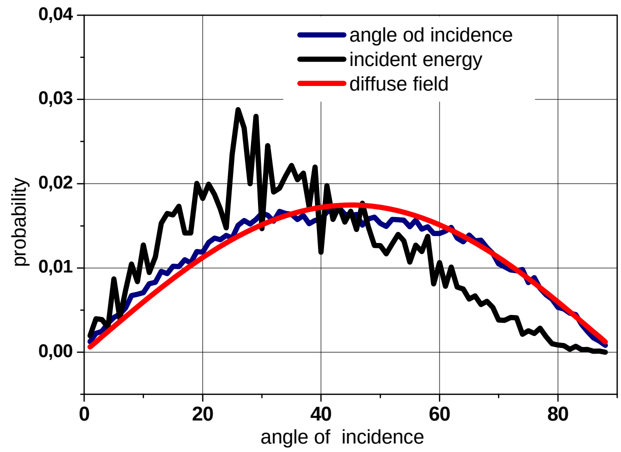

Fig.9. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 5 x 4 m in room R1 and for scattering coefficient 0.5

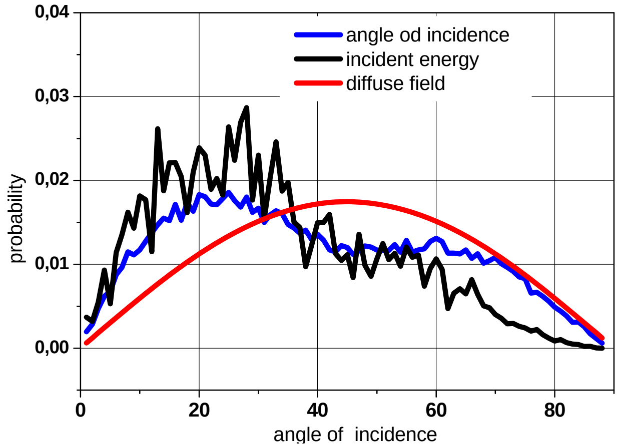

Fig.10. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 5 x 4 m in room R1 and for scattering coefficient 0.8

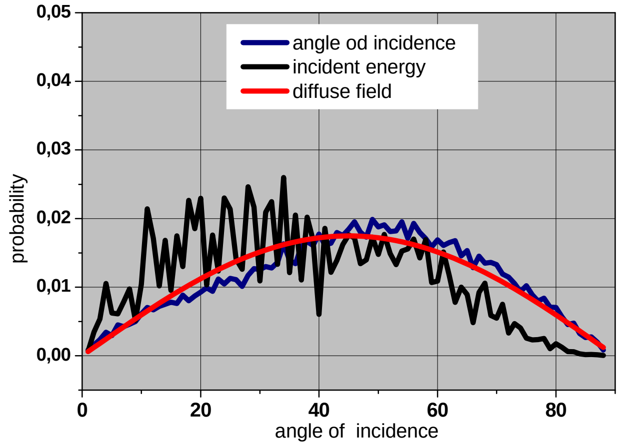

Fig.13. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 4 x 2, 6 m in room R1 and for scattering coefficient 0.8

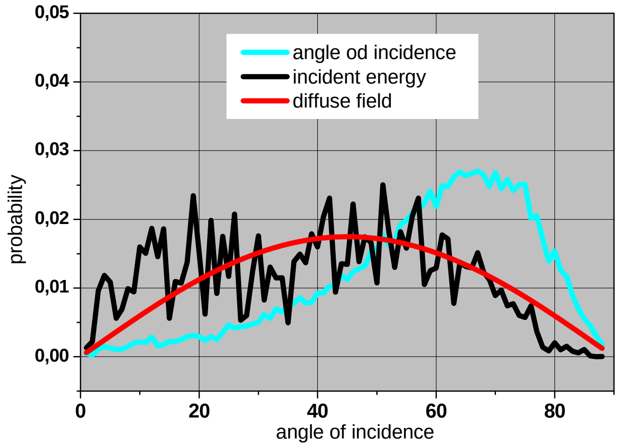

Fig.11. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 4 x 2, 6 m in room R1 and for scattering coefficient 0.3

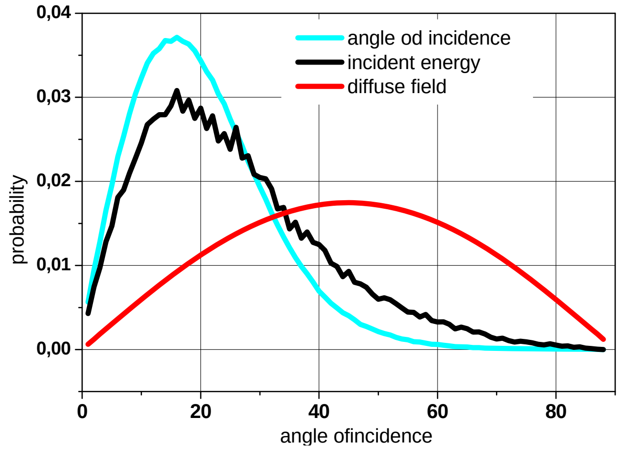

Fig.14. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 25 x 20 m in room R2 and for scattering coefficient 0.3

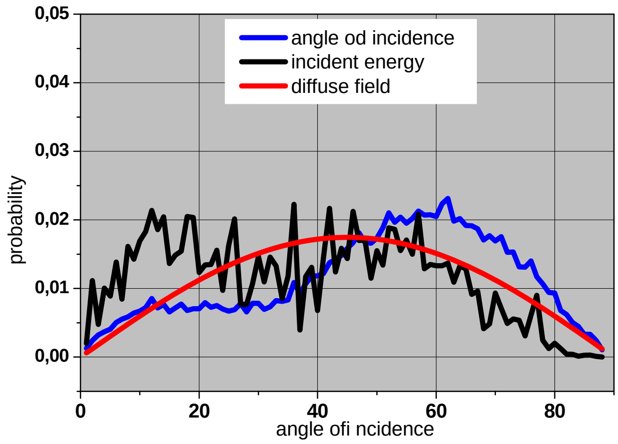

Fig.12. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 4 x 2.6 m in room R1 and for scattering coefficient 0.5

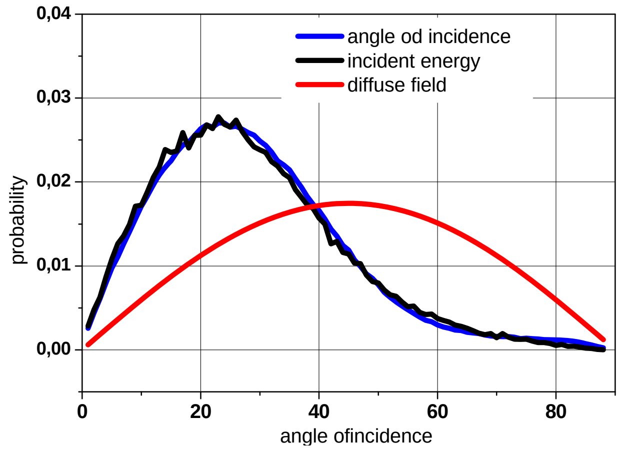

Fig.14. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 25 x 20 m in room R2 and for scattering coefficient 0.5

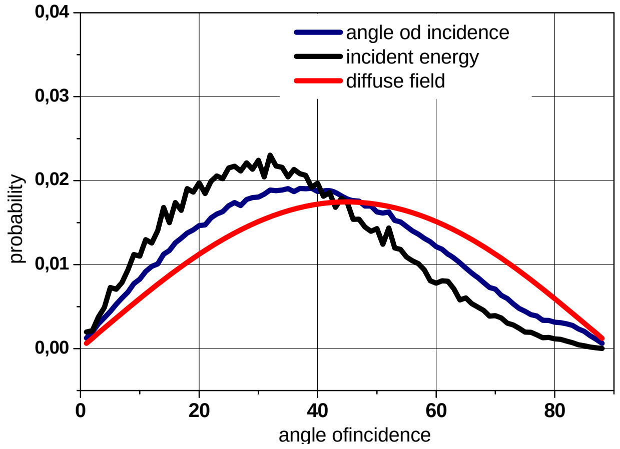

Fig.16. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 25 x 20 m in room R2 and for scattering coefficient 0.8

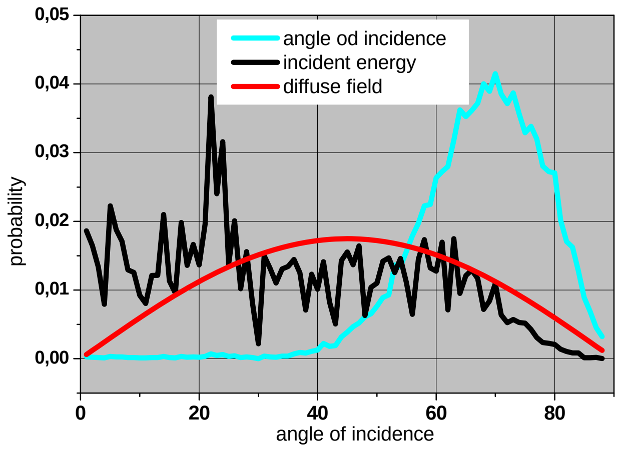

Fig.17. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 20 x 2.6 m in room R2 and for scattering coefficient 0.3

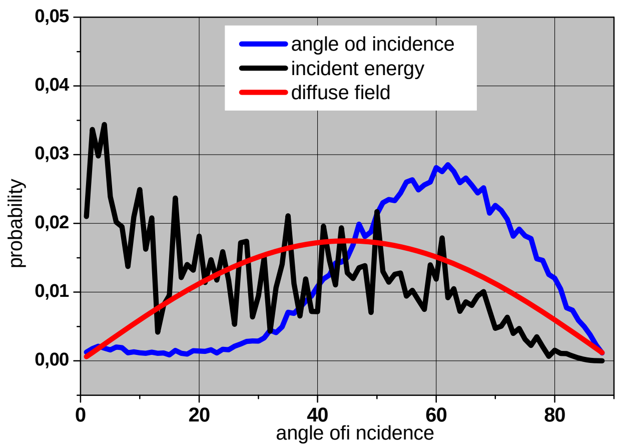

Fig.18. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 20 x 2.6 m in room R2 and for scattering coefficient 0.5

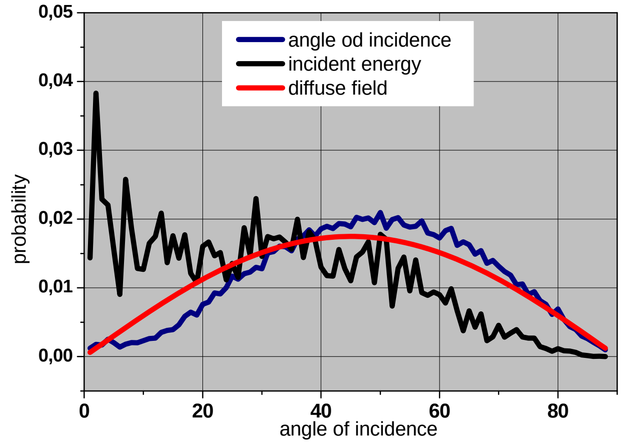

Fig.19. Calculated angle of incidence distribution, angular incident energy distribution and diffuse field energy distribution for surface with dimension 20 x 2.6 m in room R2 and for scattering coefficient 0.8

4. DENSITI OF INCIDENT ENERGY

Although the distribution of angles of incidence observed in all analysed situations are different, distribution of angular incident energy does not vary significantly from the distribution of the angular incident energy in diffuse field. Another consequence of not diffuse conditions in the field is the quantity or density of energy that affects every area.

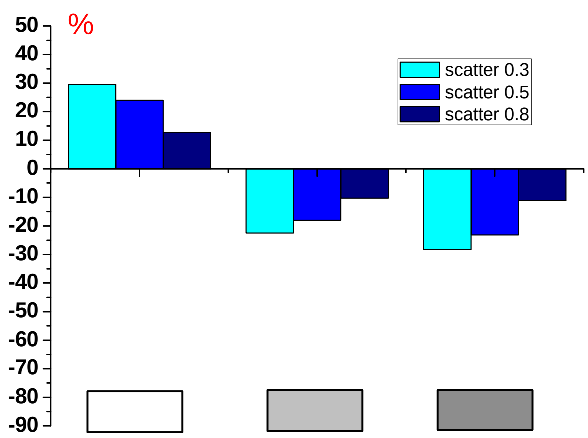

Fig.20. Incident energy density compared relatively to the average incident energy density for diffuse field for room R1 (gray scale – indication of surface in room)

Pictures 20 and 21 show the relative differences in the incident energy densities for surfaces in a room R1 and R2.Deviations of the calculated values from the uniform distribution of energy per surface are expressed in % relative to the expected value for all surfaces. It is notable that in both rooms, energy density is greater at largest surface and exceeds a mean value while smaller areas are affected with less energy than it would be expected in a diffuse field. The differences become more pronounced with increasing disproportion in size.

The differences are directly proportional to the differences in the coefficient of absorption that material shows when it is placed on certain surface.

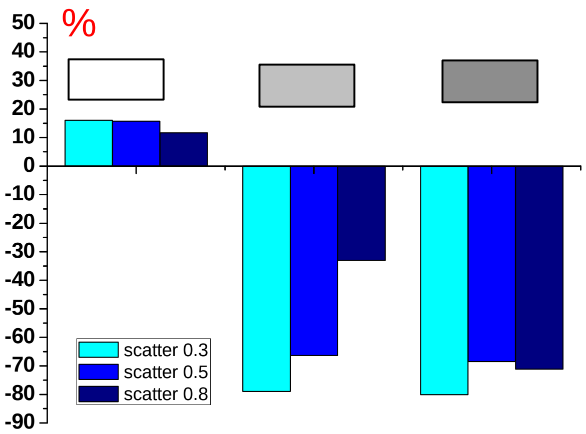

Fig.21. Incident energy density relatively compared to the average incident energy density for diffuse field in room R2 (gray scale – indication of surface in room)

4. CASE STUDY – A LARGE SPORTS HALL

The preceding analysis shows that the density of the incident energy can be considered as an indicator for the effective absorption of a surface. In this chapter similar analysis were done to show what we can expect in the real hall when we apply absorption materials on different surfaces. The analysis was performed at example of Belgrade arena sport hall. We use commercial software for sound field simulation. Two cases were observed. In one case absorption material were put on sports bleachers while in the other case absorption material were put on ceiling. Simulations were done for several setups of different scattering coefficients. Scattering coefficient values of 0.1, 0.25, 0.35, 0.5, 0.75 were used in simulations.

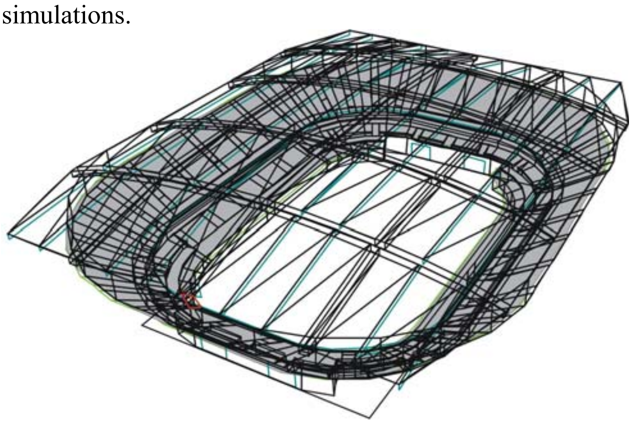

Fig.22. Perspective view of Belgrade arena hall with absorption on the sports bleachers

Simulations were performed also for three values of absorption coefficient 0.5, 0.8 and 1. 0. 1, 0.25, 0.35, 0.5, 0.75 and 1. Effective absorption coefficient were calculated according to simulated reverberation time and with reverberation time obtained from Sabine formula. Fig. 22 presents the perspective view of Belgrade arena hall in a case with absorption materials which were put on the sports bleachers. Calculated effective absorption coefficient of the materials was presented on the figure 23.

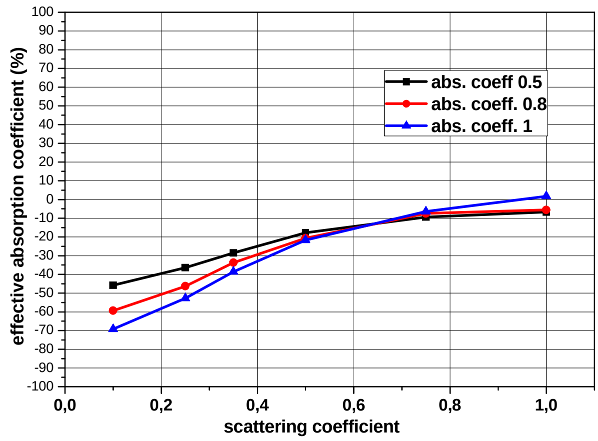

Fig.23. Calculated values of effective absorption coefficient when absorption were applied on sports bleachers

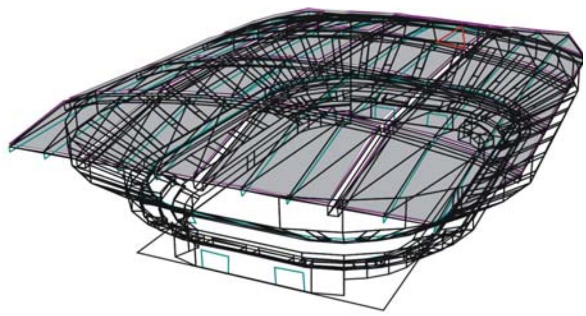

Fig.24. Perspective view of Belgrade arena hall with absorption on the ceiling

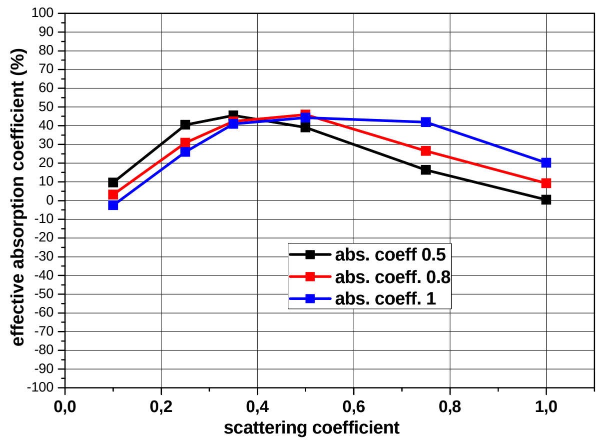

Fig.25. Calculated values of effective absorption coefficient when absorption were applied on ceiling

3. CONCLUSION

The analysis presented in this study confirmed the hypothesis that variation of room shape and proportion change the diffusivity of sound field in it. As a consequence, there are differences in density and angular distribution of incident energy on room's interior surfaces. The simulation in models of simple parallelepiped rooms has shown that differences in the density of energy hitting their interior surfaces can vary within the limits of ± 30% for relatively proportional rooms and with increasing the disproportion between dimensions these variations become larger. It was shown that in a large real sports hall manifested absorption coefficient of a material can vary in the range of -60% to +50% from its nominal value depending on its position in such room. The results of this analysis guides to the conclusion that information about diffuseness of the sound field is necessary precondition for room acoustic design and for calculation of absorption that should be applied to achieve the desired acoustic response.

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