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EFFECTIVENESS OF EN 12354-6 AND OTHER CALCULATION METHODS OF ROOM ACOUSTICS IN ENSURING REQUIRED ACOUSTIC CONDITIONS IN TYPICAL ENCLOSED SPACES

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ABSTRACT

Standard EN 12354-6 concerns the estimation of sound absorption and reverberation time in enclosed spaces. Annex D of the standard deals with the estimation of reverberation time in spaces where absorption coefficient varies much between the pair of opposite surfaces. The object of this study is to evaluate the usefulness of EN 12345-6 as acoustical consultant's design tool.

Reverberation times of a classroom, a patient room and an open-plan office were calculated as examples. Results were compared with those calculated according to traditional Sabine's formula and a quick engineering method. Open-plan office was also modelled with a room acoustical computer program.

In acoustical design of buildings, the calculated reverberation time does not need to be scientifically exact but it has to be calculated so reliably that required acoustical conditions will be achieved in the final situation when rooms will be furnished. Reverberation times according to traditional Sabine's formula do not deviate significantly from those achieved by EN 12354-6. Because of the complexity of the EN 12354-6 method, calculation needs more time.

The standard contains useful knowledge like the effect of furniture and its contribution in calculations, but in order to be a useful design tool EN 12354-6 needs to be simplified further. At the moment, consultants would probably prefer existing commercial solutions of room acoustical modelling when more exact calculation is required.

1 INTRODUCTION

Standard EN 12354-6 [1] contains a method for estimation of sound absorption and reverberation time in enclosed spaces. Annex D of the standard gives a method for estimation of reverberation time in spaces where absorption coefficient varies much between the pair of opposite surfaces. The object is to get information of the usefulness of the EN 12345-6 in acoustical designer's practical daily work. The paper deals only with the differences between calculation methods, not with the accuracy compared with measurements.

2 COMPARISON PROCEDURE

2.1 Assumptions

Target values for reverberation times have been taken from the Finnish standard SFS 5907:en [2]. For class rooms and open-plan offices, the standard includes requirements and recommendations for the Speech Transmission Index STI, too. The Finnish standard SFS 5907:en divides buildings in four acoustic classes. Here, target values for reverberation times are taken from class C which is corresponds to the official requirements. The allowed variation of the reverberation time is ± 0,1 s at each octave band except ± 0,3 s at 125 Hz. In class rooms, the general tolerance interval does not apply.

Table 1. Target values for the rooms studied. The allowed interval is given in table values too. Recommended value is given as bold text. STI for classrooms is not considered in this study.

Room	T (125 Hz)	T (250-4000 Hz)	STI
Classroom	**0,6 s … 0,8 s**…1,1 s	**0,6 s … 0,8 s**	(≥ 0,70)
Patient room	0,5 s … **0,8 s** … 1,1 s	0,7 s … **0,8 s** … 0,9 s	-
Open-plan office	0,2 s … **0,5 s** … 0,8 s	0,4 s … **0,5 s** … 0,6 s	≤ 0,55

Requirements are values in furnished rooms which means that the room has built-in furniture. In Finnish class rooms and patient rooms, the amount of built-in furniture is very small and its effect on the reverberation time is negligible. Both these room types are considered empty. In open-plan offices, furniture can have a large effect on room acoustical parameters as the recommended STI values mean that workstations have to be separated by screens. In the calculation of open-plan offices the built-in furnishing has been taken into account. However, it has a limited effect on the reverberation time.

Absorption material used in calculations is 50 mm thick mineral wool which is glued directly to the ceiling surface. The surfaces in the three studied room types are specified in chapter 2.2. Scattering coefficients have been considered low (between 0,1 and 0,3 for walls, floors, ceilings, windows and doors) as the rooms are empty.

2.2 Calculated rooms

Dimensions of calculated classrooms and patient room are shown in Figure 1. Room height of the class room is 2,9 m and volume 179 m^3. Height and volume of the patient room are correspondingly 2,68 m and 108 m^3. Outer walls in both rooms are concrete sandwich elements with 80 mm thick inner panels. Separating walls are lightweight partitions with two 13 mm thick plasterboards in both sides connected with 70 mm thick steel supports. The cavity is totally filled with mineral wool. Bearing structure of the ceiling is 320 mm thick hollow core slab (mass 400 kg/m^2). There is a soft vinyl floor covering, the ceiling is painted. In the class room, the absorbing mineral wool is placed on the ceiling so that there is a reflecting surface left in the middle of the ceiling. In the patient room, mineral wool is placed evenly on the ceiling.

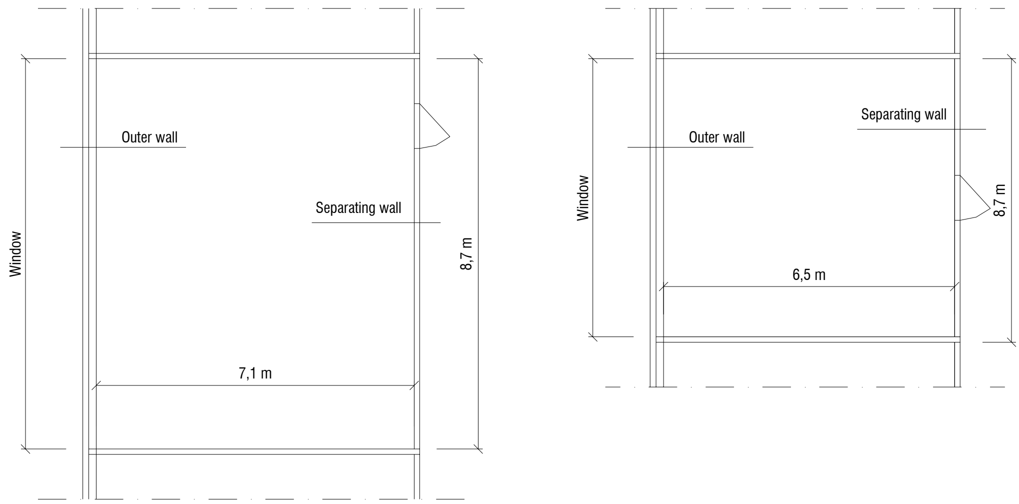

Fig. 1. Dimensions of calculated class rooms (left) and patient room (right).

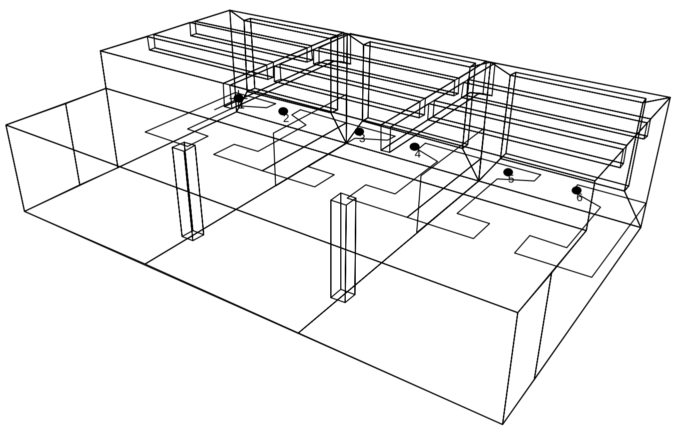

Fig. 2. The calculated open-plan office. Dots show the location of the workstations.

The calculated open-plan office is shown in figure 2. The office is located in an old industrial building, the room height is 3,47 m and volume 343 m^3. There is a installation channel which runs through the office. There the room height is 2,42 m. Outer walls are made of massive brickwork with inner surface plastered. Separating walls are lightweight partitions like in other rooms. Bearing structure is an old concrete slab-beam-column construction, slab thickness is 100 mm. Ceiling is painted and floor is covered with soft vinyl covering.

Absorbing mineral wool is placed on the ceiling between the old beams. Screens between adjacent work places are also absorbing as well as the surfaces of the installation channel.

2.3 Calculation methods

A simple engineering method is used for estimation of the amount of absorption material. Needed amount k [%] of absorption material is calculated as proportional area to the floor area. Only absorption material having high absorption coefficient (> 0,5 at high frequencies) is taken into account. Calculation is carried out only at octave band of 500 Hz from the reverberation time T [s], room height h [m] and absorption coefficient α_{500} of the material at 500 Hz:

$$k = \frac{16h}{T\alpha_{500}} \tag{1}$$

Second calculation method is Sabine's formula in its classical form. Reverberation time T is calculated from total absorption area A [m^2] and room volume V [m^3] as

$$T = 0{,}16\frac{V}{A} \tag{2}$$

Air absorption is also taken into account according to the standard EN 12354-6. However, it has some meaning only at the highest octave band of 4000 Hz.

Third method is calculation according to the annex D of the standard EN 12354-6. Temperature is chosen to be 22 ºC and relative humidity of 50-70 %. Method presented in the annex D of the standard divides the sound field into parts that graze the different surfaces and a part that is non-grazing. The different effect of the sound fields is taken into account by considering the balance of power between sound fields. At higher frequencies, the sound field is divided into diffuse sound field and three fields grazing the surfaces perpendicular to the axis x, y and z. Number of modes in those fields determines the importance of each field. At the lower frequency bands, the total sound field is considered with a reduced absorption effect due to the lack of diffusion.

In the case of open-plan office, instead of the Sabine's formula, room acoustical modelling software has been used for comparison of reverberation times (Odeon 6.5). If good acoustical environment was to be achieved, three following conditions should be in force at the same time [3]: reverberation time should be short (around 0,4 s); the background sound level should be sufficient to support speech privacy between workstations; screens should be relatively high to cut direct sound between workstations. This means that modelling is actually the only suitable method as the three conditions cannot be determined by the other methods.

2.4 Calculation procedure

Calculation and comparison procedure goes further as follows:

- when using engineering method, the target value is the upper end of the allowed interval in recommended reverberation times (Table 1). In class rooms, reverberation time is 0,8 s, in patient rooms 0,9 s. At this stage of the evaluation only the absorbing material is taken into account. In the final situation, the presence of other materials will contribute to lower the above reverberation time values. From those values, amount of needed mineral wool area is calculated as percentage of floor area.

- Sabine's formula. Absorption of all surfaces in room and air absorption are taken into account. The objective is to keep reverberation time of the room below the upper limit. The amount of the needed area of absorbing mineral wool is also given as percentage of floor area. For open-plan office, this has been achieved by modelling.

- European Standard EN 12354-6, annex D.2. The amount of the needed area of absorbing mineral wool is taken as amount given by Sabine's formula. Mean values of reverberation times are considered as the results. The standard gives three possibilities to choose the correct the result: reverberation time T_d in diffuse sound field, mean of the three reverberations in x, y and z directions and diffuse sound field denoted as $T_{estimate}$ and combination of $T_{estimate}$ and reverberation time at low frequencies; this is denoted here as $T_{combination}$. Results from the calculation procedure are shown in Tables 2-4.

Table 2. Calculated values for the class room.

Method	Predicted reverberation time						Absorption amount
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 HZ	4000 Hz	
Engineering	-	-	0,8 s	-	-	-	61 %
Sabine	1,1 s	0,7 s	0,6 s	0,7 s	0,6 s	0,5 s	50 %
T_d	1,1 s	0,8 s	0,7 s	0,7 s	0,7 s	0,6 s	50 %
$T_{estimate}$	1,4 s	1,1 s	1,0 s	1,0 s	0,9 s	0,6 s	50 %
$T_{combination}$	1,3 s	1,0 s	1,0 s	1,0 s	0,9 s	0,6 s	50 %

Table 3. Calculated values for the patient room.

Method	Predicted reverberation time						Absorption amount
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 HZ	4000 Hz	
Engineering	-	-	0,9 s	-	-	-	54 %
Sabine	0,9 s	0,7 s	0,7 s	0,7 s	0,7 s	0,5 s	50 %
T_d	1,0 s	0,8 s	0,7 s	0,8 s	0,7 s	0,6 s	50 %
$T_{estimate}$	1,3 s	1,0 s	0,9 s	1,0 s	0,9 s	0,6 s	50 %
$T_{combination}$	1,2 s	1,0 s	1,0 s	1,0 s	0,9 s	0,6 s	50 %

Table 3. Calculated values for the open-plan office.

Method	Predicted reverberation time						Absorption amount
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 HZ	4000 Hz	
Engineering	-	-	0,6 s	-	-	-	97 %
Modelling	1,0 s	0,8 s	0,5 s	0,5 s	0,5 s	0,4 s	106 %
T_d	0,8 s	0,5 s	0,4 s	0,4 s	0,4 s	0,4 s	106 %
$T_{estimate}$	1,1 s	0,7 s	0,6 s	0,6 s	0,5 s	0,4 s	106 %
$T_{combination}$	1,0 s	0,8 s	0,6 s	0,6 s	0,5 s	0,4 s	106 %

3 CONCLUSIONS

European Standard EN 13354-6 offers three alternative ways to calculate reverberation times. The designer is thereby entitled to ask which of the three results is most reliable. When conducting predictions, decisions have to be taken regarding situations which the standard does not address. For example, EN 12354-6 requires that scattering coefficients of surfaces are used. However, no scattering coefficients are available at this date, nor advice to estimate these. Such information lacks also in the literature and handbooks. This means of the use of EN 12354-6 relies a lot on experience and estimation from acoustic consultants.

In normal temperature and humidity conditions, air absorption and sound speed have quite a small effect on the reverberation time. Usually, the sound speed affects the second decimal of reverberation time. Air absorption has a meaningful effect only on reverberation time at the octave band of 4000 Hz. In practical solutions, the result does not need to be scientifically exact. Though, it has to be so accurate that reverberation time can be calculated so reliably that good acoustic conditions can be achieved. Comparison of results from Sabine based calculation and calculations based on EN 12354-6 will in some cases indicate that EN 12354-6 is conservative and will tend to ask for higher amount of absorption to achieve a certain reverberation time. However, this does not always correspond to practical experience: furniture will correct the reverberation time in the final situation. Thus, it can be seen that the method of EN 12354-6 does not necessarily give much additional value. In regards of the time spent to conduct the calculations, it could even be asked whether EN 12354-6 is even smaller.

In this study, the two first room types were very simple but the file used in the calculations is around 90 lines long. This implies also a risk for errors. If the spaces become a bit more complicated, the calculation method should be coded as a computer programme. However, there are already commercial solutions like Odeon, and consultants designing complicated spaces use them in any case. When an expert designs simple spaces, he uses his experience and simple solutions. The actual problem is the final result, the acoustical behaviour of the real space. A method to achieve and fulfil the requirements is a secondary question.

The chapter “Scope” of the standard EN 12354-6 says that the method presented in the standard “is intended for acoustical experts”. So it should be even though acoustical experts probably would prefer other methods than this standard. For ordinary users like architects, who should decide about the amount and quality of the absorption material to be used, this method is far too complicated. Future revision of European Standard EN 12354-6 should strive for a more simple and user-friendly method. A simple alternative calculation method will be presented in this conference by Erling Nilsson.

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