BNAM 2018
Baltic-Nordic Acoustics Meeting
15-18 April 2018
Harpa, Reykjavík, Iceland

Suggested acoustical requirements for restaurants, canteens, and cafeterias

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The concept of 'universal design' means accessibility for all in public buildings, and this includes the acoustical conditions. The acoustical challenges are particularly pronounced in restaurants and similar eating facilities. Especially elderly people and people with impaired hearing rate restaurants high on the list of public spaces with serious acoustical problems. The most important noise source in a crowded restaurant is the speech from conversation among other guests. With many people gathered, the noise from speech can reach a very high sound pressure level if the room does not have a sufficient amount of sound absorption. The 'acoustic capacity' can be used to specify the maximum number of persons in a restaurant that allows a sufficient quality of verbal communication for people with normal hearing, and this can be used as a guide for existing restaurants. However, the reverberation time may be more convenient for defining acoustical requirements for new spaces. A closer study of the conditions for verbal communication in a noisy environment has shown that the volume per person is a key parameter in connection with the reverberation time and the distance of communication. Maximum reverberation times as function of volume per person are suggested for the purpose of sound classification of restaurants.

1 Introduction

In many countries, there is a growing awareness of the concept called universal design, which means accessibility for all in public buildings [1]. This is not limited to the physical access to a building, but includes also the acoustical conditions, which should be suitable for everybody. A recent investigation in Norway had the aim to throw light on the problems due to the acoustical conditions in various kinds of rooms and spaces for people with impaired hearing or vision [2]. It was found that the acoustical problems were particularly pronounced in cafeterias, restaurants and cafés and 52 % of people with impaired hearing were severely or much disturbed by noise in these places. The data in Table 1 show that 51 % of the people with impaired hearing report "often/always" difficulties having a conversation in these places. If "sometimes" is included, the percentage increases to 88 %. For the people with impaired vision (but normal hearing) the percentage having difficulties with conversations in the same kind of places "often/always" and "sometimes" is 51 %.

It is a well-known problem that many restaurants have poor acoustics, and it gets very noisy when the restaurant is fully occupied. Having a conversation can be difficult when the ambient noise is too high. Measurements during a dining party showed sound pressure levels of 83 dB to 87 dB (2 h averaging), Rindel [3]. In a recent study of school cafeterias, measured sound pressure levels of 80 dB to 88 dB (15 minutes averaging) were reported, Pinho et al. [4]. Such high noise levels are clearly unacceptable from the point of view of universal design. In many cases the acoustical problems are so severe, that it is not realistic to expect simple and inexpensive solutions. On the contrary, a general solution to the problem may require a radical change in how restaurants and other eating facilities are designed.

Table 1. Statistics of replies to the question: How often is it difficult to have a conversation in cafeterias, restaurants and cafés due to noise from speech? Data from [2].

Reply	Hearing impaired		Visually impaired	
	Number	Percent	Number	Percent
Often / always	129	51 %	49	23 %
Sometimes	92	37 %	59	28 %
Seldom	22	9 %	34	16 %
Never	8	3 %	70	33 %
Total	251	100 %	212	100 %
No reply	20		38	
N	271		250	

2 Prediction models

2.1 Speaking in a noisy environment

The vocal effort varies with the ambient noise due to the Lombard effect. For noise levels above 45 dB, the speech level in a distance of 1 m $L_{S,A,1m}$ can be expressed by the equation:

$$L_{S,A,1m} = 55 + c\,(L_{N,A} - 45), \quad \text{(dB)} \tag{1}$$

where $L_{N,A}$ is the A-weighted sound pressure level (SPL) of the noise and c is the Lombard slope, which can be set to c = 0.5,see [5].

2.2 A simple prediction model for the speech noise level

A calculation model for the ambient noise level was derived by Rindel [5] applying simple assumptions concerning sound radiation and a diffuse sound field in the room. The suggested simple prediction model can be expressed in the equation:

$$L_{N,A} = 93 - 20\lg\left(g\left(\frac{0.16\,V}{N \cdot T} + A_p \right) \right), \quad \text{(dB)} \tag{2}$$

The group size g is the average number of people per speaking person. The room has the volume V (m^3), and the reverberation time is T (s) in unoccupied state. The number of people in the room is N, and A_p is the sound absorption per person in m^2, which may be between 0.2 m^2 and 0.5 m^2 depending on the clothing. The interesting consequence of Equation (2) is that the ambient noise level increases by approximately 6 dB for each doubling of number of people present. The prediction model is based on statistical conditions meaning that it may not apply to small rooms with a capacity less than, say 30 persons.

Figure 1 shows the predicted ambient noise level using Equation (2) with g = 3.5 and A_p = 0.35 m^2. Both the reverberation time and the volume per person are important parameters for the control of the noise level. If the reverberation time is more than 1.5 s and the volume per person is less than 10 m^3, the ambient noise level may exceed 80 dB, i.e. very loud and clearly unpleasant.

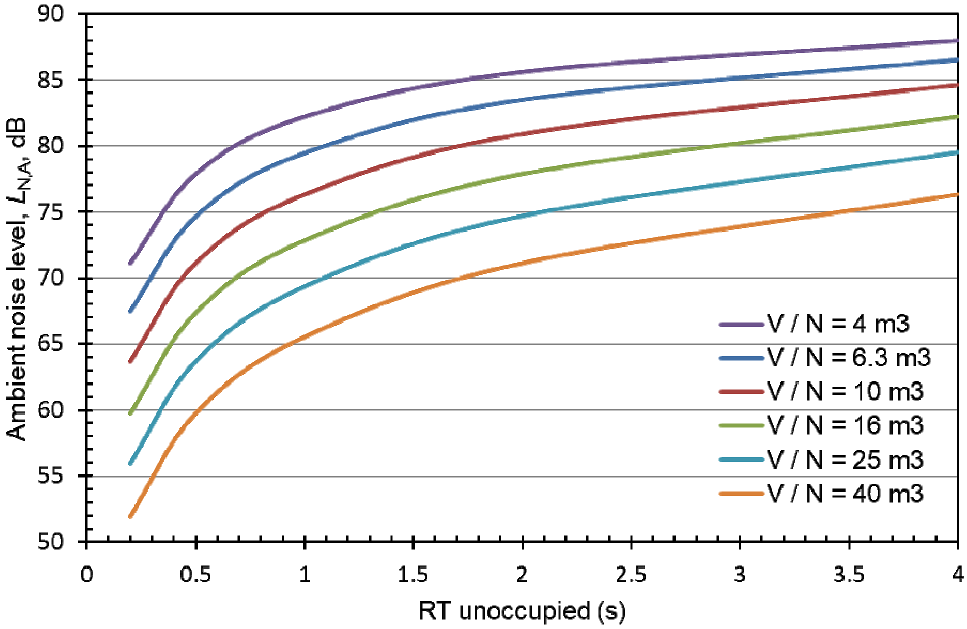

Figure 1. The ambient noise level as function of reverberation time (RT) and volume per person according to the prediction model, Equation (2).

2.3 A prediction model for the quality of vocal communication

The quality of vocal communication is related to the signal-to-noise ratio (SNR), defined as the difference between the A-weighted SPL of the direct sound from a speaking person in a certain distance *r* and the A-weighted SPL of the ambient noise in the room.

The SNR is not influenced by the Lombard effect, because we can assume that on average all speaking persons in the room use the same vocal effort. The increase in vocal effort due to ambient noise is the same for the speaker we are listening to and for all the other speaking persons in the room. The SNR in the distance *r* can be calculated from the absorption area per person (*A*/*N*) and the group size *g*:

$$\mathrm{SNR} = L_{\mathrm{S,A,1m}} - L_{\mathrm{N,A}} = 10\lg\left(\frac{Q\,A\,g}{16\pi r^2 N}\right) \cong 10\lg\left(\frac{Q\,g}{100\pi r^2}\cdot\frac{V}{N\,T}\right),\ \mathrm{(dB)} \tag{3}$$

where Q is the directivity of a speaking person ($Q = 2$ is assumed in front of the mouth). A similar formula was derived by Pierce [6, pp 276-277]. It applies to A-weighted ambient noise levels between 45 dB and 85 dB, or a range of speech levels between 55 dB and 75 dB. The corresponding SNR range is from – 10 dB to +10 dB.

For the evaluation of the acoustics, we can apply the quality of verbal communication, which is related to SNR, see Table 2. Thus a SNR between 3 dB and 9 dB is characterized as "good", the range between 0 dB and 3 dB is "satisfactory", and SNR below -3 dB is "insufficient" [7]. It is suggested to focus on the border between sufficient and insufficient, i.e. SNR = -3 dB, as a minimum requirement for acoustical design of restaurants. These considerations may be valid for normal hearing people. However, ISO 9921 [8, Section 5.1] states that "people with a slight hearing disorder (in general the elderly) or non-native listeners require a higher signal-to-noise ratio (approximately 3 dB)". This improvement is relative to that required for normal-hearing listeners, and thus for this group of people a SNR $\geq$ 0 dB should be applied to represent "sufficient" conditions, and SNR $\geq$ 3 dB to represent "satisfactory" conditions.

The quality of communication can be improved if the listener can come closer to the speaking person. Reducing the distance from 1 m to 0.7 m means a 3 dB better SNR, and coming as close as 0.5 m yields another 3 dB improvement. This is the obvious solution for maintaining communication in a too noisy environment, but it does not change the noise level, which makes the environment unpleasant for a longer stay.

Table 2. Quality of verbal communication, dependent on the signal-to-noise ratio. Adapted from Lazarus [7, Table 2].

Quality of verbal communication	SNR dB
Very bad	< -9
Insufficient	(-9; -3)
Sufficient	(-3; 0)
Satisfactory	(0; 3)
Good	(3; 9)
Very good	> 9

3 Acoustic capacity and quality of verbal communication

3.1 The concept of acoustic capacity

The above findings can be used for a room with known absorption area to estimate the maximum number of persons in order to keep a certain quality of verbal communication. So, the concept acoustic capacity for an eating establishment is defined as the maximum number of persons in a room allowing sufficient quality of verbal communication in a distance of 1 m [9].

For a person with normal hearing, a sufficient quality of verbal communication requires SNR > -3 dB. This means that the ambient noise level must not exceed 71 dB for communication in a distance of 1 m. From Equation (2) is found the number of persons corresponding to 71 dB, i.e. the acoustic capacity:

$$N_{\max} \cong \frac{V}{20T} \tag{4}$$

where V is the volume in m^3 and T is the reverberation time in seconds in furnished but unoccupied state at mid frequencies (500 Hz to 1000 Hz). Here is used group size $g = 3.5$ and absorption per person $A_p = 0.35$ m^2.

3.2 Table size and distance of communication

Table 3 gives the SNR as function of ambient noise level and distance of communication. The most important cells in the table are those with SNR = -3 dB, because this is the limit for sufficient quality of verbal communication.

Examples of tables in a restaurant are shown schematically in Figure 2. Sitting at a long table you can have a conversation with the person next to you ($r = 0.5$ m) or across the table ($r = 0.7$ m to 1.0 m) where distance depends on the width of the table. The round table for 10 people is very common in a banquet, and having a conversation across the table ($r = 2$ m) is often quite impossible, as this would require a noise level of maximum 59 dB, see Table 3. However, conversations may be possible between two or three persons ($r = 1.0$ m and $r = 0.5$ m). If the noise level goes up to 83 dB, it is only possible to speak with a person sitting next to you. Similarly we get the typical distances of conversation for the other tables in Figure 2; round table with six people ($r = 1.4$ m), square table with four people ($r = 1.0$ m), and small table with two people ($r = 0.7$ m). These distances are approximate and rounded to match the examples shown in Table 3.

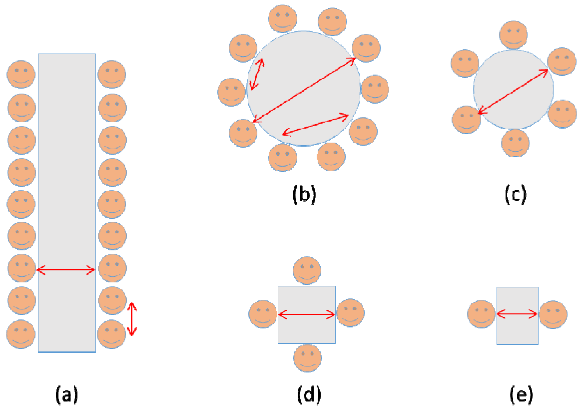

Figure 2. Examples of tables with indication of distances of verbal communication. (a) Long table, typical distances 1.0 m and 0.5 m; (b) Round table for ten, typical distances 2.0 m, 1.0 m and 0.5 m; (c) Round table for six, typical distance 1.4 m; (d) Square table for four, typical distance 1.0 m; (e) Square table for two, typical distance 0.7 m

Table 3. Quality of verbal communication in terms of calculated SNR as function of distance and ambient noise level.

Distance	SNR (dB) - quality of verbal communication						
	Ambient noise level, $L_{N,A}$, dB						
r, m	53	59	65	71	77	83	89
0.35	15	12	9	6	3	0	**-3**
0.5	12	9	6	3	0	**-3**	-6
0.7	9	6	3	0	**-3**	-6	-9
1.0	6	3	0	**-3**	-6	-9	-12
1.4	3	0	**-3**	-6	-9	-12	-15
2.0	0	**-3**	-6	-9	-12	-15	-18

4 Suggested acoustical requirements for restaurants

The adaptation of the universal design concept [1] means that it is necessary to define acoustical requirements for restaurants, cafeterias and other public eating facilities. The key parameters that control the acoustical conditions are volume V, reverberation time T and number of people N, i.e. number of seats. The graphical presentation in Figure 3 is based on Equation (3), which yields the SNR as function of $V/(N\,T)$ and the distance of verbal communication r.

In the reference distance $r = 1.0$ m we have $V/(N\,T) = 20$ for the borderline between sufficient and insufficient quality of vocal communication, so this is taken as basis for the acoustical requirement. However, this might be too strict because it is seldom that a restaurant fully occupied. An 80 % occupancy is considered a more realistic basis for the requirement. Then the borderline becomes $V/(N\,T) = 16$ and the requirement for the reverberation time yields:

$$T \leq \frac{1}{0.80 \times 20} \cdot \frac{V}{N} \cong 0.063 \cdot \frac{V}{N}, \quad \text{(s)} \tag{5}$$

This shows that the requirement must be related to the volume per person, which means that it is necessary to know the maximum number of seats in the room. In some cases, this maximum number has to be accepted by the fire authorities, and an emergency escape plan that states the allowed maximum number of guests must be mounted clearly visible in the room. In other cases, the intended maximum number of occupants is provided on the architect's drawing.

In order to fulfil the acoustical requirement there are three possibilities to consider:

- The volume should be as big as possible. This is something to consider in the early stage of planning. Actually, many acoustically good restaurants have a high ceiling.
- Sound absorbing materials must be applied on surfaces where it is possible. The ceiling is obvious, but often parts of the walls must also be included
- The seating plan should not be too crowded. The acoustic capacity should not be exceeded by more than 25 %.

Some countries use sound classification for buildings, e.g. four classes A, B, C, and D where class A is best, class C is minimum requirements for new buildings, and class D is applicable for older buildings. Table 4 shows suggested requirements for the reverberation time in restaurants divided into four classes. These sound classes are indicated in Figure 3.

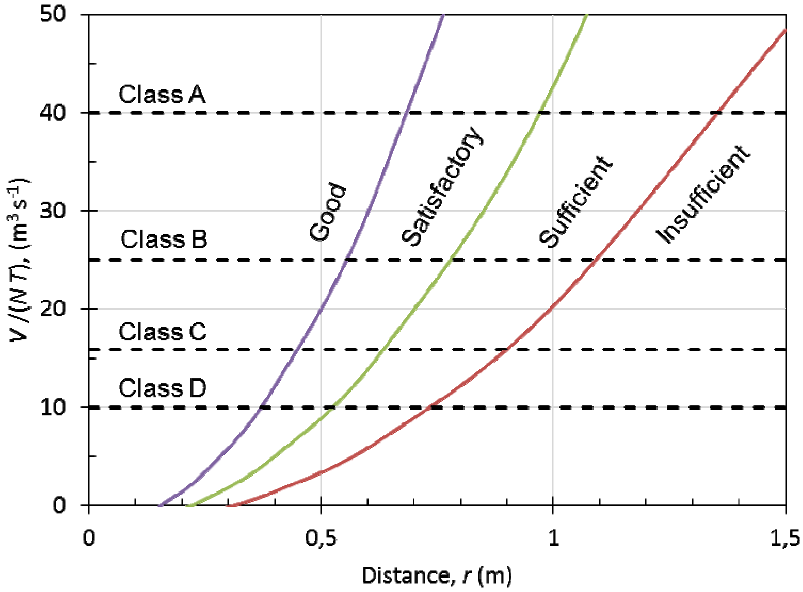

Figure 3. Quality of verbal communication as function of distance and the parameter *V*/(*N T*). Suggested acoustical requirements in four sound classes are shown with dotted lines.

Table 4. Suggested acoustical requirement in restaurants in four sound classes. The SNR in a distance of 1 m is shown as a function of the occupancy (number of people in percentage of the total number of seats).

	Sound class			
	Class A	Class B	Class C	Class D
Volume per person / Reverberation time (m^3/s)	40	25	16	10
Occupancy	SNR (dB) in 1 m distance			
100 %	0	-2	-4	-6
80 %	1	-1	-3	-5
63 %	2	0	-2	-4
50 %	3	1	-1	-3
40 %	4	2	0	-2
32 %	5	3	1	-1
25 %	6	4	2	0

Table 4 also shows the quality of verbal communication in terms of SNR in a distance of 1 m for different percentages of occupancy. For instance, 100 % occupancy in class A gives SNR = 0 dB, which is the borderline between satisfactory and sufficient. The same SNR = 0 dB is obtained in class C with 40 % occupancy. Figure 4 shows the estimated ambient noise level as function of occupancy for the four sound classes.

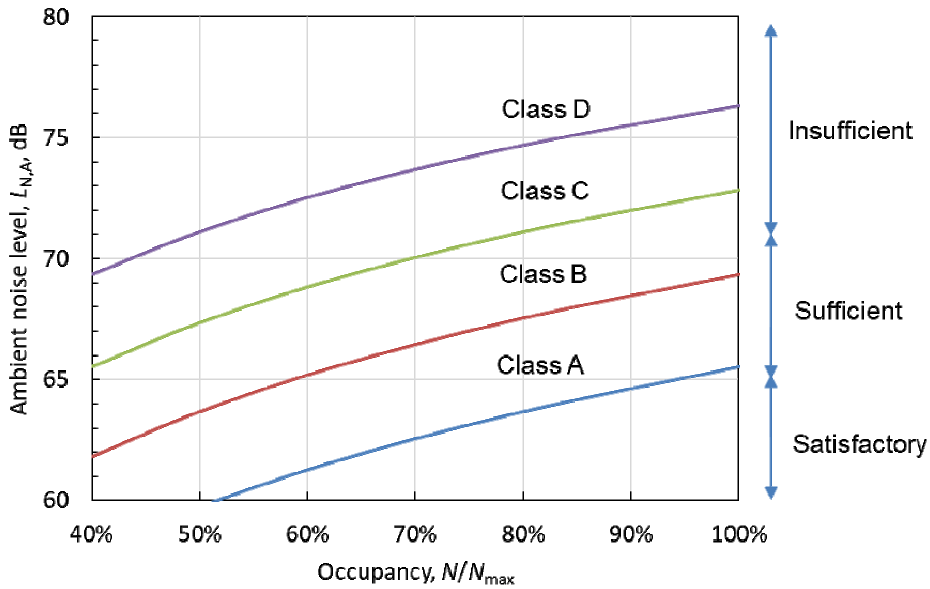

Figure 4. The ambient noise level as function of occupancy and the suggested sound classes, estimated with the prediction model, Equation (2). The quality of verbal communication in a distance of 1 m is indicated on the right side of the figure.

5 Discussion

Restaurants and other eating facilities cannot be considered a homogeneous group of spaces. There is a huge spread from restaurant with an esteemed chef in the kitchen to a school cafeteria or a pub. The sound classification system may be used to reflect the ambition level with respect to a pleasant environment with acoustic comfort. So, class A may be applied for the finest restaurants, class B for banquet halls, class C for bistros, foot courts and other restaurants, class D for cafeterias, canteens and pubs.

It is obvious that the suggested acoustical requirements are not easy to fulfil, which could also be expected because the problems to be solved are quite significant. The physical parameters that controls the problem shall be discussed here. They are the reverberation time, the volume, and the total number of seats. They are connected, which gives some freedom for possible solutions.

In some cases the total number of seats is more or less given from the start. Then the necessary volume can be estimated, although it also depends on the reverberation time. As an example we assume that it is possible to get a reverberation time T = 0.5 s, which will require a significant amount of sound absorption. Then the volume requirement can be split into the room height and the floor area, i.e. the area per seat. Table 5 gives examples of how this can be solved in each of the four sound classes. In class A is needed a quite high room (H = 5 m) and a spacious seating plan. Actually, even higher ceilings are not unusual in restaurants and banquet rooms. If the height is 8 m, it is possible to reduce the area per seat to 2.5 m^2 and still fulfil the class A requirement.

The next design question may be, how to achieve a sufficiently short reverberation time. Surfaces on the walls must be used for sound absorbing materials, in addition to the obvious ceiling area. Of course, a thick carpet on the floor could help, but in most cases this is not an option. Then a possibility may be to use sound absorbing screens or half-walls.

Table 5. Examples of room heights and seat densities in restaurants in four sound classes. The assumption in these examples is a reverberation time $T = 0.5$ s.

($T = 0.5$ s)	Sound class			
	Class A	Class B	Class C	Class D
Volume per person / Reverberation time (m^3/s)	40	25	16	10
Room height, H (m)	5	4	4	3
Area per seat, S/N (m^2)	4.0	3.2	2.0	1.7

6 Conclusion

For the characterization of the acoustical conditions in restaurants and similar environments, the quality of verbal communication is applied in addition to the ambient noise level. A signal-to-noise ratio of -3 dB for a speaker in a distance of 1 m corresponding to an ambient noise level of 71 dB is suggested as a basis for requirements. This leads to a combined requirement for the reverberation time and the volume per person. The reverberation time should be as short as possible, and in addition a sufficient volume is a physical necessity for satisfactory acoustical conditions. A sound classification with four classes, A through D is suggested. This makes sense because the same acoustical requirements may not apply to all kinds of eating facilities, e.g. the need for acoustical comfort is different in a fine restaurant and in a pub or a school cafeteria. However, in order to fulfil the principle of universal design, the acoustical design of restaurants and similar environments must be changed significantly, meaning larger volumes and shorter reverberation times than has been usual.

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