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a European perspective

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Classroom acoustics design for speakers' comfort and speech intelligibility: a European perspective

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Summary
Current European regulatory requirements or guidelines for reverberation time in classrooms have the goal of enhancing speech intelligibility for students and reducing noise levels in classrooms. At the same time, school teachers suffer frequently from voice problems due to high vocal load experienced at work. With the aim of improving teachers' working conditions, this paper proposes adjustments to current regulatory requirements on classroom acoustics in Europe from novel insights on classroom acoustics design that meet simultaneously criteria of vocal comfort for teachers and speech intelligibility for students. Two room acoustic parameters are shown relevant for a speaker: the voice support, linked to vocal effort, and the decay time derived from an oral-binaural impulse response, linked to vocal comfort. Theoretical prediction models for room-averaged values of these parameters are combined with a model of speech intelligibility based on the useful-to-detrimental ratio and empirical models of signal-to-noise ratio in classrooms in order to derive classroom acoustic guidelines, taking into account physical volume restrictions linked to the number of students present in a classroom. The recommended values of reverberation time in fully occupied classrooms for flexible teaching methods are between 0.45 s and 0.6 s (between 0.6 and 0.7 s in an unoccupied but furnished condition) for classrooms with less than 40 students and volumes below 210 m^3. When designing larger classrooms, a dedicated acoustic study taking into account considerations about geometry, material and speaker/audience placements can help to provide good speech intelligibility across the audience, while increasing the voice support and reducing the vocal effort.

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1. Introduction

The acoustic design of classrooms, both in terms of noise control and room acoustics, is relevant because it affects the quality of oral communication between teachers and students, which is still the most common way of teaching and learning. Students need a physical environment which preserves speech intelligibility, makes the oral message easy to listen and engages them into the process of learning. At the same time, teachers' speech needs to be understood; they have to speak comfortably and without straining their voice.

Traditionally, classroom acoustic guidelines and regulatory requirements have been designed based on speech intelligibility considerations. The present paper is based on a recent publication [1] and it summarises the results of past years' research on teachers' vocal comfort and effort in order to derive guidelines that meet simultaneously criteria of vocal comfort for teachers and speech intelligibility for students. This novel approach may be useful to update existing regulatory requirements on classroom acoustics.

2. Current European guidelines and regulatory requirements

Classroom acoustics is a concern of increasing awareness, as demonstrates the increasing number of countries in Europe which have included classroom acoustic regulatory requirements in their building codes during the last 5-10 years (e.g. Spain) or which have made these requirements more strict (e.g. Denmark and Norway). A summary of the requirements regarding reverberation time in ordinary classrooms for general primary and secondary education is shown in Table I. Some of the countries (Denmark, Norway, UK, Spain) establish maximum values for the reverberation time whereas others (Germany, France) establish target ranges as a function of the volume. In particular, Germany establishes a relationship between the volume and the target reverberation time T_{soll} (*soll* is the German word for target) and defines a range of accepted values around that target reverberation time for different frequency bands. This is a trend that other European countries follow (e.g. Austria [2], Switzerland [3], Belgium [4]).

The Norwegian Building Code expresses the acoustic requirements of classrooms as class C of Classification Scheme NS8175:2012 [8]. A Classification Scheme sets acoustic criteria to classify classrooms (and other spaces) in different levels of acoustical quality, called classes. In NS8175:2012, class A has the highest acoustic quality and class D has the lowest (Classification Schemes in other countries might have different criteria and denomination for the classes). In NS8175:2012, reverberation time in classrooms should be not higher than 0.4 s to achieve class A or B, 0.5 s for class C or 0.6 s for class D. Sweden and Iceland also have Classification Schemes. The trend in Classification Schemes is that classrooms are rated better the shorter the reverberation time.

A more thorough presentation of classroom acoustic requirements and recommendations in European countries is found in [1]. Rasmussen *et al.* [11] present a similar study focused on Nordic countries.

3. Room acoustic parameters for a speaker

Room acoustics parameters that aim at characterising the propagation of sound between the mouth and the ears of a speaker are derived from an *oral-binaural room impulse response* (OBRIR), i.e. an impulse response measured at a microphone located at the end of the ear canal of a dummy head when a loudspeaker inside its mouth acts as the source. The derivations that follow assume the use of a head and torso simulator (HATS) from Brüel & Kjær type 4128. Two parameters are found relevant: the *voice support* ST_V and the *decay time* $\text{DT}_{40,\text{ME}}$.

3.1. Voice support

The voice support ST_V is a measure of the degree of amplification of a room to the voice of a speaker at his own ears [12]. More specifically, it is defined as the difference between the reflected sound level (L_R) and the airborne direct sound level (L_D) of the voice of a speaker, as found in an OBRIR:

$$\text{ST}_V = L_R - L_D \text{ (dB)}. \tag{1}$$

The voice support is related to the *vocal effort* experienced by a speaker in different rooms [13–18], and is negatively correlated to the radiated voice power level L_W. An empirical model that represents the average variations in voice power level ΔL_W of a speaker, with respect to the average voice power level used in free-field ($L_{W,0}$), as a function of ST_V [13, 14] when low background noise levels are present is

$$\Delta L_W = L_W - L_{W,0} = \begin{cases} -13 - 0.78\,\text{ST}_V \text{ (dB)}, & -14.5\text{dB} \le \text{ST}_V \le -6.5\text{dB} \\ 0.5 - 135\log\left(10^{\text{ST}_V/10} + 1\right) \text{ (dB)}, & \text{ST}_V \le -14.5\text{dB} \end{cases} \tag{2}$$

A prediction model for ST_V [12], averaged across positions in a room, is presented in Fig. 1, considering a flat T_{60} across frequency and a room of proportions 2.8:1.6:1. ST_V decreases almost linearly with the logarithm of V (except for the largest volumes at low reverberation times) and increases with T_{60}. The axis on the right edge shows ΔL_W according to Eq. (2).

3.2. Decay time $\text{DT}_{40,\text{ME}}$

The decay time $\text{DT}_{40,\text{ME}}$ [18] (in which the subindex ME stands for Mouth-to-Ears) is defined as the time it would take for the backwards integrated energy curve of an OBRIR to decay 60 dB after the arrival of the direct sound, calculated from the initial decay of 40 dB (value of the subindex in $\text{DT}_{40,\text{ME}}$) and assuming a linear decay. Differently from traditional impulse responses in which the receiver is far away from the source, in an OBRIR source and receiver are located very close to each other, so the direct sound has much more energy than the reflected sound. Therefore, the $\text{DT}_{40,\text{ME}}$ is very sensitive to the direct-to-reflected sound level difference.

In a previous study [18], it was found that the general sensation of *vocal comfort* $\hat{C}$, a score given by talkers on questionnaires, is non-linearly related to $\text{DT}_{40,\text{ME}}$ for talkers with healthy voices. A fitted quadratic regression model ($R^2 = 0.65; p < 0.001$) is

$$\hat{C} = -6.4\,\text{DT}^2_{40,\text{ME}} + 5.8\,\text{DT}_{40,\text{ME}} - 1.0, \tag{3}$$

The optimum vocal comfort $\hat{C}_{\text{opt}}$ is located at $\text{DT}_{40,\text{ME,opt}} \approx 0.45$ s. Three categories of vocal comfort are defined: recommended, acceptable, and non-acceptable. The recommended vocal comfort range is where the vocal comfort $\hat{C}$ is more than 70% of the optimum value, thus for $\text{DT}_{40,\text{ME}}$ between 0.35 and 0.55 s. In the acceptable range, the vocal comfort is less than 70% of the optimum value but it is higher than the average ($0 \le \hat{C} \le \hat{C}_{\text{opt}}/\sqrt{2}$), which occurs at two different intervals: $\text{DT}_{40,\text{ME}}$ from 0.25 to 0.35 s and from 0.55 s to 0.65 s. The non-acceptable range is given by a less than average vocal comfort ($\hat{C} \le 0$), which occurs for $\text{DT}_{40,\text{ME}} < 0.25$ s and for $\text{DT}_{40,\text{ME}} > 0.65$ s.

Table I. Regulatory requirements for classroom reverberation time in different European countries, in addition to details about the conditions of the criteria.

Country	Standard/ Guideline	Year	Required T [s]	Occupancy	Details of T
Denmark	BR 2010 [5]	2010	≤ 0.6	Furnished unoccupied	125 Hz to 4 kHz. Limit for each 1/1 octave band. 125 Hz: +20% accepted.
France	Arrêté du 25 avril 2003 [6]	2003	$V < 250$ m^3: $0.4 \leq T \leq 0.8$ $V > 250$ m^3: $0.6 \leq T \leq 1.2$	Furnished unoccupied	Average 500–1000–2000 Hz
Germany	DIN 18041:2004 [7]	2004	$T_{\text{soll}} = 0.32 \log \frac{V}{\text{m}^3} - 0.17$ ($V = 100\text{m}^3 \rightarrow T_{\text{soll}} = 0.47$s $V = 250\text{m}^3 \rightarrow T_{\text{soll}} = 0.60$s)	Fully occupied	Requirement for 100 Hz to 5 kHz. Frequency band values with ±20% tolerance in 250 Hz – 2 kHz, extending progressively to +20%/ − 40% toward 100 Hz and 5 kHz. Unoccupied values +0.2 s.
Norway	NS8175:2012 [8]	2012	≤ 0.5 (Class C in [8])	Furnished unoccupied	125 Hz to 4 kHz. Limit for each 1/1 octave band. 125 Hz: +30% accepted.
Spain	CTE DB-HR [9]	2009	$V < 350$ m^3: ≤ 0.5	Fully occupied	Average 500–1000–2000 Hz. Limit for empty unfurnished classroom: $T < 0.7$s
UK	BB93 [10]	2003	Nursery & primary: ≤ 0.6 Secondary: ≤ 0.8	Unfurnished unoccupied	Average 500–1000–2000 Hz. T may gradually increase at low frequencies (250 Hz and 125 Hz) but no more than 30% over limits

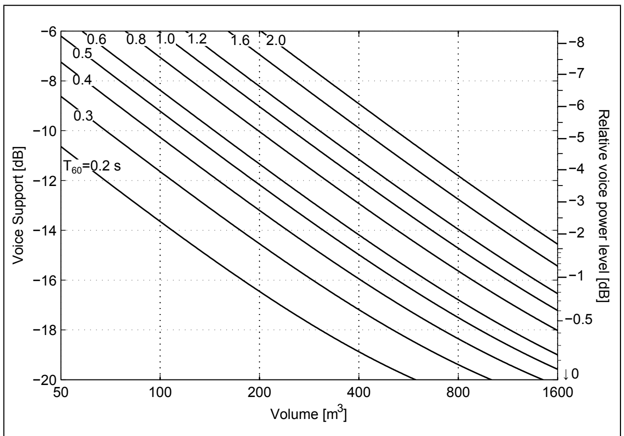

Figure 1. Average voice support versus room volume for different values of T_{60}, considering a flat T_{60} across frequency. The axis on the right edge shows average voice power level variations according to Eq. (2).

A prediction model for the room-averaged $\text{DT}_{40,\text{ME}}$ [18] as a function of the reverberation time and the volume in the room, as an average in the octave bands of 2 kHz and 4 kHz, considering a flat T_{60} across frequency and a room of proportions 2.8:1.6:1, is shown in Fig. 2. In typical rooms, $\text{DT}_{40,\text{ME}}$ is shorter than T_{60} and decreases with V.

3.3. Optimisation of speakers' parameters

The recommended and acceptable categories of vocal comfort, defined by the ranges of $\text{DT}_{40,\text{ME}}$ obtained in the previous section, provide a first guideline for classroom acoustic design and are shown in Fig. 2. The same figure shows also the target reverberation time which optimises the vocal comfort. A suitable empirical fit for the target reverberation time is

$$T_{\text{target,VC}} = 0.032\sqrt[3]{V} + 0.38 \text{ (s)}, \tag{4}$$

In principle, the reverberation time in classrooms for optimum vocal comfort should be within the recommended range, i.e. for $0.8T_{\text{target,VC}} \leq T \leq 1.2T_{\text{target,VC}}$, $0.35 \text{ s} \leq \text{DT}_{40,\text{ME}} \leq 0.55$ s.

Moreover, Fig. 2 shows different lines for ΔL_W (at -1, -3 and -5 dB), obtained through the prediction model for ST_V and Eq. (2). These lines are correlated with the vocal effort in silent conditions. The more negative ΔL_W, the better for keeping a low vocal effort. The line $\Delta L_W = -3$ dB should be considered as a reference for a classroom that does not put high demands on teachers' voices. Classroom acoustic designs at the left of this line in Fig. 2 should be sought.

4. A prediction model for speech intelligibility

The useful-to-detrimental ratio U_{50} is a suitable measure of speech intelligibility [19]. In this case, the useful part $L_{\text{SL,early}}$ is the sound signal arriving in the first 50 ms after the arrival of the direct sound (including it) and the detrimental part $L_{\text{SL,late+noise}}$ contains the late reflections (arriving later than 50 ms after the direct sound) and the noise. Thus,

$$U_{50} = L_{\text{SL,early}} - L_{\text{SL,late+noise}} \text{ (dB)}. \tag{5}$$

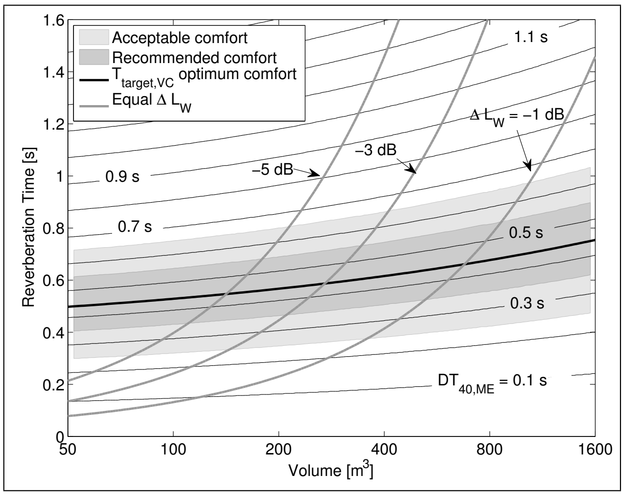

Figure 2. Predicted $\mathrm{DT}_{40,\mathrm{ME}}$ and ΔL_W (derived from ST_V), as a function of reverberation time and volume. The areas of $\mathrm{DT}_{40,\mathrm{ME}}$ providing recommended and acceptable voice comfort levels are indicated in darker and lighter gray color. Bold black line: target reverberation time $T_{\mathrm{target,VC}}$ which maximises vocal comfort. Bold gray lines: Equal ΔL_W curves derived from ST_V model

According to Nijs and Rychtarikova [19], $L_{\mathrm{SL,early}}$ is given by

$$L_{\mathrm{SL,early}} = L_W + 10\log\left(\frac{Q}{4\pi r^2} + \frac{4(1-\bar{\alpha})^{\beta_{\mathrm{fb}}\cdot r/l_{\mathrm{mfp}}}}{\bar{\alpha}S}\left(1-\mathrm{e}^{-0.69/T_{60}}\right)\right) \quad (\mathrm{dB}), \quad (6)$$

where L_W is the radiated sound power level, Q is the directivity of the speaker in the direction aiming at the listener, r is the distance between speaker and listener, $\bar{\alpha}$ is the mean absorption coefficient of the room, β_{fb} is an experimental parameter related to the spatial decay rate of the reverberant field and l_{mfp} is the mean free path of the room ($l_{\mathrm{mfp}} = 4V/S$). It is assumed that the reflected sound follows an exponentially decaying random process with an amplitude that decays with longer distances to the source, as suggested by Barron in the context of acoustics for performance spaces (without any parameter β_{fb}, i.e. $\beta_{\mathrm{fb}} = 1$) [?] and experimentally refined by Sato and Bradley [21] in the context of classroom acoustics by introducing the parameter β_{fb}, usually > 1.

The late arriving speech level $L_{\mathrm{SL,late}}$, on the other hand, contains the effect of sound reflections arriving later than 50 ms after the arrival of the direct sound and the signal-to-noise ratio (SNR):

$$L_{\mathrm{SL,late+noise}} = L_W + 10\log\left(\frac{4(1-\bar{\alpha})^{\beta_{\mathrm{fb}}\cdot r/l_{\mathrm{mfp}}}}{\bar{\alpha}S}\mathrm{e}^{-0.69/T_{60}} + \frac{4\cdot 10^{-\mathrm{SNR}/10}}{\bar{\alpha}S}\right) \quad (\mathrm{dB}), \quad (7)$$

A formal definition of SNR is the difference between the sound power levels of speech $L_{W,\mathrm{speech}}$ and student-activity noise $L_{W,\mathrm{SA}}$,

$$\mathrm{SNR} = L_{W,\mathrm{speech}} - L_{W,\mathrm{SA}} \ (\mathrm{dB}). \quad (8)$$

Empirical models that link A-weighted student-activity noise level L_{SA}, instructor voice power levels $L_{W,\mathrm{speech}}$, volume V, acoustic absorption of the room A_0 ($A_0 = S\bar{\alpha}$)and the number of students N in university classrooms are given by Hodgson *et al* [20]. The inputs to the models were measurements during 18 lectures in 11 classrooms with V between 110 and 957 m^3, between 6 and 254 students present in the classroom, and total occupied absorption areas between 30 and 305 m^2. The A-weighted student-activity noise level L_{SA} is described as:

$$L_{\mathrm{SA}} = 83 + 10\log N - 34.4\log A_0 + 0.08A_0 \quad (\mathrm{dB\ re\ }20\mu\mathrm{Pa}). \quad (9)$$

The A-weighted student-activity noise power level $L_{W,\mathrm{SA}}$ is

$$L_{W,\mathrm{SA}} = L_{\mathrm{SA}} - 10\log\left(\frac{4(1-\bar{\alpha})}{S\bar{\alpha}}\right) \quad (\mathrm{dB\ re\ 1\ pW}), \quad (10)$$

where it is assumed that L_{SA} is homogeneous throughout the classroom.

The A-weighted sound power levels of speech $L_{W,\mathrm{speech}}$, averaged for male and female teachers, is [20]:

$$L_{W,\mathrm{speech}} = 53.5 + 0.5\ L_{\mathrm{SA}} + 0.016\ V - 9.6\log A_0 \quad (\mathrm{dB\ re\ 1\ pW}). \quad (11)$$

Using Eqs. (8)–(11) for SNR, the resulting U_{50} depends on the number of students N. Figure 3 shows the U_{50} values as a function of the volume, the reverberation time and the number of students (N = 10, 20, 40 and 80). The horizontal axis has been adjusted to display volumes of at least 4 m^3 per student. For simplicity, it is assumed that the speaker can be oriented toward any direction ($Q = 1$), that the speaker-to-listener distance is the geometrical mean of the length and the width of the room, and that $\beta_{\mathrm{fb}} = 1$. In the figure, the equal U_{50} contours are shown in steps of 1 dB. In the same figure, the upper and lower limits of reverberation time that result in recommended vocal comfort levels are shown with bold dashed lines. The hashed areas in Fig. 3 indicate areas for which the prediction of SNR is not valid due to unavailable data for the model. The reverberation time curve that defines maximum U_{50} as a function of the volume is close to the lower limit of recommended vocal comfort zone ($0.8T_{\mathrm{target,VC}}$) for 10 or 20 students. This curve increases with the number of students and falls

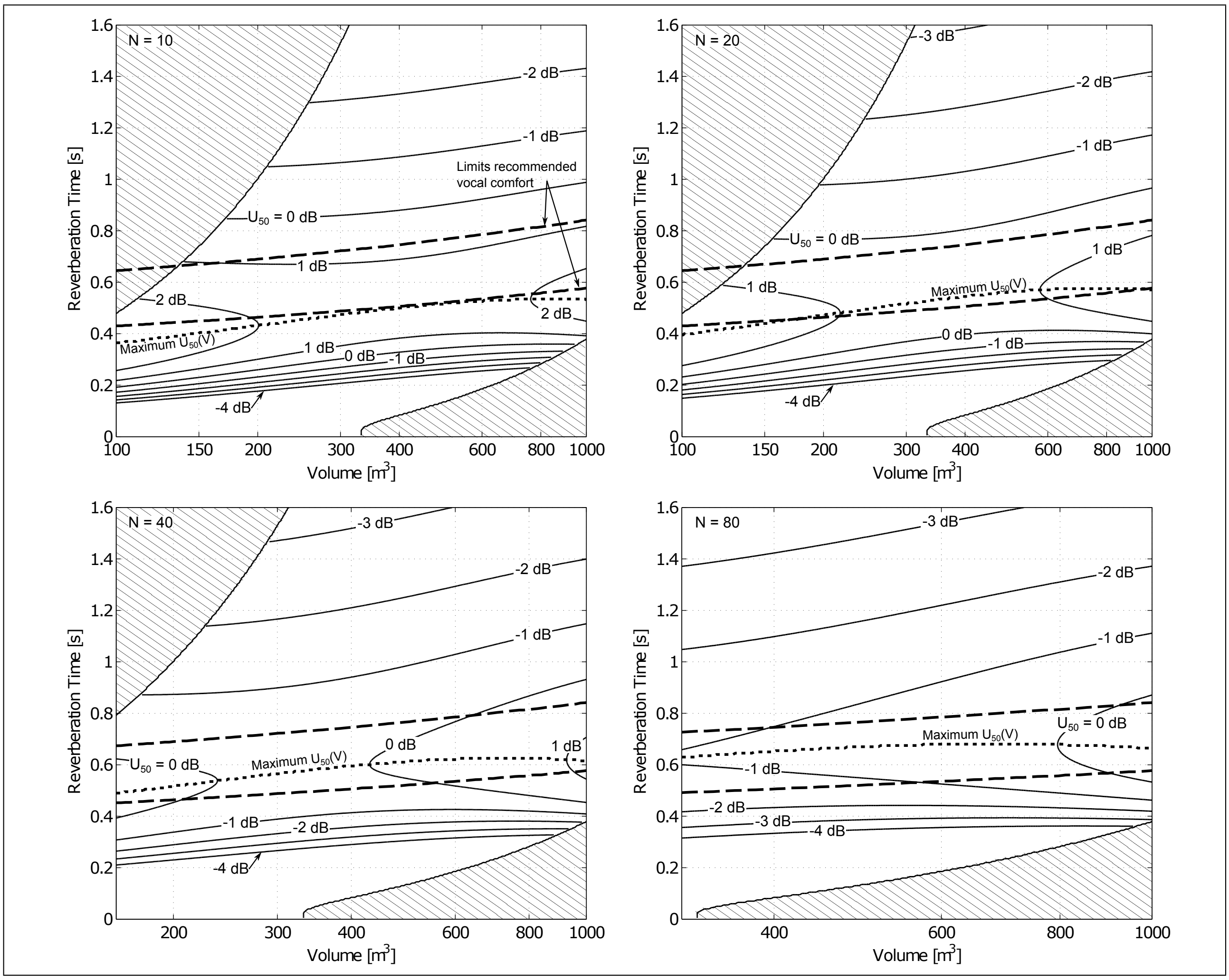

Figure 3. U_{50} as a function of room volume and reverberation time, considering typical SNR measured in classrooms, for $N = 10$ students (top left), $N = 20$ (top right), $N = 40$ (bottom left) and $N = 80$ (bottom right). The upper and lower limits of reverberation time to achieve recommended vocal comfort levels are indicated in bold dashed lines. Bold dotted lines indicate reverberation times that maximize U_{50} for each volume. Hatched areas correspond to combinations of volume and reverberation time for which the SNR predictions are not valid.

within the recommended range of reverberation time that optimises vocal comfort.

None of the U_{50} values in Fig. 3 exceeds 3 dB (i.e. STI > 0.65), even with a low number of students. Nevertheless, the student-activity noise levels used for the SNR calculations are median levels of the periods when the teacher is not talking. It is likely that these levels are an overestimate of the actual noise levels present while the teacher is talking.

5. Guidelines for classroom acoustic design

A classroom acoustic design that maximises simultaneously criteria of vocal comfort and speech intelligibility is found as the intersection of areas of recommended vocal comfort ($0.8T_{\text{target,VC}} \leq T \leq 1.2T_{\text{target,VC}}$) and the areas that provide speech intelligibility higher than a minimum value $U_{50} \geq U_{50,\min}$. An additional requirement of $\Delta L_W < -3$ dB is set to limit vocal effort in silent conditions. If, for example, $U_{50,\min}$ is taken as 1.5 dB (STI > 0.6), the overlap between areas decreases with the number of students, and there is no overlap for 40 students. This overlap is summarised in Fig. 4(a) as target values of V and T in occupied classrooms as a function of N. The area of recommended design decreases with N. Beyond $N = 20$ students, speech intelligibility criterion becomes too restrictive. In this case, the best acoustic conditions for small groups of students (up to 20 pupils) are obtained for T values around 0.45 s (and volumes up to 120 m^3) in occupied classrooms.

The choice of 1.5 dB for $U_{50,\min}$ leads to small groups of students, which is advisable for groups with special needs (e.g. students with hearing impairment or non-native speakers). A more realistic choice of $U_{50,\min} = 0$ dB (STI > 0.55) is used to derive Fig. 4(b), which shows the combinations of volume

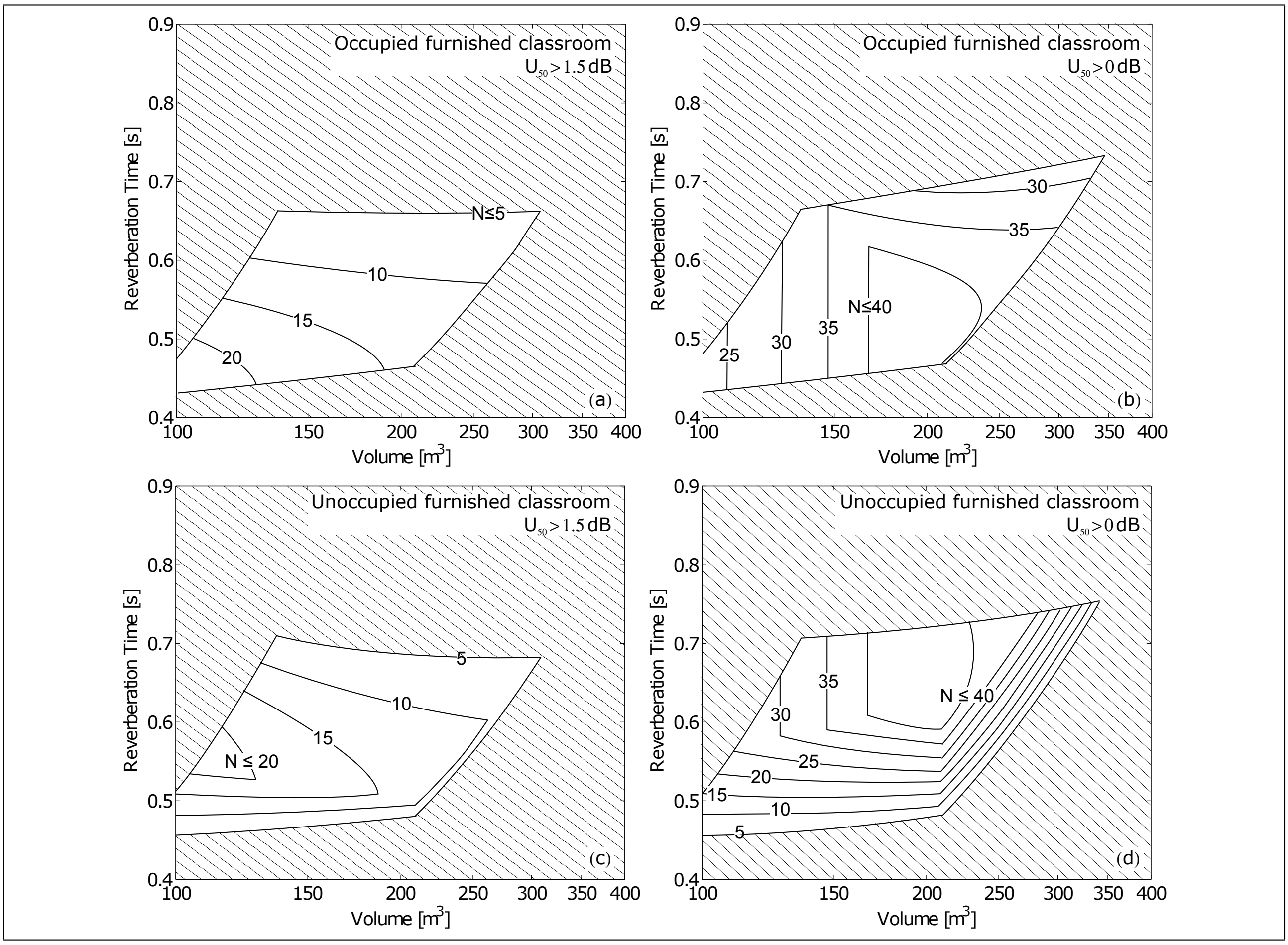

Figure 4. Areas of recommended volume and reverberation time in occupied (a,b) and unoccupied (c,d) classrooms, for a given number of students N, which satisfy simultaneously criteria of vocal comfort and speech intelligibility for $U_{50,\min} = 1.5$ dB (a,c) and $U_{50,\min} = 0$ dB (b,d). For each N, the design area should be considered as the interior of the boundary line.

and reverberation time that provide simultaneously good vocal comfort and satisfactory speech intelligibility ($U_{50} > 0$ dB) for any number of students up to 40. For a classroom for flexible teaching with 40 students, design possibilities become restricted to reverberation times between 0.45 and 0.6 s and volumes between 160 and 210 m^3. For less students, volumes are restricted and depend on T. For $T = 0.45$s, the maximum volume is 210 m^3, and for $T = 0.7$s, it is approximately 350 m^3.

Whereas the derivation of guidelines has been suggested for fully occupied conditions, regulations in classroom acoustics are most often referred to unoccupied but furnished conditions. In an occupied classroom with volume V, total surface area S and reverberation time T_{occ}, the mean absorption coefficient $\bar{\alpha}_{\text{occ}}$ according to Eyring's formula is

$$\bar{\alpha}_{\text{occ}} = 1 - \exp\left[-0.161V/(T_{\text{occ}}S)\right]. \tag{12}$$

In order to obtain an estimate of the acoustic conditions in unoccupied furnished classrooms, the absorption corresponding to the students and the teacher, considering that each person in the classroom absorbs $A_s = 0.28$ m^2 (according to Sato and Bradley [21]), is subtracted from the total absorption area in the occupied classroom $A_{\text{occ}} = S\bar{\alpha}_{\text{occ}}$. Thus, the mean unoccupied absorption coefficient $\bar{\alpha}_{\text{unocc}}$ results in

$$\bar{\alpha}_{\text{unocc}} = \frac{A_{\text{occ}} - (N+1)A_s}{S}, \tag{13}$$

which leads to a reverberation time in unoccupied but furnished conditions T_{unocc} of

$$T_{\text{unocc}} = \frac{0.161V}{-S\ln(1-\bar{\alpha}_{\text{unocc}})}. \tag{14}$$

Each of the curves limiting an area of recommended design in Figs. 4(a-b) is transformed into a curve which expresses the recommended design areas of volume and reverberation time in unoccupied furnished classrooms for a number of students by applying Eqs. (12)–(14). Figures 4 (c-d) show the areas of recommended design in unoccupied but furnished classroom for a number of students between a minimum of $N_{\min} = 5$ and a maximum N.

According to Fig. 4(c), reverberation times in unoccupied furnished classrooms designed for high speech intelligibility should not exceed 0.7 s in any case, whereas the minimum recommended reverberation time depends on the number of students. Such a classroom with up to 20 students should have a T_{unocc} of around 0.55 s. In classrooms with less strict speech intelligibility requirements, as shown in Fig. 4(d), the minimum T_{unocc} for classrooms with $N \leq 20$ students is slightly higher than 0.5 s, whereas the minimum T_{unocc} for classrooms with $N \leq 40$ students is 0.6 s.

6. Concluding remarks

In classrooms for flexible teaching methods with no more than 40 students, reverberation times above 0.6 s (in conditions of full occupancy) or 0.7 s (in unoccupied furnished classrooms) should be avoided. Volumes should be kept no larger than 210 m^3 for the highest occupancy (paradoxically, volumes can be larger for less students). Higher reverberation times would decrease speech intelligibility, which at the same time would disengage students from learning. Whereas some guidelines, like the one proposed by the BATOD [22], stand for reverberation times shorter than 0.4 s based on speech intelligibility considerations, the present study suggests that reverberation times slightly higher (between 0.45 s and 0.5 s in occupied classrooms) might be optimal, and that lower reverberation times are not necessarily better, based on vocal comfort considerations. Furthermore, reverberation times lower than 0.3 s might generate 'overdamping', i.e. an excessive attenuation of speech levels at the last rows [19]. Therefore, guidelines should include target reverberation times (or upper and lower limits) rather than maximum allowed reverberation times, and should include limitations in volume and number of students—at least regarding the necessity of having a dedicated study with geometrical considerations and distribution of absorbing material on the surfaces of the classroom, if designing larger classrooms for more students.

In some European countries (see Table I), like France or UK (for secondary schools), reverberation times up to 0.8 s in unoccupied spaces are allowed, which may be detrimental for speech intelligibility if, with students present, the reverberation time does not descend below 0.6 s. On the other hand, in Norway, reverberation times in empty furnished classrooms are limited to 0.5 s (0.4 s for the highest quality class in the classification scheme), which might be too restrictive and lead to low vocal comfort levels. From the studied countries, only Germany and France set maximum and minimum limits to reverberation times. Regarding volume limitations, France includes the prescription of a dedicated study for classrooms larger than 250 m^3, Spain for classrooms larger than 350 m^3 and Germany gives special design guidelines for classrooms larger than 250 m^3. According to the present findings, it is apparent that some guidelines should be adjusted: Denmark, Norway, Spain and UK should add minimum limits for their required reverberation times. France and UK (for secondary schools) should lower the maximum allowed reverberation time. Spain should lower the volume of 350 m^3 for the need of doing a dedicated study. Moreover, Denmark, Norway and UK should take the volume of the classroom into consideration. Classification standards, such as the Norwegian NS8175:2012 should also be revised to consider what are the best quality standards and include target reverberation times instead of upper limits. According to the present findings, a limitation of the maximum reverberation time to 0.4 s in furnished but unoccupied classrooms for the highest quality classes is detrimental for vocal comfort.

Current European regulations differ in the methods they use to express the requirements in terms of reverberation time, volume, occupancy conditions and additional demands on the frequency dependency and validation of the design. With the existing knowledge in classroom acoustics, there is an excellent opportunity to work towards the harmonisation of regulations among European countries.

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