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Reverberation time in class rooms – Comparison of regulations and classification criteria in the Nordic countries

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Regulatory requirements or guidelines for classroom reverberation time exist in all five Nordic countries and in most of Europe – as well as other acoustic criteria for schools, e.g. concerning airborne and impact sound insulation, facade sound insulation and installation noise. There are several reasons for having such requirements: Improving learning efficiency for pupils and work conditions for teachers and reducing noise levels, thus increasing comfort for everyone.
Instead of including acoustic regulatory requirements for schools directly in the building regulations, Iceland, Norway and Sweden have introduced acoustic quality classes A, B, C and D in national standards with class C referred to as regulatory requirements. These national classification standards are dealing with acoustic classes for several types of buildings. A classification scheme also exists in Finland, but with no link to the building regulations. During the last few years acoustic classification and labelling criteria have appeared also in other types of standards and schemes, among these indoor climate classification schemes with other class denotations.
This paper presents the classroom reverberation time requirements and classification criteria in the Nordic countries and compares and discusses the limit values and trends.

1 Introduction

Classroom acoustics is an issue having had significantly increased attention during the last 5-10 years. Among the five Nordic countries, four have implemented stricter reverberation time requirements during the last five years. In the past, requirements were stated directly in the building codes, but now, in three of five Nordic countries, the building code refers to Class C in a national classification scheme with criteria for schools and other types of buildings. In Table I is found an overview of the building codes and classification schemes in the Nordic countries. This paper deals with classroom reverberation time only, although other acoustic parameters are relevant both for classrooms and other spaces in school buildings.

Table I: Overview Building codes and sound classification schemes in the Nordic countries with criteria for classrooms

Country	Building Code (BC)	Classification Scheme (CS)	BC link to CS	BC reference to CS	Comments
Denmark (DK)	BR 2010 [1]	None	–	N/A	BC refers to [6] for details
Finland (FI)	RAKMK C1:1998 [2]	SFS 5907:2004 [7]	–	N/A	
Iceland (IS)	Byggingarreglugerd 2012 [3]	IST 45:2011 [8]	+	Class C	
Norway (NO)	TEK'2010 [4]	NS 8175:2008 [9]	+	Class C	
Sweden (SE)	BBR 2012 [5]	SS 25268:2007 [10]	+	Class C	

2 Regulatory requirements in the Nordic countries

The regulatory requirements in the five Nordic countries for reverberation times in classrooms are found in Table II. For each country are indicated the publication year of the present main document with the limits, the required reverberation time and details of importance for design and control of compliance with the limits.

Table II: Reverberation time in class rooms - Regulatory requirements in the Nordic countries

Reverberation time in class rooms - Regulatory requirements in the Nordic countries (1)						
Status (1) March 2012 / **Country & year(2)**	Ordinary classrooms Req. T (s)	Requi-rement	Fur-nished room	Freq. range [Hz]	Details of requirement/criterion(3)	Comments
Denmark (2010) [1] & [6]	≤ 0.6	+	+	125-4000Hz	T20 according to ISO 3382-2 [11] Max. in each 1/1 octave band 125Hz: Max. +20% accepted	Requirements implemented in BC in 2008 and unchanged in the new BC in 2010. BC refers to [6] for details.
Finland (1998) [2]	0.6 - 0.9	See com-ment	Not speci-fied	From 500 Hz and higher	Measurements should follow ISO 3382 [12]	There is no requirement, only instructive regulation [13]
Iceland (2011) [8]	≤ 0.6	+	+	125-4000Hz	T20 according to ISO 3382-2 [11] Max. in each 1/1 octave band 125 Hz: Max. + 20% accepted	Furnished rooms [13]
Norway (2008) [9]	≤ 0.6	+	+	125-2000Hz	T20 according to ISO 3382-2 [11] Max. in each 1/1 octave band 125Hz: Max. +40% accepted	Furnished rooms specified in [9], Ch.1 with general information.
Sweden (2007) [10]	≤ 0.5	+	+	125-4000Hz	T20 according to ISO 3382-2 [11] Arithmetic avg. 1/1 octaves 250 Hz – 4 kHz. Single bands may exceed by max 0.1 s 125 Hz: Max + 0.2 s accepted	Further guidelines found in SS 25 268 [10], Sections 5.4.3 & 5.5

Notes

(1) Overview information only. Detailed requirements and conditions are found in the BC (building codes) or documents referred to.

(2) The year indicated is for the publication year of the present main document with the limits. The implementation of requirements could be earlier, if requirements were not changed (like in DK) or later like in IS with the CS published in 2011, but BC referring to the CS published in 2012.

(3) Standards are referred to using the ISO references, although national references would normally include country and EN, e.g. SS/EN ISO 3382:2 as an example from Sweden. Note that year could be different for ISO, EN and national versions.

From the information in Table II, it can be seen that the requirements in DK, IS, NO, SE are quite close concerning limit value and conditions (furnished room), although there are differences in details and in rules for evaluation of compliance with regulations. In Finland, there are recommendations only, and furniture is not specified as part of the room conditions.

Furniture in class rooms is important for two reasons: as absorption and as scattering objects. A typical classroom is shoebox shaped, with most of its absorption in the ceiling. This type of space can be said to be ‘non-Sabine’, as it will not have a diffuse sound field, and the decay process will not follow a straight line according to Sabine’s theory. Instead the decay curve will be broken, with an early part more or less following the Sabine theory, and a late part with a longer reverberation time. This has been thoroughly examined by Nilsson [14, 15]. The explanation is that the sound field modes associated with directions incident on the absorbing ceiling will attenuate faster than the modes associated with directions parallel with the ceiling. Introducing scattering objects as furniture in such a sound field will force the waves towards the ceiling. The reverberation time in an unfurnished classroom is typically higher than in a furnished classroom and thus not representative for the room in actual use.

3 Limit values in classification schemes in the Nordic countries

Acoustic classification schemes including class rooms exist in Finland, Iceland, Norway and Sweden, but not in Denmark. All schemes operate with classification denotations A, B, C, D, and the corresponding limits are found in Table III. The table also includes information about the previous versions of the classification standards, thus providing an overview of the trend in reverberation time criteria for class rooms. The trend for classification criteria is clear: Shorter and shorter reverberation time limits, assuming shorter is better. For more aspects related to this issue, see section 4.

Table III. Reverberation time in classrooms - Criteria in sound classification schemes in the Nordic countries

Reverberation time in classrooms – Classification criteria(1) in (s) – Status March 2012						
Country	**Standard(2)**	**Class A**	**Class B**	**Class C**	**Class D**	Details of requirement/criterion
DK	**None**	**N/A**	**N/A**	**N/A**	**N/A**	N/A
FI	**SFS 5907:2004** [7]	**0.5 - 0.6**	**0.5 - 0.6**	**0.6 - 0.8**	**N/A**	Frequency range 125-4000 Hz T_{20} according to ISO 3382 [12] Spaces with built-in furniture Limits max. for each 1/1 oct. 250-4000 Hz For 125Hz: Max. +50% accepted
IS	**IST 45:2011** [8]	**≤ 0.5**	**≤ 0.5**	**≤ 0.6**	**≤ 0.8**	See Table II
NO	(NS 8175:1997) (NS 8175:2005) **NS 8175:2008** [9]	(≤ 0.6) (≤ 0.6) **≤ 0.3**	(≤ 0.6) (≤ 0.6) **≤ 0.5**	(≤ 0.8) (≤ 0.8) **≤ 0.6**	(≤ 0.9) (≤ 0.9) **≤ 0.6**	See Table II
SE	(SS 25268:2001) **SS 25268:2007** [10]	(≤ 0.5) **≤ 0.5**	(≤ 0.6) **≤ 0.5**	(≤ 0.6) **≤ 0.5**	(≤ 0.8) **≤ 0.8**	See Table II
Notes (1) Class denotations A / B / C / D indicated in descending order, i.e. the best class first (2) Previous versions are indicated with numbers in brackets.						

During the last few years acoustic classification and labelling criteria have appeared also in other types of standards and schemes, among these indoor climate classification schemes. The schemes have been developed in indoor climate committees and with main focus on several indoor climate characteristics other than acoustics, and the class denotations are not always consistent with those of the acoustic classification schemes. Examples of such schemes are found in Table IV.

Table IV. Reverberation time in classrooms - Criteria in indoor climate standards – Nordic examples

Indoor climate standards – Reverberation time in classrooms – Classification criteria in (s)							
DK	**DS 3033:2011 (1)** [16]	Class A++ 0.6	Class A+ 0.6	Class A 0.6	Class B 0.9	Class C > 0.9	Furnished rooms. ISO 3382-2 [11]
FI	**LVI 05-10440 en:2008 (2)** [17]	S1 0.6 - 0.8	S2 0.6 - 0.8	S3 0.6 - 0.8	N/A	N/A	Target value by designing. Furnished rooms Average of 1/1 oct. 250-4000 Hz
Notes (1) The five quality classes are described in DS 3033, Section 4.2 [16] Class A++ The excellent indoor climate Class A+ A good indoor climate - clearly better than the minimum requirements of the Building Regulations Class A The good, satisfactory indoor air equivalent to the requirement of building regulations Class B Indoor climate poorer than the minimum requirements of the Building Regulations Class C The poor indoor climate (2) The three quality categories are described in LVI 05-10440 en:2008, Section 1.2 [17] S1 Individual indoor environment S2 Good indoor environment S3 Satisfactory indoor environment							

4 Discussion and trends

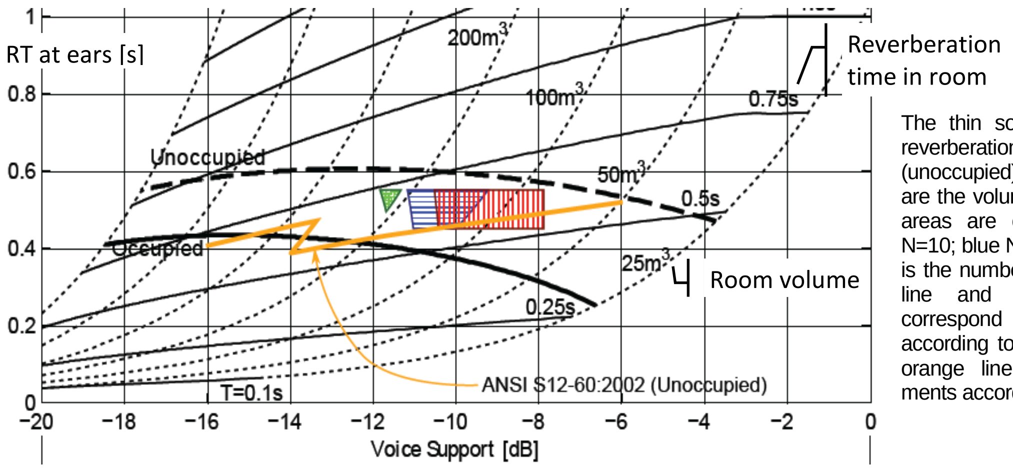
In addition to reverberation time, also noise levels in classrooms is important, see Section 4.1 and 4.2. All Nordic countries have criteria for noise from technical installations, but this issue is outside the main topic of this paper.

4.1 Speech intelligibility

The purpose of having requirements regarding the reverberation time as well as the background noise from installations/traffic in classrooms is to ensure that speech intelligibility is good enough, and to avoid poor working conditions. It is a well-established fact that a too long reverberation time reduces speech intelligibility. However, most studies have shown that excessive levels of background noise (from installations, traffic or students) is a larger problem than the reverberation time regarding speech intelligibility in classrooms [18]. Leaving aside the source (the speaker), and assuming otherwise ideal conditions, we easily realize that a shorter reverberation always provides better speech intelligibility. But the actual situation in a classroom is not as simple as that. The speaker cannot raise his voice strength without problems, and speech intelligibility also depends on the total background noise, which is largely generated by other students close to the listener (and influenced by the reverberation time). Early-arriving reflections, arriving within 50 ms after the direct sound, will be beneficial for speech intelligibility, increasing the signal-to-noise ratio (SNR). This is especially true, if the noise source is closer to the listener than the talker is, which typically is the case in classrooms, [19]. In real rooms the early reflections can increase the SNR by 6 to 8 dB [20]. Yang and Bradley [21] have shown that if taking this effect into account, for each age group (grades 1, 3 and 6 in Canada, and adults), maximum intelligibility is found at between 0.6 and 0.7 s reverberation time. Moreover, the changes in speech intelligibility in the range 0.3 to 1.2 s reverberation time were small.

4.2 Teachers' comfort

Reverberation in classrooms can affect the teacher in two ways: it will together with the background noise annoy and stress the teacher and pupils, and it will affect the vocal comfort and vocal health of the teacher. The latter has recently been studied in a joint Swedish-Danish project [22]. In a prevalence study of the voice problems 487 teachers in 22 schools in southern Sweden answered a questionnaire regarding voice problems [23]. The result showed that 13% of the whole group reported voice problems. The room acoustics was found to be one of the causes of the voice problems. Teachers will automatically raise their voice in presence of background noise (the Lombard effect), but it has recently also been shown that they will raise their voice also in absence of supporting reflections from the room [24], described with the parameters Room Gain or Voice Support. The teacher will also raise their voice due to the visual distance to the receiver [25]. The new parameters Room Gain or Voice Support are closely related to the size of the room and the reverberation time in the room [26]. In his PhD thesis [27], Pelegrin-Garcia combined these findings with models of students' noise generation and the present knowledge on speech intelligibility in classrooms (as described above), which is illustrated in Figure 1. It can be concluded that the needs for both the teacher and pupils are fulfilled around 0.6 s. Moreover, the optimal design area (the hatched areas in the figure) decreases with increasing number of pupils.



The thin solid lines are the ordinary reverberation time in rooms (unoccupied) and the thin dashed lines are the volumes of the rooms. Hatched areas are optimum regions for: red N=10; blue N=20; green N=40, where N is the number of pupils. The thick solid line and the thick dashed line correspond to the requirements according to DIN 18041, and the solid orange line corresponds to requirements according to ANSI S12-60:2002.

Figure 1: Optimum acoustic conditions for a speaker as a function of the reverberation time at ears and the voice support. Hatched areas are optimum regions for N=10 (red) and 20 (blue) pupils. Reference: Fig.3.3 in [27].

Presence of too long reverberation and too high background noise will also increase the annoyance among the teachers. This has been studied in a recent Danish project, using self-reported estimates of noise exposure and disturbance attributed to noise among 419 secondary school teachers in 10 schools in Copenhagen [28]. The reverberation time where measured in the classrooms, and the schools where grouped in three categories: short (0.38 - 0.46 s), medium (0.46 - 0.66 s) and long (0.61 - 0.86 s) reverberation time. The reverberation time categories played a significant role for the disturbance attributed to noise from children in the class, and there was also a tendency that long reverberation time was associated with higher self-reported noise exposure. The findings however also showed that the influence of the degree of noise attributed to children in the class has a stronger impact than sole reverberation time. Moreover, the number of children in the classroom was significantly associated with self-reported noise exposure.

4.3 Trends

Among the five Nordic countries, four have implemented stricter classroom reverberation time requirements during the last five years. Denmark and Iceland implemented stricter reverberation time limits in 2008 and 2012, respectively. The trend in classroom classification criteria in Norway and Sweden is the same. These two countries refer to class C, and limits were tightened in 2008 and 2007, respectively. In general, the trend is clear: Reverberation time limits are getting shorter in regulatory requirements and classification criteria.

Another trend is that acoustic criteria are being included in indoor climate classification standards prepared by indoor climate committees and that class denotations and conditions differ from those in the acoustic classification standards.

5 Summary and conclusions

From findings in the literature, it can be concluded that regarding both optimizing the speech intelligibility for the listeners and minimizing the voice load of the teachers, there is an optimal range for the reverberation time around 0.6 s. Regarding the noise annoyance among the teachers, a lower reverberation time seems preferable. However, keeping a small size of the student group is a way of having a good environment for both the teachers and the students.

Two trends have been observed concerning reverberation time requirements and classification criteria for classrooms. One is that reverberation time limits are getting shorter. Another trend is that acoustic criteria are being included in indoor climate classification standards with class denotations and conditions differing from those in the acoustic classification standards.

Although there is a rather good agreement between the actual requirements in the Nordic countries, the differences in the classification schemes in connection with the newer scientific findings and the trends observed should encourage future Nordic cooperation concerning regulatory requirements and classification criteria for reverberation time in classrooms.

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