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Sound insulation and reverberation time for classrooms - Criteria in regulations and classification schemes in the Nordic countries

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Acoustic regulations or guidelines for schools exist in all five Nordic countries. The acoustic criteria depend on room uses and deal with airborne and impact sound insulation, reverberation time, sound absorption, traffic noise, service equipment noise and other acoustic performance characteristics. In four of the countries – Finland, Iceland, Norway and Sweden – schools are also included in voluntary classification schemes published as the national standards SFS, IST, NS and SS. These classification schemes have four quality levels with the same denotations A, B, C and D, but otherwise not identical. The national criteria for quality level C correspond to the national regulations or recommendations for new-build. The quality levels A and B are intended to define better acoustic performance than C, and D lower performance. Typically, acoustic regulations and classification criteria for schools have become more extensive and stricter during the last two decades.
The paper focuses on comparison of sound insulation and reverberation time criteria for classrooms in regulations and classification schemes in the Nordic countries. Limit values and changes over time will be discussed as well as how the role of classification schemes could be optimized in the future.

1 Introduction

The acoustic design of schools and other educational institutions is important for optimizing the learning conditions for students and working conditions teachers as well as for the well-being of all people during the variety of situations, room types and uses. This paper focuses on ordinary classrooms - being the most common room type in schools - and on sound insulation properties and reverberation time.

2 Acoustic regulations and classification schemes in the Nordic countries

All five Nordic countries have building codes including acoustic requirements, but in quite different ways and with different extent of building types. The same applies for acoustic classification schemes. An overview of regulations and classification schemes related to schools is found in Table 1.

Table 1: Overview Building codes and acoustic classification schemes in the Nordic countries with criteria for classrooms.

Country	Building Code (BC)	Classification Scheme (CS)	Class denotations(1)	BC link to CS	BC ref. to CS	Comments on schools
Denmark (DK)	Building Regulations 2015 [1]	None	**N/A**	–	N/A	BC refers to [6] for details
Finland (FI)	RAKMK C1:1998 [2]	SFS 5907:2004 [7]	A / B / C / (D)	–	None	No regulatory requirements
Iceland (IS)	Byggingarreglugerd 2012 [3]	IST 45:2016 [8]	A / B / C / D	+	Class C	
Norway (NO)	TEK'2010 [4]	NS 8175:2012 [9]	A / B / C / D	+	Class C	
Sweden (SE)	BBR 2012 (BBR 22) [5]	SS 25268:2007 [10]	A / B / C / D	+	Class C	

Abbreviations: BC = Building Code (regulatory requirements); CS = Classification scheme
(1) Class denotations A / B / C / D indicated in descending order, i.e. the best class first. The Finnish class D for schools is applied for sites that does not fulfil criteria in class C and could therefore rather be considered as npd (no performance determined).

For housing, all five countries have acoustic requirements and acoustic classification schemes, although different detailing. For schools, there are quite extensive regulations – more than 25 limit values – in DK, IS, NO and SE, but in FI no requirements and only a few criteria as recommendations. Acoustic classification schemes in FI, IS, NO and SE include schools, but in DK there is only a classification scheme for housing and thus no classification criteria for schools or other types of buildings. In general, classification schemes in the Nordic countries operate with classification denotations A, B, C, D, originating in the joint Nordic draft for classification of dwellings [11]. However, the Finnish class D for schools is different, as it just means "no performance determined", including that Class C is not fulfilled.

In the following sections, sound insulation and reverberation time requirements and classification criteria for ordinary classrooms are found. It should be noted that in some countries, e.g. Sweden, there are different criteria for primary schools and buildings for higher education. The limit values indicated are for primary schools. In all countries, stricter criteria apply for e.g. workshops, rooms for music and singing and for rooms for pupils with special needs. It is important to consult the references for detailed criteria and conditions. Sound insulation between classrooms is dealt with in Section 3, façade sound insulation in Section 4 and reverberation time in Section 5.

3 Sound insulation between classrooms – Regulations and classification criteria

The main criteria for airborne and impact sound insulation between ordinary classrooms in schools are found in Tables 2 and 3. The classification schemes also include several other sound insulation criteria, e.g. between classrooms with a door connection, sound insulation from stairways and from noisy premises.

Table 2: Airborne sound insulation between classrooms.
Main criteria in acoustic classification schemes in the Nordic countries.

Airborne sound insulation between classrooms(1),(2) - Main classification criteria in dB - April 2016					
Country	**Class A [dB]**	**Class B [dB]**	**Class C [dB]**	**Class D [dB]**	**Acoustic regulations**
DK	N/A	N/A	N/A	N/A	BC [1],[6]: H: $R'_w \geq 48$ dB; V: $R'_w \geq 51$ dB
FI [7]	$R'_w \geq 48$	$R'_w \geq 48$	$R'_w \geq 44$	npd	None, $R'_w \geq 44$ recommended
IS [8]	$R'_w \geq 56$	$R'_w \geq 52$	$R'_w \geq 48$	$R'_w \geq 44$	BC refer to Class C
NO [9]	$R'_w \geq 56$	$R'_w \geq 52$	$R'_w \geq 48$	$R'_w \geq 44$	BC refer to Class C
SE [10]	$R'_w \geq 48$	$R'_w \geq 44$	$R'_w \geq 44$	$R'_w \geq 40$	BC refer to Class C
(1) Overview information only. Detailed criteria and conditions are found in the references [1]-[10]. (2) The criteria indicated are for ordinary classrooms only.					

Table 3: Impact sound insulation between classrooms.
Main criteria in acoustic classification schemes in the Nordic countries.

Impact sound insulation between classrooms(1),(2) - Main classification criteria in dB – April 2016					
Country	**Class A**	**Class B**	**Class C**	**Class D**	**Acoustic regulations**
DK	N/A	N/A	N/A	N/A	BC: $L'_{n,w} \leq 58$
FI [7]	$L'_{n,w} \leq 63$	$L'_{n,w} \leq 63$	$L'_{n,w} \leq 63$	npd	None and no recommendations
IS [8]	$L'_{n,w} \leq 53$	$L'_{n,w} \leq 58$	$L'_{n,w} \leq 63$	$L'_{n,w} \leq 68$	BC refer to Class C
NO [9]	$L'_{n,w} \leq 53$	$L'_{n,w} \leq 58$	$L'_{n,w} \leq 63$	$L'_{n,w} \leq 68$	BC refer to Class C
SE [10]	$L'_{nT,w} \leq 56$ $L'_{nT,w} + C_{I,50\text{-}2500} \leq 56$	$L'_{nT,w} \leq 56$ $L'_{nT,w} + C_{I,50\text{-}2500} \leq 56$	$L'_{nT,w} \leq 60$	N/A	BC refer to Class C
(1) Overview information only. Detailed criteria and conditions are found in the references [1]-[10]. (2) The criteria indicated are for ordinary classrooms.					

When comparing regulations and classification levels in the Nordic countries, no logical structure is found in general, although the use of descriptors is quite consistent with R'_w for airborne sound insulation and $L'_{n,w}$ for impact sound insulation. However, there is of course an exception, namely impact sound limits in Sweden, where $L'_{nT,w}$ is applied and in addition $L'_{nT,w} + C_{I,50\text{-}2500}$ for the higher classes A and B. All descriptors are defined in ISO 717 [12].

Comparing airborne sound insulation requirements in the five countries, it is seen that DK, IS and NO have the strictest values, and in fact the Danish requirement for vertical sound insulation is 3 dB stricter to compensate for a larger area of the dividing construction. FI and SE have 4 dB lower limits. IS and NO have clearly stricter criteria for the higher classes A and B, 4 and 8 dB, respectively. FI and SE starts at a lower value for Class C and have only 4 dB up to Class A.

For impact sound, the lack of overall logic is similar. The strictest requirement is found in DK, namely $L'_{n,w} \leq 58$ dB, which is 2-5 dB stricter than in the other countries and corresponding to e.g. Class B in IS and NO.

In total, when considering the airborne and impact sound insulation criteria for ordinary classrooms and knowing that there are several other criteria, it seems obvious that the Nordic countries could benefit from cooperation instead of continuing updating classification schemes separately.

4 Facade sound insulation – Regulations and class criteria

In the Nordic countries, the classification schemes and regulations define limits for indoor traffic noise levels – in contrast to other countries in Europe, where requirements are defined as a function of the outdoor level, implying that often a whole table is included in the document with the regulations. For regulations and classification schemes in the Nordic countries, the limits for classrooms are found in Table 4.

Table 4: Nordic schemes for acoustic classification of schools. – Criteria related to facade sound insulation.

Nordic schemes - Main class criteria for traffic noise levels in classrooms – April 2016							
Country with indication of reference		**Required performance for quality levels(1)**, [dB]					**Acoustic regulations**
		Descriptor	Class A	Class B	Class C	Class D	
DK	N/A		N/A	N/A	N/A	N/A	BC [1],[6] requires L_{den} (indoor) ≤ 33 dB
FI	[7]	$L_{Aeq,\ 07\text{-}22}$ (indoor)	≤ 30	≤ 30	≤ 35	≤ 35	No requirements in building regulations. Traffic noise limits in different regulations.
IS	[8]	$L_{p,Aeq,24h}$ (indoor)	≤ 25	≤ 25	≤ 30	≤ 30	BC refers to Class C
NO	[9]	$L_{p,AF}$ (indoor)	≤ 24	≤ 27	≤ 30	≤ 30	BC refers to Class C
SE	[10]	L_{pAeq} (indoor)	≤ 26	≤ 30	≤ 30	≤ 30	BC refers to Class C
		L_{pAFmax} (indoor)	≤ 41	≤ 45	≤ 45	≤ 45	
(1) Overview information only. Detailed criteria and conditions are found in the references. (2) DK: Day 07-19 (default), Evening 19-22, Night 22-07. L_{den} is defined in END (2002), see [13]. The Danish Building Code refers to L_{den} as the only limit and valid for roads and railways separately.							

It is seen from Table 4 that none of the Nordic countries have identical criteria, although the criteria for IS and NO are almost the same. Common for IS, NO and SE is that regulations refer to Class C in the national classification scheme. The most noticeable difference between countries is that L_{den} is used in DK as descriptor for the indoor level, which is not defined in [13] and not used in any other country until now.

The advantage of the Nordic way is that the requirement is expressed as a – seemingly – simple limit value. However, a guideline is needed for how to check compliance using field measurements or calculations, because the indoor level cannot be measured directly, and the descriptor applied for the limit is not defined in any of the building acoustic standards. When using the required facade sound insulation as a function of the outdoor level (as in other European countries), fulfilment of the requirement can be checked directly by measuring the facade sound insulation according to ISO 16283-3 (replacing ISO 140-5). Nevertheless, as facades could have different distances, height and angles compared to the noise source, a guideline is still needed.

In total, as for sound insulation between classrooms, it seems as if a Nordic cooperation could be useful, when revising limits for indoor traffic noise levels.

5 Reverberation time in classrooms – Regulations and classification criteria

The regulatory requirements in the five Nordic countries for reverberation times in classrooms are found in Table 5. 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 check of compliance with the limits.

Table 5: Reverberation time in class rooms - Regulatory requirements in the Nordic countries

Reverberation time in class rooms - Regulatory requirements in the Nordic countries (1) – April 2016						
Status (1) April 2016 **Country & year(2)**	Ordinary classrooms Req. T (s)	Requi-rement	Fur-nished room	Freq. range [Hz]	Details of requirement/criterion(3)	Comments
Denmark (2015) [1] & [6]	≤ 0.6	+	+	125-4000Hz	T20 according to ISO 3382-2 [14] Max. in each 1/1 octave band 125Hz: Max. +20% accepted	Requirements implemented in BC in 2008 and unchanged in the BCs in 2010 and 2015. 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 3382-2 [14]	There is no requirement, only recommendation. Usually, Class C is applied, see Table 6.
Iceland (2016) [8]	≤ 0.6	+	+	125-4000Hz	T20 according to ISO 3382-2 [14] Max. in each 1/1 octave band 125 Hz: Max. + 20% accepted	
Norway (2012) [9]	≤ 0.5	+	+	125-4000Hz	T20 according to ISO 3382-2 [14] 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 [14] 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

(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 2016, but BC from 2012 referring in general to the CS, Class C.

(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.

From the information in Table 5, 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.

The classification criteria for classrooms in IS, NO, SE are found in Table 6. 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 is quite clear: Shorter and shorter reverberation time limits, assuming shorter is better – although speaker's comfort suffers from too short reverberation times. For more aspects related to this issue, see [15] and [16]. It should however be noted that NO has increased the limit value for Class A from 0,3 s to 0,4 s at the revision in 2012. Apart from the speaker's comfort it's also difficult to design for such short reverberation times.

The reverberation time for classrooms is only one of several room acoustic criteria for a typical school with many different rooms. Again – as suggested in the previous sections – it seems obvious to consider Nordic cooperation.

Table 6: Reverberation time in classrooms - Criteria in acoustic classification schemes in the Nordic countries

Reverberation time in classrooms – Classification criteria[(1),(2)] in (s) – Status April 2016						
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**	**npd**	Frequency range 125-4000 Hz T_{20} according to ISO 3382-2 [11] Spaces with built-in furniture Limits max. for each 1/1 oct. 250-4000 Hz For 125Hz: Max. +50% accepted
IS	(IST 45:2011) **IST 45:2016** [8]	(≤ 0.5) ≤ 0.5	(≤ 0.5) ≤ 0.5	(≤ 0.6) ≤ 0.6	(≤ 0.8) ≤ 0.8	See Table 5
NO	(NS 8175:1997) (NS 8175:2005) (NS 8175:2008) **NS 8175:2012** [9]	(≤ 0.6) (≤ 0.6) (≤ 0.3) **≤ 0.4**	(≤ 0.6) (≤ 0.6) (≤ 0.5) **≤ 0.4**	(≤ 0.8) (≤ 0.8) (≤ 0.6) **≤ 0.5**	(≤ 0.9) (≤ 0.9) (≤ 0.6) **≤ 0.6**	See Table 5
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 5

(1) Overview information only. Detailed criteria and conditions are found in the references.
Current versions are indicated in bold. Previous versions are indicated with numbers in brackets.

(2) Class denotations A / B / C / D indicated in descending order, i.e. the best class first.

6 Discussion and conclusions

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, although the Finnish Class D is “npd”. Acoustic conditions are of high importance for learning in schools. A typical school has many different facilities, both rooms for different purposes and open-plan areas for group work. When studying the regulations, it was found that in Denmark, Norway and Sweden, regulations include more than 25 different acoustic criteria, including sound insulation, noise limits and room acoustic parameters. It’s probably the same for Iceland, although not checked. Finland has no regulations and a few recommendations only, but the classification scheme is also quite detailed like the schemes in the other countries.

In Denmark there is no classification scheme for schools, and it’s also not considered important, since facilities could be optimized for the uses and the need for more classification levels has been questioned.

Since the intention is that Class C corresponds to regulatory requirements, Class A and B better, and Class D is not for new buildings, it could be asked what the purpose of Class D is. Is Class D suitable to describe the acoustic conditions in existing schools built before tightening of requirements? The Norwegian classification criteria for reverberation time has been tightened over the years, also for Class D, see Section 5. It could also be asked, whether any older schools would comply with Class D. It might be considered instead to use Class D and maybe even add one or two lower classes to describe actual conditions in older schools, thus making the poor conditions more visible like for energy rating and hopefully encourage improvements.

Although there is a reasonable agreement between the actual acoustic requirements in the Nordic countries for schools, there are still many differences, and it seems as if each country continues to develop and revise requirements and classification schemes independently and asynchronously, which is a pity, since cooperation could prove useful to optimize more criteria and design of schools.

An advantage by having a classification scheme and building code reference to Class C as is the case for schools in Iceland, Norway, Sweden, is that the building code and the acoustic regulations could be updated independently. As before - and especially at BNAM2010 and BNAM 2012 - Nordic cooperation should be encouraged and actually get started, see also [17], which describes parts of the process, when preparing the latest Icelandic classification standard valid from May 2016. Maybe BNAM2016 could be the starting point for real cooperation replacing intentions? The cooperation should of course include more building types like housing, office buildings etc. and start with an agreement about the role and purposes of an acoustic classification scheme and how the use could be optimized.

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