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Rasmussen, Birgit; Guigou-Carter, Catherine

Published in:
Proceedings of Inter-Noise 2016

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

inter.noise HAMBURG 2016

A pilot study on acoustic regulations for schools – Comparison between selected countries in Europe

Birgit RASMUSSEN[1]; Catherine GUIGOU-CARTER[2]

[1] Danish Building Research Institute (SBi), Aalborg University Copenhagen (AAU-CPH), Denmark

[2] Health and Comfort Department, CSTB, 38400 Saint Martin d'Hères, France

ABSTRACT

Acoustic regulations for schools exist in most countries in Europe, the main reasons being improving learning conditions for pupils and work conditions for teachers. As a pilot study, comparison between requirements in selected countries in Europe has been carried out. The findings show a diversity of descriptors and limit values for acoustic requirements.

The paper includes examples of acoustic regulations for schools, including specific sound insulation requirements on airborne and impact sound insulation, limit values for noise from traffic and from service equipment and in addition on reverberation time for class rooms. Furthermore, the discrepancies between countries are being discussed and some priorities for adjusting acoustic regulations in some countries indicated.

Keywords: Acoustic regulations, schools, sound insulation, reverberation time, noise

I-INCE Classification of Subjects Number(s): 51.1.4, 86.

1. INTRODUCTION

The importance of the acoustic environment in the learning process is obvious. As a matter of fact, noise exposure can result in poor speech intelligibility, memory and attention disorders, and can also lead to auditory fatigue and behaviour deterioration, see e.g. [1]. Recent studies have investigated classroom acoustics design with respect to time reverberation but also in regards of speakers' comfort and speech intelligibility [2-3], and acoustics conditions have also increasingly got attention in relation to the indoor climate [4].

Following the work carried out in the last decade concerning comparison of European acoustic requirements for dwellings [5-9], this paper presents comparison between requirements for classrooms in six selected countries in Europe. Previous comparisons were limited to reverberation time, see e.g. [2-3] and in addition [10] for the Nordic countries.

2. ACOUSTIC REGULATIONS FOR SCHOOLS

Typically acoustic requirements for schools concern airborne and impact sound insulation, façade sound insulation or indoor traffic noise level, service equipment noise level, reverberation time and other parameters related to room acoustic conditions, e.g. in open-plan schools. Regulations vary considerably with room types. This paper focuses on acoustic requirements for classrooms, which is the most common room type in schools. Regulations have changed considerably over time. Below is found brief information about the history of regulations in Denmark and France as examples.

2.1 History of acoustic regulations – Examples

Denmark – Brief history of acoustic regulations for schools

For schools the first acoustic regulations were introduced in 1966 with requirements for classrooms on reverberation time, airborne and impact sound insulation, service equipment noise. In subsequent building regulations, requirements were extended to other room types and with more detailed require-

[1] bir@sbi.aau.dk

[2] catherine.guigou@cstb.fr

ments. As an example, the first classroom reverberation time requirements were introduced in 1966 with required frequency independent reverberation time 0.6-1.0 s for 125-2000 Hz, and the requirements remained almost the same over the years, although compliance conditions changed. It was not before 2008, the requirement was made much stricter, max 0.6 s. Traffic noise limits were introduced in 1995. Concerning acoustic requirements for schools, the current building regulations [11] refer to [12].

France – Brief history of acoustic regulations for schools

France introduced the first acoustic regulations for schools in January 1995; this regulation was then updated in April 2003 [13]. The reason for the new regulation was the changes in sound insulation ratings following the revision of ISO 717-1 and -2 from 1996. The impact sound level requirement was therefore modified from the index L_{nTA} of 67 dB(A) to $L'_{nT,w}$ of 60 dB (considered equivalent). The interior airborne sound insulation requirement level remained almost the same, although the single number rating was changed from D_{nAT} to $D_{nT,A}$ (= $D_{nT,w}$ + C). Requirements for reverberation time or service noise equipment were not modified. Concerning external noise, the requirement for façade sound insulation is the same as for dwellings. There was a regulation update in May 1996 and then in 2013. However, the minimum facade sound insulation remains 30 dB (as set in 1978 for housing).

2.2 Current regulations and guidelines on compliance with requirements

It was aimed at choosing minimum five countries from different parts of Europe, so various legislative traditions would be represented. Other considerations included language concerns, as it was found important to study the legislative documents directly. Below is found references to acoustic regulations and brief information about the measurement and rating methods applied in six countries chosen for this pilot study. Typically, standards applied for sound insulation field measurements are the ISO 140 parts 4, 5 and 7 or the new ISO 16283 series (replacing the ISO 140 field standards), for reverberation time ISO 3382-2 and for service equipment noise either ISO 16032 or ISO 10052. Information about main acoustic requirements related to standard classrooms is found in Section 3-6. Similarly, extensive requirements in most countries exist for many other room types, but not included in this paper. For definitions of descriptors are in general referred to regulations or standards.

Belgium

The acoustic regulations for schools are found in NBN S01 400-2 [14]. This standard refers to the ISO 140 series for sound insulation measurements and to ISO 717 for rating. For measurements of reverberation time and service equipment noise are referred ISO 3382-2, and ISO 10052, respectively.

Denmark

The building regulations [11] refer to other publications concerning acoustic requirements, for schools e.g. [12]. Field measurements are carried out according a guideline [15] referring to measurement and rating methods to be applied, i.e. the ISO 140 field standards for sound insulation (will be changed to the ISO 16283 series this year), ISO 717 for rating and ISO 3382-2 for reverberation time measurements and to ISO 10052 for service equipment noise.

France

The legal text from 2003 regarding the application of the acoustic regulation in buildings other than housing [16] is referring to the French standard NF S31-057 for in-situ measurements; this standard dating from 1982 is expired and cancelled since May 2008 and is no longer available or distributed by the French agency for standardization (AFNOR). A special guide for in-situ measurements has been written for apartment buildings in 2014 [17]; this guide should have been completed by a new version concerning educational buildings, but nothing has been produced yet. The measurement methods described in the guide are inspired by ISO 10052 and ISO 3382-2. Measurements of sound insulation and reverberation time cover octave bands from 125 to 2000 Hz, service equipment noise frequencies from 50 to 10000 Hz .Rating of sound insulation follows ISO 717-1 and 717-2. For rating index expressed in dB a margin of 3 dB in the measurement is allowed with respect to the required level.

Spain

The acoustic regulations for schools are found in [18], which refers to ISO 140-4, ISO 140-7, ISO 140-5 for sound insulation, to ISO 717 for rating and to ISO 3382-2 for reverberation time. There are no national requirements for service equipment noise.

Switzerland

Requirements for schools are included in the standard SIA 181 [19] concerning protection against noise in buildings. This standard is rather complex as explained in [20] and is mostly used by acoustic specialists. However, concerning schools and classrooms, the only requirement concerns reverberation time and sound insulation with respect to outdoor noise. Annex G of [19], being informative, sets recommendations for airborne and impact sound insulation between spaces inside a school. Preliminary discussions have started to change these recommendations into actual requirements as well as having a standard specific to schools. Measurement methods in [19] follow the ISO 140-4, ISO 140-5, ISO 140-7 for sound insulation, ISO 717 for rating, ISO 3382-2 for reverberation time and ISO 16032 for service equipment noise.

UK

Requirement E4 of Document E [21] sets the acoustic conditions in schools; it only states that each room or other space in a school building shall be designed and constructed in such a way that it has the acoustic conditions and the insulation against disturbance by noise appropriate to its intended use. Requirement E4 is therefore rather general; however, Section 8 of Document E [21] specifies that the normal way of satisfying Requirement E4 is to meet the values given in Building Bulletin 93 [22]. The measurements methods to verify conformity with acoustic regulations are listed in [23]. The internal ambient noise level IANL includes noise contributions from external noises outside the school premises and service equipment. Measurement methods are ISO 16283-1 for interior airborne sound insulation, ISO 140-7 for impact noise insulation, ISO 3382-2 for reverberation time and ISO 16032 for ambient noise level.

3. AIRBORNE AND IMPACT SOUND INSULATION BETWEEN CLASSROOMS

Table 1 presents the requirements with respect to airborne sound insulation. For four of the six selected countries, the presence of a communication door between two classrooms is taken into account with a decrease of sound insulation level to reach.

Table 1 – Airborne sound insulation requirements for schools – Normal classrooms

Airborne sound insulation requirements(1),(2) for schools – Normal classrooms			
March 2016 Country	**Between classrooms** Requirement [dB]	**Between classrooms with door** Requirement [dB]	**Between hallway/corridor and classroom** Requirement [dB]
Belgium	$D_{nT,w} + C \geq 44$	$D_{nT,w} + C \geq 40$	$D_{nT,w} + C \geq 36$
Denmark	R'_w H: ≥ 48 V: ≥ 51	$R'_w \geq 44$	$R'_w \geq 36$, if door $R'_w \geq \geq 44$ with no door
France	$D_{nT,w} + C \geq 43$	$D_{nT,w} + C \geq 40$	$D_{nT,w} + C \geq 30$
Spain	$D_{nT,w} + C \geq 50$, if no door or window	$R'_w \geq 50$ for wall $R'_w \geq 30$ for door/window	$R'_w \geq 50$ for wall $R'_w \geq 30$ for door/window
Switzerland(3)	$D_{nT,w} + C - C_V \geq 45^{(3)}$	$D_{nT,w} + C - C_V \geq 45^{(3)}$	$D_{nT,w} + C - C_V \geq 35^{(3)}$
UK	$D_{nT,w} \geq 45$	$D_{nT,w} \geq 45$	Separating wall: $R_w \geq 40$ Door: $R_w \geq 30$

Notes
(1) Overview information only. Detailed requirements and conditions are found in the building codes and related documents.
(2) The descriptors applied are found in ISO 717-1. No generally applicable conversion between the different descriptors exists, as the relations depend on characteristics of rooms and constructions. Exact conversion can only be made in specific cases.
(3) Recommendations only. C_V is volume dependant and 0 in case of $V \leq 200$ m^3 (typically the case for classrooms).

Concerning sound insulation between classrooms, Denmark is – due to the use of R'_w and larger floor than wall areas - differentiating between horizontal and vertical requirements. In the case of Spain, the global index rating the sound insulation is modified depending on the situation considered. The sound insulation level is comparable for Belgium and France except for sound insulation with respect to a circulation zone. However, for Belgium the sound insulation level between a circulation area and a classroom depends on the use of the circulation; the level given in Table 2 corresponds to the one for a circulation used during class; for circulation used only after classes the level is decreased down to 32 dB (which is closer to the requirement French level). The UK sets component requirement for the separating wall and door acoustic performance when sound insulation between circulation area and classroom is considered.

Table 2 presents the requirements with respect to impact sound insulation. The adaptation term C_I is only used for Belgium and Switzerland; however this term is close to zero for heavy building types. Therefore in that case, the requirement in terms of the weighted standardized impact sound pressure level ($L'_{nT,w}$) are similar for the different countries using it, except for Spain (less restrictive by 5 dB). Denmark uses the weighted normalized impact sound pressure level which is more commonly used in the Nordic countries. As for the airborne sound insulation, Belgium takes into account the use of the circulation zone to set required level for impact sound insulation. The other considered countries do not have specificity for impact sound in hallway: the requirement is the same as the one between classrooms.

Table 2 – Impact sound insulation requirements for schools – Normal classrooms

Impact sound insulation requirements(1),(2) for schools – Normal classrooms			
March 2016 Country	**Between classrooms** Requirement [dB]	**Between classrooms with door** Requirement [dB]	**Between hallway/corridor and classroom** Requirement [dB]
Belgium	$L'_{nT,w} + C_I \leq 60$	The same	The same
Denmark	$L'_{n,w} \leq 58$	The same	The same
France	$L'_{nT,w} \leq 60$	The same	The same
Spain	$L'_{nT,w} \leq 65$	The same	The same
Switzerland(3)	$(L'_{nT,w}+C_I+C_V \leq 60)$(3)	The same	The same
UK	$L'_{nT,w} \leq 60$	The same	The same

Notes - General

(1) Overview information only. Detailed requirements and conditions are found in the building codes and related documents.

(2) The descriptors applied are found in ISO 717-2. No generally applicable conversion between the different descriptors exists, as the relations depend on characteristics of rooms and constructions. Exact conversion can only be made in specific cases.

(3) Recommendations only. C_V is volume dependant and 0 in case of $V \leq 200$ m^3 (typically the case for classrooms). C_I taken into account only in the case of $C_I \geq 0$ dB.

4. FAÇADE SOUND INSULATION – EXAMPLES

Regulatory requirements for facade sound insulation can be expressed in more ways:

- Minimum facade sound insulation as a function of outdoor noise level (e.g. FR, DE, LT, NL, AT)
- Max indoor noise levels (e.g. DK, FIN, IS, NO, SE)
- Max “night event” levels - combined with other criteria (e.g. NO, SE)
- Some countries combine with a minimum sound insulation.

Consequently, descriptors related to regulations for sound insulation against traffic noise are not always defined in ISO 717. Nevertheless, all methods lead to sound insulation requirements for the façade components. The required sound insulation depends on the outdoor noise level and maximum indoor level. In EU countries, mapping of the outdoor traffic noise level is carried according to END. Examples of the variety of ways expressing requirements are found in [8-9].

The advantage of using a maximum indoor level is that a single value can be fixed for regulations. When façade sound insulation is required, calculation (simplified approach or more precise numerical method to consider construction environment in details) is usually necessary at the building design stage to determine the outdoor noise level from which the required insulation level is deduced.

In Denmark, the required indoor level for classrooms is L_{den} (indoor) ≤ 33dB. Thus, design of the façade depends on the outdoor level, see above. L_{den} is defined in [24]. Procedures for compliance with regulations are found in [15].

In Belgium, the requirements are found in NBN S01 400-2 [14]. The required façade sound insulation depends on the outdoor level, but a minimum is required, $D_{Atr} \geq 26$ dB. Procedures for determination and verification of the façade sound insulation are found in Annexes D, E and F in [14].

In France, façade sound insulation depends on the outdoor sound level [25]; however a minimum façade sound insulation of 30 dB is fixed [16, 25]. The single number rating is expressed in terms of $D_{nT,w}+C_{tr}$. The façade sound insulation is generally set in order to have a noise level in a room of 35 dB(A) during daytime (30 dB(A) during night time from 10pm to 6 am). This method allows more practical in-situ measurements with a loudspeaker even though the measurement can be complicated. The use of real sources (traffic for example) is however allowed for in-situ measurement phase. It should be noted that it is also possible to make measurement of the outdoor noise level before the building construction. For further information about the procedure, see [16, 25].

For Switzerland, façade sound insulation is part of the requirements for schools [19]. The single number rating is expressed in terms of $D_{nT,w}+C_{tr}+C_V$ (C_V being a correction factor depending on room volume). For low to moderate outdoor noise level ($L_r \leq 60$ dB), this index should be at least 27 dB. For higher outdoor noise level ($L_r > 60$ dB), this minimum value of this index is evaluated as L_r–33 dB. The outdoor noise level L_r (combining averages L_{Aeq} levels with some correction terms depending on source type and traffic density) can be obtained from calculations or measurements as well as from a published noise mapping cadastre [26]. For a classroom volume up to 200 m^3 (correction term C_V null), the minimum Swiss façade sound insulation is therefore 3 dB lower than the one set in France.

For the UK, ambient noise level is rather used [22]. The upper limit for indoor ambient noise levels is expressed in terms of $L_{Aeq,30min}$ and is set to 35 dB during normal teaching hours. This level is close to the objective value used in France to determine the façade sound insulation. However, it should be added that the upper limit for indoor ambient noise levels includes sound sources external to the building as well as building services sound sources (i.e. internal sources).

5. SERVICE EQUIPMENT NOISE LIMITS

Table 3 presents the requirements with respect to service equipment noise for stationary sources. First, it should be noticed that a variety of indicators are used in the considered countries; it can or not be normalized to reverberation time, obtained from an average over a certain time or a max level. Therefore, a direct comparison is rather hazardous. However, A-weighting is used in all cases. Surprisingly, Switzerland does not provide any requirement or even recommendation for service equipment noise; however, acoustic consultants aware of the potential problematic effect of service equipment noise in classrooms generally apply recommendations for workrooms and offices.

Table 3 – Service equipment noise limits for schools – Normal classrooms

Service equipment noise limits(1),(2) for schools – Normal classrooms			
March 2016 Country	**Stationary sources** Requirement [dB]	**Furnished**	**Comment**
Belgium	$L_{Aeq,nT,stat} \leq 35$	Corrected to ref. T	
Denmark	$L_{Aeq} \leq 30$	+	
France(3)	$L_{nAT} \leq 33$	Corrected to T	
Spain(4)	No national rules.	N/A	There is legislation, but not on a national level.
Switzerland(5)	$(L_{r,H} + C_V \leq 35)$	+	Not a requirement or recommendation. Usually recommendation for workrooms and offices are followed.
UK	$L_{A,eq,30min} \leq 35$	+	Indoor ambient noise level incl. sources external to the building and service equipment in the building.

Notes - General
(1) Overview information only. Detailed requirements and conditions are found in the building codes and related documents.
(2) No generally applicable conversion between the different descriptors exists, as relations depend on the source characteristics.
(3) $L_{nAT} = L_{ASmax,nT}$, i.e. L_{ASmax} referenced to averaged reverberation time measured on octave bands 500, 1000 and 2000 Hz.
(4) Each region, even local municipality can regulate maximum immission levels due to service equipment. C_V is volume dependant and is 0 in case of volume ≤ 200 m^3, which is typically the case for classrooms.
(5) C_V is volume dependant and is 0 in case of volume ≤ 200 m^3, which is typically the case for classrooms; $L_{r,H} = L_{AFmax} + K1 + K4$ with K1 a correction factor relative to the absorption on the room and K4 a correction relative to the service equipment type.

6. REVERBERATION TIME LIMITS FOR CLASSROOMS

Table 4 presents the requirements with respect to reverberation time in classrooms. This parameter is of prime importance since it has a great influence on learning efficiency for pupils and on work conditions for teachers as well as on reducing noise levels. Thus, it is strongly related to comfort for everyone in the classroom. In general, the limits are set as a function of the classroom volume, except for Denmark and the UK. For the six selected countries, only Switzerland set limits for occupied rooms. France and Switzerland also define a lower limit for the reverberation time. This is important for the teacher comfort as too much dampening in the room is usually associated to voice straining, see [2-3]. The frequency range taken into account also differs. France, Belgium and UK use mostly octave bands from 500 to 2000 Hz, while Denmark and Switzerland cover a common wider building acoustic frequency range, see Table 4, to establish "balanced" acoustics in the classroom. Switzerland establishes a relationship between the volume and the target reverberation time T_{soll} and defines a range of accepted values around that target reverberation time for different frequency bands; this approach is also used in Germany, see [2-3].

Examples of room acoustic requirements for classrooms and open-plan schools are found in [10] and [27] for the five Nordic countries. In [2-3], optimization of classroom acoustics taking into account teachers' comfort and speech intelligibility is described in detail in the context of regulations, and recommendations on principles for reverberation time requirements are found for classrooms.

Table 4 – Reverberation time requirements for schools – Normal classrooms

Reverberation time requirements(1) **for schools – Normal classrooms**					
March 2016 Country	Ordinary classrooms Req. T (s)	Furnished room	Freq. range [Hz]	**Details of requirement/criterion** Non-occupied rooms, if no other information is given	**Comments**
Belgium	≤ 0.8 (example)	+	500-2k	Avg. 500, 1k, 2k Hz	Example: Volume 150 m^3
Denmark	≤ 0.6	+	125-4k	T20 according to ISO 3382-2 Max. in each 1/1 octave band. 125Hz: Max. +20% accepted	The building code refers to [12] for details.
France	0.4 ≤ T ≤ 0.8	+	500-2k	Averaged 500, 1000 and 2000 Hz octave bands	For volume ≤ 250 m^3
Spain	T ≤ 0.7 T ≤ 0.5	- +	500-2k	Average of 500, 1000, 2000 Hz.	For volume ≤ 350 m^3
Switzerland	T/T_{soll} ≤ 1.2	+	100-5k	Occupied room See SIA 181, Section 3.3 for details on upper and lower limits.	For volume 150 m^3,.max T is 0.63 s. Min T is 0.42 s between 250 et 2000 Hz
UK	≤ 0.6 ≤ 0.8	+	Midfreq.	Primary school Secondary school	500-2k oct. bands or 400-2.5k for 1/3 oct. bands
Notes (1) Overview information only. Detailed requirements and conditions are found in the building codes and related documents.					

7. DISCUSSION AND CONCLUSIONS

Since acoustic conditions are of prime importance for learning conditions, acoustic regulations exist in most countries in Europe, although they differ from country to country. Acoustic requirements (or recommendations) for schools typically concern airborne and impact sound insulation, traffic noise, service equipment noise, reverberation time, equivalent sound absorption area and sometimes other room acoustic parameters. The requirements for a room depend on the use of the room and neighbour rooms, implying different limit values for e.g. classrooms, workshops, music rooms and sports halls, open-plan teaching areas.

To get more information about the situation, a pilot study about comparison of acoustic regulations for classrooms – being the core type of room in schools - has been carried out in six countries in Europe. The importance of the acoustic conditions in classrooms has been supported by several studies, e.g. in the PISA 2012 survey from OECD [28], about 20% of the students reported that they did not feel able to work well because of noise and disorder in the classroom. A German field study on elementary school children demonstrated that significant effects of reverberation on speech perception and short-term memory of spoken items [29]. The children from reverberating classrooms performed lower in a phonological processing task, reported a higher burden of indoor noise in the classrooms, and judged the relationships to their peers and teachers less positively than children from classrooms with good acoustics. In France, the Observatoire de la Qualité de l'Air Intérieur (OQAI, Indoor Air Quality Observatory) did start in 2013 a national campaign on 300 schools located in France. Measurements and questionnaire-based investigations are performed in order to evaluate exposure level to air pollutants, as well as visual, thermal and acoustic comfort [4]. Results will certainly help in improving the acoustic design of classrooms and regulation if necessary.

The six countries selected for the pilot study were Belgium, Denmark, France, Spain, Switzerland and the UK. The results from the pilot study show that methods, descriptors and limit values differ significantly. Although conversion between different descriptors cannot be made in general, it seems as if max difference for airborne and impact sound insulation is minimum 5 dB. For façade sound insulation, the situation is more unclear, and specific cases would be needed to explain differences. Concerning service equipment the diversity is also clear, as all six countries apply different descriptors, and a fair comparison would require a more detailed study. The limits set for airborne sound insulation, impact sound insulation, traffic noise and service equipment noise have the goal to limit background noise that is not related to the pupils and the teacher in the classroom and are in general defined in order to have a background noise level in the classroom about or lower than approx. 35 dB. Noise associated to pupils and teacher is usually higher.

A major parameter for classroom design and speech intelligibility is definitely reverberation time. For reverberation time, there are some variations in limit values in the six countries selected for the pilot study, see Table 4. In addition, the frequency range taken into account differs, as four of six countries only use 500-2000 Hz, and the remaining two countries 100-4000 Hz. Differences also exist with respect to the procedures used to verify compliance with respect to regulation. In [2-3], the improvement of teachers working conditions was discussed in terms of classroom acoustics and especially reverberation time, and use of target values with lower and upper limits are recommended. Recommended values for reverberation time in an unoccupied, furnished classroom were between 0.6 and 0.7 s for a classroom volume below 210 m^3. These values were found to optimize teacher vocal comfort and good intelligibility for the pupils. From Table 4 it can be seen that the six countries are inside or close to the reverberation time range. In the considered six countries, only Switzerland sets lower and upper limit for the full building acoustic frequency range. To have target values with limits for the full frequency range would be very useful for renovation of classrooms to ensure a frequency balanced reverberation time, as there could otherwise be a high risk for lack of absorption at the lower frequencies.

Another learning point could be cooperation about simplifying regulations, starting with layout to make it easier to find the relevant limit values In addition, the pilot study showed that minimum three of six countries have a guideline for acoustic field testing, and it could be recommended preparing a joint guideline and thus benefit from more countries' experience. As a last recommendation could be mentioned preparation of a guideline for acoustic design of façade performance, e.g. based on the Annexes found in the Belgian standard [14].

Last, it should be reminded that all tables in this paper provide overview information only. Detailed requirements and conditions are found in the building codes and related documents, which must be consulted at planning and design.

ACKNOWLEDGEMENTS

The authors are grateful to the European acoustic colleagues, who assisted interpreting information about acoustic regulations for schools in their country. In general, comments, corrections and update of information will be appreciated.

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