Sound Insulation Descriptors in Europe—Special Rules Complicate Harmonization within Lightweight Industry

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Many European countries have a sound classification standard connected to the building regulations in order to specify minimum requirements. The various national standards have a lot of similarities, however the acoustic descriptors differ more than what is obvious by a quick comparison of current classification standards. The different descriptors in each country are to some extent a heritage from the past, successively adapted to the building industry in each country and their certain traditions in building technique. The descriptors and the requirements are necessarily not based on subjective experience. Furthermore, to fulfil national interests and to fit to new design trends of housing units etc, the descriptors involve small local adaptations to each country. These local adaptations are not easy to find unless the standards are read carefully. This causes problem since the building industry is not restricted to national boundaries anymore. Many companies have activity in countries adjacent to each other and in future the probability for increased activity all across Europe and also outside Europe is to be expected, unless regulations restrict this development. Combining national special rules and some severe uncertainties in the measurement and evaluation procedures of sound insulation, the situation is more critical for lightweight structures. This is partly due to the fact that the development of building systems are made in one country, the production takes place in production plants, i.e. the production and the process are fitted to local regulations and are "standardized". The standardized process is fast and dry but also needed due to lack of prediction models. And once the light weight system and the system process are established in one country it is complicated and expensive to adapt them to other countries. In this paper an overview of special national rules in some European countries and major problems connected to lightweight construction are presented.

INTRODUCTION

This paper considers sound insulation descriptors, requirements and special rules in some European countries. The paper focuses on multi-storey housing and briefly describe the differences between building codes in different European countries and their effect on the lightweight building industry, see also [1, 2, 22, 23]. It is partly based on a work within Building With Wood BWW with the acronym "LowFreCon",

All European countries have sound insulation requirements specified either in the building regulations and/or in sound classification schemes. In some countries the sound classification schemes and the regulations are closely connected since the regulations referred to national standards (classification schemes). The schemes and the regulations are normally based on similar descriptors, originating from the international standards ISO 140 and ISO 717 [18,19]. However, the descriptor in the regulations are completed with additional national rules and consequently they differ more than what is obvious at the first glance. The details and differences from seven European countries will be described more in detail further on in this article. A summary of current legislation in these particular seven European countries is given in table 1.

During different periods in history attempts have been made to coordinate the sound insulation requirements in some countries. In the Nordic countries a far-reaching attempt was made during the mid 90's. The work was partly funded by a joint governmental organization called "the Nordic Committee on Building Regulations", and by a Nordic standardization organization, Inter Nordic STAndardization—Building (INSTA-B). However, the work did not fully succeed even though an equal basic system for sound classification was presented. All Nordic countries agreed upon four classes (A, B, C and D) and that sound class C should correspond to the minimum requirement according to national building regulations. Nevertheless, today there are huge differences between the requirements in each country, both regarding descriptors and their evaluations but also values for different classes. Furthermore, even if the figures or the descriptors, really appears to be equal at a glance, they might actually be rather different due to national special rules.

Analyzing all differences, a coordination of National regulations across all Europe would be a huge challenge and probably not exhaustively possible. However it would be of great benefit, if at least the descriptors could be similar, which is also one of the main goals within the ongoing COST action (European Organization of Scientific and Technical Research), COST TU 0901. In parallel, there is some ongoing, simplification work within ISO/TC 43/WG 18, revision of ISO 717 [18]. If successful, this would be very helpful for the industry and their future development and trade, in particular for the lightweight industry. With regard to building regulations, the market is indistinct today, thus impeding exchange of building systems and products. It is an important task for acousticians working in the field of building acoustics today to overcome national protectionism and politics in order to encourage and simplify the

Table 1. Sound insulation of dwellings. Overview building codes and sound classification schemes in some European countries—july 2010.

Country	Building code (BC)	Classification scheme (CS)	BC link to CS	BC Reference to CS	BC References	CS References
Sweden (SE)	BBR 2008	SS 25267:2004	+	Class C[(1)]	[7]	[17]
Finland (FI)	RAKMK C1:1998	SFS 5907:2004	(+)	(Class C)[(1)]	[4]	[14]
Austria (A)	OIB Guideline V:2007 and Building Codes federal states referring to ÖNORM B 8115-2: 2006	in preparation as ÖNORM B 8115-5			[11, 12]	[–]
Germany (D)	Musterbauordnung (MBO) 2002, 2008	DIN 4109	–	–	[8]	[9, 10]
Switzerland (CH)	SIA 181:2006 (Schallschutz im Hochbau)[(2)] SIA 260–267[(2)]	SIA 181:2006	Complementary	Complementary	[–]	[–]
Denmark (DK)	BR 2008	DS 490:2007	+	Class C[(1)]	[3]	[13]
Iceland (IS)	Byggingarreglugerd Nr. 441/1998	IST 45:2003	(–)	Class C[(1)] recommended	[5]	[15]
Norway (NO)	TEK'97	NS 8175:2008	+	Class C [(1)]	[6]	[16]

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

[(2)]Switzerland does not have a building code master document. The Swiss building code is made of a series of standards. The different standards in the series deal with distict building aspects. The documents in the series all start with the letters SIA (Schweizerische Ingenieur- und Architektenverein) and are numbered: E.g. SIA 265:2003 regulates the structural issues of timber buildings. Similar SIA standards exist for masonry, concrete etc. They do not contain reference values of other standards in the series but may refer to the relevant SIA standard. Sound insulation issues are regulated in SIA 181:2006 (covers the sound requirements of all types of construction) trade between the countries in an "open Europe". Unfortunately, the unnecessary differences in acoustic regulations create a trade barrier which is more extensive and expensive than necessary with regard to cultural differences between countries.

Instead of cooperation and coordination and strict use of current standards based on knowledge, revisions of the building codes have been adapted to current building tradition and to former requirements due to national experiences solely, i.e. changes have been made by adding special rules to the international standards [18, 19], to fit to national building traditions and classification standards. Additional special rules were introduced and included, for example as notes or rules explained somewhere in the document-not necessarily in the tables with limited values-or even in other documents like e.g. guidelines. The reason is, in many cases, that no one wants to make changes that can affect the local industry negatively even if the best would be to encourage improved constructions and to simplify trade. Today, the industry put a lot of energy to adapt building systems to various regulations without any scientific reason.

BUILDING REGULATIONS REGARDING LIGHTWEIGHT STRUCTURES

The use of the extended frequency range down to 50 Hz is a topic which is currently frequently discussed all across Europe. In Sweden it has been mandatory to apply spectrum adaptation terms ($C_{50\text{-}3150}$ and $C_{I,50\text{-}2500}$ from 50 Hz) in the building code since 1999. The main reason for the revision at that time was to secure the development of an increasing amount of lightweight structures, primarily in wood.

It should be favourable for the lightweight structural development if the rest of Europe introduces frequencies down to 50 Hz according to current standard. Nevertheless, in the mean time several issues might require further analysis and discussion especially concerning

1. the predicting performance methods
2. reproducibility problems of the laboratory and field measurement methods
3. Transfer the results from theory to practice (the process [27])

in order to improve accuracy of measurements, calculations and evaluation of single numbers [20, 21, 24]. But still it is necessary to include low frequencies for lightweight structures since they are prevailing regarding subjective experience [25].

Hence, even if there are practical problem such as measurement uncertainties, it is of importance that current legislation is adapted to the future development of building technique. Building technique that includes very light structures. If not, the development will not go in the right direction, Today, the evaluation principles are certainly not adapted to these new structures and there is a potential risk for failure and product development towards "old fashioned" measures which might cause big problems for the industry in future [26]. Hence, there is a need for fast implementation of new regulations but also a need for extended research directed to lightweight structures. The acoustic research has to be more oriented to solutions for lightweight industry rather than problems.

The quantity of buildings using lightweight structures for multi storey residential buildings is increasing and it is going fast. For example, in Sweden more than 15% of all new multi-storey residential buildings are built with lightweight structure (the main part with wooden structural material). This is increasing due to several factors, for example

1. governmental support
2. its highly industrialized production
3. environmental issues et.c.

Furthermore the knowledge regarding fire resistant and stability is mainly solved. It is possible to build rather high rise buildings (at least eight storeys) in wood today, fulfilling current regulations. A lot of effort has been made in order to adapt the fire resistance regulations to promote wooden structures in multi-storey family houses. This has been necessary since no one wants the inhabitants to experience severe fire damage with high risk for human life. Furthermore, no one expects damage or structural break emanating from lack of strength. Nevertheless, still the sound insulation requirements are a remnant from the history and not adapted to current development of new systems. The risk of failure during the process is also a big risk when introducing lightweight structures adding yet another risk factor, see [27].

MAIN REASONS FOR INCLUDING LOW FREQUENCIES IN THE EVALUATION PROCEDURE

Poor sound insulation is not a problem that is obvious to those who will buy an apartment immediately. They will become aware of it after they have moved into their new housing unit. In case the problem becomes severe and involves diffuse low frequencies and perhaps also includes disturbing vibrations it might cause long term effects on human beings. In case it is high frequency problems it might be irritating but often these problems will be solved more easily even if the inhabitants have already moved in. It could be some leakage problem, sound transmission through ducts, high frequency impact sound etc. As soon as the failure is detected it is easy to solve.

Unfortunately, lightweight structures normally exhibit behaviour involving diffuse low frequency problems and in case of failure it is very difficult to accomplish sufficient measures afterwards. Hence, in order to prevent an adverse development of the lightweight building industry in general there is a need for quick action regarding target values and evaluation principles for sound insulation, and then in particular low frequency impact sound and vibrations caused by household activities.

In order to consolidate the future position of lightweight residential buildings compared to heavy weight buildings there is a need for future development of the acoustic evaluation methods and raised knowledge within the industry regarding vibrations and material characteristics. As far as concerned, the most immediate needs are also important in order to actually fulfil the essential requirement “Protection against noise” of the European Construction Productive Directive (CPD). First of all it is absolutely necessary to establish well founded criteria for evaluation of impact sound insulation in order to make minimum requirements and various sound classes in classification schemes reasonably comparable to the corresponding requirements of heavy building structures [26]. In this context it is important to consider the vibration behaviour due to household activities and its effect on the experienced low frequency impact sound. The lightweight industry is also in need of quick implementation of new criteria in International and European standards (i.e. ISO 717) in order to facilitate the trade of lightweight building systems. The systems complexity, the difficulties to replace single products and the lack of calculation models make this issue even more urgent. But still, there is a need for research in parallel in order to improve the figures in future and to promote and support an advisable development of new lightweight building systems.

CURRENT BUILDING REGULATIONS IN EUROPE

Within Europe, Sweden is the only country which has adopted the low frequency spectrum adaptation term for sound insulation as a mandatory requirement in the national building regulations [7]. The sound insulation indices used in Sweden are (some special rules should be applied additionally, see table 2 and 3):

1. $R'_{w} + C_{50\text{-}3150}$
2. $L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$

The reason for this was to adapt the requirement as far as possible using current international standards to new building technique for multi storey houses, with lightweight structures. However, research work indicates that the introduction of the low frequency spectrum adaptation terms is not harsh enough in order to prevent bad constructions to enter the market [25], at least for impact sound. It is necessary to rather quickly create completely new measures or new evaluation curves for impact sound and perhaps introduce some sort of requirement regarding vibrations from household activities.

Current situation regarding sound

Table 2. Regulatory requirements for impact sound insulation between dwellings in seven european countries including remarks of national special rules—july 2010.

		Requirements impact sound	
Country	**Requirements found in**	**Impact sound [dB]**	**Remarks–National special rules [1]**
SE	CS (Class C)	$L'_{n,w} \leqslant 56$	$V_{r,max} = 31$ m^3 ➔ $L'_{n,w} = L'_{nT,w}$ when $V_r \geqslant 31$ m^3
		$L'_{n,w} + C_{I,50–2500} \leqslant 56$	Bathrooms are excluded from requirement in case the level from service equipment is kept below some certain limits. Also floor (1 m^2) immediately inside the entrance door is excluded.
FI	BC or CS (Class C) (Identical limits)	$L'_{n,w} \leqslant 53$	Volume limit in: $V_{r,max} = 60$ m^3 ➔ $L'_{n,w} = L'_{nT,w} + 3$ dB when $V_r \geqslant 60$ m^3 Bathrooms are excluded from requirement
A	BC (federal states referring to ÖNORM and OIB Guideline)	$L'_{nT,w} \leqslant 48$ (row houses $L'_{nT,w} \leqslant 43$, special requirements in buildings with commercial units)	—
D	DIN 4109	$L'_{n,w} \leqslant 53$	National special rules (additional rules compared to ISO 140-7)
CH	SIA 181:2006 Schallschutz im Hochbau	$L' \leqslant 53$(1) $L' \leqslant 48$	bedroom (in case of normal sensitivity to noise) school (in case of normal sensitivity to noise)
DK	CS (Class C)	$L'_{n,w} \leqslant 53$	Balconies and floors in rooms with floor area less than 2.5 m^2 do not need to fulfil the requirements. This is stated directly in DS 490 just above the Table with limited values. For light-weight constructions it is recommended to extend the frequency range down to 50 Hz, applying $L'_{n,w} + C_{I,50\text{-}2500} \leqslant$ 53 dB. This recommendation is found in a separate guideline
IS	BC	$L'_{n,w} \leqslant 58$ Row housing: $L'_{n,w} \leqslant 53$	$L'_{n,w}$ is calculated by applying the former "8-dB max rule" ($L'_{n,w,8dB} \leqslant 58$). It is expected to disappear in the next revision of the building code. Classification scheme is not yet referred to in the BC
NO	CS (Class C)	$L'_{n,w} \leqslant 53$	Volume limit $V_{r,max} = 100$ m^3 ➔ $L'_{n,w} = L'_{nT,w} + 5$ dB when $V_r \geqslant 100$ m^3 It is recommended to include $C_{I,50\text{-}2500}$

(1) $L' = L'_{nT,w} + C_I + C_V$ (as in ISO 717-1). C_I can be given either for the frequency band 100–2500 Hz or 50–2500 Hz. The frequency band is mentioned in the index, e.g. $C_{I,\ 50–2500}$. ➔ Converted and expressed as $L'_{n,w}$ a L' of 50 dB is around 52–45 dB.

Table 3. Regulatory requirements for airborne sound insulation between dwellings in seven european countries including remarks of national special rules—july 2010.

			Requirements airborne sound insulation
Country	**Requirements found in**	**Airborne sound insulation [dB]**	**Remarks–special national rules [2]**
SE	CS (Class C)	$R'_w + C_{50\text{-}3150} \geqslant 53$	Relation V/S must not exceed 3.1 m when evaluating the single number, R'_w (i.e D_{nTw}). Hence, R'w in Sweden corresponds to $D_{nT,w}$ when $V/S > 3.1$.
FI	BC or CS (Class C) (Identical limits)	$R'_w \geqslant 55$	Receiving room volume limitation in the evaluation, $V_{r,max} \leqslant 60$ m^3
A	BC (federal states referring to ÖNORM and OIB Guideline)	$D_{nT,w} \geqslant 55$ (row houses $D_{nT,w} \geqslant 60$)	special requirements in buildings with commercial units
D	DIN 4109	$R'_w \geqslant 53/54$	National special rules (additional rules compared to ISO 140-4)
CH	SIA 181:2006 Schall-schutz im Hochbau	$D_i \geqslant 52$ dB$^{(1)}$ $D_i \geqslant 57$ dB	bedroom (in case of normal sensitivity to noise) school (in case of normal sensitivity to noise)
DK	CS (Class C)	$R'_w \geqslant 55$	If the area of the common part of the partition between two rooms is less than 10 m^2, the area applied is largest of the values of the actual area and the receiving room volume divided by 7.5. If there is no common area, the normalized level difference D_n is applied instead of R' It is recommended to include $C_{50\text{-}3150}$ at the same level and in particular for light-weight constructions (walls < 100 kg/m^2 and floors < 250 kg/m^2) it is recommended to extend the frequency range down to 50 Hz and apply $R'_w + C_{50\text{-}3150} \geqslant 53$ dB The special rules are found in SBi Guideline 216 and 217
IS	BC	$R'_w \geqslant 52/55$	R'_w is calculated with old "8 dB max rule" as in old I_a-value. $R'_{w,8dB}$ = Ia (it is expected that this wilkl disappear in the next revision). Min. value 52 dB, recommended 55 dB for apartments, min. value 55 dB for row-houses
NO	CS (Class C)	$R'_w \geqslant 55$	Receiving room volume limitation in the evaluation, $V_{r,max} \leqslant 100$ m^3 It is recommended to include $C_{50\text{–}5000}$ at the same level. If the partition contains a door, and the total dividing surface is smaller than 10 m^2, then S = 10 m^2. If there is no common partition between the rooms, then S = 10 m^2. In this case, it is the normalised level difference, $D_{n,w}$, that is determined (see NS-EN ISO 140-4). The resulting value of $D_{n,w}$ is then compared with the limit value set for R'_w.

$^{(1)}D_i$ ($D_i = D_{nT,w} + C - C_v$ (as in ISO 717-1)) ➛ Converted and expressed as R'_w a D_i of 54 dB is around 54–57 dB

insulation requirements in some other European countries are presented in table 2 and table 3. Apart from different single numbers there exist national special rules which are not immediately discovered in the regulations, see next section. For those companies working in different European countries these additional special rules further complicate the trade, quite contradictory to the aim of European Union.

For vibrations, no strict minimum requirement exists, hence in case of annoying vibrations there is no building code taking care of this except in parts of Austria, where OIB Guideline V is introduced (OIB Guideline V - sub-clause 4) demands a protection against vibrations. Due to these facts there is a need for a reconsideration of current evaluation of impact sound but also to consider vibrations. This is of immediate interest since

- The experienced sound insulation is normally worse than the objective value exhibit, perhaps reinforced due to combined low frequency noise and vibrations
- The sound class for a lightweight construction do not correspond to the sound class for a heavy weight construction even if the objective values are identical
- The lightweight industry is rapidly increasing its market share. Hence, in case current objective measures retain, the risk of increased numbers of bad constructions entering the market grows

Perhaps, new evaluation principles are not necessary for all types of living accommodations. For some certain types of housing units current evaluation principles might work. However, there is certainly a need for raised knowledge regarding modern living habits in order to state well founded criteria in those cases. Hence the results might become different single numbers applicable to various multi storey residential buildings.

SPECIAL RULES

COMPLIANCE WITH REGULATIONS

Apart from the differences stated above, some further additional differences might confuse the market, and these differences and their effect on the national adaptations for various systems is far from clarified. Typical users might think that each measured value must fulfil the requirements. However, it is not always perfectly clear, if each single measured value really must comply with the requirement. In some countries, deviations in single values are accepted as long as the mean value from a number of measurements, fulfil the requirement. The number of measurements needed to fulfil the requirement in each country is - or should be - stated in each national standard.

In addition to the issue of measurement uncertainty and related national compliance rules, other factors might influence whether a building system fulfils the regulations or complies with a specific limit or not. As earlier mentioned regarding impact sound insulation and airborne sound insulation, field results or rather the modified field results can depend on the national special rules.

It would be a great advantage, if the rules and procedures could be minimized and/or further clarified in the international standards and thus harmonized between countries. In addition to the before-mentioned special rules, there might be other national special rules related to limited values. Hence, it is of course also relevant and probably even more important to review descriptors and limit values. Furthermore, there are differences in requirements between countries depending on the type of living accommodation, dwellings for elderly, normal dwellings etc.

In spite of different building practices, there seems to be no scientific reason for various national requirements and special rules, since people living in the countries represented in this paper are considered to have approximately the same living habits and equal expectations of their home environment. The reason for differences is rather traditions in each country and lack of cooperation.

Complaints from residents in light-weight housing indicate a need to include lower frequencies in the evaluation for such construction types. Low frequencies in lightweight structures might cause new disturbances from vibrations, implying a need to also developing regulations for vibrations. However, there are a lot of issues in need of clarification in order to finally state the proper and predictable procedure to measure, evaluate and compare the results to a suitable value in the building code [26].

BENEFITS OF REVIEWING SOUND INSULATION DESCRIPTORS, LIMITS AND RULES

More work on the findings stated in this paper, cooperation and implementation would have the following benefits:

1. Increased exchange of knowledge—better understanding regarding the basis for national special rules
2. Less complicated national adaptations—some adaptations might be unnecessary with regard to subjective response
3. Facilitate and encourage more cross country trade between countries
4. Lower costs for the building industry
5. Less risk for mistakes due to the fact that some special rules may not be discovered by consultants and other parties involved

The need for some of the special rules may be caused by a non-optimal choice of descriptors. Thus, it is important to understand the reasons and to investigate if other descriptors are more optimal.

The building industry today is not national any more. Almost all building companies and manufacturers are working all across Europe or at least in limited parts of Europe, for instance on the Nordic market. Each company makes their own investigations which involve expensive, national adaptations in order to enter new markets or to market new products. Besides, if the national adaptations are not discovered when transferring building systems or building products from one country to another, the costs will raise even more afterwards. Often, it is necessary to involve consultants from each country in order to understand and clarify the differences for the developer.

SUMMARY

This paper is summarizing national special rules for sound insulation requirements in the building regulations in some European countries.

In terms of coordination the Nordic countries were rather close to meeting an agreement in the mid 90's. However, lack of consensus and the asynchronous revisions of building regulations led to stop of cooperation soon after. Since then, differences between the Nordic countries have increased. Descriptors and other rules differ more than what is obvious at the first glance, when comparing the regulations or classification standards. When comparing the diversified requirements and standards existing now—approximately fifteen years later—it seems to be time to reconsider the situation and reopen cooperation to the benefit of the residents of dwellings, building industry and development of building constructions. The largest differences in requirements and classes are found for impact sound insulation. Adding potential national special rules from the rest of Europe will probably make the picture even more complicated. The present situation impedes development and creates trade barriers, and there seems to be a high interest for all parties involved in the building process to change the situation.

It is concluded that more close cooperation could contribute to identify the most important special rules, and it would be proper to prepare a document with an overview of all national building acoustic requirements (including special rules) and classes in the European countries, starting with dwellings. The document should state the reason for special rules and identify which of the current rules are important to retain, if any. The document would then include 1; proposals for change of descriptors to fit also to the lightweight structures, 2; evaluation if there is a need for certain special rules for lightweight structures to be included in ISO standards, 3; perhaps further work directed to lightweight industry in particular. The results of such work is urgent and could provide useful input for the revision of ISO 717, and for the work within the COST Action TU 0901 aiming at harmonization of descriptors and classification schemes in Europe.

REFERENCES

1. K Hagberg and B Rasmussen, "Impact sound insulation descriptors in the Nordic building regulations—Overview special rules and benefits of changing descriptors". BNAM, Bergen, Norway, 2010.

2. H Helimäki and B Rasmussen, "Airborne sound insulation descriptors in the Nordic building regulations—Overview special rules and benefits of changing descriptors". BNAM, Bergen, Norway, 2010.

3. Building Regulations 2008, Danish Enterprise and Construction Authority, Danish Ministry of Economic and Business Affairs.

4. RakMK C1:1998, The National Building Code of Finland: C1 Sound insulation and noise abatement in building, Regulations and guidelines.

5. Byggingarreglugerd Nr. 441/1998.

6. Teknisk Forskrift 1997 (TEK'97) Technical Regulations under the Planning and Building Act 1997, National Office of Building Technology and Administration, Norway

7. BBR 2008, Boverket 2008

8. Musterbauordnung—MBO—Fassung November 2002. Online Resource: http://www.is-argebau.de

9. DIN 4109 :1989-11, Schallschutz im Hochbau; Anforderungen und Nachweise

10. DIN 4109 Beiblatt 2: 1989-11, Schallschutz im Hochbau; Hinweise für Planung und Ausführung; Vorschläge für einen erhöhten Schallschutz; Empfehlungen für den Schallschutz im eigenen Wohn- oder Arbeitsbereich

11. OIB Guideline V: 2007, Schallschutz; OIB, Vienna

12. ÖNORM B 8115-2: 2006 Schallschutz und Raumakustik im Hochbau Teil 2: Anforderungen an den Schallschutz; Österreichisches Normungsinstitut Wien

13. DS 490:2007, "Lydklassifikation af boliger". (Sound classification of dwellings), Denmark.

14. SFS 5907:2004, "Rakennusten Akustinen Luokitus", Finland. English version "Acoustic classification of spaces in buildings" published in July 2005.

15. IST 45:2003, "Acoustics—Classification of dwellings", Iceland. Note: Under revision, cf. Draft IST 45:2010, "Acoustic conditions in buildings - Sound Classification of Various Types of Buildings" (publication expected in 2010).

16. NS 8175:2008, "Lydforhold i bygninger, Lydklassifisering av ulike bygningstyper" (Sound conditions in buildings—Sound classes for various types of buildings), Norway.

17. SS 25267:2004, "Byggakustik—Ljudklassning av utrymmen i byggnader— Bostäder". (Acoustics—Sound classification of spaces in buildings—Dwellings). Sweden.

18. ISO 717, Acoustics—Rating of sound insulation in buildings and of buildings elements
    - Part 1: Airborne sound insulation, 1996.
    - Part 1 Amd. 1: Rounding rules related to single-number ratings and single-number quantities, 2006.
    - Part 2: Impact sound insulation, 1996.
    - Part 2 Amd. 1: 2006.

19. ISO 140, Acoustics—Measurement of sound insulation in buildings and of building elements
    - Part 2: Determination, verification and application of precision data, 1991.
    - Part 4: Field measurements of airborne sound insulation between rooms, 1998.
    - Part 5: Field measurements of airborne sound insulation of facade elements and

facades, 1998.

- Part 7: Field measurements of impact sound insulation of building elements, 1998.
- Part 14: Guidelines for special situations in the field, 2004.

Note: ISO 140 consists of more parts. The above parts are those relevant to field measurements.

20. Kylliäinen, M. Uncertainty of impact sound insulation measurements in field. Report 125, Tampere University of Technology, 2003

21. Christian Simmons, "Managing uncertainty in building acoustics: comparisons of predictions with the 12354 standards to measurements". Dissertation, Luleå University of Technology, 2009.

22. .*"Sound insulation between dwellings—Descriptors in building regulations in Europe"* by Birgit Rasmussen & Jens Holger Rindel. Applied Acoustics, 2010, 71(3), 171–180.

23. *"Sound insulation between dwellings—Requirements in building regulations in Europe"* by Birgit Rasmussen. Applied Acoustics, 2010, 71(4), 373–385.

24. Hagberg, K., Thorsson, P. "Uncertainties in standard impact sound measurement and evaluation procedure applied to lightweight structures", Proceedings, International conference on Acoustics, ICA 2010.

25. Hagberg, K. "Evaluating field measurements of impact sound", Building Acoustics, Volume 17, no 2, 2010, p.105–128.

26. Hagberg, K. ¨Acoustic development of lightweight building system", Proceedings Euronoise 2009

27. COST "MICC-Flexible industrialized open lightweight building systems require a good process to make them robust, COST TU0901 meeting Florens 2011

MEASURING FATIGUE THROUGH THE VOICE

Scientists can learn a lot from watching a group of people sitting around, chatting, playing movies, reading, and happily making new friends according to Australia acoustician Adam Vogel, who carefully observed this sort of group in a fatigue management study he and his colleagues describe in The Journal of the Acoustical Society of America (December 2010). Their report shows the effects of sustained wakefulness on speech and describes a novel method to acoustically analyze the effects of fatigue on the central nervous system as revealed through speech. The findings are significant to workers, employers, public safety officials, and military leaders who are concerned with managing fatigue over long shifts, notes Vogel. "There is increasing interest in the development of objective non-invasive systems that can be used to assist the identification and management of fatigue in both health and workplace settings," he says. Measuring fatigue by analyzing a person's speech and quantifying any changes from their normal, rested speech may enable doctors to make objective decisions about a person's ability to function in a work environment. It may also be a useful tool for monitoring fatigue in clinical trials where alertness is a key measured outcome. The Australian study involved 18 young adults who provided speech samples (sustained vowels, reading counting and reading tasks) every two hours. Vogel and his colleagues looked at components of speech such as length of pauses and total time to complete a spoken task. Their results showed that as fatigue progresses, speech slows and variations in pitch increase and tone diminishes. Their conclusion is that we have less control over the muscles that produce speech as we become more and more tired.