Acoustic design of open plan schools and comparison of requirements

Møller Petersen, Claus; Rasmussen, Birgit

Published in:
Proceedings of BNAM2012

Publication date:
2012

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

Link to publication from Aalborg University

Citation for published version (APA):
Møller Petersen, C., & Rasmussen, B. (2012). Acoustic design of open plan schools and comparison of requirements. In P. Juhl (Ed.), *Proceedings of BNAM2012* Nordic Acoustic Association. Joint Baltic-Nordic Acoustics Meeting (BNAM), Proceedings Vol. 2012
http://vbn.aau.dk/files/69932466/BNAM2012_Paper73CMP_BiR_AcousticDesignOpenPlanSchools.pdf

BNAM2012
Joint Baltic-Nordic Acoustics Meeting
June 18th - 20th 2012 Odense, Denmark

Acoustic design of open plan schools and comparison of requirements

Claus Møller Petersen
Grontmij A/S – Acoustica Department, Denmark, cmp@grontmij.dk

Birgit Rasmussen
SBi, Danish Building Research Institute, Aalborg University, Denmark, bir@sbi.aau.dk

In the Nordic countries several new schools have open plan areas for teaching and group work. However, to optimize learning efficiency for pupils and working conditions for teachers and to reduce noise levels, such spaces require special acoustic design to obtain sufficient sound attenuation between groups and satisfactory speech intelligibility internally in groups. This paper describes the newest Danish requirements and recommendations for such open plan areas and presents the design, measurements and subjective evaluation of two newer Danish schools. According to the users, the general conditions at both schools are satisfactory due to both optimized acoustical conditions and teaching methods adapted to the special open environment. The results from room acoustical modelling, verification measurements and questionnaire survey are presented and evaluated in relation to the newest Danish criteria. Requirements and recommendations from the other Nordic countries and from UK are summarized and the different criteria discussed.

1 Introduction

Open plan schools are again a trend. During the 1960's there were huge adverse experiences with this type of school buildings and they were therefore rebuilt to the more traditional school type with enclosed classrooms. During the recent approximately 10 years a new era has begun, in which the open plan schools have been built or rebuilt with acoustical conditions preventing the massive disturbance and annoyance problems caused by noise. This development is supported by revised regulations or guidelines in most of the Nordic countries.

2 Acoustic regulations for open plan schools in Denmark and other countries

2.1 Denmark, DK

The Danish requirements are stated in the Building Regulations BR2010 [1]. For schools, the requirements are identical to those in the 2008-edition, where previous recommendations for schools and day-care centres were implemented as regulatory requirements. The detailed text is found in [2], Guideline 218 published by SBi (Danish Building Research Institute). Besides requirements on large amounts of absorption areas (corresponding to very short reverberation times), it contains recommendations and guidelines on limiting sound propagation as well as managing the speech intelligibility (STI-index) in and between groups [3]. In the guideline it is remarked that open plan schools are not recommended for pupils younger than 10 years due to their not fully developed hearing and their limited capacity to understand words in noisy environments compared with elder pupils and adults [4]. The specific criteria are shown in Table 1, all valid for unoccupied, furnished rooms.

Table 1: Danish acoustic regulations for open plan schools [1, 2]

Measuring parameter	Measurement value	Remarks
A, absorption area [(a)]	$A^{(c)} \geq 1.3$ x Floor area	Requirement
R'_w, Sound Reduction Index (for flexible separating elements)	$R'_w \geq 20$ dB	Requirement
T, Reverberation time in shared rooms/corridors for group work [(b)]	$T^{(c)} \leq 0.4$ sec	Requirement [(b)]
$DL_{2,S}$ rate of spatial decay of sound pressure level per distance doubling	$DL_{2,S}{}^{(d)} \geq 5$ dB	Recommendation
STI, Speech Transmission Index - inside working groups	$STI^{(e)} \geq 0.6$	Recommendation
STI, Speech Transmission Index - between working groups	$STI^{(e)} \leq 0.2$	Recommendation
Effective reduction of sound[(f)] level between groups	15-20 dB	Recommendation

Notes
(a) For open plan teaching areas, the limit corresponds to a maximum reverberation time about 0.4 sec., cf. [2].
(b) Requirement for common rooms and shared corridors used for group work.
(c) Applies for individual 1/1 octave bands 125 – 4000 Hz. In the 125 Hz band, 20% lower absorption / higher rev. time is allowed.
(d) This definition is an application of DL_2 defined in ISO 14257 [5], but using the spectrum of normal speech and A-weighting over the whole frequency range. The spatial decay is not determined for individual octave bands [6].
(e) According to EN 60268-16 [7].
(f) Normal speech, A-weighted.

2.2 The Nordic countries and UK

In the Nordic countries only Finland does not have regulations for open plan schools. The Finnish guideline [8] RIL 243-2:2007 states that reasonable acoustic conditions cannot be achieved in open plan schools, where class rooms are acoustically freely connected to aisles and neighbouring class rooms. However, almost perfect visual openness can be achieved by using glazing which fulfil the sound insulation requirements. The regulations in the other Nordic countries and in UK are listed in Table 2.

Table 2: Nordic and UK acoustic regulations for open plan schools

Country, reference and year.	Measurement parameter	Measurement value	Remarks [(a)]
Norway, NS 8175:2008 [9] Class C	T, Reverberation time	$T \leq 0.4$ sec.[(b)]	An additional criterion $STI \geq 0.7^{(c)}$ is proposed in prNS 8175:2011 [10]
Sweden, SS 25268, 2007 [11] Class C	T, Reverberation time	$T \leq 0.4$ sec. [(d)]	For higher education only, not for primary schools [(e)]
Iceland, IST 45:2011 [12] Class C	T, Reverberation time	$T \leq 0.4$ sec.	
	STI, Speech Transmission Index - inside working groups [(f)] - between working groups Noise reduction between groups Noise reduction by doubling the distance	 $STI \geq 0.6^{(f)}$ $STI \leq 0.2$ $L_A > 15$-20 dB ΔL_A 5 to 8 dB	Recommendations. The additional criteria are found in Appendix B in [12] as a guideline for the special acoustic design.
Finland [8]	None	None	None
UK, BB93[13]	T, Reverberation time STI, Speech Transmission Index	$T \leq 0.8$ sec.[(g)] $STI \geq 0.6$	Currently under revision

Notes
(a) In general, special acoustic design is requested for open plan schools.
(b) Room averaged reverberation time in each of the 1/1 octave bands 250 – 2000 Hz. For 125 Hz, +40% is accepted.
(c) Proposal for additional parameter in prNS 8175:2011 [10]. Furthermore emphasis on special acoustic design and other measures.
(d) Mean value in 1/1 octave band ranges 250 – 4000 Hz, max +0.1 sec. in each band. In the 125 Hz band + 0,2 sec. allowed.
(e) Applies for high-schools, colleges and universities only, whilst open plan teaching spaces are not mentioned for primary schools.
(f) Limit with background noise. An additional limit without background noise is $STI \geq 0.75$.
(g) The values apply for average reverberation time in each of the octave bands 500 – 2000 Hz for unoccupied, unfurnished spaces.

In the Nordic countries the limit values are valid for furnished rooms, while in UK for unfurnished rooms. The latter makes it difficult to ensure how the acoustics in real use will be. Generally it is agreed that noise reducing measures are required to minimize distraction and annoyance caused by noise, whilst ensuring adequate speech intelligibility inside groups and speech privacy between groups [3], [14]. To serve these purposes, more countries have introduced rules on speech intelligibility in their guidelines. The most efficient technique to ensure optimum acoustic conditions in this type of schools is to use a semi-open plan design for the schools including e.g. absorbent ceiling at a height below 3.5 m, partitioning between groups, sufficient distance between openings and sound attenuation between groups.

The basic acoustic requirements on reverberation time for open plan schools are similar in those of the Nordic countries including such schools in the building regulations. It is agreed that special acoustic design is necessary, and recommended additional criteria exist in two countries. Nordic cooperation could prove useful to collect experience about open plan schools and prepare common guidelines. The cooperation should include other acoustic requirements for schools as well as requirements for other types of buildings like e.g. housing. Comparison of regulations and classification criteria in the Nordic countries have been presented in [15] and [16] for classroom reverberation time and sound insulation of dwellings, respectively, and in both cases Nordic cooperation is recommended. Regional efforts are made in a Swedish-Danish project Silent Spaces [17] to contribute to proposals for harmonized requirements, primarily for dwellings.

3 Two newer Danish open plan schools - Case stories

3.1 Hellerup School, Copenhagen

Hellerup School is one of the first newer open plan schools in Denmark built since the 1960’s, and it has become well-known as a reference and a success also outside Denmark. The reason is likely not to be the optimized acoustics alone, but most probably the combination of pedagogy, architecture and acoustics and the good will from ”sponsors” and from teachers, pupils and parents. Hellerup School was built in 2000-2002 as the main renewing element in a larger process involving several schools in the Gentofte Municipality. In this renewing, it was the goal to investigate and introduce a more modern experimental way of teaching. Quoting from the first Headmasters presentation [18] about this new school: “It represents a paradigm shift in Danish pedagogical thinking. It illustrates how theories on learning and pedagogy can be applied actively to the architecture and furnishing of a school. Theories from Sweden, Italy and the USA underlie the design of Hellerup School in Denmark. A synthesis of these theories and the school's moulding thereof is known as "Hellerup pedagogy". Not only the flexible learning space, but also the pedagogical mindset has become trendsetters for Danish, Swedish and Norwegian pedagogical thinking.” The cost amounted to 86 MDKK (appr. 14,3 MEUR), excl. VAT. Its gross area is 8200 m^2 and it has 3 storeys. The number of students is 750 (including Nursery class to 10^{th} grade). This gives 9.1 – 9.6 m^2 (net) / student. The school is naturally ventilated which requires open plan due to the necessary air flow from facades to atrium. It contains a central stair room – an atrium, 9 “home-areas” at 330-400 m^2 and 75-100 students in each.

Figure 1: Hellerup School. Internal view in the atrium

There are only few enclosed rooms: Gymnasium, Music, Kitchen, Woodwork and Administration. During the planning phases the end users and acoustical consultants had some concerns – how would this openness sound? Listening tests on auralizations using acoustical computer models were performed and it was decided to add some more sound absorptive surfaces than the minimum requirements. The open plan school requirements, at the time it was built, was Absorption area, A ≥ 0.9 * Floor Area as stated in the Building Regulations BR1995. In addition to the general acoustical regulation (ceilings), also some internal screening between groups was established by means of the "Hexagones" (some minor "instruction rooms" without roofs made of 5 folded wall elements – planned for around 20 younger pupils) as shown on Figure 2.

Figure 2: Hellerup School. Floor plans (ground and first floor) with area names and the "hexagones"

In the period 2007 to 2010 extra acoustical improvements were performed due to wishes among others on reducing noise from the youngest pupils during their "after-school-care" hours in the "Mars" area. In the open areas more absorbers were added on walls and the surfaces inside and outside the hexagons were shifted to absorbent types. Where the sound propagation was to free partitioning glass elements were added at specific places without closing the rooms still considering the natural ventilation. In this way a more semi-open design was introduced. Also moveable free standing sound absorbing and light-transparent screens was introduced to form subspaces for group work. The objective results before and after is shown in table 3 – 5 and it is clear that acoustical improvements are achieved. From the questionnaires it is told that you generally now are more satisfied with the acoustical conditions compared to before.

Table 3: Hellerup School. Reverberation time and Absorption area before and after acoustical treatment

Area	Reverberation time / Absorption area re Floor Area		
	Measured before	Measured after	Change
Open common area	0.57 sec. / 0.9 [(a)]	0.36–0.40 sec. / 1.3-1.4 [(a)]	33 / 50 %
Note: (a) Calculated based on diffuse field and room height 3.2 m			

Table 4: Hellerup School. Speech Transmission Index, STI after acoustical treatment

Condition	Speech Transmission Index, STI [(a)]
Direct sight, silence	≥ 0.8
Direct sight, real-life noise	≈ 0.73
Source or receiver behind hexagone, real-life noise	≈ 0.43
Between two hexagons, real–life noise	<< 0.2
Note: (a) Teacher speaks with raised voice	

Table 5: Hellerup School. Mars internal - sound propagation, $DL_{2,S}$ and $DL_{f,S}$ before and after acoustical treatment

Condition: Direct sight	Before	After
$DL_{2,S}$, Rate of spatial decay if sound pressure level per distance doubling	5 dB	5 dB
$DL_{f,S}$, Excess of sound pressure level re free field	7 dB	4 dB

3.2 Absalon School, Holbæk

Absalon School in Holbæk is another new semi-open plan school built in 2004-2005 "mostly" according to the requirements of that time the Building Regulations BR1995 meaning Absorption area, $A \geq 0.9$ * Floor Area. The school's gross area is appr. 2570 m^2 combined in four buildings creating "the small school in the large one". The first building is for younger pupils "Indskoling" (0^{th} – 3^{rd} grade), the next for middle "Mellemtrin" (4^{th} – 6^{th} grade), the third for the eldest pupils "Overbygning" (7^{th} – 9^{th} grade) and the last building contains library, administration and gymnasium. An external view is shown in Figure 3.

Figure 3: Absalon School. External view

Each of the three education-buildings are built like an ancient roman villa in two storeys (some with a basement) with enclosed rooms along the perimeter with open common near-areas in front used for group-work and with an atrium – in this case roofed – in the central part. In the atrium is an open building element called "Furniture" (in Danish "Møbel") with several minor niches used for group-work as well as leisure and lunch. This is shown on Figure 4.

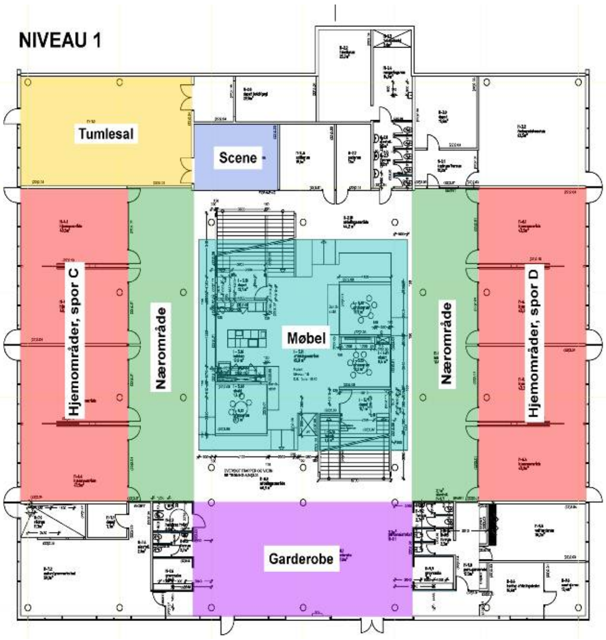

Figure 4: Absalon School. Plan of first floor with area names
(the Danish words Møbel and Nærområde means Furniture and Near-area)

Most of the ceilings are absorbing (covered with cement-bonded wood wool and dampened cavity above), but all vertical surfaces were hard and sound reflecting. This combination gave a lot of reflections and creates a more or less diffuse reverberant sound field. Due to an enforcement order dated June 2009 from the Danish Working Environment Authority an acoustical renovating project was introduced in the spring 2010. The acoustical conditions had to be optimized given the economic conditions, and the procedure involved interviews with the staff, preliminary acoustic measurements – and modelling for prediction. The optimization was based on minimizing the reverberation time and the room amplification, as well as maximizing propagation damping. In practise the walls in the open areas and to some extent also in the "Furniture" was covered with absorbers. In the different niches the purpose of the absorbers are to dampen the internal noise level and reduce the radiation to the open near areas. In the primary school were used more than 450 m^2 absorbers, and in the open areas were placed more than 30 moveable absorbing screens. Also the back sides of all the existing bookshelves were covered with absorbents. The following data in Tables 6 and 7 represent the primary school building in which the largest acoustical treatments were performed – because the youngest pupils have the greatest acoustical needs.

Table 6: Absalon School. Reverberation time and Absorption area before and after acoustical treatment

Area	Reverberation time / Absorption area re Floor Area		
	Measured before	Measured after	Change
Open common near-area	0.63 sec./ 0.9 (a)	0.41 sec. / 1.3 (a)	35 / 44 %
Inside "Furniture"	0.49 sec. / -	0.38 (b) sec. / -	22 / - %
Notes: (a) Calculated based on diffuse field and room height 3.4 m (b) Predicted based on room acoustical modelling			

Table 7: Absalon School. Sound propagation data in the open common near-areas before and after acoustical treatment

Open common near-area at level	"Room amplification" $L_{p,A,S,4m}$ (a) / Excess of sound level re free field $DL_{f,S}$		
	Measured before	Measured after	Change
Level 1	49-52 dB / 9—12 dB	47-49 dB / 3-4 dB	2-3 dB / 6-8 dB
Level 2	50 dB / 8 dB	45 dB / 3 dB	5 dB / 5 dB
Note: (a) $L_{p,A,S,4m}$ = 45,4 dB in free field based on sound power level 68,4 dB. $L_{p,A,S,4m}$ < 48 dB means good acoustical conditions in open plan offices, according to ISO 3382-3 [6].			

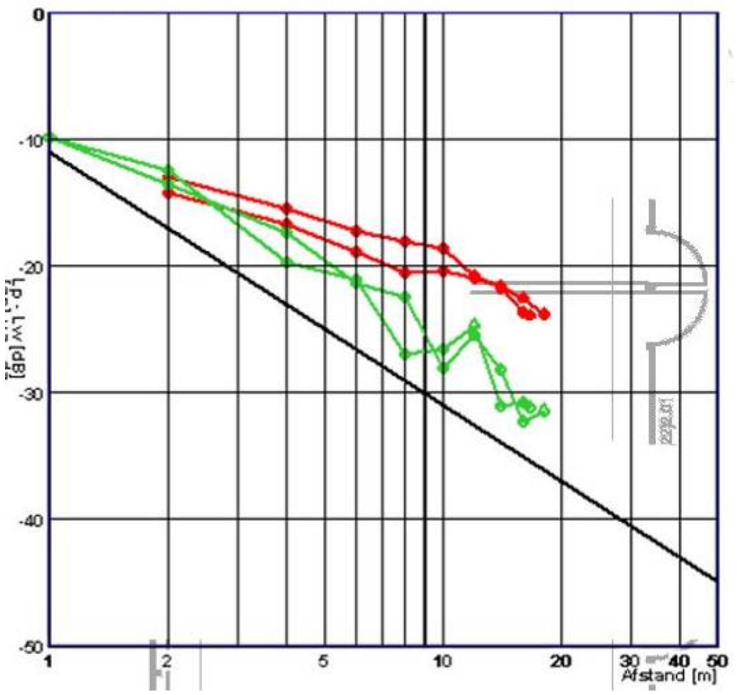

Figure 5. Absalon School. Sound propagation along measurement paths before (red) and after (green) acoustical treatment in one of the open near-areas. The straight line represents free field conditions.

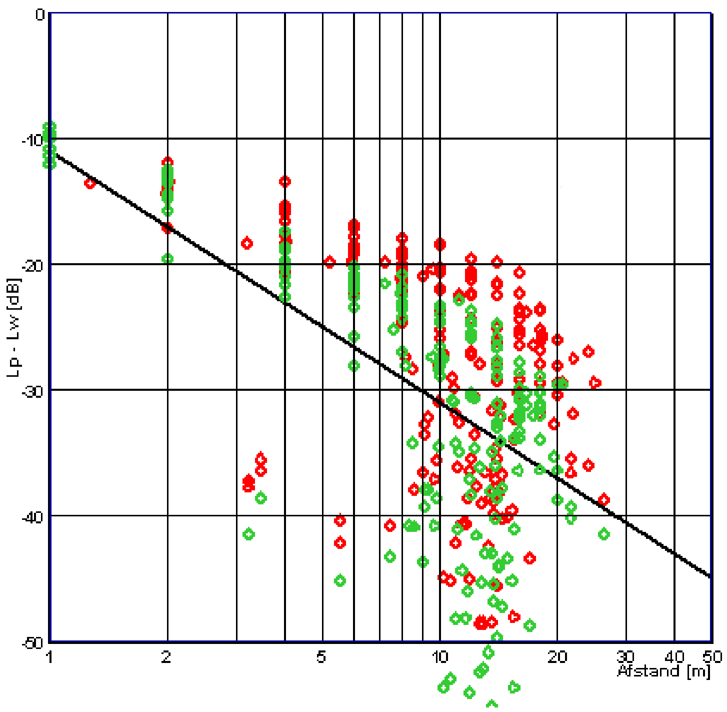

Figure 6. Absalon School. Sound propagation as function of distance before (red) and after (green) acoustical treatment in all the open areas. The straight line represents free field conditions.

The improving effect of the acoustical treatment is clearly seen in figure 5 and 6 where the dampened after-situations replace the more or less diffuse field conditions before the treatment. From the interviews it is e.g. told that “Earlier the ”Furniture” was very noisy – now the noise is clearly reduced. After the acoustical treatment it is easier to point out from where the noise origins”.

4 Summary and conclusions

The newest regulations and guidelines in most of the Nordic countries and in UK contain rules on dampening the room acoustical conditions as well as managing the speech intelligibility. In this way it is possible to optimize both the reverberation and the sound propagation ensuring some privacy between different groups. Results have been presented from two newer Danish open plan schools, where this practice has been applied, and the schools in general are characterized as having good acoustics. It can be concluded that successful open plan acoustics seems to approach anechoic conditions. The traditional idea that the acoustic environment must reflect the size of the room and thereby require some reverberation – ”living” acoustics – seems not useable in open plan schools and other working environments, where many people simultaneously must perform intellectual, cognitive work.

When comparing the regulations and guidelines in the Nordic countries for open plan schools, it is found that Finland abstains from open plan schools, Sweden has rules for higher education schools, but does not mention primary schools, and Denmark does not recommend such schools for younger pupils up to 10 years. There is a general agreement that special acoustic design is a necessity for open plan schools, and recommendations for additional acoustic criteria exist in some countries. It is concluded that Nordic cooperation could prove useful to collect experience about open plan schools and prepare common guidelines and that the cooperation should include also other acoustic requirements for schools as well as acoustic requirements for other types of buildings.

References

[1] Building Regulations 2010, Danish Enterprise and Construction Authority, Danish Ministry of Economic and Business Affairs. http://www.ebst.dk/file/155699/BR10_ENGLISH.pdf

[2] D. Hoffmeyer, Lydforhold i undervisnings- og daginstitutionsbygninger (Acoustic conditions in educational and day care buildings). SBi Guideline 218, Hørsholm, 2008. (In Danish)

[3] C. M. Petersen, Acoustics in open plan schools and day-care centres – problems and opportunities in M. L. Bistrup, Children and noise prevention of adverse effects, National Institute of Public Health, Copenhagen, 2002

[4] P. B. Nelson. The ASA Classroom Acoustics Effort, Acoustics Today, October 2005

[5] ISO 14257: 2001, Acoustics - Measurement and parametric description of spatial sound distribution curves in workrooms for evaluation of their acoustical performance

[6] ISO 3382-3: 2012, Acoustics — Measurement of room acoustic parameters — Part 3:Open plan offices

[7] EN 60268-16:2011, Sound system equipment - Part 16: Objective rating of speech intelligibility by speech transmission index

[8] RIL 243-2-2007, Acoustic design of buildings. Schools, auditoria, schools and libraries. Finnish Association of Civil Engineers, 78 pages, Helsinki, Finland, 2007. (In Finnish)

[9] NS 8175:2008, Lydforhold i bygninger, Lydklassifisering av ulike bygningstyper” (Sound conditions in buildings - Sound classes for various types of buildings), Norway, 2008 (In Norwegian).

[10] prNS 8175:2011, “Lydforhold i bygninger, Lydklassifisering av ulike bygningstyper” (Sound conditions in buildings - Sound classes for various types of buildings), 2011, Norway (In Norwegian).

[11] SS 25268:2007, Byggakustik - Ljudklassning av utrymmen i byggnader - Vårdlokaler, undervisningslokaler, dag- och fritidshem, kontor och hotell (Acoustics - Sound classification of spaces in buildings - Institutional premises, rooms for education, preschools and leisure-time centres, rooms for office work and hotels). Sweden, 2007 (In Swedish).

[12] IST 45:2011, Hljóðvist – Flokkun íbúðarog atvinnuhúsnæðis (Acoustic conditions in buildings - Sound classification of various types of buildings), Icelandic Standards, Iceland, 2011 (In Icelandish).

[13] BB93, Building Bulletin 93 – Acoustic Design of Schools, Department for Education and Skills, TSO London 2003.

[14] B. Shield, E. Greenland, J. Dockrell, Noise in open plan classrooms in primary schools: A review, Noise Health 2010.

[15] B. Rasmussen, J Brunskog, D Hoffmeyer, “Reverberation time in class rooms – Comparison of regulations and classification criteria in the Nordic countries”. BNAM 2012, Odense, Denmark, June 2012.

[16] B. Rasmussen, “Sound classification of dwellings in the Nordic countries – Differences and similarities between the five national schemes”. BNAM 2012, Odense, Denmark, June 2012.

[17] Silent Spaces, Interreg IV project 2010-2013. www.interreg-oks.eu/en/Menu/Projects/Project+List+%c3%96resund-Kattegat-Skagerrak/Silent+Spaces

[18] A. Mikkelsen, Hellerup School - A novel teaching paradigm in Denmark, ISCEI-conference, Sydney Australia, 2003.