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NOISE CONTROL FOR A BETTER ENVIRONMENT

Applicability Of Acoustic Capacity In Regulations Based On Study Of Noise Enviroment In Danish Nusery Schools

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ABSTRACT

The room acoustics of 20 nursery school rooms in day-cares (age 0.5-2.5 years) or pre-schools (age 2.5-6.0 years) were investigated by means of reverberation time measurements according to 3382-2:2008, registration of significant acoustical surfaces and noise sources, and interviews. The investigations were part of a project run by The Danish Ecological Council including 20 nursery schools representative for the current Danish building stock, that investigates numerous indoor climate parameters.

In Denmark reverberation time according to building code is argued to relate to acceptable noise environment in nursery schools [1]. Although most rooms lived up to building code, interviews of employees indicate noise problems still exist.

Observations showed that, there were relations between ceiling types and how fast reverberation time increases with volume. The smallest and largest rooms had seldom wall absorbers, whereas mid-size rooms often had wall absorbers. This lead to investigations of acoustic capacity in the rooms similar to the suggestions by Rindel for restaurants [2].

Conservative estimates of Lombard effect of small children and number of “talkers” were made for the basis of ranges for appropriate reverberation time vs. m^3/child. It was found that a large majority of rooms did not have sufficient conditions and almost none fit the criterion for satisfactory acoustic capacity.

Keywords: Noise, Room Acoustics, Building Code, Nursery School, Pre-School, Day-Care, Acoustic Capacity, Annoyance, Lombard.
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1. INTRODUCTION

Noise problems in day-care and pre-school facilities are well known. Over time this have led to very strict demands on reverberation time to deal with the noise. The Danish building code demands a reverberation below 0.5 s in the 125 Hz octave band and below 0.4 s in octave bands from 250 Hz to 4kHz, but with allowance to exceed this with not more than 0.1 s in not more than 2 octave bands [1].

Most often the issues are debated from the perspective of the employees and not the children. For children in day-care and pre-school, language is not fully developed and one cannot expect the same level of cocktail-party effect in children as in adults. One could therefore advocate for new demands, that include concerns on noise in relation to speech perception.

Noise in the day-care and pre-school facilities are for the most part generate by the children themselves. This is somewhat similar to the noise generated in a restaurant, where many small groups communicate within the same room. Rindel [2] suggested a model for *acoustic capacity* in restaurants, which relates reverberation time, volume and number of seated people to a quality assessment of the acoustic conditions. This paper suggests a similar approach for day-care and pre-school rooms relating number of children with reverberation time and volume.

20 rooms in Danish day-care or preschools were investigated as part of a project run by The Danish Ecological Council, investigating numerous indoor climate parameters [3]. The project includes 20 nursery schools, that are representative of the current Danish building stock.

All nursery rooms are assigned a specific group of children and works as their "base" each day. This means that children besides this room also visit common rooms, outdoor area, etc. during one day. A normal day in a day-care consist of: a) a morning in a common area. b) From 9:00 am to 11:00 am an activity selected and governed by one or more employees is conducted. c) From 11:00 am to 2:30 pm Lunch and then nap. d) from 2:30 pm to 5 pm the children have time to self-initiated play, where children themselves select who to play with and what they would like to do. A normal day in a preschool is similar to the day-care, but instead of a nap the children go outside on a playground. They then go indoor around 2:30 and have time to self-initiated play. Children are normally picked up between 3 pm and 5 pm.

The controlled activities can be based in the room, but also outdoors or in a common area. Lunch and the self-initiated play in the afternoon are most often situated in the "base" room.

2. SUGGESTED APPROACH

It has been suggested by Rindel that in a restaurant, a criterion for *sufficient* quality of verbal communication can be defined using *acoustic capacity*, N_{max}, which is the maximum number of seated people related to the volume, *V*, and reverberation time, *T* [2]. Rindel finds using a Lombard slope of c = 0.5 dB/dB, which is argued well fitting for dining situations, that the required absorption area, *A*, divided by number of speakers, N_s, is [4]:

$$\frac{A}{N_s} = 10^{(SNR+14)/10}, \qquad \text{Equation 1}$$

where SNR is the signal to noise ratio of speech level to the background noise level.

One can argue, that in heavily damped rooms like in the nursery school rooms or in a case with seated people, that the added absorption per person is not important.

Thereby A can be estimated using the Sabine equation, and the number of speakers are related to the maximum number of people by $g = N_{max}/N_s$. So, we get:

$$N_{max} = \frac{0.16 \cdot g}{10^{(SNR+14)/10}} \cdot \frac{V}{T} \qquad \text{Equation 2}$$

Rindel uses a SNR of -3 dB fitting with *sufficient* quality of verbal communication [5]. Rindel set his criteria to fit with group size, g, of four people, meaning one out of four is talking. This gives you [2]:

$$N_{max} \cong \frac{V}{20 \cdot T} \qquad \text{Equation 3}$$

Noisy situations in nursery school rooms can be similar to the restaurant during self-initiated play, where children are interacting with each other by themselves and are spread over the whole room. If it conservatively is expected that children follows the same Lombard slope of c = 0.5 dB/dB, and that they are playing in groups of three, a similar relation for *acoustic capacity* can be reached for *sufficient* quality of verbal communication:

$$N_{max} \cong \frac{V}{25 \cdot T} \qquad \text{Equation 4}$$

And for *satisfactory* quality of verbal communication meaning SNR of 0 dB [5]:

$$N_{max} \cong \frac{V}{50 \cdot T} \qquad \text{Equation 5}$$

In a room with a reverberation time, T, of 0.4 s and a volume, V, of 140 m^3 the maximum number of children, N_{max}, of 14 to reach the *sufficient* quality conditions, and 7 to reach *satisfactory* conditions.

In terms of building regulations, it seems more appropriate to talk about maximum reverberation time related to volume per child. From Equation 4 and 5, one can get Equation 6 and 7 for *sufficient* and *satisfactory* conditions, respectively:

$$T_{max} \cong 0.04 \cdot \frac{V}{N} \qquad \text{Equation 6}$$

$$T_{max} \cong 0.02 \cdot \frac{V}{N} \qquad \text{Equation 7}$$

3. APPROACH FOR NOISE INVESTIGATIONS

To map the noise problems in the day-cares and preschools, three main topics were addressed: 1) Acoustic capability of the rooms (reverberation time), 2) observations of room design, building parts, and relevant acoustical surfaces, e.g. wall absorbers, and 3) employee opinions.

Only the acoustic capability was a physically measured, whereas both observations and opinions were collected to get an idea of behavioural and annoyance aspects.

In section 3.1-3.3 summaries of the results and approach for the measurements are presented. In Figure 1 all reverberation time measurements are shown in octave bands. Figure 2(a) compares average reverberation time (250 Hz – 4 kHz) with volume, using indicators of ceiling type, building code status and type of wall absorbers. The same indicators are used in figure 2(b) where the average reverberation times are compared to volume per child assigned to the room, $V/_N$. Notice that none of the reverberation times are rounded off to one decimal, which is done before comparing to the Danish building code demands.

3.1 Summary of reverberation time measurements

Reverberation times were measured according to ISO 3382-2:2008 for ordinary rooms. The reverberation times of the 4 kHz band were above the building code demand of 0.4 s in five out of the 20 rooms and six rooms had reverberation times above the building code demand of 0.5 s at the 125 Hz band. When the limits in the 4 kHz band was exceeded, it was always within the 0.1 s allowance, whereas in the 125 Hz band, three rooms had values more than 0.1 s above the limit.

The building code demand in Denmark is 0.4 s for all frequencies from 250 Hz to 4 kHz. Average frequencies from 250 Hz to 4 kHz range from 0.27 s to 0.53 s, with only three rooms being higher than 0.4 s in average when rounded off to one decimal.

All in all, one must conclude that all rooms are heavily acoustically damped, even in the cases where the rooms do not comply with the Danish building code.

3.2 Summary of observations

The 20 rooms ranged in volume from 70 to 210 m^3. Mainly three types of ceilings were used: Perforated gypsum on 45 mm battens with empty cavity, directly mounted mineral wool (approx. 20-30 mm thick), and more than 100 mm suspended ceilings of either mineral wool or perforated gypsum. Figure 2(a) shows tendencies for how fast the average reverberation times increase with volume for these three types of rooms. Based on these findings, one can conclude that perforated gypsum ceilings serves worse as a ceiling when the volume is increased. Second is directly mounted mineral wool ceilings, whereas suspended ceilings seem to be best for larger volumes.

Rooms had either good wall absorbers based on at least 40 mm mineral wool, not so good (poor) wall absorbers of around 20 mm in thickness or no wall absorbers. The smallest (<90 m^3) and the largest rooms (>150 m^3) had in all but one case no wall absorbers, whereas the midsize rooms around 110 m^3 most often had good wall absorbers. The not so good wall absorbers were used in rooms of volume of 105-150 m^3. The type of absorbers could be an indicator for the severance of the noise problems. Large problems with noise would lead you to invest in a solution, that has a significant and documented effect, like the good wall absorbers, even though these are costly. Less severe problems could make you choose a less costly and not so good absorber, whereas limited noise problems would probably not get you to invest at all. Based on this approach one can argue that the midsize rooms around 110 m^3 are the most problematic and the they become less problematic with increase in volume.

The number of children assigned to each room varied significantly from 6 to 25. The corresponding volume per child ranges from 3 to 24 m^3 per child. Figure 2(b) is a rearrangement for figure 2(a) with the average reverberation time plotted versus the volume per child in each room. The rearrangement forms new groups, e.g. for rooms with less than 6 m^3 per child the averages reverberation time is in all cases 0.4 s or less.

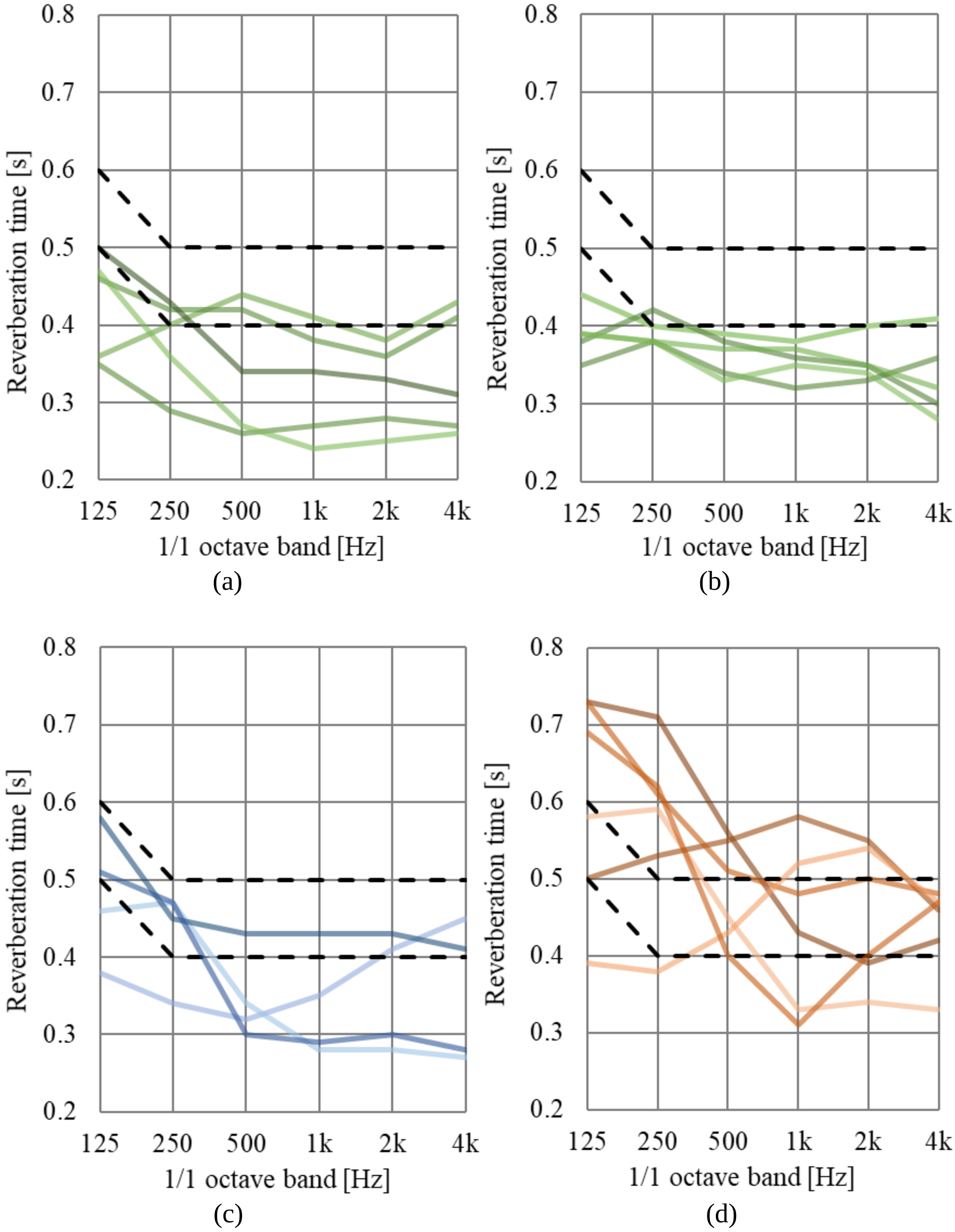
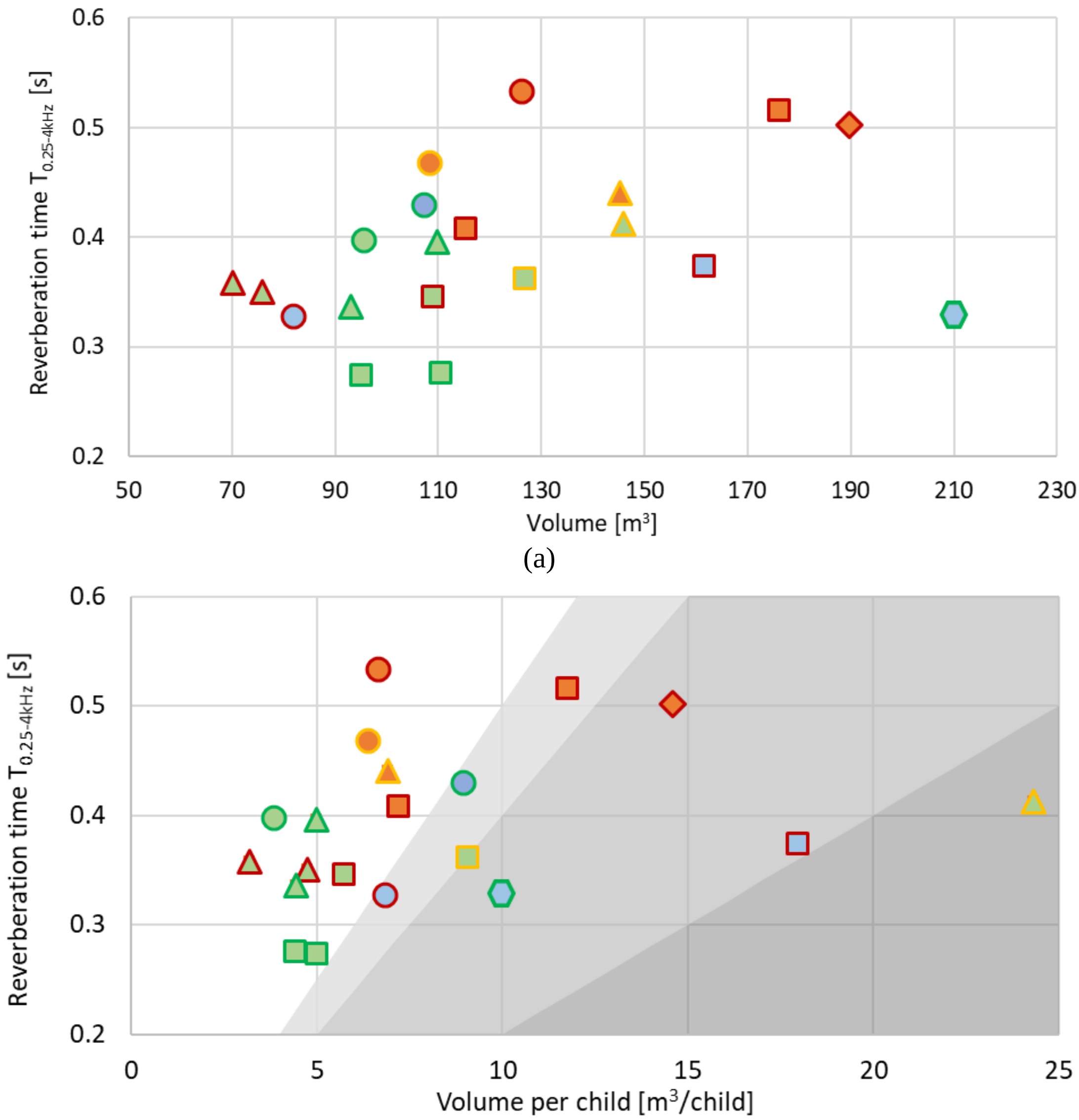


Figure 1: Reverberation time measurements performed according to ISO 3382-2:2008. Dotted lines show the Danish building code demand and the 0.1 s additional allowance in not more than two octave bands. Notice that comparisons with the building code are made after rounding off to one decimal. (a) and (b) show distributions for rooms that comply with the demands. (c) show distributions for rooms that use the allowance of max. 0.1 s in not more than two octave bands. (d) show the distributions for rooms that do not comply with the Danish building code.



(b)

Ceiling types base on visual inspection

- □ Mineral wool ceiling mounted directly to slab or subroof
- ○ Perf. gypsum ceiling mounted on 45 mm battens
- △ Suspended ceilings >100 mm
- ◇ 50% of ceiling with directly mounted mineral wool
- ⬡ Perf. gypsum, glass roof, and low hanging islands

Wall absorbers

- No wall absorbers
- Poor wall absorbers
- Good wall absorbers

Building code status

- Does not comply with demands
- Only just comply with demands[1]
- Comply with building code

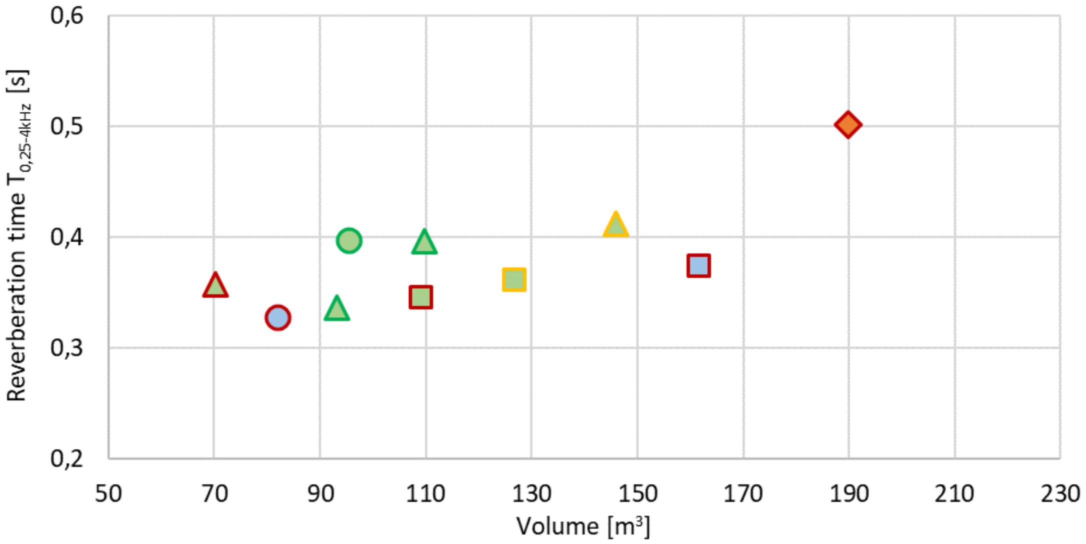
[1] Complies with building code with reverberation times less than 0.1 s above the limit in 1-2 frequency bands.

Figure 2: Average reverberation times (250 Hz – 4 kHz) versus volume of room (a) and volume per child assigned to the room (b). Indicators of ceiling type, quality of wall absorber, and status according to Danish building code are included. Also included in (b) are ranges for sufficient *and* satisfactory *acoustics based on Equations 6 and 7.*

3.3 Summary of interviews

Interviews focussed on employees working daily in the investigated rooms. Only one employee was interviewed for each room and selected randomly. The interviews were conducted over the phone and a random selection was simply made by interviewing the person who picked up or was handed the phone at the other end. In one case the answers were received by email and the manager of the nursery school was involved in the answering. Ten interviews were made, out of which one room did not live up to building code and 2 made use of the 0.1 s allowance. The results of the average reverberation time from the ten (number 1-10) interviewed places are repeated in figure 3.

First the employees were reminded to consider their answers in relation to the past few month and then they were asked three questions on 1) Are there certain situations were problems with noise exist? E.g. lunch, controlled activities, self-initiated play? 2) How often do you find that there are issues with noise? E.g. everyday, often, seldom (only once a week)? 3) Do the children seem annoyed or impacted? And in what way?



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Wall absorbers

- No wall absorbers
- Poor wall absorbers
- Good wall absorbers

Building code status

- Does not comply with demands
- Only just comply with demands [1]
- Comply with building code

[1] Complies with building code with reverberation times less than 0.1 s above the limit in 1-2 frequency bands.

Figure 3: Average reverberation times (250 Hz – 4 kHz) versus volume of the room for the ten interviewed nursery school rooms. Indicators of ceiling type, quality of wall absorber, and status according to Danish building code are included. Numbers are referenced in the text. No. 2, and 7-10 are day-cares (age 0.5-2.5 years) and no. 1, and 3-6 are pre-schools (age 2.5-6.0 years).

All the interviewees answered, that during controlled activities like singing sessions, reading aloud, assignments for the children, etc. noise was not a problem. One reported that in all other cases noise was a problem and that it was an everyday problem (No. 10, cf. fig. 3). Others named different specific times during the day like just before or after lunch (No. 1 and 9, cf. fig. 3). Eight out of ten said that noise was an issue during self-initiated play in the afternoon or in the morning (No. 1, 3-5 and 7-10, cf. fig. 3). Seven out of ten said, that noise was an everyday occurrence (No. 1, 3, 5, 7, 8, 10, cf. fig. 3), and the three other said that noise was an issue more than once during a week. Six out of ten reported that the children never or seldom reacted to the noise (No. 1, 2 and 4-6, cf. fig. 3). Two reported that the new children sometimes reacted negatively to the noise (No. 7, 10, cf. fig. 3) and one reported that some children leave the room if it is too noisy (No. 3, cf. fig. 3).

Based on the interviews it is worth singling out rooms 2 and 6 cf. fig. 3, that both report, that noise is not an everyday problem and both do not mention time of self-initiated play as an issue. Considering the notes of the observations, the rooms have no special characteristics, one is heavily furnished and have no traffic or ventilation noise, whereas the other is far less furnished and is influenced by noise from a railway.

4. COMMENTS ON LOMBARD AND COCKTAIL-PARTY EFFECT IN SMALL CHILDREN

It is not obvious that noise results in equal annoyance in children and grown-ups. The primary communication tools for small children is not necessarily speech as for normal-hearing adults, and it must be expected, that children's awareness of their noise influence on the surroundings is very different to that of an adult. If this is true, one should not expect the same level of cocktail-party or Lombard effect in children, since they simply are not influenced the same and will not react to noisy environments like adults.

One thing is certain; that children with limited language skills are not yet ready to fill in the gaps in speech, when spoken in a noisy environment. For this reason, they are also expected to be more sensitive than adults or even school children, in terms of understanding speech with noise present. One could therefore argue that the acoustic environments in day-cares and pre-schools should aim for better speech perception than restaurants and teaching facilities.

5. CONCLUSIONS

20 nursery rooms have been investigated out of which 30 % was found not to comply with the demands of the current Danish building code. It was found, that typically three types of ceilings are used: Perforated gypsum on 45 mm battens, directly mounted mineral wool ceilings, and suspended ceilings (either perforated gypsum or mineral wool ceilings). Tendencies were found for the increase of the average reverberation time with volume for rooms with each type of ceiling. Based on these findings, one can conclude that perforated gypsum ceilings serves worse as a ceiling when the volume is increased. Second is directly mounted mineral wool ceilings, whereas suspended ceilings seem to be best for larger volumes.

A suggestive approach for new regulations of the acoustic environment have been reached. This links speech conditions between children during self-initiated play in groups of approx. three.

Periods with self-initiated play have been pointed out as the main noisy period during a day, whereas lunch and other periods of controlled activities governed by the employees are not reported as noisy.

It is not clear from the random interviews of employees that the suggested approach is well fitting or not. One reason could be, that only very few rooms fall into the *sufficient* or *satisfactory* categories, why one should expect mostly negative feed-back. It is just as likely, that the questions asked and the approach do not give significant results and that the differences in answers could simply be due to the differences in people. However, the approach of *acoustic capacity* still seems reasonable from a noise perspective, since the number of noise sources and acoustic room gain are linked to the overall noise level. More studies are needed on group sizes, distance between children in a group, and annoyance in small children, to investigate whether the 0.02 and 0.04 factors in Equations 5 and 6 are appropriate.

6. ACKNOWLEDGEMENTS

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