

Classification of rooms in educational buildings using different noise indicators

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Introduction

Noise in educational institutions is a well known problem not only affecting adults but also children. In 2008, Shield and Dockrell [10] already showed that noise can have negative effects on children's health and cognitive development. This is why, acoustic optimization of rooms, where children learn and spend a considerable part of their day, are very important, but current approaches might be insufficient. Noise assessment methods, as they are mostly conducted nowadays, cannot represent the complexity of noise regarding its temporal and spectral structure. Furthermore, there is little knowledge about the impact of different noise scenarios on children's perception. Therefore, an aurally-accurate analysis of the noise situation in consideration of the different noise components is the first step to a plausible reproduction of real-life noise scenarios using virtual acoustics for future listening experiments on cognitive tasks and to gain more knowledge on children's perception of complex sound environments.

Noise in educational buildings is mostly generated by the present children in the rooms and its propagation is shaped by the room acoustic designs of the room. To assess the suitability of a room for its learning and teaching purposes, the DIN 18041 [1] for example only considers room acoustic parameters which are gathered in a silence situation in the absence of children. However, it is unclear whether it is sufficient to base the simulations of virtual environment and to predict noise exposition in classrooms solely on room acoustic parameters.

For an extended analysis of the acoustic quality of educational institutions, the measurement of room acoustic parameters was extended by in situ measurements in occupied rooms during teaching activities. Subsequently, the measured rooms were clustered and compared to each other by contrasting the two measurement conditions.

Methodology

Educational buildings

For this study, nine educational buildings in Aachen (Germany) were selected, including six are daycare centres and three are primary schools.

In total, following types could be studied in primary schools:

- classrooms ($n = 8$), and
- gyms ($n = 4$).

In the daycare centres three room types could be assessed:

- main rooms ($n = 10$) where the children spend most of the time during their stay,
- multi-purpose rooms (MP-rooms) ($n = 3$) which were used for sportive and other activities,
- sports rooms ($n = 3$) which were specifically designed for sportive activities.

For better differentiation of the individual rooms in the following cluster analysis, an initial categorization and a colour coding system was introduced. The rooms were categorized based on the educational level, type of use and depending on the existence or absence of acoustic treatment such as acoustic optimized ceiling. This leads to the initial categorization shown in Figure 1.

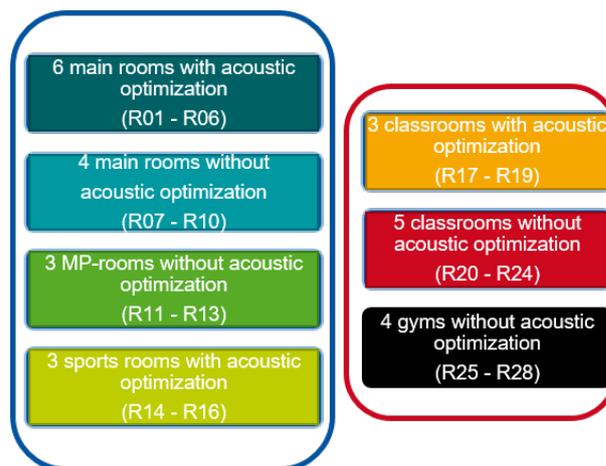


Figure 1: Initial categorization based on educational level and acoustic optimization. Blue frame: daycare centres. Red frame: schools.

Room acoustic and in situ measurements

The room acoustic measurements were carried out following the standards DIN 3382-2 [2], DIN 60268-16 [5] and ISO 9568 [8] to obtain a full set of room acoustic parameters including the speech transmission index (STI) and the equivalent A-weighted background noise level over 30 seconds ($BNL_{eq30,A}$).

As a major part of the noise in educational buildings is generated by the children themselves, long-term in situ measurements were conducted to access the acoustic situation during a day of educational activity. For this purpose, the acoustic situation in the main rooms and classrooms were recorded for two days while the in situ measurements in the gym, sports rooms and multi-purpose

rooms were carried out for one day only during sportive activity with the children. As shown in Figure 2, the adult dummy head, the child dummy head and the reference microphone were positioned together in the middle of the room so that the children were able to move around them. It was important to make sure that there were no restriction in the usual behavior of the adults and children during any activities in the room. Furthermore, the measurement setup should not attract too much children's attention. Only periods with children present in the room were considered. This leads to six hours of recordings in average, which were used for the evaluation.



Figure 2: Example of a long-term in situ measurement in a primary school classroom.

Psychoacoustic parameters represent a more aurally-accurate way to evaluate sound environments with respect to noise exposition and perception. Thus, loudness N_{ref} [3] and sharpness S_{ref} [4] were calculated using the ArtemiS SUITE by HEAD Acoustics. To consider binaural perception, binaural parameters were calculated using the binaural signals from the adult and child dummy head following Fels and Klemenz [6], resulting in binaural loudness $\text{Bin}N_{\text{adult}}$, $\text{Bin}N_{\text{child}}$ and binaural sharpness $\text{Bin}S_{\text{adult}}$, $\text{Bin}S_{\text{child}}$. single values were calculated by averaging the (binaural) loudness and the (binaural) sharpness over the measured time period (e.g. $N_{\text{ref,mean}}$). Further, the N5 value was calculated for the (binaural) loudness, e.g. $N_{\text{ref,N5}}$, which shows a better correlation to loudness perception over long-time periods [7].

Clustering method

Data analysis was conducted using IBM SPSS. A hierarchical clustering using the Ward method [11] was chosen to achieve the smallest increase in total variance between groups. For the room acoustic parameters, the variables $D_{50,\text{mid}}$, $T_{20,\text{mid}}$, EDT_{mid} , STI and $BNL_{\text{eq}30,\text{A}}$ were chosen after a correlation analysis. The relation of each room acoustic parameter to all other room acoustic parameters were tested using the Pearson's correlation coefficient. Similar room acoustic parameters represented by significant correlations were excluded. For the psychoacoustic analysis, all calculated parameters were chosen. The squared Euclidean distance was used as the distance function to find the biggest differences between the groups.

The elbow criterion [9] suggested five to nine groups as the optimal choices for the group number. The initial categorization of rooms showed seven groups, therefore the group number for the clustering was chosen to seven groups.

Results

The average values of selected parameters per cluster, also known as centre values, are shown in Table 1 and Table 2.

Table 1: Centre values of the main room acoustic parameters per cluster.

| Mean | $T_{20,\text{mid}}[s]$ | $BNL_{\text{eq}30,\text{A}}[dB]$ | STI |
|------|------------------------|----------------------------------|-------|
| CLU1 | 0.52 | 29.9 | 0.76 |
| CLU2 | 0.79 | 22.1 | 0.69 |
| CLU3 | 0.41 | 23.4 | 0.79 |
| CLU4 | 0.58 | 25.7 | 0.73 |
| CLU5 | 1.06 | 21.7 | 0.61 |
| CLU6 | 1.97 | 34.2 | 0.53 |
| CLU7 | 2.05 | 24.6 | 0.56 |

Table 2: Centre values of the main psychoacoustic parameters per cluster.

| Mean | N [sone] | | | S [acum] |
|------|------------|-------|-------|------------|
| | Ref | Adult | Child | Ref |
| CLU1 | 15.1 | 19.5 | 18.0 | 1.47 |
| CLU2 | 14.0 | 19.0 | 17.1 | 1.59 |
| CLU3 | 9.1 | 19.2 | 10.3 | 1.42 |
| CLU4 | 28.4 | 34.5 | 33.6 | 1.50 |
| CLU5 | 14.9 | 33.6 | 18.5 | 1.48 |
| CLU6 | 22.6 | 30.5 | 32.0 | 1.36 |
| CLU7 | 29.3 | 37.7 | 38.3 | 1.44 |

A colour-coded clustering result using room acoustic parameters is shown in Figure 3. The clustering algorithm yielded a clear categorization which is similar to the initial categorization shown in Figure 1. There were single outliers like the school rooms R22 and R19 as well as the daycare centre room R16 which were clustered together with the rooms of the reverse category.

When considering the in situ measurements and the resulting psychoacoustic parameters, a clustering result shown in Figure 4 was obtained. Almost all main rooms in daycare centres and classrooms in primary schools were clustered together in two big groups. Apart of some special rooms, like gyms and sport rooms, the noise situation seemed to be similar in primary schools in comparison to daycare centres. Therefore, the conclusion can be drawn, that the noise situation was not mainly depending on the room acoustic design of the rooms but more likely on the activity type(sports lessons) which was carried out during the in situ measurements since the only exceptions were rooms for this purpose.

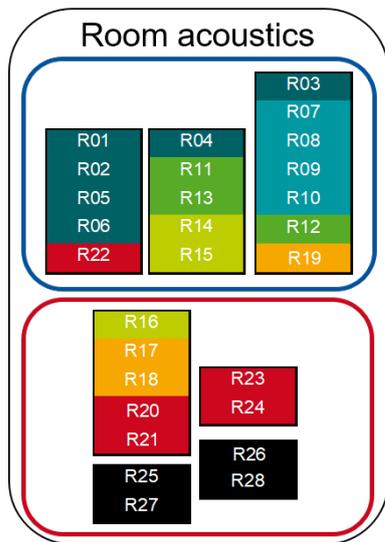


Figure 3: Clustering result using room acoustic parameters with colour coding. Blue frame: daycare centres. Red frame: schools.

Conclusion and Outlook

The classification of rooms in educational institutions in the presence of activity-based noise is not representative if based on room acoustic parameters only. The presence of children as sound sources affect the noise situation significantly. In the scope of auditory research, the simulation of such rooms must therefore not be limited to room acoustic parameters when simulating noise situations in educational institutions. Further, it is necessary to consider in situ measurements and psychoacoustic parameters during noise assessment for a more holistic assessment. The results of measurements in unoccupied rooms might be potentially insensitive to predict the actual noise situation.

In further studies, it is interesting to examine the individual noise situations in more detail to aim a more realistic reproduction of noise situations in educational buildings for future listening experiments on children's cognition in complex sound environments.

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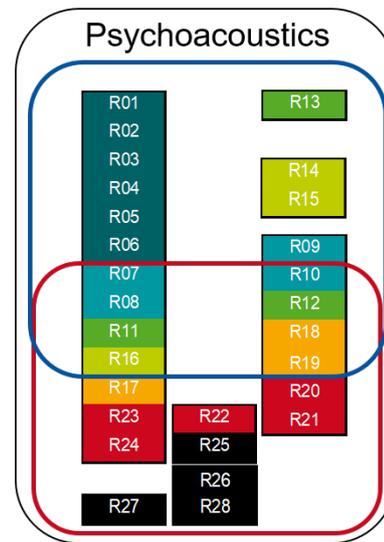


Figure 4: Clustering result using psychoacoustic parameters with colour coding. Blue frame: daycare centres. Red frame: schools.

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