Room Acoustics and Compliance of Austrian Classrooms

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This paper is a revised version of the authors' submitted manuscript that was peer-reviewed by at least two anonymous reviewers.

Abstract

A dataset of 416 reverberation time measurements, collected in rooms of Austrian educational institutions enable a quantitative characterization of current room acoustics in education. 144 classrooms in schools are looked at to assess compliance with national requirements for reverberation time. Occupied conditions are calculated using ÖNORM B 8115-3 (2023) with a fixed per-pupil absorption. Results are classified and interpreted according to the building regulation OIB-5 (2023) as compliant, compliant within tolerance (±20% in all octave bands), or non-compliant. Overall, 27% of all surveyed classrooms meet requirements. Restricting to new/renovated rooms since 2007 (n=97), compliance is at 34%. For the whole classroom dataset (N=144), technical absorption is present in 96 rooms (mostly ceilings), most frequently used materials are stated. Frequent causes of non-compliance are insufficient effective absorption, over-absorbing rooms (too short reverberation times), and exceedances of reverberation times at 250 Hz. Limitations include potential selection bias (e.g. measurements followed by complaints), fixed person-absorption assumptions, and uneven distribution above the nine Austrian states. Findings indicate that roughly one third of Austrian classrooms in this dataset achieve current targets.

Keywords: *room acoustics, reverberation time (RT), educational institutions, classrooms, measurements*

1. Introduction

There are already well documented studies, conducted in different settings from perceptional studies to field studies, which support the fact that educational institutions should have acoustically well-equipped rooms [e.g. 1, 2]. Some studies execute the effects that long reverberation times (and poor speech intelligibility) have on communication and learning, especially for younger children [e.g. 3], the main effects one can observe regarding teacher's voices and health [4] or their correlation with high noise levels that are often measured in primary school institutions [5]. It must be pointed out that difficulties occur when studying room acoustics situations, on the one hand when doing impulse response or noise level measurements, but also mainly with subjective ratings that are provided in a questionnaire. Measured results sometimes happen to be hard to compare, as there are different ways to get them and also described parameters differ from reverberation time to STI or C50 for example. The Speech Transmission Index is an acoustic parameter to assess speech intelligibility [6]. C50 refers to speech clarity and indicates the ratio of the energy components in the signal (the first 50 ms vs. the rest) [7].

In room acoustics surveys on the other hand, main problems lie in the way questions are asked. Implicit questions appear in both teacher surveys and student surveys, making the results difficult to interpret.

The aim of this examination is a case study of the real room acoustics situation in Austrian schools using a large dataset of measured classrooms. The results are intended to assess problems existing with room acoustics in praxis and should help to estimate the extent of the problem in Austria. A similar study was conducted 2023 in Germany, where a dataset with over 2000 German classrooms was looked at similarly [8].

2. Method and Dataset

This dataset started with self-conducted measurements of 33 classrooms in 2023 (see [9]). It has grown to a total of 147 rooms by now, thanks to the help of building physics consultancies and testing laboratories, which have provided their latest measurement data from schools (schools were anonymized). Regarding the selection of measured locations, the reasons varied: self-measured institutions from the authors were selected in terms of construction year, type of institution and willingness to participation – every effort was made to ensure a normal distribution. Nevertheless, it should be

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noted that the data shared by colleagues also includes measurements taken following complaints from teachers or school management. The total number of such complaints in the dataset is unknown.
For each room measurement the same data is available:

- Austrian state of the measured institution
- type of institution (e.g. kindergarten, elementary school, middle school, etc.)
- room condition (categorized by building type): pre-2007, not renovated; pre-2007, renovated; post-2007 new construction; special building (e.g. container)
- room type (e.g. classroom, sports hall)
- reverberation times
- room measurements and volume
- information about technical absorbers and materials.

To measure reverberation times, the NTI XL2 was used by the authors as well as by most of the measurements from the engineering offices for building physics. For shared data, the procedure is consistent with the requirements for building physics reports (see ÖNORM B8115-3). The sources of the impulses varied and included bursting balloons and alarm guns.
In total, besides 147 classrooms, the dataset includes 72 kindergarten group rooms, 66 sports halls/exercise rooms, 32 lecture halls/seminar rooms, 25 corridors, 20 working rooms for teachers, 19 music rooms, 15 cafeterias and other rooms. The rooms were classified in terms of their intended use and regarding the Austrian guideline for room acoustics in educational institutions (see OIB-5 [10]) into rooms with the targets of speech intelligibility or noise reduction.

3. Overview on Austrian Guidelines and the Amount of Educational Institutions

For all new buildings, as well as for renovated institutions, the guideline 5 from the Austrian Institute of Construction Engineering (OIB) is mandatory. Besides sound insulation values and other structural requirements, it includes a chapter of room acoustics for different rooms in educational institutions. The classification separates rooms where language and understanding are focused on (rooms for audibility, e.g. both classrooms and lecture halls) and on the other hand, rooms where the main aim is to keep the sound pressure level low (noise reduction rooms, e.g. kindergarten rooms, sports halls). The difference lies in how the proof of requirements is made: where in communication rooms a specific reverberation time is required, noise reduction rooms are evaluated regarding the mean absorption values (α) across all boundary surfaces. Of course, the method of measurement is the same (reverberation times) – the absorption area is subsequently determined using the Sabine formula and is then compared with the stated minimum values mentioned in OIB-5.
The first guideline of OIB was published in 2007, whereby the described requirements for reverberation time have not been changed since then. This is also the reason for the chosen classification of institutions in the dataset by its year of construction (e.g. pre-2007, not renovated). Furthermore, relevant but not mandatory guidelines about room acoustics in Austria include the ÖNORM B 8115-3 [10] and the ÖISS guideline chapter 10 [12]. The following table summarizes the requirements for a communication room with an exemplary room volume of 208,7 m^3 like stated in OIB-5, ÖISS chapter 10 and an additional comparison with the German guideline DIN 18041 [13] to illustrate the main differences.

Table 1. Example for a comparison with current room acoustics requirements for a communication room with 208,7 m^3 in OIB-5 (1), ÖNORM B 8115-3/ ÖISS chapter 10[1] (2) and DIN 18041 (3). Reduction for inclusion is marked in parentheses (), if separated in the guideline.

for a classroom with 208,7 m^3:				
	RT values	f in Hz	Tolerance	Occup.
1	0,57 s	250-2000	±20 %	100%
2	0,46 s	125-4000	±20 %	50%
3	0,57 (0,46) s	125-4000	±35,45,20%	80%

The measured relevant frequency bands differ between each of the guidelines with only in the DIN standard and the ÖISS guideline, the verification is also performed in the low-frequency band at 125 Hz and the 4kHz. Nevertheless, the German standard accepts a wider tolerance range in this bands.[2] The occupation is further provided from 50 to 100 percent, which could be discussed in terms of the purpose of an educational space.
Also different, but not visible in the table is the classification of rooms in each guideline as well as the wording. Whereas in Austria all the guidelines refer to communication rooms as only classrooms or other learning rooms, the DIN also includes kindergarten rooms here. Further, the OIB talks about a "required RT", the ÖISS states a "recommended RT" and the values in DIN are mentioned as "maximal RT". Within Austria, the ÖISS (just like ÖNORM B8115-3) has the strictest requirements, which is because inclusion (like hearing impairment and other, but also teaching foreign language) is already considered in the standard value for each classroom.

Data on the total number of educational institutions in Austria is also available and is published every few

[1] ÖISS refers to ÖNORM in its requirements.
[2] The DIN 18041 (2016) tolerates deviations depending on the frequency band. For 125 Hz, -35% as well as +45% are excepted, for frequencies 250-2000 Hz, the standard ±20% are common. 4000 Hz can differ -35% and +20% from the requirements.

years by the federal ministry. For the school year 2018/19, this number accounts for a total of 5661 schools [14] and is furthermore separated for all the nine Austrian states regarding the type of institution (see Fig. 1, top). What the numbers don't tell is how many of these schools were built before 2007 or were renovated over time. Figure 1 shows a colored map of Austria with the numbers of all schools in each state (top), as well as the distribution of the present dataset for a comparison (bottom).

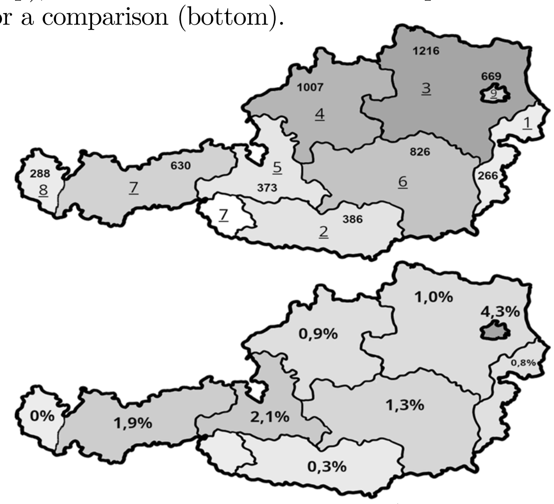

Figure 1. On top: Number of schools in Austria according to statistics from the Federal Ministry (for the 2018/19 school year) and their distribution across individual states. On bottom: number of schools measured for each state in comparison to the total amount of existing schools (in percent), shown as shading brightness (the darker – the more schools were measured).

Overall, the dataset consists of 84 schools when kindergarten and higher education like universities are excluded. The overall distribution is quite equal except for Styria (AT-2) and Burgenland (AT-1), which are the most underrepresented in the dataset. Vienna (AT-9) shows a high data density, followed by Salzburg (AT-5) and Tyrol (AT-7) – these three states have the best existing vs. surveyed school number. There is no measurement data for Vorarlberg (AT-8).

4. Results

4.1 Descriptive data

From the 147 communication rooms analyzed here, three rooms had incomplete information and therefore had to be excluded from the analysis. The 144 rooms encompass regular classrooms and specialized spaces where biology, computer science, or music theory is taught. Only three classrooms of the whole dataset were explicitly reported as 'rooms with inclusion' as the measurement were made in a school for hearing impaired children. Regarding the type of facility, the measurement data is divided as shown in Table 2.

Table 2. Classification of the 144 classrooms by type of educational institution

type of school	number of data points
elementary school (6-10 years old)	56
middle school (10-14 years old)	36
high school (10-18 years old)	38
secondary school (14-19 years old)	6
others (e.g. music school)	8

The mean classroom of the dataset is 208.7 m³ (range: 55.8-480 m³) big and has a mean measured reverberation time for all octave frequency bands (125-4000 Hz) of 0.8 s (range: 0.39 to 1.89 s). Figure 2 illustrates the frequency of each reverberation time range, when considering mean values for 250-2000 Hz and the frequency of room volumes (see histograms). The scatter shows measured reverberation times for all six frequency bands in terms of their specific volume (bottom).

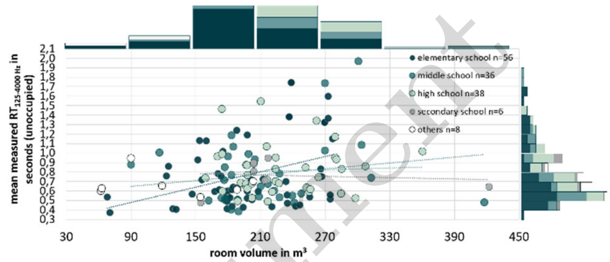

Figure 2. Relation of reverberation time to room volume by school type (colored): scatter shows mean RT250–2000 Hz, unoccupied; side histograms cover 125–4000 Hz, unoccupied.

4.2 The influence of 125 Hz

To understand the possible influence of low frequencies, the proportion of mean reverberation times for six octaves (125-4000 Hz, RT = 0.8 s) is compared to five octaves (250-4000 Hz, RT = 0.78 s). These mean values are looked at in terms of their deviations. In the sample of 144 rooms, the deviations for $RT_{125\text{-}4000}$ and $RT_{250\text{-}4000}$ are ≤5% in more than half of the cases, followed by 41% between 5 and 20% (Fig. 3).

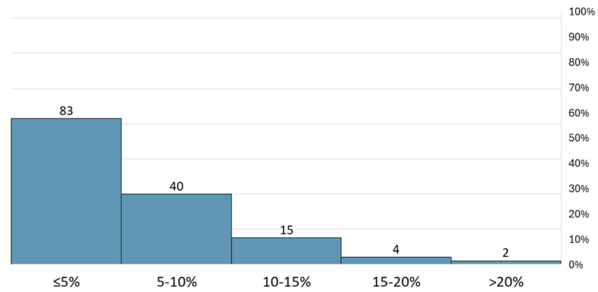

Figure 3. Frequency of cases with deviations between ≤5% and >20% when comparing the mean reverberation times for 125-4000 Hz and 250-2000 Hz.

A deviation greater than 20% is observed in only 1.4% of rooms, suggesting that the 125 Hz band in this dataset has a minimal effect on the overall mean values.

4.3 Comparison with Austrian Guidelines

Since all rooms were measured in the unoccupied state, the initial step for compliance comparison with the guideline is a theoretical calculation of the occupied condition. Therefore, the formula from ÖNORM B 8115-3 (2023) is used (see Equation 1).

Per-person equivalent absorption areas are also taken from the ÖNORM. Because the same value is applied across all classroom types and most of the data refers to elementary schools, we use the average value for a child up to (and including) 4th grade (see p. 16 in [11]). The fully occupied condition, as required in OIB-5, is assumed with 20 children since daily changes in the occupation are common in schools.

$$RToccupied = \frac{RTunoccupied}{(1+RTunoccupied*\frac{Aperson}{0{,}16*V})} \qquad (1)$$

RTunoccupied...	Measured reverberation time for each frequency band
Aperson...	Equivalent sound absorption area for all person in m²
V...	Rooms volume

The final occupied reverberation times for each frequency band are then averaged in the frequency bands 250-2000 Hz and 250-4000 Hz. Each room is compared separately with the requirements in terms of room volume. First mean reverberation times for demanded frequency bands are compared. In a second step, each frequency is looked at in terms of the accepted tolerance in reverberation time. Results are then interpreted according to three categories: compliant; compliant within tolerance across all octave bands; non-compliant. If one octave is not within tolerance (but all others were), the room is calculated as non-compliant.

4.3.1 Mandatory OIB-5 (2023)

When comparing all 144 classrooms, 27% (39 rooms) meet the requirements for reverberation times, whereby most of these rooms (n=32) are only within the tolerance of ±20% of the requirements.
The question arises instantly, to that extent the rooms' conditions are responsible for this number and how it would change if only new and renovated buildings were considered. From the dataset, a total of 97 (67%) newly built or renovated rooms since 2007 can be summarized.

Performing the same comparison as before but with only these institutions, for which OIB-5 is mandatory, the number of rooms that comply with the guidelines slightly increases, now 34% meet the requirements. The following table illustrates the exact numbers, separated by room volume groups (see Table 3).

Table 3. Comparison of 97 classrooms built or renovated since 2007 that are subject to OIB-5 (2023), grouped by room volume (m³). For each fully occupied room, compliance with the OIB-5 reverberation time requirement is classified as fully compliant, compliant within a ±20% tolerance in each octave band, or non-compliant.

		The rooms are ... with OIB-5.		
V in m³	N	compliant	compliant within tolerance	non compliant
50-175	20	1	10	9
175-200	27	4	6	17
200-225	21	2	4	15
225-275	17	0	6	11
275-480	12	0	0	12
total	97	7	26	64

4.3.2 Comparison with ÖISS guideline Chapt. 10 (2025)

Although the ÖISS is not mandatory, it's interesting to draw a contrast between the OIB-5 and the requirements from chapter 10 in the ÖISS. As a reminder, the main differences are that now only the half-occupied room condition is considered, the 125 Hz and 4000 Hz are added, and the required reverberation time is lower than in the OIB-5 (see Chapter 3 'Overview ').
The results are slightly surprising when comparing 97 classrooms like before, as the number of compliant rooms only slightly decreases. About 26.8% of rooms (n=26) now meet the required reverberation times. As already seen before, most of them achieve the standard with the respected ±20% tolerance in each frequency band.

4.4 Information about the rooms' materials

The collected data should also allow us to assess the rooms and their interiors, even if not all were seen in person. Therefore, where acoustic absorbers were present, information on their materials and construction was documented in the dataset, if possible.
In general, of all the 144 communication rooms, 96 are listed as having technical absorbers built on the ceiling or on the ceiling and the wall. But only 35.4% of these 96 rooms meet the required reverberation time in OIB-5, from which 8 rooms had absorption on the ceiling and the wall vis-à-vis from the blackboard. Those rooms who meet the requirements have the following frequency of materials built in (see Table 4):

Table 4. Specified absorbing materials built on the ceiling in the communication rooms that show required RT values (n=34).

material	frequency
suspended ceiling (mineral wool)	10
perforated gypsum board ceiling	6
wood wall	4
perforated metal ceiling with porose absorbers on top	4
wooden ceiling or perforated wooden ceiling	2
acoustic ceiling panels	1
unknown	7
overall	**34**

Interestingly, there are also two rooms who meet the required acoustics but don't have any technical absorbers installed. The first room was measured with fully open, thick curtains and the other one had self-made acoustic panels made of mineral wool hanging from the ceiling.
In rooms where acoustic absorbers are installed but the required reverberation times are nevertheless not achieved, the causes can be summarized by three principal factors: For a smaller number of rooms, the total equivalent sound absorption area simply isn't high enough or the chosen absorbing system doesn't fit the room purpose, e.g. rooms equipped with a perforated ceiling that incorporates a U-shaped, non-perforated

area along three room sides (a peripheral zone) acting as a reflector. (e.g. Fig. 4).

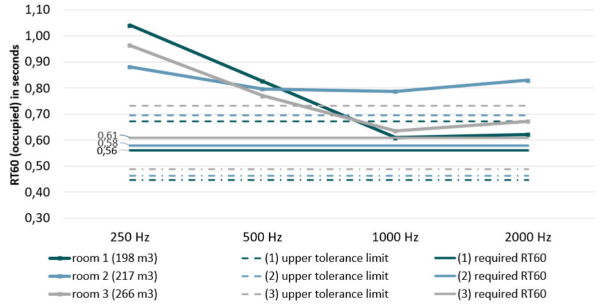

Figure 4. Too high reverberation time curves in three different example rooms of the dataset. Straight solid line = required reverberation time in OIB-5; dashed line = upper tolerance limit in terms of the rooms volume; Curved solid line = calculated occupied reverberation time in the room.

The second reason is way too low measured reverberation time in all relevant frequency bands (e.g. see Fig. 5), this applies for many of the rooms equipped with suspended ceilings from wall to wall.

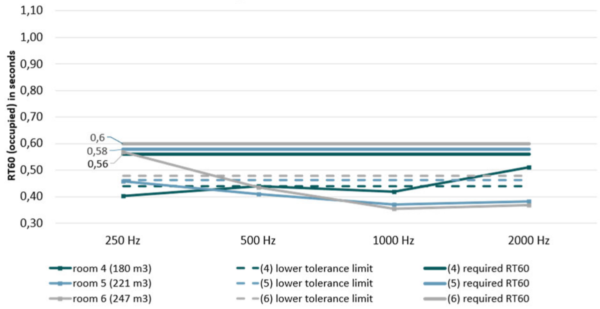

Figure 5. Too low reverberation time curves in three different example rooms of the dataset. Straight solid line = required reverberation time in OIB-5; dashed line = lower tolerance limit in terms of the rooms volume; Curved solid line = calculated occupied reverberation time in the room.

In terms of communication these rooms should also be considered as 'compliant', but the OIB-5 clearly states exceedances and undershoots of the demanded reverberation time. Just two of the 97 classrooms in the dataset are >10 m long (Ø 8,4 m), besides that, teaching in school is often a more interaction process with teachers walking and getting closer to the learners – a meaningful reduction in speech intelligibility because of reducing levels is therefore not highly likely. A closer look at the number of rooms which have too low reverberation in at least one octave (and no exceedances) shows, this affects 23 rooms out of all 65 rooms (35,4%), which don't meet the requirements.

The last reason for non-compliant rooms lies in the frequency band 250 Hz. Often, especially this frequency (when considering 250-2000 Hz) shows way to high reverberation times in the fully occupied condition extending even the tolerance of ±20 % of requirements and therefore do not comply with the guideline (e.g. see Fig. 6). Examples for existing absorbing materials in these rooms include wood wool acoustic ceilings without acoustic lining, with low alpha values under 500 Hz.

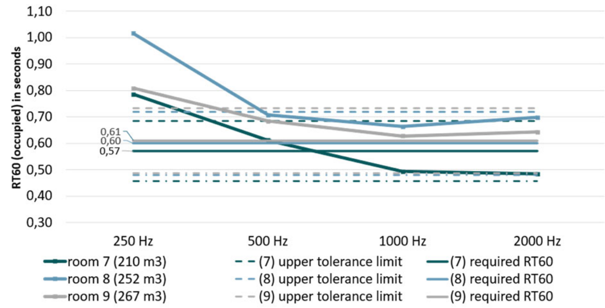

Figure 6. Three different example rooms of the dataset, where only reverberation times in 250 Hz octave are above tolerances. Straight solid line = required reverberation time in OIB-5; dashed lines = upper and lower tolerance limits in terms of the rooms volume; Curved solid line = calculated occupied reverberation time in the room.

5. Conclusion and Limitations

To summarize this study, measurements from a total of 144 communication rooms of schools in Austria were analyzed in terms of their measured reverberation times. The main aim was the comparison with current Austrian guidelines like the building regulation OIB-5, which is mandatory for new built and renovated educational institutions. Overall, about one-third of the observed rooms meet the requirements for reverberation times in the theoretically occupied room condition. A second comparison with the ÖISS guideline for room acoustics in educational institutions reveals surprisingly just a small change for the worse. Having the here reduced occupation and added frequency bands in mind, one might conclude that – at least for some rooms – the problem is a too short reverberation time when calculated in fully occupied condition. In way too dry sounding rooms the early reflections are missing and therefore, speech intelligibility can be bad, but as said before, for communication and learning purposes and considering the mainly small sizes of these classrooms, the problem maybe lies in the guidelines which consider too short reverberation times to be fully non-compliant.

Taking a look at the similar study conducted in Germany and drawing comparison, the number of rooms who met the current required reverberation time was much lower than in this study. It has to be noted that the approach for comparing with the guidelines was different in this study, looking not only at mean values but also at each frequency band. Further, the similar study included mainly schools with inclusion purpose, so mean reverberation times were also compared with the guideline values for inclusion. Therefore, a side-by-side comparison with the actual study is not appropriate.

Besides reverberation times, information about the rooms was obtained here. It shows that more than half of all the classrooms were equipped with technical absorbers, mostly on the ceiling, but only about a third of them could meet the required reverberation times mentioned in the Austrian OIB-5.

Limitations of this study are first of all, that the reason for the measurement is not available for each datapoint.

It's possible that some of the rooms were measured due to complaints regarding the room acoustics or noise. Nevertheless, the dataset also includes required acceptance measurements for compliance testing with the standard/guideline, which are requested in rooms of newly built institutions.

Further, the theoretical calculation of the occupied condition required the assumption of a specific absorption value per person. The results could therefore differ, taking another alpha value into account like the maximum value for adults, as the dataset also includes schools in which 18-19 year old pupils are placed as listeners (e.g. secondary schools). The final reverberation times would slightly be lower if alpha values of adults were calculated, instead of children.

Although efforts were made to ensure balanced coverage, the number of data points by Austrian state is not ideal. For example, Upper and Lower Austria have the most schools, but the available measurements do not fully reflect this. Therefore, to really draw statistically significant conclusions about room acoustics in educational institutions in Austria, the contribution and number of data points must be normalized and enlarged in the future.

6. Acknowledgments

The authors want to thank all colleagues from the building physics bureaus and testing laboratories for their effort, data and help to create this dataset.

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Equation:

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