

Evaluation of Acoustic Comfort in and Around High-School Classrooms in Jakarta

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Abstract: *This work focuses on the evaluation of acoustical comfort in high-school classrooms through in-field measurements and self-reports. The acoustic quality of the classrooms have been analyzed based on measurements of the reverberation time, sound pressure level inside and outside the classrooms, and sound insulation. Measurements of ambient noise (external and internal) followed the Indonesian Standards SNI 7231-2009.. Measurement of reverberation time and sound insulation followed the international Standards ISO 140-4, ISO 140-5, ISO 717-1, and ISO 3382. Results (sound insulation and reverberation time) have been compared with reference values found in the Indonesian SNI 6368 and SNI 6629. Results reveal poor acoustical quality of the surveyed classrooms It was found that the acoustic environment of these high schools is not adequate. With open windows, the noise levels at both Private School classrooms and Public School classrooms are 62.3 dB for windows open and 60.6 db for windows closed. The average reverberation time and early decay time measured in five classrooms at frequencies 250 Hz, 500 Hz, 1000 Hz and 2000 Hz.. The sound insulation inclassrooms calculated standard level difference 'DnT,w' The calculated values are 27.7 dB for Private School classroom and 20.6 dB for Public School classrooms.*

Keywords: acoustic, classroom, noise levels, reverberation time, sound insulation

1. Background

Recently, research in the acoustic field was focused on listening quality and on noise effects in learning environments [1]. A good acoustic environment is primarily achieved by the minimization of the contributions of noise from external (e.g. traffic, aircraft) and from internal (e.g. HVAC systems, chatting) sources. In addition, good communication is ensured when room acoustics and intelligibility parameters are in the acceptable ranges for teaching and learning purposes [2].

Poor acoustic environments in schools are known to negatively affect pupils' learning and achievement [3]. Learners who are hearing impaired or who have other additional learning needs are at increased risk of the negative effects of poor school acoustics. Furthermore, the negative impact of noise in schools is worse in schools featuring open plan classroom designs or that are near to external noise sources.

Classroom acoustics is an important, often neglected aspect of learning environment [4]. More than 60% of classroom activities involve communication between teachers and students or between students indicating the importance of environment that support clear communication. (Accredited Standards Committee, Noise, 2002). The efficiency of this communication, and hence, the efficiency of the learning environment, is measured by the acoustic conditions of the classrooms [5]. High levels of noise in classrooms make students prematurely tired, consuming their cognitive abilities which could be better employed in paying attention to and understanding the content of their classes [6]. The acoustic comfort parameters (ambient noise, reverberation time, sound insulation, intelligibility and acoustical materials) in classrooms have been the focus of several studies in different countries of the world [7].

The subject of acoustical comfort (ambient noise, sound insulation, reverberation time, speech intelligibility, auralization, acoustical materials) in classrooms of primary schools, in secondary schools, as well as in University classrooms has been the focus of several studies around the world [8]. Another focus of studies has been the perception of noise by students and teachers, and the influence of noise on those people [9].

The goal of the present study was to evaluate the acoustical conditions of two school constructive models from the State of Jakarta. Thus, two schools have been chosen i.e. public school and private school, and one of each of same types of standard construction. The acoustical parameters evaluated were the external and internal ambient noise, strictly following the Indonesian Standard on community noise, SNI 10151.

2. Introduction

2.1 Description of designs classroom

Public schools in the state of Jakarta are designed in standard modules adjustable to the need for new schools, depending on the forecast of the number of students and on the type of terrain where they are to be installed. The characteristics of the construction designs, which consists of a proposal of independent blocks with a central circulation area and classrooms arranged on both sides of a corridor. In order to improve the quality of teaching there were introduced performance standards for the acoustics of school buildings in most countries. In Indonesia performance standards for the acoustics of school buildings are currently defined in national law. Table 1 presents Indonesian acoustic legal requirements for school buildings

Table 1: Indonesia acoustic legal requirements for school buildings

No	Parameter	Legal requirements
1	Airborne sound insulation of façade – $D_{1s,2m,nT,w}$	>33 (dB), in noisy areas >28 (dB), in quiet areas
2	Airborne sound insulation between classrooms – $D_{nT,w}$	>45 (dB)
3	Airborne sound insulation between classrooms and corridors – $D_{nT,w}$	>30 (dB)
4	Impact sound insulation between classrooms – $L_{0 nT,w}$	<65 (dB)
5	Reverberation time in classrooms – T	$60.15V^{1/3}$ (s) (V – room volume)

(Source : Indonesia Standards Nationality)

Young [10] measurements acoustic university classrooms with and without occupants at Kangwon National University (KNU), The results showed that the effect of the added absorption of occupants is dependent on the acoustical conditions of the classroom. The changes in acoustical parameter values, due to added occupants in the classrooms, tended to be largest for the more reflective classrooms. The occupants may contribute to achieving more ideal reverberation times for speech (typically 0.4–0.7 s in classrooms) in the more reflective classrooms, but not in the more absorptive classrooms.

Lisa et al [11] studied about overall comfort aspects performed in a secondary-school building during the winter season. The campaign aimed at describing the conditions of the school both from an objective and a subjective point of view, thus the building acoustics requirements are affected by outdated constructive solutions, classrooms were found too reverberant, lacking in clarity and with a low performance in supporting oral communication due to the acoustically untreated surface.

Naziah et al [12] studied examined the IEQ of 240 refurbished kindergarten buildings in Malaysia. The four IEQ factors, Colleagues, Management, Attractiveness, and Colours, are considered as the most satisfactory factors from the occupants' point of view. Daylight is also an important factor, and occupants were pleased with the daylighting in the buildings, which allow for the maximum penetration of light. The occupants referenced Noise, followed by Smell, Glare Level and Distance to window as the least satisfactory features. Noise was given a negative score because of the high external noise from the main roads, as well as internal noise in the small classrooms. The occupants were not also satisfied with the air quality in general, and therefore, they considered Humidity, Freshness, and Ventilation as moderately low features of satisfaction

2.2 Acoustic in Classroom

A school classroom is an environment where a teacher works and children and young people acquire skills and knowledge, and prepare for higher education. To for all this to happen, a classroom should have conditions that make it easy to discriminate between words, understand spoken language, and also remember the content of the message.

The main external factors impairing communication conditions in classrooms are noise and poor acoustics. The acoustic quality of the classrooms have been analyzed based on measurements of the background noise levels in classrooms, reverberation time, and sound insulation

Classroom acoustics is an important, often neglected aspect of learning environment [13]. More than 60% of classroom activities involve speech between teachers and students or between students indicating the importance of environment that support clear communication. (Accredited Standards Committee, Noise, 2002) The acoustic comfort parameters (ambient noise levels, reverberation time, sound insulation, speech intelligibility and acoustical materials) in classrooms have been the focus of several studies in different countries of the world [14]. Influence of noise and its perception by students and teachers has been another focus of study by researchers [15]. A school classroom is an environment where a teacher works and children and young people acquire skills and knowledge, and prepare for higher education. To for all this to happen, a classroom should have conditions that make it easy to discriminate between words, understand spoken language, and also remember the content of the message. If these premises are fulfilled, speaking and hearing conditions are appropriate for learning. Standards are an attempt to set appropriate levels for noise and room acoustics in order to limit the deleterious consequences of noise. Unfortunately, optimal learning and communication conditions during teaching were not found in many schools [16]. The main external factors impairing communication conditions in classrooms are noise and poor acoustics. Noise is always non-informative sound that has several detrimental effects on human functions. Poor acoustics further exacerbates the harmful effect of noise by making it more continuous and restricting its attenuation [17]. Although a good learning environment is of the utmost importance, so far little is known about the acoustic aspects.

Background noise levels in classrooms

To evaluate the acoustic composition of the school environment, continuous equivalent sound levels were measured at different locations within the school site. Investigation was made on the internal ambient noise levels inside the classrooms in two situations (i) all windows and doors open in order to obtain the actual noise level in classroom. (ii) All windows and doors closed to verify the noise reduction provided by the existing windows. The measurement was taken at three spots positioned at front row, center and last row and the average was taken. The frequency analysis of the measured sound levels in classrooms was carried out to identify the frequency of the maximum sound level. The sound spectrum of the maximum sound levels was superimposed on the family of Noise Rating curves (NR) and the single value of NR was obtained.

Reverberation time

Reverberation time measurement is the most widely used acoustic measure in classrooms. Reverberation refers to sounds reflected from surfaces and, depending on the volume and shape of a room, the total absorption area and

the placing of absorption materials or structures. The time most typically measured is the period during which the sound level decreases to 60 dB after the sound source has ceased to operate (T60). The recommended limit for reverberation time (0.5–0.6 s according to the Indonesian standard [18] is usually exceeded in classrooms [14]. Namely, mean reverberation times in classrooms have been measured to be 0.7 s [1] or to vary from 0.2 to 1.27 s [19]. However, the recommendations given in standards have started to take effect: Shield et al. [20] found that in enclosed classrooms reverberation times (0.5–2 kHz) were 0.64 ± 0.20 s some years ago and after the passing of legislation times had decreased 0.08 s on average (new value 0.56 ± 0.11 s). Reverberation interacts with noise, the more reverberant the room, the lower the noise level and the better the signal-to-noise ratios (SNR) required.

Sound insulation

Sound insulation, classroom designs must achieve a certain level of comfort and effectiveness that will promote optimum conditions for study, listening, reading, and interaction [21]. Poor ventilation causes students to feel drowsy and not alert. Proper air flow and ventilation while keeping the quiet operation of mechanical systems in classrooms is an important factor [22].

This article describes how classroom sound conditions affect speech communication and what is so far known about the sound environment of a classroom. The goals of this research are (1) to evaluate the acoustic environment of high school classrooms by analyzing the important acoustic comfort parameters, background noise levels, reverberation time (RT, and Sound insulation.

3. Method Experiment

3.1 Classroom Sample

The aim of this work was to verify the acoustic quality of classrooms built according to standard designs for school buildings. Two schools are Public high school 30 and Angloo high schools were evaluated in the metropolitan region of Jakarta. The surveyed schools are attended by student from the 10th to the 12th grades (16-18 years old) of our fundamental education system, which corresponds to the high school. The study included 10 classrooms in two different comprehensive schools in Jakarta. The schools were built between 2005 and 2013. In one school the windows and in another school the ventilation had been renewed. The learning spaces were standard classrooms for comprehensive school. In all but two classrooms the acoustic panes had been installed when they were built or afterwards. In one classroom special attention had been paid to acoustic treatment because of a teacher's hearing loss. The classroom dimensions with floor area was 64 ± 1.5 m² and volume 224.0 ± 1.0 m³ in all classrooms studied. The classrooms were ordinary classrooms used in comprehensive schools. The mean number of student's per classroom was 35 and all the student's did not have any difficulties affecting learning. The results of this work were obtained by in situ measurements of the ambient noise (outside the classrooms and inside the classrooms), reverberation time

RT, sound insulation coefficients (sound insulation of façades and between classrooms and corridors), expressed by the continuous equivalent sound level, LAeq, in dB.

3.2. Measurement of background noise levels in classrooms

To evaluate the acoustic composition of the school environment, continuous equivalent sound levels were measured at different locations within the school site. Investigation was made on the internal ambient noise levels inside the classrooms (vernacular and modern classrooms) in two situations (1) all windows and doors open in order to obtain the actual noise level in classroom. (2) All windows and doors closed to verify the noise reduction provided by the existing windows. The measurement was taken at three spots positioned at front row, center and last row and the average was taken. The frequency analysis of the measured sound levels in classrooms was carried out to identify the frequency of the maximum sound level. The sound spectrum of the maximum sound levels was superimposed on the family of Noise Rating curves (NR) and the single value of NR was obtained. The measured values in the vernacular and modern classrooms were compared. The sound pressure levels were measured using a sound level meter BK 2250 (Bruel and Kjaer). In all situations the continuous equivalent sound levels LAeq has been measured along with its range of variation LAFmax and LAFmin for a duration of 3 min each, at three points and the average was taken.

3.3. Measurement of reverberation time RT

Reverberation time measurement is the most widely used acoustic measure in classrooms. Reverberation refers to sounds reflected from surfaces and, depending on the volume and shape of a room, the total absorption area and the placing of absorption materials or structures. The time most typically measured is the period during which the sound level decreases to 60 dB after the sound source has ceased to operate (T60). The recommended limit for reverberation time (0.5–0.6 s according to the Indonesian standard is usually exceeded in classrooms. Namely, mean reverberation times in classrooms have been measured to be 0.7 s or to vary from 0.2 to 1.27. However, the recommendations given in standards have started to take effect: Shield et al. [20] found that in enclosed classrooms reverberation times (0.5–2 kHz) were 0.64 ± 0.20 s some years ago and after the passing of legislation times had decreased 0.08 s on average (new value 0.56 ± 0.11 s). Reverberation interacts with noise: the more reverberant the room, the lower the noise level and the better the signal-to-noise ratios (SNR) required. This concerns in particular the environments of children: the younger the child, the better signal to noise ratios are called for [7].

The RT was measured inside furnished unoccupied classrooms at three different points and the average value was taken. When the general investigation of RT was done in ten vernacular and ten modern schools, the impulse method (balloon burst) was used and the measurement recorded are for T20 only. This procedure was repeated for all classrooms in which RT was measured. However, when detailed investigation in five classrooms was done, the

interrupted method by the sound source (BK 4292) was used. The measurement was then transferred to the computer and then export to QualifierTM Light type 7831 software from Bruel and Kjaer which documented the reverberation time and EDT (T10 value) for each frequency. All the RT measurement was taken only in unoccupied situations, with windows open and doors closed. The measured values of RT in vernacular and modern schools were compared and the effect of background noise on RT was studied.

3.4. Measurements of the sound insulation

The methodology specified in National Building Code of Indonesia – 2009 Section-6 (specification of sound insulation) was adopted for the measurement of sound insulation. The standardized level difference „DnT” which specifies the sound insulation between rooms was calculated using the formula given below, for the wall between classrooms. The „DnT,w” was compared with the minimum recommended sound reduction.

$$D_nT = (L_S - L_R + 10 \log_{10}(T/T_0))$$

LS = Noise levels in source room

LR = Noise levels in receiving room

T = RT of receiving room

T0 = 0.5 s (reference value).

A pink noise was generated by the BK 2260 sound analyzer during the measurements of the sound insulation coefficients between the classrooms and the corridors. This noise was amplified with a BK 2716 power amplifier and then distributed through the classroom using the BK 4296 omnidirectional dodecahedron sound source. Two BK 4190 microphones, one in the corridor and the other in the classroom, picked up the sound simultaneously. As outlined by the ISO 140-4 standard, the noise level at the back of the reception room and the reverberation times were recorded in order to make the corrections as a function of the areas of absorption of the reception room, following the procedures of the ISO 3382 standard. The number of points evaluated was determined according to the dimensions of the spaces, observing a minimum distance of 0.5 m between the wall and the microphone and of 1.5 m between the microphone and the floor.

4. Results and Discussion

4.1. Background noise levels in classrooms

The average sound levels measured in five unoccupied modern classrooms and five vernacular classrooms at Eravipuram School along with the recommended noise level are listed in Table 2. As observed in the preliminary survey it was found that irrespective of the character of the building, the background noise levels in all the classrooms was above 40–45 dB. The ambient noise levels measured in

unoccupied modern classrooms with windows & doors open, and closed ranged between 59.5–63.2 dB and 58.3–62.1 dB respectively. The ambient noise levels in unoccupied vernacular classrooms with windows and doors open ranged between 61.6–68.5 dB and for windows and doors closed between 59.6–67.1 dB. Noise level above 55 dB exceeds the normal speaking voice level impairs the listeners attention [1]. The influence of background noise of the school inside the classrooms was evaluated. It was observed that the difference in LAeq were only 1–3 dB in both vernacular and modern classrooms. This implies that the sound insulation performance of windows is very low. The windows shutters and frames of vernacular and modern schools are made of wood. It was observed that the window shutters do not fit properly into the windows frame fixed on the walls, promoting noise transmission through the gaps, especially in vernacular classrooms. It was also observed that ratio of window area with respect to total wall area was higher in vernacular classrooms (1:10.5) compared to modern classrooms (1:15.3).

Table 2: Measured background noise levels (LAeq) in classrooms

No	Classroom	Average sound levels in unoccupied classroom (windows open) (dB)	Average sound levels in unoccupied classroom (windows closed) (dB)	Recommended sound level in classroom (dB)
1	IPA 1	63.2	61.9	60.6
2	IPA 2	63.3	59.4	
3	IPA 3	62.3	61.5	
4	IPS 1	63.8	62.1	
5	IPS 2	59.9	58.1	
6	IPS 3	63.8	60.6	
	Average	62.3	60.6	

4.2 Reverberation time in classrooms

Summary of the average reverberation time and early decay time measured in five classrooms at frequencies 250 Hz, 500 Hz, 1000 Hz and 2000 Hz are shown in Table 3. The high reverberation time in public high school classroom indicate the lack of absorbing materials inside the classrooms. High reverberation time also increases the background noise and hampers the speech intelligibility in classrooms. The comparison of RT and EDT in d 2000 Hz are shown in Table 3. The high reverberation time in classroom IPS 2 and Angloo school classroom IPS 1, having almost the same reverberation time at 1000 Hz. It was observed that the RT is high at lower frequencies in public school classroom and private high school classrooms showing low absorption of low frequency sounds. Shorter value of EDT than reverberation time in Public School classrooms indicates higher clarity of sound while higher EDT in Private School classroom indicating low speech intelligibility [14].

Table 3: Reverberation time and early decay time measured in public school and private classrooms

Frequency (Hz)	IPA 1		IPA 2		IPA 3		IPS1		IPS 2	
	T60	EDT	T60	EDT	T60	EDT	T60	EDT	T60	EDT
250	1.73	1.32	2.66	1.68	1.90	1.64	1.46	0.92	1.46	0.92
500	1.54	1.84	1.80	2.03	1.47	1.70	1.23	0.95	1.23	0.93
1000	1.42	1.26	1.73	1.54	1.24	1.39	1.23	1.02	1.23	1.02
2000	1.25	1.23	1.76	1.36	1.18	1.09	0.91	0.77	0.90	0.77

4.3. Sound insulation in classrooms

Table 4 shows the calculated standard level difference „DnT,w“ of the wall separating two vPublic School and Private School classrooms. The calculated values are 27.7 dB for Private School classroom wall made 25 cm thick brick masonry, plastered with cement mortar and 20.6 dB for Public School classrooms walls made of 35 cm thick laterite stone masonry with lime plaster. Both the values are low when compared to the recommended minimum sound reduction of 35 dB between classrooms [22]. High noise levels in Public School classrooms also indicate poor sound insulation by the walls.

Table 4: Calculated DnT,w of the vernacular and modern classroom.

	Weighted standardized level difference DnT,w (dB)		Recommended minimum insulation (dB)
	Private school Anglo classroom	Public school 77 classroom	
Wall separating classrooms	27.7	20.6	35

4.4. The Impact of Classroom noise on Teaching and Learning

Responses on the remaining subscales create a detailed impression of listening conditions and the impact of noise in classrooms. For example, the situations identified as being the hardest in which to hear the teacher were when “other students are talking in my classroom” (85%) and “when other students are making a noise in nearby classrooms” (46%). The highest rated responses to impact of noise in the classroom subscale n response to the prompt “When it’s noisy or hard to hear in my classroom...” were “my concentration is easily broken” (92%) and “I don’t learn as much as in a quiet lesson” mean (52%). Lastly, the activities during which student;s reported being most sensitive to the disruptive effects of noise were while “...doing a test or exam” (94%) and when reading (48%).

4.5 Level of annoyance

Table 5 shows the result of the interviews with the students from Public School 77 concerning the question: „what are the main sources of sound that interfered with your classes?” It was seen that all students referred the noise from the roads as the major source of noise having a level of annoyance above 3.6. The students of the Private School classrooms referred the noise generated from the neighboring class (noise by the students and voice of the teachers) as the second major source of noise while the students of modern classroom referred an equal annoyance level to the noise generated outside and from neighboring class, which stood as the second major source of noise. The result supports the scientific investigation proving a higher noise transmission in vernacular classrooms

Table 5: Level of annoyance

Sources of Sound	Level of annoyance
Inside class	3.4
Sound from neighbouring class	3.8
Sound from outside	3.6
Road	3.9

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