Case Study

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Enhancing the classroom acoustic environment in Badr University, Egypt: A case study

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Abstract

The acoustic environment of the classroom is deemed significant to enhance the learning quality and the learning outcomes. Noise exposure levels and reverberation are the main acoustic parameters to consider in the classroom because it affects speech intelligibility. As a result of the modern teaching methods especially in the practical faculties. Workgroup activities have become a common tool for learning, it has a higher noise level than independent work. Therefore, the specialists become face a great challenge to achieve acoustic comfort in classrooms. In spite of that, in Egypt, acoustic conditions are rarely implemented into classroom design practice. This study evaluated the acoustic performance of a typical classroom in Badr University, Egypt in unoccupied condition for four cases. Unoccupied ambient noise level (ANLs) and reverberation time (RTs) were measured by using Testo 815 device, and Ecotect software. Additionally, the measurements were compared with the standards and norms. Acoustic treatments using absorbent materials were suggested by simulation in Ecotect for three cases (four scenarios).

Keywords

Acoustic environment, ambient noise level, reverberation time, Ecotect software, Badr university, Egypt

Introduction

In fact, students spend 45%–75% of their time in schools or universities. 80% of their time schedule was in classrooms.[1] Accordingly, the acoustic environment inside the classroom is a vital issue that must be appropriately designed according to the acoustic standards, as it affects the performance and cognition of students.[2] Recently, the initiatives of studying the acoustic environment inside the classroom by researchers were increased rapidly for many reasons as such:

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Figure 1. Interior shot to the investigated classroom.

- The shift in teaching methodology to be focused on group work, especially in the practical faculties, and thus, increases the dynamic noise level,[3]
- The need for natural ventilation to reduce covid-19 infection, where the dependence on the opened windows and doors for classroom become mandatory to increase the percentage of fresh air. Therefore, the probability to hear lecturers in contiguous classrooms and outdoor noise become possible, thus generating more noise sources (background noise),[4]
- The transition to formative education, the students spend their educational time in different classrooms according to the types of activities.[5]

According to these reasons, achieving a good acoustic environment in classrooms becomes a challenge for specialists in this field. In the same context, achievement of acoustic levels standards and norms represented in, signal-to-noise ratios (SNRs), unoccupied ambient noise levels (ANLs), occupied background noise levels (BNLs), and reverberation time (RTs) measurements are required to obtain a good acoustic environment in classrooms.[6] In addition, these standards levels differ with respect to many factors, including the student's age,[7] the condition of the classroom (open or enclosed-unoccupied or occupied), and the student's hearing ability (normal or with hearing impairments).[8] Similarly, finishing materials (absorbent or reflective) affect interior acoustic design efficiency.[9] This study was initiated to assess the unoccupied ambient noise level (ANLs) and reverberation time (RTs) in a typical classroom at Badr University; as illustrated in Figure 1. Next, suggest acoustic treatments using Ecotect software for three cases (four scenarios).

Background

A good acoustic environment is described as a multidisciplinary-task.[10] In addition, it was mentioned that it could help space users to live and follow their outdoor environment, adapt to the daily variables,[11] and protect them from noise.

Acoustics in classrooms-brief from examined literature

Based on the previous literature, Zhou et al.[12] stated that the acoustic environment is important. They further added that soundscape is not always intentionally designed to obtain accurate listening. They estimated acoustic environmental properties by virtual reality "VR." In addition, Christensen et al.[13] investigated a short-term relation between multi-dimensional acoustic properties of surrounding sounds and well-being. Likewise, Kang et al.[14] reported three studies about acoustic environment changes and its perception due to the lockdown of COVID-19. The first study results revealed that the sound level decreases depending on the urban setting type, while the

Table 1. Acoustic recommendations for classrooms with age (+12).

Signal-to-noise ratios (SNRs)	+15 to +20 dB
Unoccupied ambient noise level (ANLs)	40–45 dBA
Occupied background noise level (BNLs)	50–56 dBA
Reverberation times (RTs) unoccupied	0.3–0.6 s
Speech transmission index scores (STIs)	0.6–0.75

second study surveyed data pre-lockdown to predict how lockdown soundscapes would be experienced and the third reported noise complaints in London, where the results from the three studies demonstrated that reduced urban activity reduces the sound level in urban spaces.

The scrutinized literature indicated that many researchers are involved in the investigation of acoustics in classrooms. Siebein[15] observed classrooms in Florida in order to investigate the classroom infrastructure on children's speech perception, where he conducted 120 computer models in virtual classrooms. He recommended the importance of selecting AC system to minimize interference with listening. Moreover, Klatte et al.[16] analyzed the impacts of classroom echo on reading ability. Their study was conducted on school second graders, where they collected questionnaire data from 487 children from 21 classrooms. Their results underlined the importance of good acoustical conditions in elementary school classrooms.

The effect of noise and reverberation on classrooms

The classroom is an environment for communication between lecturer and students through direct interaction (hearing and speaking) to achieve learning outcomes.[17] Therefore, it is important for teaching and learning. In fact, "Speech intelligibility"[18] is a critical constraint for assessing the acoustic environment of the classroom. A bad vocal environment (high noise and reflective sound) affects both lecturer and student performance and efficiency.[19] For instance, it makes conversation reception hardener. Also, more concentration from students will be required, which causes mental fatigue among students, and increase the complexity level of the tasks.[20] Furthermore, noise also affects the educational process whether dynamic or background, indoor or outdoor noise. It influences the short-term memory of the students,[21] decreases the working memory performance by 10% in the attendance of four speakers in bubble noise,[22] and affects task cognitive performance of the students whatever the age, gender, or native language.[23]

Classroom acoustic standards and recommendations were mentioned in local and international codes, academic papers, and empirical studies that evaluate noise and reverberation in classrooms. The permitted acoustic parameters (noise and reverberation) values have a high degree of diversity between countries. For instance, in UK,[24] for unoccupied existing classrooms, the maximum accepted ambient noise level (ANLs) of 40 dBA, and the maximum reverberation times (RTs) of 0.7 s. In Egypt, the Egyptian environmental affairs agency (EEAA) determined the maximum (ANLs) of 40 dBA, and the maximum reverberation times (RTs) of 0.8 s. In the same context, Mealings[25] summarize the acoustic conditions from research conducted in 15 countries and from codes, then provide recommendations on what is acceptable for typically developing students with age (+12) as illustrated in Table 1.

Acoustic solutions for classrooms: Materials and location

Surface material, size, location, and shape play a critical role in accomplishing a good acoustics environment in the classroom. A variety of Acoustic Problems can occur as a result of bad acoustic treatments for the classroom surfaces (walls, ceiling, floors, and curtains).[26] The problems that may be heard for instance; the classroom is too loud, boomy, and bass-heavy; flutters, echoes, and frequency anomalies; the difficulty hearing due to dead spots, hot spots, and excess reverberation.[27]

More specifically, square rooms are the nastiest for standing wave problems and echo. Also, the flat reflective materials on walls and ceiling such as: bricks, glass, concrete, plastic painting, and ceramic tiles affect increasing echo and standing wave problems.[28] Therefore, adding a combination of absorbent and diffusive treatments for classrooms to minimize reflective and parallel paths can enhance Speech intelligibility and reduce the reverberation time RTs.[29]

Accordingly, the use of heavy curtains in the front of the glass windows, hush absorber or fabric wrapped-dense fiberglass wall panels, and acoustic ceiling tiles are some of the most common popular absorptive treatments to eliminate echo and reverberation time.[30] Similarly, diffusive treatments such as two-dimensional diffusers can improve the overall listening environment.[31] These treatments are adequate for improving the acoustic environment for existing classrooms through economic price, fast installation, and decorative effects as illustrated in Figures 2 and 3.

The optimal locations of the absorbing and diffusive materials were discussed deeply in the literature. For instance: (a) Adding absorptive material at the rear wall and ceiling could enhance the speech intelligibility,[32] (b) The most efficient location in the case of the low sound diffusion is the upper part of the side and back walls,[33] (c) Applying absorptive material in the reflective area on the ceiling and on the upper and middle area of the side walls improve listening conditions and results in a good acoustical uniformity for the classroom,[34] (d) It is appreciated to include diffusers in the classroom treatments to avoid the negative effect of the excessive absorption on the speech level.[35]

Methodology

This research aims to evaluate the acoustic quality of a typical classroom at Badr university by measuring unoccupied ambient noise level (ANLs) and reverberation time (RTs) in unoccupied condition. Then proposing alternative acoustic treatments to achieve the acoustic standards through three cases using the Ecotect software and Testo 815 device. In the same context, this research has been performed in three phases as illustrated in Figure 4 and as discussed below.

First, based on the *previous studies*, and by using inductive method. The research investigated the importance of achieving a good acoustic environment in classrooms and how the noise and reverberation affect the learning process and speech intelligibility. In addition, acoustic standards and principles for classroom design are summarized. Acoustic solutions for classrooms are also examined whether absorbent or diffusive materials, and their locations to accomplish the standards and the best performance. Were, it will be part of the input data for the classroom simulation.

In the second phase, is based on the *experiment procedure* and by using Testo 815 device. unoccupied ambient noise levels (ANLs) are acquired for an unoccupied typical classroom. Seven measurement points are distributed in the classroom as shown in Table 2. The experiment was conducted and data were assembled in a single day to maintain the environmental conditions (temperature and humidity). Four cases were inspected as follows:

- (C1) Opened classroom (completely open),
- (C2) Semi opened classroom (one leaf of the middle window opened + one door opened),
- (C3) Enclosed classroom without HVAC & open curtains,
- (C4) Enclosed classroom without HVAC & closed curtains.

The seven points measurements were assembled and the average was calculated. That was replicated for the four cases.

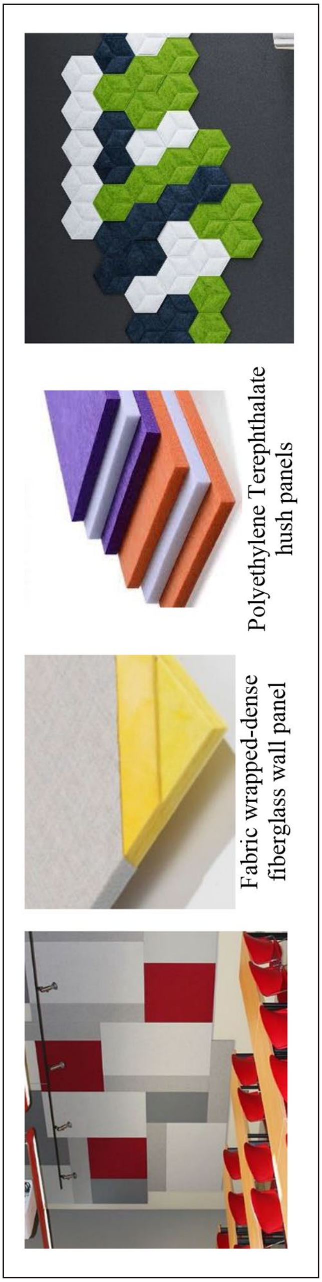


Figure 2. Absorptive treatment panels.

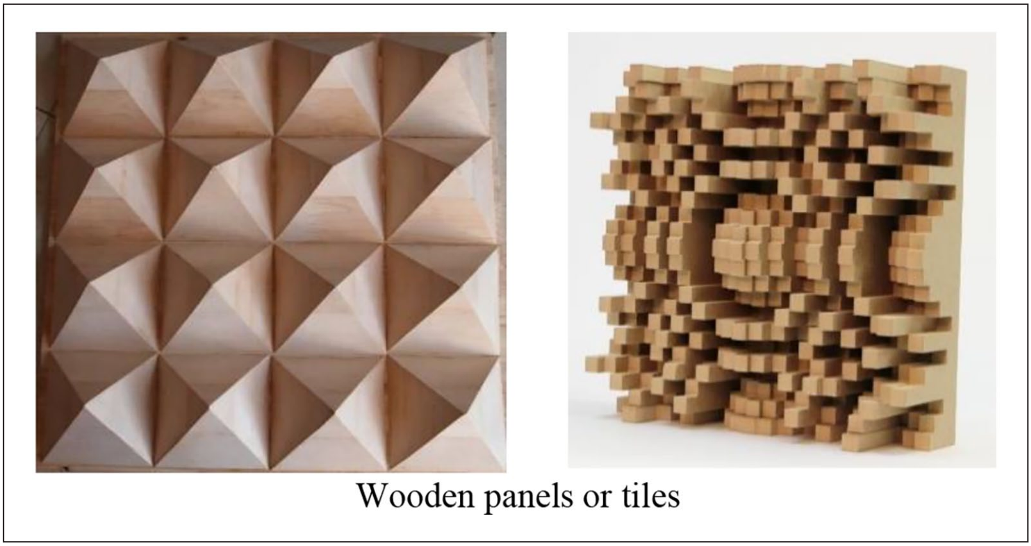


Figure 3. Diffusive treatment panels.

The third phase, is based on *classroom simulation* by using Ecotect software, and by using analytical method. The classroom description and characteristics represented in classroom dimension, finishing materials for walls, floor, ceiling, curtains, windows, doors, and furniture were described. The noise reduction coefficient (NRC) for each characteristic was determined as listed in Table 3. A voice source 500 Hz was placed in the lecturer location at 1.3 Hight, and (NRC) values were entered into the software. Two simulation trials were carried out to compare the RT_{avr}, and $RT_{0.5–500Hz}$ before and after modifying the acoustic treatments.

The first simulation was performed to evaluate the current situation for the four cases mentioned above and to identify the acoustic problems as illustrated in Table 4. The second simulation was carried out for three cases after modifying the acoustic treatments. The open classroom (completely opened) case was excluded. The three cases were described in Table 5 and summarized as follows:

- Semi opened classroom (one leaf of the middle window opened + one door opened). Three fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9), and heavy curtains (NRC = 0.6) were modified and as illustrated in Figure 5(a).
- Enclosed classroom without HVAC & open curtains. Three fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9) were modified and as illustrated in Figure 5(b).
- Enclosed classroom without HVAC & closed curtains. Two sceneries for this case were conducted. The first scenario; Three fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9), and heavy curtains (NRC = 0.6) were modified and as illustrated in Figure 5(c). The second scenario; the same scenario one, and acoustic ceiling (NRC = 0.8) were modified and as illustrated in Figure 5(d).

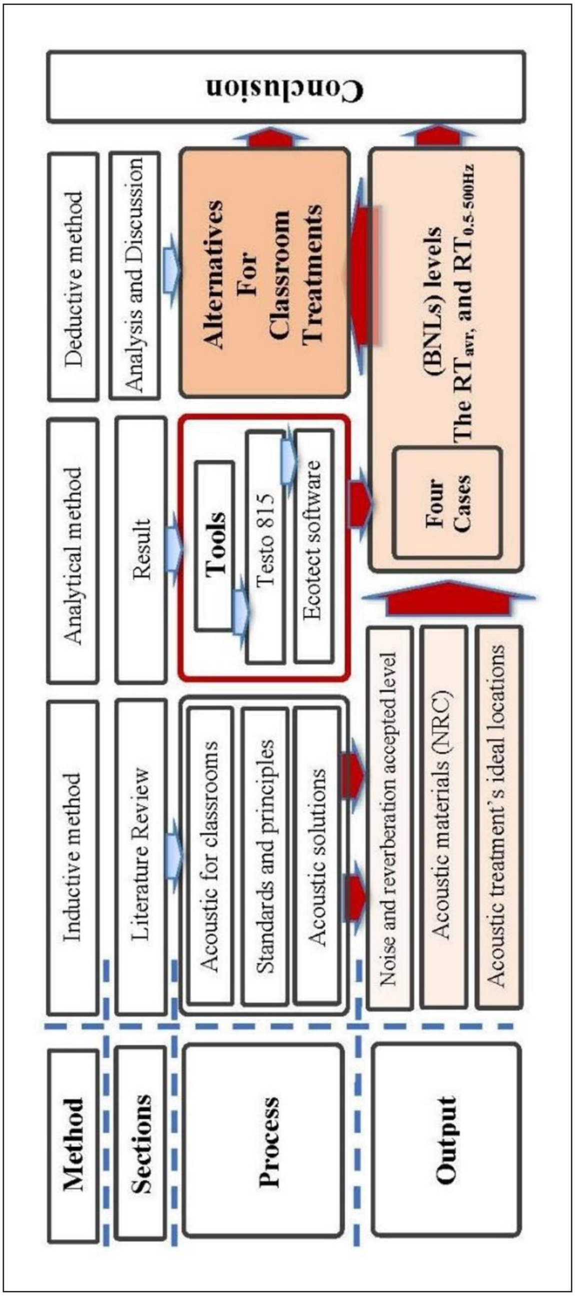
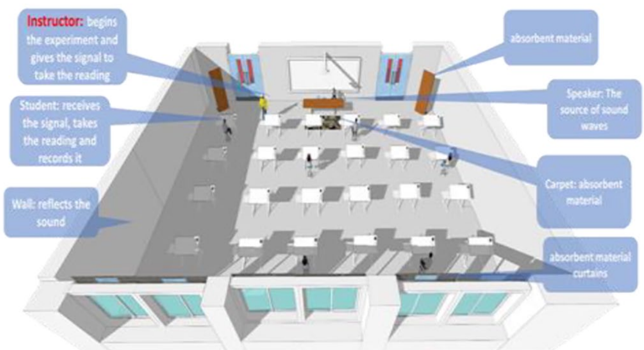


Figure 4. Research methodology.

Table 2. Distribution of the measuring points.

Measuring points	Measuring tool	Reasons for determining the measurement points
Po.1	Testo 815	Point 1 is the lecturer location.
Po.2		Point 2 is the closest source to students.
Po.3 & 5		Point 3 and 5 are points close to side wall as a measure of reflection or absorption.
Po.4		Point 4 is in the middle of the classroom.
Po.6 & 7		Point 6&7 are at the back to measure the outside noise.

Table 3. Classroom description and characteristics.



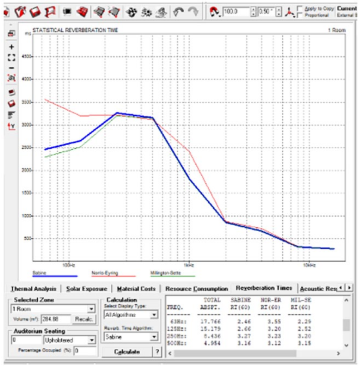
Classroom dimension	9.6 m W × 10 m L × 3.5 H.	
Classroom capacity	24 students (four rows & six columns).	
Item	*Description*	**NRC*[36,37]
Walls	Bricks, plaster, and Plastic paint.	0.02
Ceiling	False ceiling gypsum board tiles (60 × 60 cm)/9 mm thickness.	0.03
Flooring	Ceramic tiles.	0.01
Windows	Three Aluminum windows with single glass 6 mm – sliding type.	0.18
Doors	Wooden door (two leaves thickness 5 cm).	0.06
Curtains	Light and thin linen fabric curtains.	0.04
Furniture	Wooden boards 0.80 m W × 1.20 m L	0.17

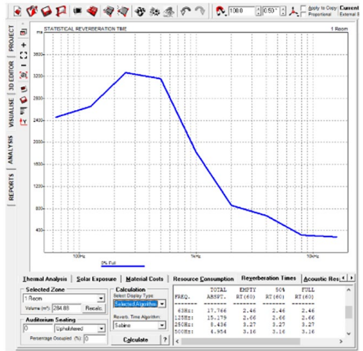
*NRC values in 500 Hz octave band.

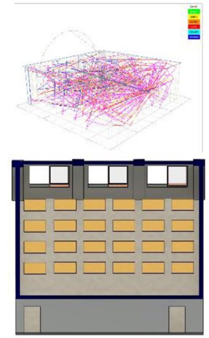
Table 4. Reverberation time (RTs) simulations (Unoccupied classroom before treatments).

Unoccupied classroom

(C1) Opened classroom (completely open)

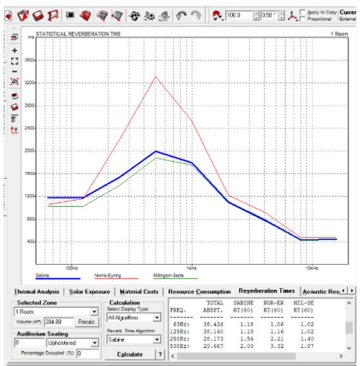


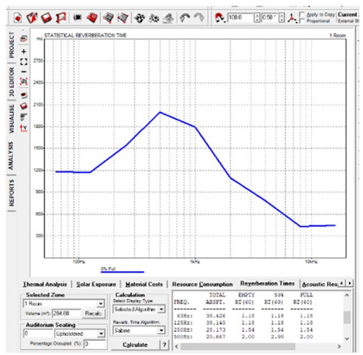


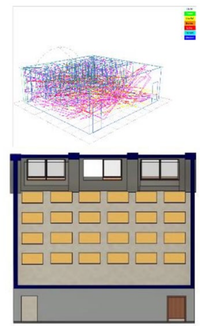


RT_{avr}	3.14 s	$RT_{0.5–500Hz}$	3.16 s

(C2) Semi opened classroom (half one window opened + one door opened)







RT_{avr}	2.4 s	$RT_{0.5–500Hz}$	2.00 s

(Continued)

Table 4. (Continued)

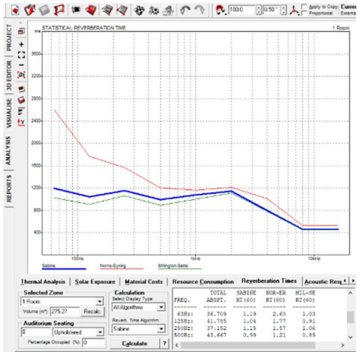
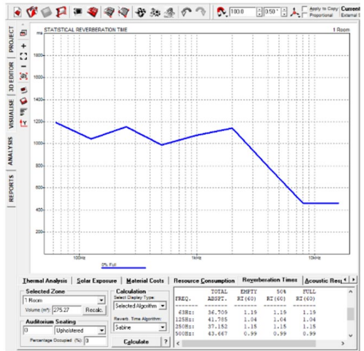
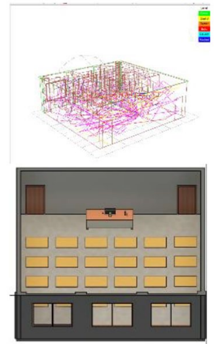
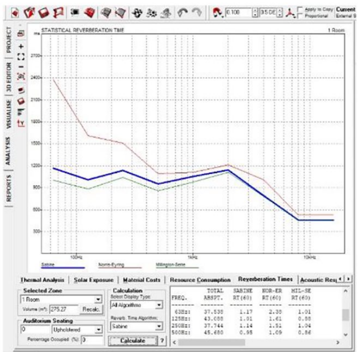
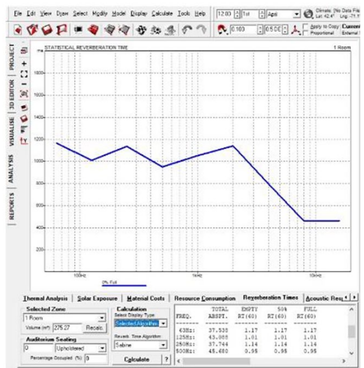
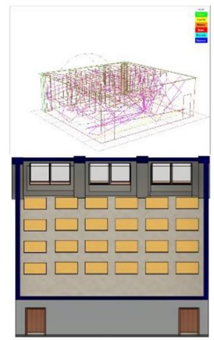
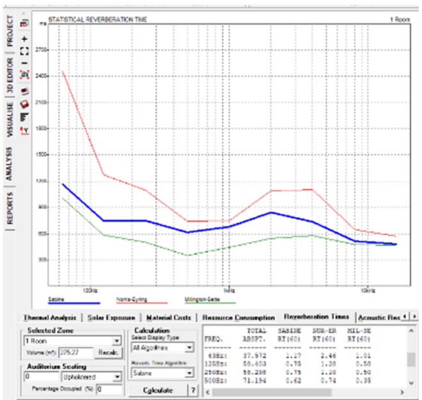
Unoccupied classroom			
(C3) Enclosed classroom without HVAC & open curtains			
			
RT_{avr}	1.03 s	$RT_{0.5\text{–}500Hz}$	0.99 s
(C4) Enclosed classroom without HVAC & closed curtains			
			
RT_{avr}	0.97 s	$RT_{0.5\text{–}500Hz}$	0.95 s

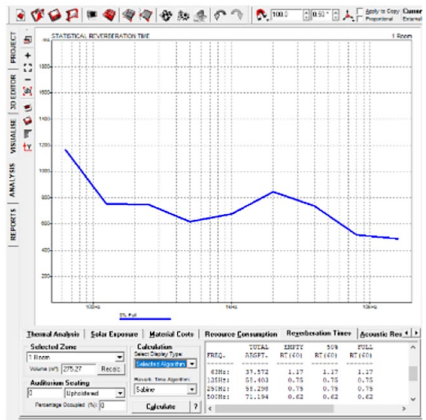
Table 5. Reverberation time (RT) simulations (Unoccupied classroom after treatments).

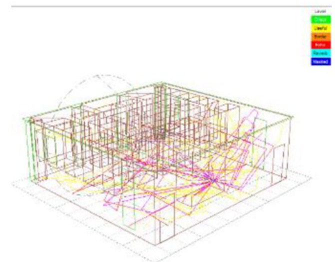
Unoccupied classroom

(C2) Semi opened classroom (half window opened + one door opened)

Treatment: Two fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9), and heavy curtains (NRC = 0.6).



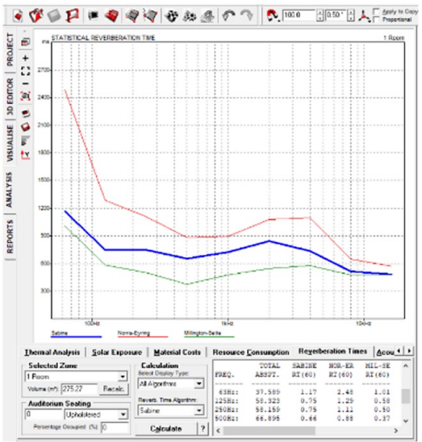
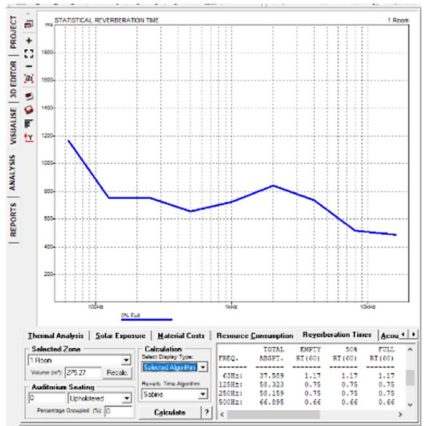
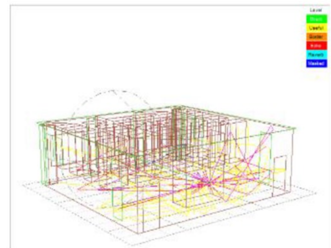




RT_{avr}	0.57 s	$RT_{0.5\text{–}500Hz}$	0.62 s

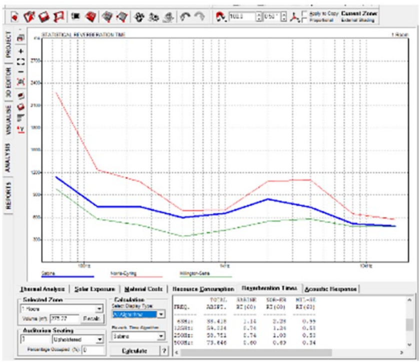
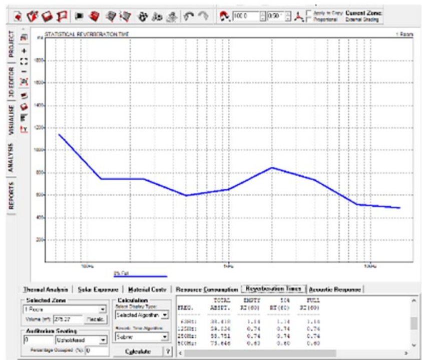
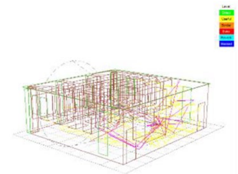
(Continued)

Table 5. (Continued)

Unoccupied classroom			
(C3) Enclosed classroom without HVAC & open curtains			
Treatment: Two fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9).			
			
RT_{avr}	0.63 s	$RT_{0.5\text{–}500Hz}$	0.66 s

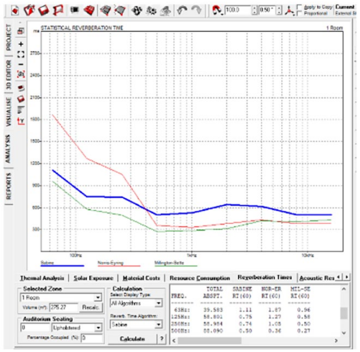
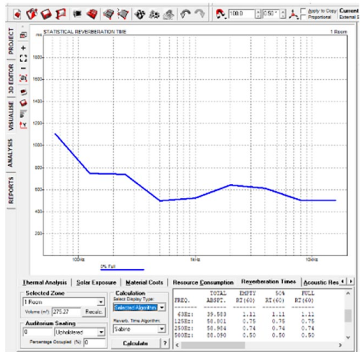
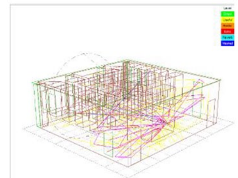
(Continued)

Table 5. (Continued)

Unoccupied classroom			
(C4) Enclosed classroom without HVAC & closed curtains (**Scenario 1**)			
Treatment: Two fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9), and heavy curtains (NRC = 0.6).			
		 	
RT_{avr}	0.54 s	$RT_{0.5–500Hz}$	0.60 s

(Continued)

Table 5. (Continued)

Unoccupied classroom			
(C4) Enclosed classroom without HVAC & closed curtains (**Scenario 2**)			
Treatment: Two fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9), heavy curtains (NRC = 0.6), and acoustic ceiling (NRC = 0.8).			
		 	
RT_{avr}	0.37 s	$RT_{0.5\text{–}500Hz}$	0.50 s

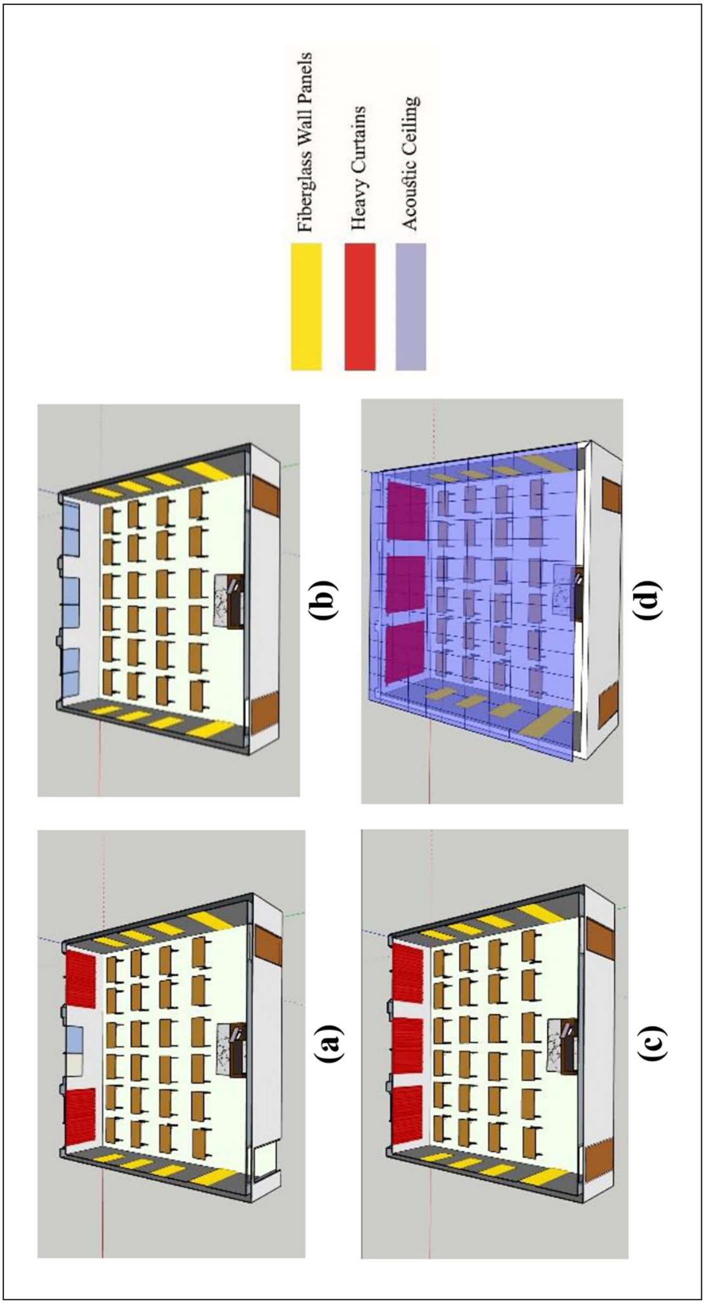


Figure 5. Classroom acoustic treatment's locations.

Table 6. Noise (ANLs/dBA) measurements.

Unoccupied classroom									
Measuring criteria		ANLs/dBA (each point and average)							
		Po.1	Po.2	Po.3	Po.4	Po.5	Po.6	Po.7	Av.
C1	Opened classroom (completely open)	57.6	57.4	54	53.4	56.4	56.5	52	55.3
C2	Semi opened classroom (half window + one door opened)	56	55.2	53.5	50.1	54.7	56	51.5	53.8
C3	Enclosed classroom without HVAC & open curtains	53.0	50.4	49.4	47.5	51.4	49.4	47.5	49.8
C4	Enclosed classroom without HVAC & closed curtains	52	48.2	48.5	45.0	43.9	45	44.6	46.7
Average of each point		54.5	52.8	51.35	49	51.6	51.7	48.9	

The RT_{avr}, (Sabin, Eyring, and Norris) were calculated by the Ecotect software before and after modifying the acoustic treatments. $RT_{0.5–500Hz}$ (Sabin value) selected because it was more common and suitable for use.

Result

The acoustic measurements were undertaken in the classroom in an unoccupied condition. Unoccupied ambient noise level (ANLs) was measured during the normal teaching hours, including external environmental noise and building service noise. The results for the four cases were summarized in Table 6 and as shown in Figure 6. Similarly, the reverberation (RT_{avr}, and $RT_{0.5-500Hz}$) were acquired by Ecotect software before and after modifying the acoustic treatments. The room finishing and normal furniture were taken into consideration. The results for the cases were illustrated in Table 7.

From Table 6 for *unoccupied ambient noise level (ANLs)*. It can be seen that there was a significant variation in the average (ANLs) measurements. It varied from 55.3 dBA in the opened classroom (C1) to 46.7 dBA in the enclosed classroom without HVAC & closed curtains (C4). Noteworthy, it didn't meet the standards. In addition, point4 (Po.4) in the middle of the classroom (ANLs) measurements ranged from 53.4 dBA in (C1) to 45.0 in (C4). It recorded the lowest values among the seven points. It can be noticed also that (Po.1) in the front (near the doors), and (Po.6) in the back (near the windows and the reflective sidewall) achieved the highest measurements.

From Table 7 for *the reverberation (RT_{avr}, and $RT_{0.5–500Hz}$)*. RT_{avr} measurements before treatments ranged from 3.14 to 0.97 s, and $RT_{0.5–500Hz}$ ranged from 3.16 to 0.95 s. Furthermore, RT_{avr} measurements after treatments ranged from 0.57 to 0.37 s, and $RT_{0.5–500Hz}$ ranged from 0.62 to 0.50 s. Substantially, the acoustic treatments (absorbent materials) greatly affected both *RT_{avr}, and $RT_{0.5–500Hz.}$* values. The enclosed classroom without HVAC & closed curtains (C4) whether (Sc1) or (Sc2) achieved optimal values and it met the standard requirements.

Analysis and discussion

In the university classrooms, the noise control is the main problem.[38] Furthermore, the older students in universities classrooms generate less noise than the students in elementary schools.[39] Regarding the RT_{avr}, and $RT_{0.5–500Hz}$ measurements by Ecotect software before adding any acoustic

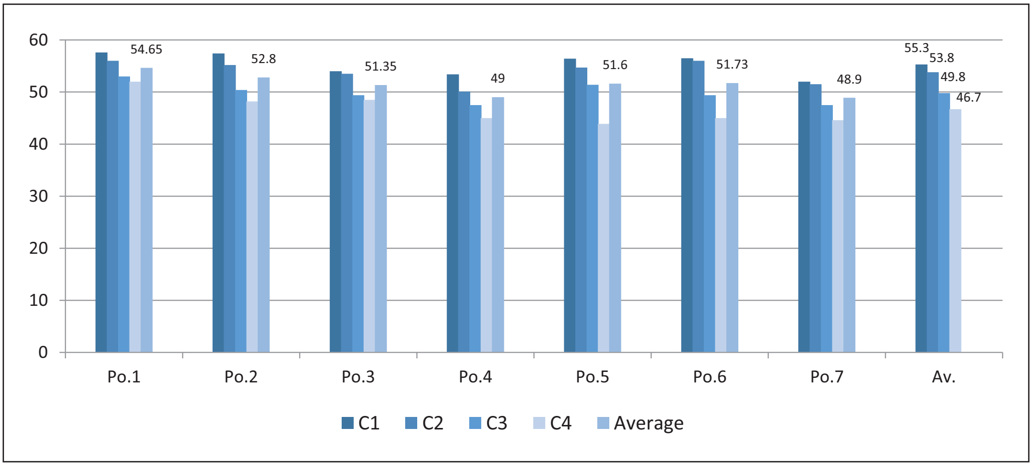


Figure 6. The measurements of the four cases (the seven points and average).

Table 7. Reverberation time (RT_{avr} and $RT_{0.5\text{-}500Hz}$) measurements.

Cases		Before		After		
		RT_{avr}	$RT_{0.5\text{-}500Hz}$	RT_{avr}		$RT_{0.5\text{-}500Hz}$
C1	Opened classroom (completely open)	3.14	3.16	**Excluded**		
C2	Semi opened classroom (half window opened + one door opened)	2.4	2.00	0.57		0.62
C3	Enclosed classroom without HVAC & open curtains	1.03	0.99	0.63		0.66
C4	Enclosed classroom without HVAC & closed curtains	0.97	0.95	**Sc1**	0.54	0.60
				Sc2	0.37	0.50

treatments in unoccupied condition, and according to the classroom description and characteristics as illustrated in Tables 3 and 4. This classroom therefore is considered a reflective classroom.[40] From this point of view, absorbent treatments were added at the mentioned locations above in Figure 5. It was placed according to the locations discussed in the literature.

The semi opened classroom (one leaf of the middle window opened + one door opened) (C2). RT_{avr}, and $RT_{0.5–500Hz}$ were 0.57 and 0.62 s after adding the absorbent treatments, they met the standards. Although, one leaf of the middle window opened, the heavy curtains in the other windows absorbed a large amount of the background noise which occurred from the outside and the Echo from inside. In fact, the authors include this case in the second simulation to evaluate the classroom acoustic environment, in case providing natural ventilation is required for the student health, especially with Covid-19 pandemic.[41]

The enclosed classroom without HVAC & open curtains, (C3). RT_{avr}, and $RT_{0.5\text{-}500Hz}$ were 0.63 and 0.66 s after adding the absorbent treatments, they met the standards. Natural lighting can be provided in this case if it required, without effect in the classroom acoustic environment.

The enclosed classroom without HVAC & closed curtains, (C4- Sc1). RT_{avr}, and $RT_{0.5–500Hz}$ were 0.54 and 0.60 s after adding the absorbent treatments, they met the standards. This case provides an economic solution for the classroom and achieving the standards, but not the optimum.

In (C4- Sc2) RT_{avr}, and $RT_{0.5\text{-}500Hz}$ were 0.37 and 0.50 s after adding the absorbent treatments, they met the standards. This scenario demonstrates how the acoustic ceiling treatment has a great effect on the RTs values. This scenario is the optimal solution for the classroom, but too expensive. Indeed, all cases RTs become meet standard value. From another perspective, a study conducted at Kangwon National University (KNU), Korea, indicated that RTs values decreased when occupants were added specially in the reflective classrooms.[42] that means in occupied classroom condition, the RTs will be better than the concluded values from the simulation.

The authors excluded (C1) in the second simulation because this case did not occur in reality, especially when the classroom is occupied with students. But it was discussed in the first simulation to demonstrate the effect of the background noise on the RTs values. Notably, The RTs values were extremely higher than standards and norms.

As regards the (ANLs) measurements, (C3) and (C4) results were 49.8 and 46.7 dBA. it is slightly higher than the standards but it can be accepted after the acoustic treatments. Noteworthy, the building envelope specially the windows, it plays a major role in eliminating the noise level.[43] Adding double glass for the back windows for (C3) and (C4) will decrease the background noise and increase the speech intelligibility level. Where the use of double glass window composed of two glass panes each in 6 mm thickness and separated by an air gap between 10 and 12 mm. That can provide strong acoustic insulation.[44] Also, it may enhance (ANLs) value for (C2).

Conclusion

Providing a good acoustic environment in the educational institutes whether schools or universities is an important issue for enhancing the education quality and facilitate a better learning. The study sought to clarify the great effect of ambient noise levels (ANLs) and the reverberation time (RT) on the acoustic design for the classrooms and discussed the acceptable standards for these acoustic parameters. Additionally, the study showed the acoustic solutions for classrooms through the absorbent and diffusive panels, and the best location to place these panels in the classrooms. Furthermore, the findings of the measurements for (ANLs) by Testo 815, and (RTs) by Ecotect software for the Badr classroom showed that they did not meet the standards. Noteworthy, the study recommended acoustic absorbent treatments for the classroom in three cases by simulation. The optimum solution was by using three fabric wrapped-dense fiberglass wall panels (W80 cm × H160 cm, 5 cm thickness, NRC = 0.9), one fabric wrapped-dense fiberglass wall panel (W80 cm × H320 cm, 5 cm thickness, NRC = 0.9), heavy curtains (NRC = 0.6), and acoustic ceiling (NRC = 0.8). the result for RT_{avr}, and $RT_{0.5\text{–}500Hz}$ were 0.37 and 0.50 s after adding the absorbent treatments, they met the standards. Similarly, the study demonstrated the importance of the building envelope specially the windows for enhancing the (ANLs), and suggested to use of double glass windows composed of two glass panes each in 6 mm thickness and separated by an air gap between 10 and 12 mm, that will provide strong acoustic insulation. In this regard, the method applied for this case study can be used to evaluate and enhance the acoustic conditions for all the university spaces. Finally, this study will be the first contribution to Badr university, and future studies will be conducted to evaluate the acoustic conditions of the existing university buildings, and suggest a group of recommendations for renovation.

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References

1. Winnipeg M. *School building, space standards*. Winnipeg, MB: The Public Schools Finance Board, 2018.
2. Klatte M, Bergström K and Lachmann T. Does noise affect learning? A short review on noise effects on cognitive performance in children. *Front Psychol* 2013; 4: 578.
3. Imms W, Mahat M, Byers T, et al. Type and use of innovative learning environments in Australasian Schools ILETC Survey No. 1. Technical report 1/2017, Melbourne, 2017. http://www.iletc.com.au/publications/reports (accessed 15 February 2022)
4. Saeed DM, Elkhatib WF and Selim AM. Architecturally safe and healthy classrooms: eco-medical concept to achieve sustainability in light of COVID-19 global pandemic. *J Asian Archit Build Eng* 2021; 1–16.
5. Mealings K, Demuth K, et al. An assessment of open plan and enclosed classroom listening environments for young children: Part 2 - teachers' questionnaires. *J Educ Pediatr Rehabil Audiol* 2015; 1: 1–19.
6. Standards New Zealand. *AS/NZS 2107:2016. Acoustics - recommended design sound levels and reverberation times for building interiors*. Wellington: Standards New Zealand, 2016.
7. Brännström KJ, Johansson E, Vigertsson D, et al. How children perceive the acoustic environment of their school. *Noise Health* 2017; 19(87): 84–94.
8. Spratford M, Walker EA and McCreery RW. Use of an application to verify classroom acoustic recommendations for children who are hard of hearing in a general education setting. *Am J Audiol* 2019; 28: 927–934.
9. Zhu P, Tao W, Lu X, et al. Optimisation design and verification of the acoustic environment for multimedia classrooms in universities based on simulation. *Build Simul* 2022; 15: 1419–1436.
10. Ricciardi P and Buratti C. Environmental quality of university classrooms: subjective and objective evaluation of the thermal, acoustic, and lighting comfort conditions. *Build Environ* 2018; 127: 23–36.
11. Astolfi A, Bottalico P and Barbato G. Subjective and objective speech intelligibility investigations in primary school classrooms. *J Acoust Soc Am* 2012; 131: 247–257.
12. Zhou T, Wu Y, Meng Q, et al. Influence of the acoustic environment in hospital wards on patient physiological and psychological indices. *Front Psychol* 2020; 11: 1600.
13. Christensen JH, Saunders GH, Porsbo M, et al. The everyday acoustic environment and its association with human heart rate: evidence from real-world data logging with hearing aids and wearables. *R Soc* 2021; 8: 201345.
14. Kang J, Aletta F, Oberman T, et al. Acoustic environments and soundscapes in London during the Spring 2020 lockdown. *J Acoust Soc Am* 2021; 149: A27–A27.
15. Siebein G. Understanding classroom acoustic solutions. *Semin Hear* 2004; 25(2): 141–154.
16. Klatte M, Hellbrück J, Seidel J, et al. Effects of classroom acoustics on performance and well-being in elementary school children: a field study. *Environ Behav* 2010; 42(5): 659–692.
17. Amasuomo J. Lecture Hall acoustics as a determinant for effective learning-teaching environment. *J Educ Sociol* 2014; 5: 26–30.
18. Cipriano M, Astolfi A and Pelegrín-García D. Combined effect of noise and room acoustics on vocal effort in simulated classrooms. *J Acoust Soc Am* 2017; 141: EL51–EL56.
19. Prodi N, Visentin C and Feletti A. On the perception of speech in primary school classrooms: Ranking of noise interference and of age influence. *J Acoust Soc Am* 2013; 133: 255–268.
20. Osman H and Sullivan JR. Children's auditory working memory performance in degraded listening conditions. *J Speech Lang Hear Res* 2014; 57: 1503–1511.

21. Sullivan JR, Osman H and Schafer EC. The effect of noise on the relationship between auditory working memory and comprehension in school-age children. *J Speech Lang Hear Res* 2015; 58: 1043–1051.
22. van Reenen C and Plessis CD. Acoustics in South African classrooms: Regulations versus reality. *Build Acoust* 2022; 29(1): 157–178.
23. Persson Waye K, Magnusson L, Fredriksson S, et al. A screening approach for classroom acoustics using web-based listening tests and subjective ratings. *PLoS One* 2015; 10: e0116572.
24. British Standards Institution. BS ISO 9921-1: 1996. Ergonomic assessment of speech communication-Part 1: Speech interference level and communication distances for persons with normal hearing capacity in direct communication (SILmethod), 1997.
25. Mealings K. Classroom acoustic conditions: understanding what is suitable through a review of national and international standards, recommendations, and live classroom measurements. In: *2nd Australasian acoustical society's conference, ACOUSTICS 2016*, Brisbane, Australia, 2016.
26. Habibi S. Improving building envelope performance with respect to thermal, sound insulation, and lighting: a case study. *Build Acoust* 2019; 26(4): 243–262.
27. Astolfi A and Pellerey F. Subjective and objective assessment of acoustical and overall environmental quality in secondary school classrooms. *J Acoust Soc Am* 2008; 123: 163–173.
28. Toyinbo O, Shaughnessy R, Turunen M, et al. Building characteristics, indoor environmental quality, and mathematics achievement in Finnish elementary schools. *Build Environ* 2016; 104: 114–121.
29. Choi Y-J. An optimum combination of absorptive and diffusing treatments for classroom acoustic design. *Build Acoust* 2014; 21(2): 175–179.
30. Russo D and Ruggiero A. Choice of the optimal acoustic design of a school classroom and experimental verification. *Appl Acoust* 2019; 146: 280–287.
31. Choi Y-J. Effects of periodic type diffusers on classroom acoustics. *Appl Acoust* 2013; 74: 694–707.
32. Mir SH and Abdou AA. Investigation of sound-absorbing material configuration of a smart classroom utilizing computer modeling. *Build Acoust* 2005; 12: 175–188.
33. Cucharero J, Hänninen T and Lokki T. Influence of sound-absorbing material placement on room acoustical parameters. *Acoustics* 2019; 1: 644–660.
34. Sanavi A, Schäffer B, Heutschi K, et al. On the effect of an acoustic diffuser in comparison with an absorber on the subjectively perceived quality of speech in a meeting room. *Acta Acust United Acust* 2017; 103: 1037–1049.
35. Shtrepi L, Astolfi A, D'Antonio G, et al. Objective and perceptual evaluation of distance-dependent scattered sound effects in a small variable-acoustics hall. *J Acoust Soc Am* 2016; 140: 3651–3662.
36. Lord P and Templeton D. *Detailing for acoustics*. New York: Spon Press, 2001.
37. Iswati TY. Evaluation of reverberation time in the auditorium: case of Assembly Hall of Engineering Faculty, Universitas Sebelas Maret. In: *18th International conference on sustainable environment and architecture. Advances in Engineering Research*, 2019, vol. 156.
38. Choi Y-J. Evaluation of acoustical conditions for speech communication in active university classrooms. *Appl Acoust* 2020; 159: 107089.
39. Sato H and Bradley JS. Evaluation of acoustical conditions for speech communication in working elementary school classrooms. *J Acoust Soc Am* 2008; 123: 2064–2077.
40. Labia L, Shtrepi L and Astolfi A. Improved room acoustics quality in meeting rooms: investigation on the optimal configurations of sound-absorptive and sound-diffusive panels. *Acoustics* 2020; 2(3): 451–473.
41. UNICEF for Every Child, UN Educational and WHO. Considerations for school-related public health measures in the context of COVID-19, 2020.
42. Choi YJ. Effect of occupancy on acoustical conditions in university classrooms. *Appl Acoust* 2016; 114: 36–43.
43. ISO. EN ISO 12354-3:2017. Building acoustics—estimation of acoustic performance of buildings from the performance of elements. Part 3: airborne sound insulation against outdoor sound. Geneva: ISO.
44. Secchi S, Astolfi A, Calosso G, et al. Effect of outdoor noise and façade sound insulation on indoor acoustic environment of Italian schools. *Appl Acoust* 2017; 126: 120–130.