Study on school classroom acoustics in urban context considering natural ventilation and speech intelligibility

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Abstract

A classroom is a place of interaction. It is a learning space for children and a workspace for teachers. A teacher's voice is an important factor in this place of interaction. Good acoustics influences the performance of its users. But most of the schools lack good classroom acoustics due to traffic noise, noise from corridors and other classrooms, etc. The classrooms adjacent to the road traffic lack acoustic comfort, and in order to tackle the issue of outdoor noise, people tend to cut off the ventilation by shutting down fenestrations like windows, doors, etc. which can affect both thermal and sonic comfort. By doing so, the reverberation time of sound increases and will affect the speech intelligibility of the classroom. This makes it strenuous for teachers to communicate concepts, thus affecting the overall speech intelligibility and intellectual performance of the students. This includes difficulty in understanding the words or sentences which in turn affects their concentration, and performance. Windows and openings are considered the weakest component of the façade from a thermal and acoustics point of view. This paper discusses noise pollution affecting classroom acoustics and also the factors affecting speech intelligibility, such as background noise, signal-to-noise ratio, reverberation, and other architectural factors. Through subjective surveys conducted in classrooms and articulation loss index, the signal-to-noise ratio is evaluated. This paper compares the signal-to-noise ratio of classrooms in various conditions with the current acoustical standards for classrooms. Also, the study brings out strategies to enhance classroom acoustics in an urban context without compromising natural ventilation.

Keywords: Classroom acoustics, Speech intelligibility, Natural ventilation, Background noise

Introduction

Classrooms are learning spaces for children and workplaces for teachers where their voice is considered important, so a noiseless environment and good acoustics in classrooms are important. Several scientific studies have determined the negative impacts of noise on human health, and well-being and shows strong evidence of non-auditory effects on health. To reduce these effects, good acoustic spaces and noiseless environments are necessary. On contrary, the acoustic design strategies in the building reduce the natural ventilation to the building. On the other hand, Sustainable design strategies such as natural ventilation challenged the common practice in acoustic design.Fenestrations are considered the

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weakest element of facade treatment from a thermal and acoustic point of view. So acoustic retrofit strategies for fenestrations in the facades are necessary to reduce noise.

This study examines how traffic noise affects the classroom acoustics and speech intelligibility, of schools in urban contexts and through subjective survey, articulation loss index, the signal-to-noise ratio is evaluated.Context-responsive acoustic retrofit strategies of windows in facades to reduce noise without affecting natural ventilation will be proposed.

The background study comprises of various literature studies regarding types of noise and factors affecting speech intelligibility. After thorough studies on speech intelligibility, as a primary study subjective survey was conducted along with field measurements for determining speech intelligibility.Analysis and inference are recommended based on comparing both field measurements and standards.

Limitation: Improper delivery of pronunciation can cause misinterpretation of words during speech intelligibility test.

Literature studies

Speech intelligibility

The degree to which listeners in a specific context are capable of correctly identifying and comprehending speech sounds (whether conversational or communication-system output). One of the most crucial elements affecting speech understanding is background or other system noise.

The highest design requirement for any space for spoken word is speech intelligibility. This is relevant in many theatres, auditoriums, classrooms, and places of worship. Sound systems are frequently utilised to overcome acoustical problems and offer understanding in even extremely vast settings. Low frequencies result in shorter reverberation times for speech. This makes speech more understandable.

Reverberation time and signal-to-noise ratio are the main factors affecting speech intelligibility.

Different analytical methodologies have been used to evaluate speech intelligibility. Speech privacy and intelligibility are assessed using acoustic measurements by the articulation index (AI).

Another objective measure of speech intelligibility is the percentage of consonant articulation loss, or %Alcons. As its name suggests, Alcons concentrates on how spoken consonants are heard. Alcons is roughly equivalent to:

$$\%\text{Alcons} \approx 0.652\left(\frac{r_{lh}}{r_h}\right)^2 \text{RT}_{60}$$

where

%Alcons = percentage articulation loss of consonants, percent

rlh = distance from sound source to listener

rh = reverberation radius, or critical distance for directional sound sources

RT60 = reverberation time, sec

Table 1 Subjective Weighting for Results of %Alcons Testing *Limit value is 15%

Subjective Intelligibility	%Alcons
Ideal	≤3%
Good	3–8%
Satisfactory	8–11%
Poor	>11%
Worthless	>20%*

Subject-Based Measures

Speech intelligibility evaluation in a space, Subject-Based Measures, or live experiments, are frequently used. As listeners in the room take notes on what the talker reads from a list of words and phrases. Important speech sound examples are included in the list. Per test, 200–1000 words are utilised. Examples of English words used in subject-based intelligibility testing are provided in Table 2.

Speech intelligibility increases with the percentage of words and phrases that are correctly understood. Listening aptitude is occasionally assessed. Although intelligibility may be great when the volume of the voice is equal to the volume of the background noise, listening requires a lot of concentration since listeners may still have trouble understanding what is being said.

Table 2 Examples of Words Used in Subject-Based Intelligibility Testing
Source : (Pohlmann, 2009)

aisle	done	jam	ram	tame
barb	dub	law	ring	toil
barge	feed	lawn	rip	ton
bark	feet	lisle	rub	trill
baste	file	live	run	tub
bead	five	loon	sale	vouch
beige	foil	loop	same	vow
boil	fume	mess	shod	whack
choke	fuse	met	shop	wham
chore	get	neat	should	woe
cod	good	need	shrill	woke
coil	guess	oil	sip	would
coon	hews	ouch	skill	yaw
coop	hive	paw	soil	yawn
cop	hod	pawn	soon	yes
couch	hood	pews	soot	yet
could	hop	poke	soup	zing
cow	how	pour	spill	zip
dale	huge	pure	still	
dame	jack	rack	tale	

Field study

Live Case studies

- Government Model Girls Higher Secondary School, Pattom
- SMV Govt.Model Higher Secondary School, Thampanoor

These are the schools located near to the Kesavadasapuram - Thampanoor NH66, Thiruvananthapuram, Kerala. During peak hours these schools experience heavy noise pollution due to the heavy traffic, announcement, etc especially SMV Govt.Model Higher Secondary School, Thampanoor is located in the city center. These school buildings are located less than 40m from the highway. So, the case studies aim to study how traffic affects the classroom environment and speech intelligibility.

Government Model Girls Higher Secondary School, Pattom

Government Model Girls Higher Secondary School, Pattom located near NH66 Kesavadasapuram - Thampanoor road, Thiruvananthapuram, Kerala. It is located 8m away from the road.

Figure 3 Location map

Figure 4 Government Model Girls Higher Secondary School

The fenestration in the road-facing facade is constructed with open jaalis. But due to the traffic noise, the jaalis were closed with cement boards from the interiors.This reduces the natural ventilation of the class.

The site was simulated in the Sound plan software to study how noise affects the school and its surrounding.

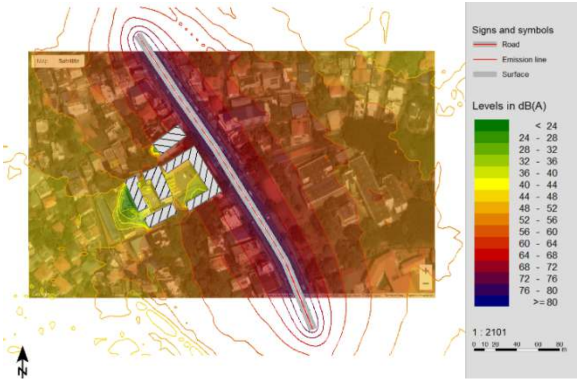


Figure 5 Noise mapping using Sound plan simulation software

From the analysis, the buildings blocks which is closer to the NH66 experience a noise level of 70 to 80 dB. Which is more the limit as per theCentral Pollution Control Board(CPCB) standards. As per CPCB school zone belongs to the silent zone, daytime the permissible noise level standard in the silent zoneis 50 dB, and at
night time it is 40 dB.

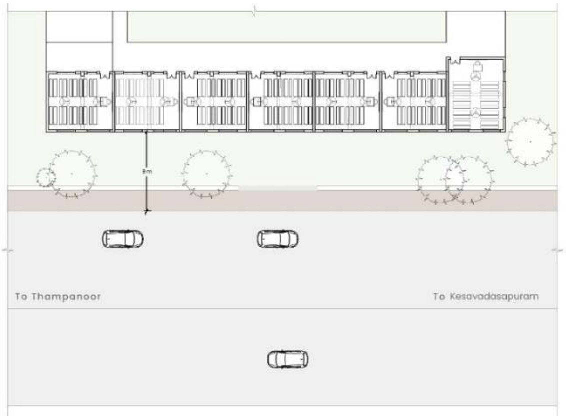


Figure 6 Site plan

Classroom selected for the test.

Selected 2classes from the second floor and first floor for the study.These are the 2 classes having openings to the road.

Classroom 01 is located on the first floor, having two windows on the west side and one jaali area towards the east side which is facing NH66. There are also other jaali openings in the façade, but due the traffic noise other jaali opening are closed with cement fibre boards.

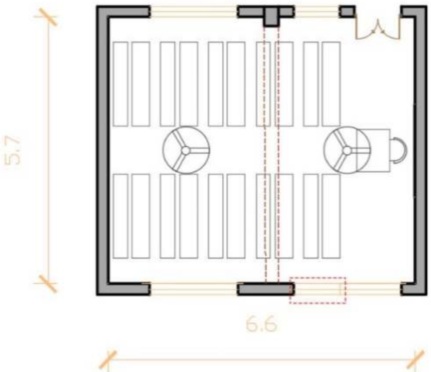


Figure 5 Plan – Class room 01

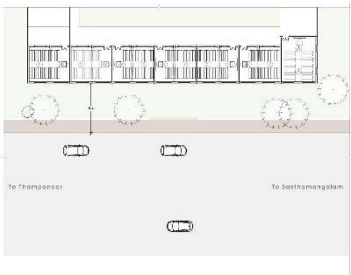


Figure 7 Keyplan

Dimension: 6.6 x 5.7m
Room height: 3.4m
Volume : 127.9 m3
RT 60 = 0.161v/A = 2.5 sec

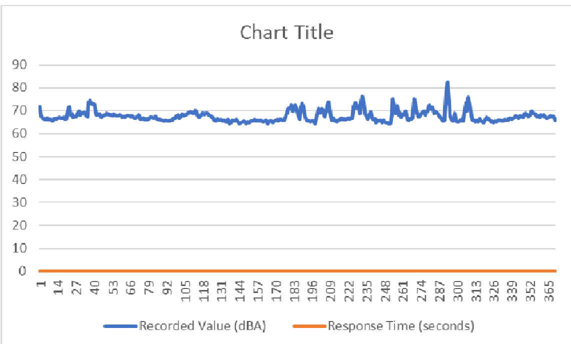


Figure 8Measured dB level in the classroom 01

Min (dBA): 56.7
Max (dBA): 82.4
Peak (dBA): 85.9
Avg (dBA): 67.2

The source of noise

- Traffic noise
- Noise from corridor
- Noise from other classrooms

- Horn noise
- Announcements (Speakers)

As per ANSI standards for classroom acoustics ANSI S12.60-2002 has specified an RT value of 0.6 to 0.7 seconds as optimum and a background noise level of 35 dBA as acceptable for classrooms of volume within 10,000Sqft.
The RT value for this classroom 01 is 2.5 with an average dB of 67.2dB.

Window-to-floor area ratio for natural ventilation

There are 3 openings in the class, 2 grill windows on the west side, and 1 jaali opening on the east side.

Window 1 : 1.9 x 1.9m
Window 2 : 1 x 1.9m
Jaali : 1 x 1.9m

Opening area: 7.41 sq.m
Carpet area: 37.62sq.m
WFR % : 19.7%
For W**FR according to ECBC 16.66 is the minimum requirement.**
The classroom complies with this requirement.

Classroom 02 is located on the second floor, having two small windows on the south side. Jaali openings in the road facing façade are closed with cement fiber boards due to the heavy traffic.

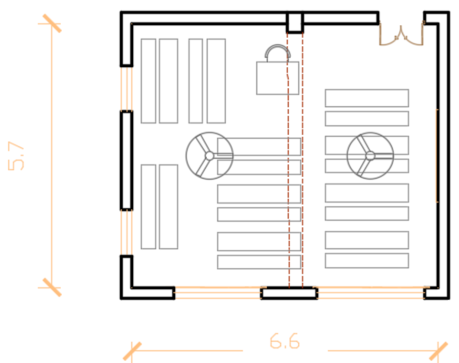


Figure 7 Plan – Class room 02

Dimension: 6.5 x 5.7m
Room height : 3.4m
Volume : 126 m3
Area : 8.245m2
RT 60 = 0.161v/A = 2.4
Occupancy : 31
Min (dBA): 60.4

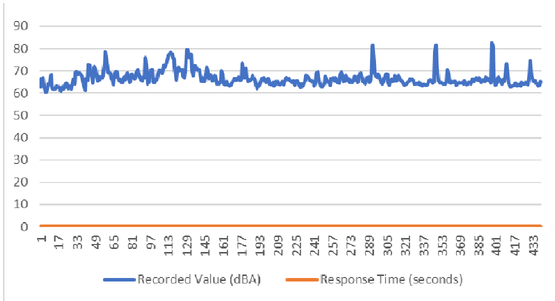


Figure 9 Measured dB level in the class room 01

Max (dBA): 85.6
Peak (dBA): 89.5
Avg (dBA): 70.3

The RT value of class 02 is 2.4 sec which is greater than the optimum RT value and the average background noise level is 70.3 dBA.

A subjective test was conducted in classroom 02 for checking speech intelligibility.
Selected words for the test are;

1. Bark
2. Boil
3. Cow
4. Neat
5. Pure
6. Shop
7. Sale
8. Trill
9. Yet
10. Zip

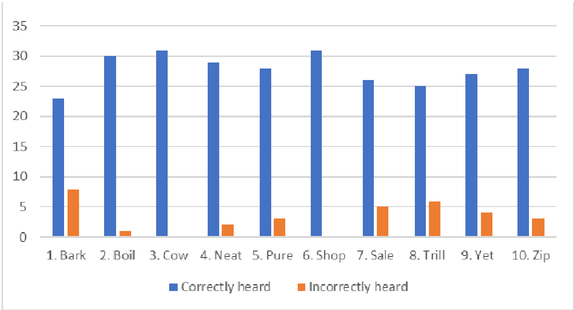


Figure 10 Speech intelligibility test result

Tests were carried out with an average speech level of 70 dB. The signal-to-noise ratios varied according to the background noise levels in each room. Due to the high RT the words are not clearly heard by the students.

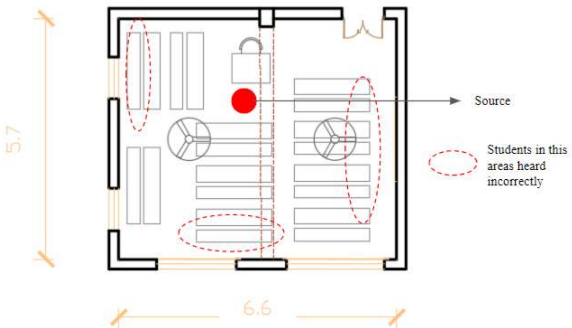


Figure 11 Positions of students who hear incorrectly

Window to floor area ratio for natural ventilation - Class 02

There are 2 openings in the class, 2 windows in the south side.

Window 1 : 1 x 1.3m

Window 2 : 1 x 1.3m

Opening area : 2.6 sq.m

Carpet area : 37.62sq.m

WFR % : 6.9%

The WFR value for class 02 is 6.9% which is lower than the minimum percentage.

In this case, the other openings towards the road were closed due to the traffic noise.

Case study - SMV Govt.Model Higher Secondary School, Thampanoor

SMV Govt.Model Higher Secondary School, Thampanoor located near to NH66 Kesavadasapuram - Thampanoor road, Thiruvananthapuram, Kerala.

Figure 12 Location plan SMV school

Figure 13 View to the school

SMV Govt. Model Higher Secondary School is located in the city center almost 500m from Thampanoor Junction. The UP class building is located only 5.2m away from NH66. The traffic noise from the highway, announcements, other noise, etc totally disturbs the classes. Due to heavy traffic noise, most of the time the windows towards the road were closed.

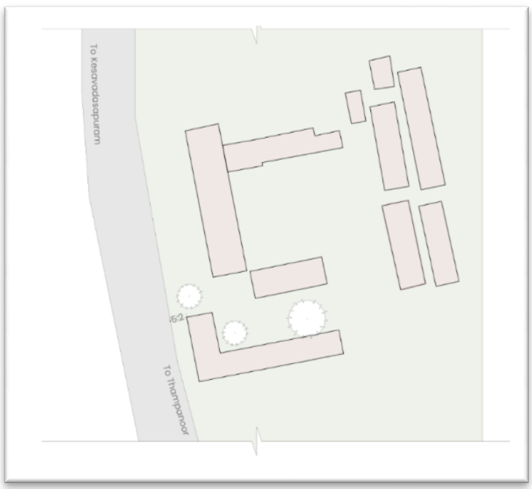


Figure 8 Site plan

The site was simulated in the Sound plan software to study how noise affects the school and its surrounding.

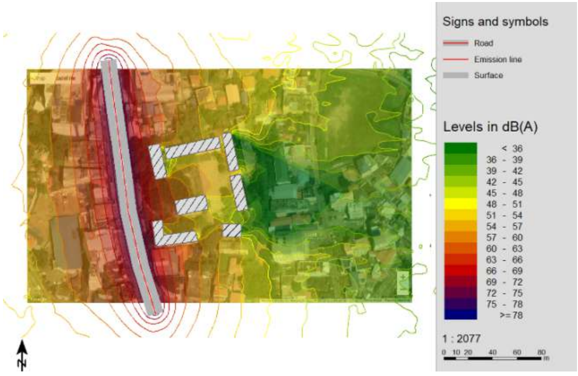


Figure 15Noise mapping using Sound plan simulation software

From the analysis, the building blocks which is closer to the NH66 experience a noise level of 70 to 80 dB. Which is more the limit as per the Central Pollution Control Board (CPCB) standards. As per CPCB school zone belongs to the silent zone, daytime the permissible noise level standard in the silent zoneis 50 dB, and at night time it is 40 dB.

The classroom selected in the SMV schoolis located on the ground floor of the building which adjacent to the NH66.

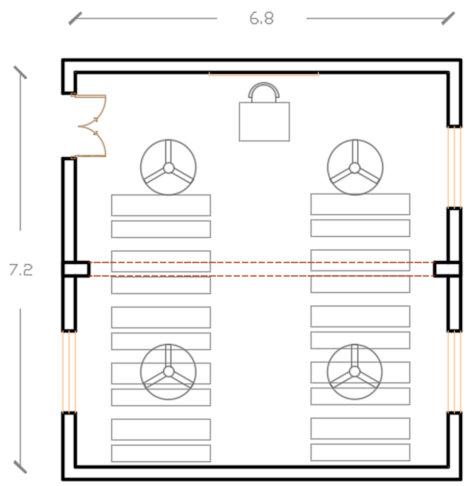


Figure 16 Plan of selected classroom

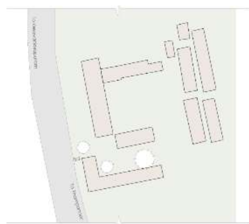


Figure 17Keyplan

Dimension: 6.8 x 7.2m
Room height : 3.7m
Volume : 181 m3
A : 10.64 m2
RT 60 = 0.161v/A = 2.7

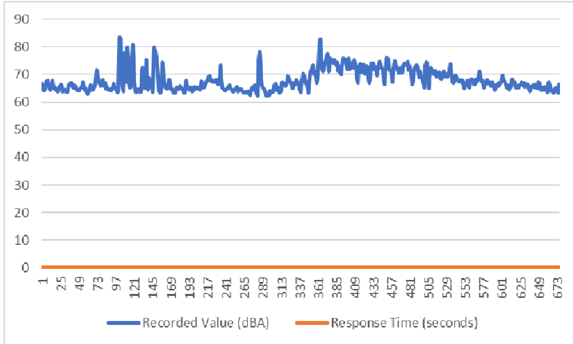


Figure 18 Measured dB level in the classroom in SMV School

Min (dBA): 61.4
Max (dBA): 83.4
Peak (dBA): 87.9
Avg (dBA): 68.1

The RT value of class 01 is 2.7 sec which is greater than the optimum RT value and the average background noise level is 68.1 dB A subjective test was conducted in SMV school for checking speech intelligibility.

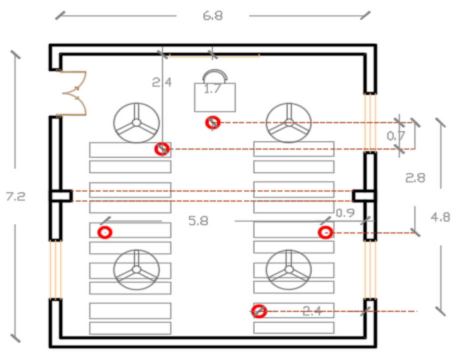


Figure 18 Table 3 Position of sound pressure level meter placed

Table 4Selected words for the speech intelligibility test

	[illegible]	[illegible]	[illegible]	[illegible]
1. Skill	[illegible]	[illegible]	[illegible]	[illegible]
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14. Lime	[illegible]	[illegible]	[illegible]	[illegible]
15. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]

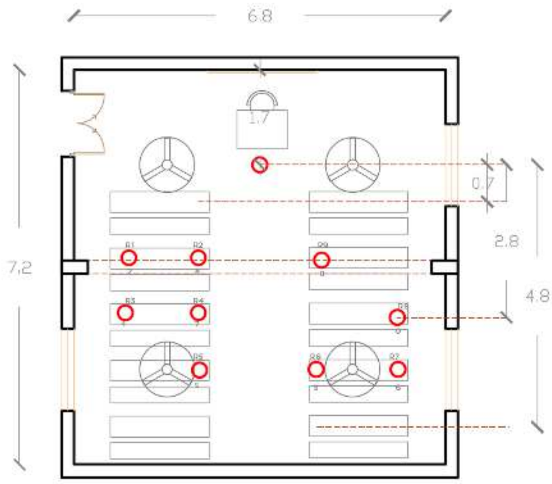


Figure 19 students position in the classroom for test

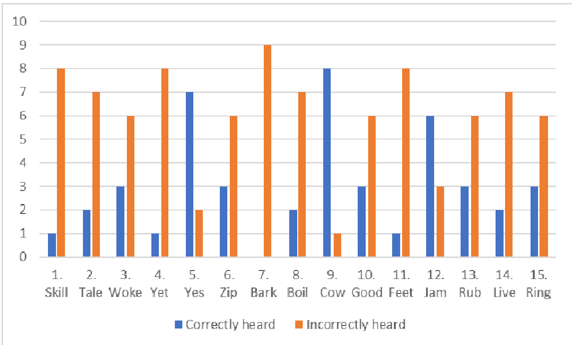


Figure 20 Result of the test

From the field measurements and subjective tests, the main issues identified are that high RT causes clarity issues during hearing. Most of the students misheard the word during the test

Window-to-floor area ratio for natural ventilation

There are 3 openings in the class, 2 windows in the west side facing the road and 1 window opening in the east side toward the corridor area.

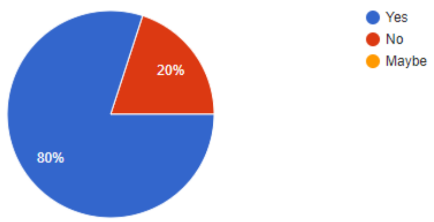
Window 1 : 1.5 x 1.4m
Window 2 : 1.5 x 1.4m
Window 3 : 1.5 x 1.4m

Opening area : 4.575 sq.m
Carpet area : 48.96 sq.m
WFR % : 9.3 %

In this classroom, the WFR value is 9.3% which is below the minimum required. During heavy traffic time the windows were closed.

Questionnaire survey

1. Does Road traffic noise affect you while taking class?



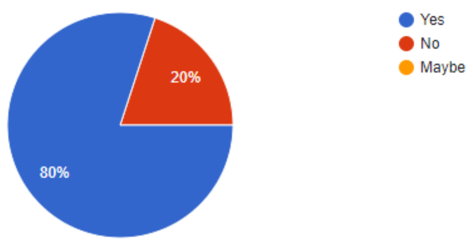
2. How does it affect you?

- It interrupts the flow of teaching. Students get distracted because of the noise.
- Concentration loss
- Repeating class

3. What types of noises affect you the most?

- Traffic noise
- Vehicle horns
- Announcements
- Corridor noise road noise

4. Does it cause any mental or physical health issues?



5. How does it affect your mental or physical well-being?

- Throat pain
- Mental stress

6. To what extent children are affected by external noise pollution while teaching in class?

- Concentration issues

- Students miss out things taught in the class. They get distracted too

7. Do you have to repeat what you said due to noise pollution during teaching?
8. Have you ever been unable to take class due to severe traffic pollution?
9. Have you ever had to shift your class because of this kind of noise pollution?

Inference

From the questionnaire survey conducted, most of the respondents concluded that traffic noise and noise from other classrooms affected students and teachers immensely during class hours. The majority of the noise consisted of traffic noise like vehicular horns, and announcements. This has negatively affectedboth the teachers causing an interruption in the flow of teaching which in turn distracts students

This in turn causes consistent repetition of classes that affects physical health causing throat pain and mental stress. Temporary solutions such as closing the windows, and changing the classroom.

From the fieldmeasurements and subjective tests, the main issues identified are that high RT causes clarity issues during hearing. As per ANSI standards for classroom acoustics ANSI S12.60-2002 has specified an RT value of 0.6 to 0.7 seconds as optimum and a background noise level of 35 dBA as acceptable for classrooms of volume within 10,000Sqft. The RT value obtained from the case studies shows that it is than the optimum RT value (more than 2 sec) and the average background noise level is above 60 dB

From the two cases, the WFR is also below the minimum requirement which affected the thermal comfort of the classroom.

Examination of the speech intelligibility subjective test confirmed that most of the students misheard the words due to background noise, high RT and signal-to-noise ratio of 15 dB is required for good intelligibility.A smaller ratio means that speech intelligibility suffers.

Conclusion

From the two cases, the RT values are higher than the standard values, which need to be addressed and reduced to a lower value of 0.6 – 0.7 secs. The dimension of the classroom cannot be altered, hence surface absorbent materials can be provided inside the classroom without alterations. Naturals ventilationcomplying with ECBC standards can also reduce the RT, so as to enhance speech intelligibility.

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