Acoustic Evaluation of Vernacular School Buildings in Kerala

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***Abstract*—This paper aims at an acoustical evaluation of Vernacular school buildings in Kollam. The two acoustic parameters, background noise levels and reverberation time has been studied and measured scientifically to assess the quality of learning environment. The measured values were compared to the acoustical recommendations of Indian standards. The study of one of the schools is presented in detail. The finding of the study reveals the lack of acoustic comfort in school environments especially in classrooms and points out the need for intervention.**

Keywords—Vernacular buildings; Acoustic comfort; background noise; Reverberation time (RT); Decibel (dB)

I. INTRODUCTION

Vernacular school architecture categorizes methods of constructions which use locally available resources and traditions to address local needs. The vernacular architecture of Kerala is known for its use of natural and passive methods for a comfortable indoor environment [1]. The orientation of buildings, internal arrangement of spaces, presence of courtyard, use of locally available materials and methods of constructions have contributed to the overall quality of the environment. Timber is the prime structural material used for columns, roof frames. The long steep sloping roofs built to protect the wall and withstand heavy monsoon rains give the distinctive visual form. Studies on Kerala vernacular buildings, related to wind flow, thermal comfort, energy efficiency and vastushastram, has been reported by researchers [2-4]. However, only limited information is available regarding acoustic comfort in vernacular buildings in Kerala.

The learning process involves intensive verbal communication between teachers and students and among students. The efficiency of the learning environment depends largely on the measure of the acoustic conditions of the school [5]. Children spend 12% of their effective time in schools. 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 [5-11]. High levels of noise in school makes students prematurely tired, consuming their cognitive abilities which could be better employed in paying attention to understanding the content of their classes. A medical report in U.S. reveals that 12.5% of school aged children has hearing loss caused by excessive noise. The survey conducted showed that 32% of the teachers reported having occasional voice fatigue and 20% have missed work due to voice problems. It has been observed that only very little studies related to acoustic comfort in classrooms has been reported in India [12].

The goal of this paper is to summarize the field measurements of the acoustical parameters (background noise, reverberation,) carried out in Vernacular school buildings in Kerala. Efforts have been made to assess the acoustical efficiency of vernacular classrooms and compare the same with stipulated standards.

A.Educational Scenario

The education scenario in Kerala is well advanced when compared to other states in India. As per the census 2011, the effective literacy rate is 93.6% [13]. There are 12,644 schools (Government/aided) in addition to the schools in private sector. In the past, school environments were silent and pleasant. Today the increased urbanization has deteriorated the acoustic environment of schools by making them relatively more noisy and reverberative. The total number of student population (age group 14-18) is 4.4 million which amounts to $1/8^{th}$ of the total population of Kerala [14]. Therefore addressing any issue related to student population has very strong impact in the state.

B.Influence of Climate

Kerala located in the south west coast of India has a characteristic tropical humid climate because of its geographic setting [15]. In this type of climate, buildings have open elongate plan shape with a single row of rooms to allow cross ventilation. All the evaluated school buildings have classrooms arranged along a corridor allowing cross ventilation *Fig.1*. This arrangement ensures thermal comfort, however there will be conflict between thermal and aural requirements in humid climates where the buildings require

openings; therefore it cannot effectively control noise penetration.

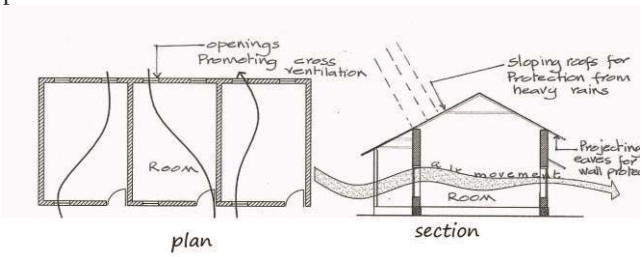


Fig. 1. Layout of Eravipuram Government school at Thattamala, Kollam.

C. Regulations on School Building design

In Kerala, the design and construction of school building is regulated by the Kerala Building Rules (KBR)[16] which set forth standards for the functional design. The only regulation specified and can be related to acoustic comfort is the minimum distance of 6 meters between roadway and school. The broad recommendations for providing acoustic comfort in school buildings given in the National building code of India (NBC-2007)[17] are mentioned later in this paper.

II. STUDY AREA

The evaluated schools are located in Kollam education district of Kerala state in India. Some of them are located in noisy areas as they abut main roads, while others are located in areas which are relatively quiet and can be approached only by private vehicles.

III. METHOD OF STUDY

A. Prelimanary investigation

The study was carried out by collecting primary data through observations, interviews, questionnaire survey and taking onsite reading. 30 Government High Schools/Higher Secondary Schools in the Kollam education district were identified, and an overall physical survey was carried out. The surveyed schools were attended by children from class V to class XII. (age 11-18years). General information on the positioning of school buildings with respect to road, building type, layout of class rooms, classroom area, and classroom volume was collected**.** On site measurement was carried out by recording the ambient background noise levels outside and inside all the school compounds. The ambient noise levels inside furnished classrooms of each school were measured. Two situations were considered for taking the measurement in the classrooms. 1) all windows open in order to obtain the actual noise level in classroom. 2) all windows closed to verify the noise reduction provided by the existing windows. The Reverberation time inside unoccupied furnished classrooms in all the schools was recorded. All measurements were taken on days without any typical noises such as rain, thunder or strong winds.

IV. RESULT AND OBSERVATIONS

A. Location with respect to road

The primary survey revealed that 52.6% of schools are located adjacent to main roads while 47.4% of the schools are located in areas which do not have bus access and can be approached only by private vehicles.

B. Layout of building blocks and building types

The study revealed that there was no organized pattern of arrangement of building blocks within the site. In most of the schools the building blocks were constructed in many phases at different periods, depending on the necessity of additional area requirement and were placed in the space available within the school site. However two predominant building types were identified, a) vernacular building blocks *Fig.2a,* and b) modern building blocks *Fig.2b.* It was also observed that in 73.3% of the surveyed schools, new construction activities have been initiated by building new blocks or by replacing the existing vernacular old buildings

Fig. 2a. Vernacular building

Fig. 2b. Modern building

Vernacular school buildings of Kerala are characterized by the humble scale, merging with nature. The long colonnaded corridors, steep sloping tiled roofs and projecting eaves are evolved from the climatic consideration. The buildings are either single or double storied as shown in *Fig.3*. Most of them are made of brick masonry walls, plastered with lime mortar and lime washed. Very few buildings have laterite or stone masonry walls. The roof frame consists of wooden rafters supported on wall plate and ridge. The reapers are fixed on the rafters and covered with mangalore tiles. The flooring is of lime concrete, finished with clay tiles.

Fig. 3. Single and doubled storied vernacular school buildings

C. Layout of classrooms

The vernacular school plans were classified according to the arrangement of classrooms along the corridor, and accordingly three predominant types of plans were identified as shown in *Table.1*.

TABLE I. TYPE OF ARRANGEMENT OF CLASSROOMS ALONG THE CORRIDOR

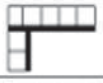
Type	Layout patterns	Description	Nos
I		Row of classes along a straight corridor	21
II		Row of classes along an `L' shape corridor	8
III		`U' shape arrangement enclosing an open space	6
IV		Others	8

Fig.4. gives the percentage of building blocks in each category.

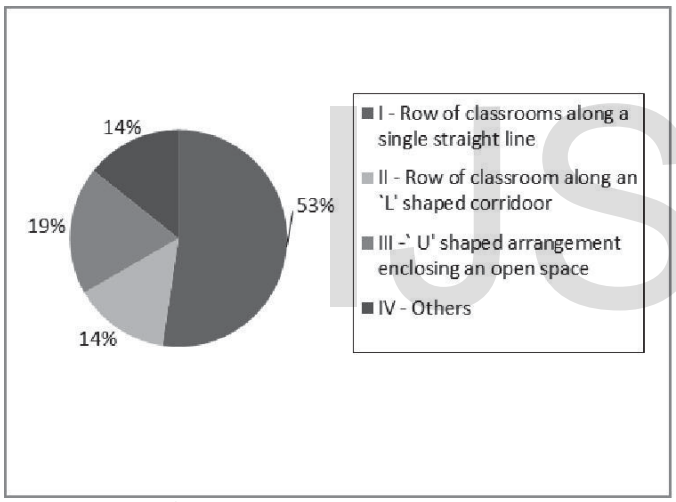


Fig.5. Percentage of buildings in each category

D. Sound levels in vernacular school environments and classrooms

The measured average background noise levels in 10 vernacular school environments abutting major roads, and the average sound levels in the classrooms are given in *Table.2.* In most of the countries, noise regulation suggests that the maximum outdoor noise level for education buildings should be 55dB (LAeq)[18].The measured sound levels were compared to the comfort and acceptability parameters of National Building Code of India, which states the maximum comfort range of 40-45dB(LAeq) for classrooms[19].

The recommended limit of background noise for classrooms, in different countries are shown in *Table 3* [20].

TABLE 2. RECORDED VALUES OF SOUND LEVELS IN SCHOOL ENVIRONMENTS AND CLASSROOMS

SCHOOL	*Average noise levels*				*Reverberation time (seconds)*
	Outside the school (dB)	*Inside the school (dB)*	*Classroom furnished and unoccupied*		
			Windows closed (dB)	*Windows open (dB)*	*Windows open*
S1	74.64	66	57.7	63.9	1.23
S2	72.44	63.35	64.1	59.8	1.63
S3	71.7	66.48	50.6	59.8	0.94
S4	82.3	73.0	59	61.2	1.42
S5	85.7	75.1	63.3	65.2	1.42
S6	68.7	71.9	60.1	68.6	0.93
S7	78.0	70.6	54.2	60.2	1.1
S8	68.6	64.8	58.1	65	1.24
S9	67.1	61.2	53.3	63.9	0.71
S10	73.8	61.3	54.8	60.2	1.48

TABLE 3. RECOMMENDED SOUND LEVELS FOR CLASSROOMS IN DIFFERENT COUNTRIES

Country	*Noise descriptor*	*Year of definition*	*Classroom (dB)*
Brazil	LAeq	1987	35-45
France	_	2002	33
Germany	_	1987	30-40
USA	_	2002	35--45
India [a]	--	2007	40-45

[a] *National Building Code of India 2007*

The average background noise measured inside all the school environs was higher than the recommended national standards (LAeq55dB). The background noise is mainly contributed by the traffic noise abutting the school compound and absence of proper noise barriers for noise attenuation.

It was observed that the average background noise level in all classrooms (with windows in open and closed positions), are higher than the recommended national standards. Noise from the adjoining classrooms, students playing in the open spaces, voice of the teacher taking class in the nearby class room, traffic noise in case of classroom close to roads and footsteps of students were the main contributors of high noise levels.

The measured average background noise levels and sound levels inside unoccupied classrooms with the recommended limits are shown in *Fig.5.*

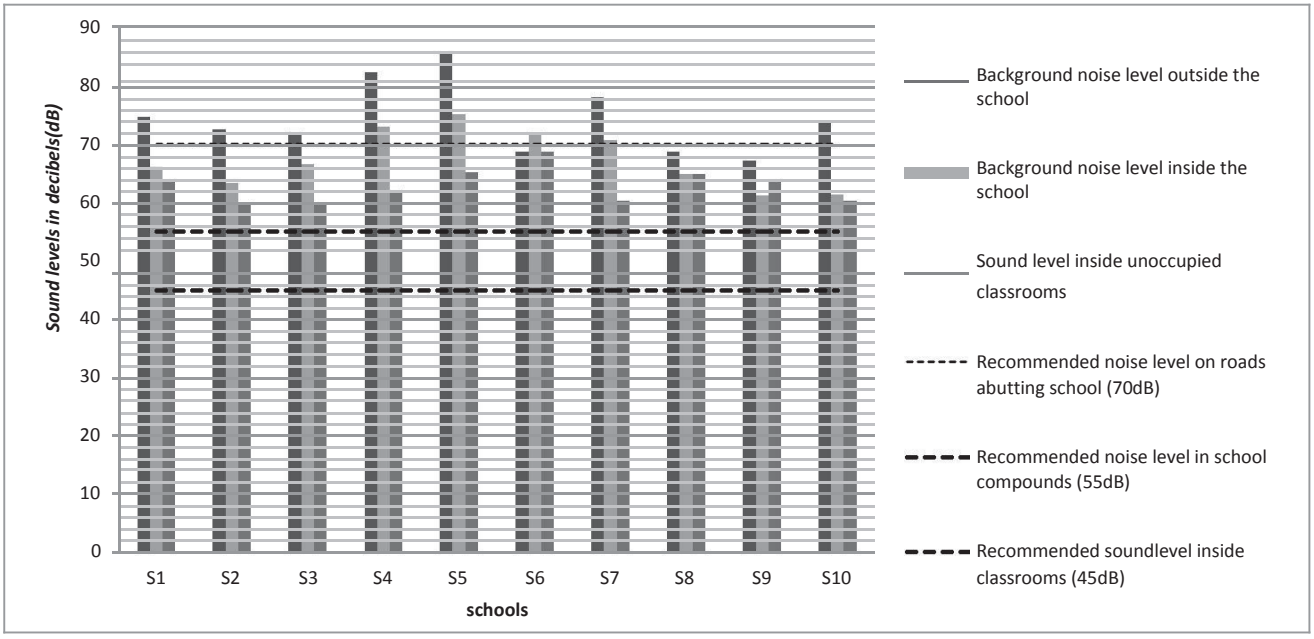


Fig. 6. Sound levels measured in 10 vernacular schools along with the recommended values.

E. Reverberation Time

Reverberation time is an important parameter that interferes with the acoustical quality of a classroom. It is dependent on volume of room, sound frequency and the total absorption in the room. *Table. 2* also lists the RT measured in unoccupied furnished class rooms of the above ten schools. According to the National Building Code of India-2007 the acceptable RT for classroom is 0.75-1.2 seconds. The established recommended reverberation time of classrooms in different countries are shown in *Table. 4*.

The measured RT values are within the recommended limits in 60% of the classrooms. In most of the schools long halls were divided into two or three classrooms by partition walls which were not built to the roof height. These openings above the walls increased the total absorption in classrooms, resulting in the reduction of RT. High reverberation time in remaining classrooms indicates the lack of absorbing materials inside the class room resulting in poor acoustical quality. Reverberating environments reduces the concentrating ability and speech intelligibility, forcing the teacher to speak louder. Increased RT also increases the background noise in the rooms.

TABLE. 4 RECOMMENDED REVERBERATION TIME IN CLASSROOMS IN DIFFERENT COUNTRIES

Country	**Reverberation Time(s)(For 500-1000-2000Hz)**	**Volume (cubic meter)**
Brazil	0.5 - 0.7	$270 \leq V \leq 600$
France	0.4 – 0.8 0.6 – 1.2	$V \leq 250$ $V \geq 250$
Germany	0.6 – 1.0	$250 \leq V \leq 750$
USA	0.6 0.7	$V \leq 283$ $283 \leq V \leq 566$
India [a]	0.75-1.2	0.75-1.2

[a] *National Building Code of India 2007*

Equipment and software

The study was conducted using the equipment and software from Bruel and Kjaer. The sound level meter BK 2250, sound amplifier BK 2716, sound source BK 4292 were used for the measurement of sound levels and reverberation time. The building qualifier BK7831, utility software BK5503, frequency analysis software BK 7223,and RT software BK 7228 were used for the analysis.

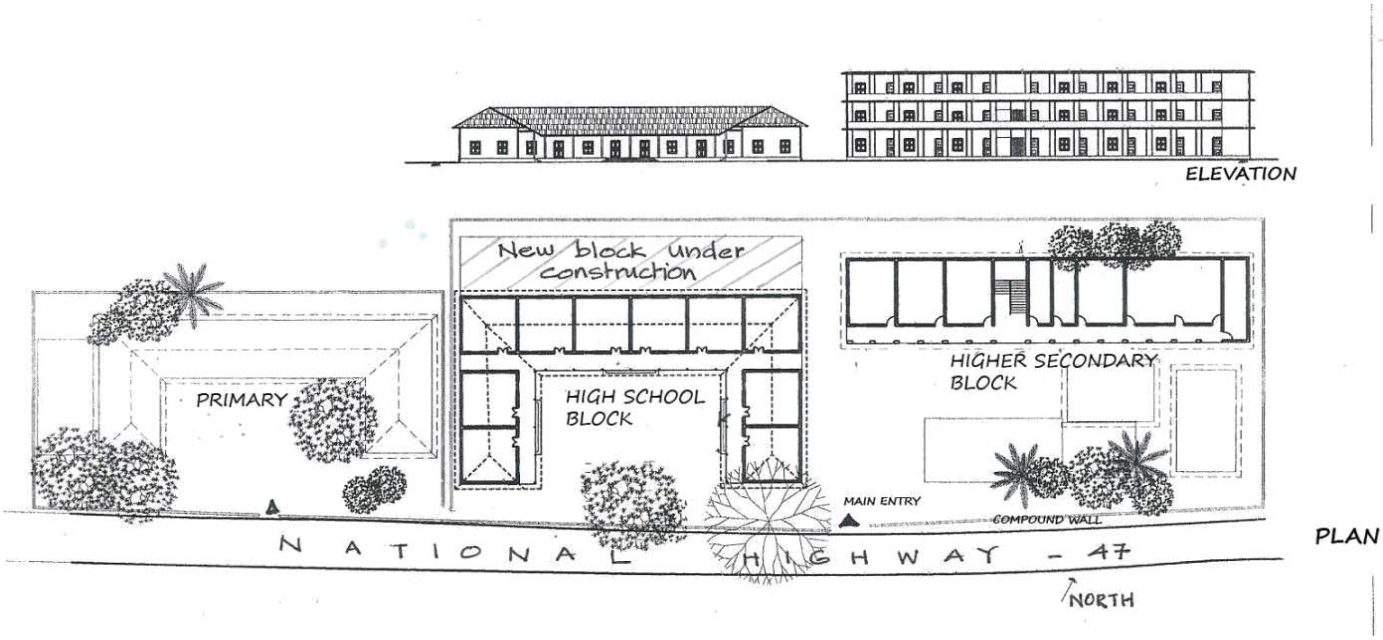


Fig.7. Layout of Eravipuram Government school at Thattamala, Kollam

V. CASE STUDY

The Eravipuram Government High school located at Thattamala, in Kollam education district, abuts the National highway-47. The school layout is shown in *Fig.6.* It has a strength of 1200 students with 53 teachers. The school has three blocks; primary, high school and higher secondary block. The high school block is single storied vernacular building and has classrooms arranged along a 1.9 meter wide corridor in a `U' shape. The classrooms have windows along the corridor and on the opposite side, promoting good cross ventilation suitable for the warm humid climate of Kerala. The walls are 35 cm thick built with brick masonry plastered with lime mortar. The flooring is of cement concrete, finished cement plaster. The inclined roof made of timber frames is supported on masonry walls and timber columns along the corridor, with mangalore tiles laid above it. This is one of the typical layouts of vernacular school design seen in Kerala.

A. Background noise in schoolenvironments and classrooms

To evaluate the acoustic composition of the school environment, the continuous equivalent sound levels were taken at different locations within the school compound. The noise contour map of the school environment was prepared to investigate the noise condition and acoustic suitability of positioning of school building in the site, as shown in *Fig. 7.*

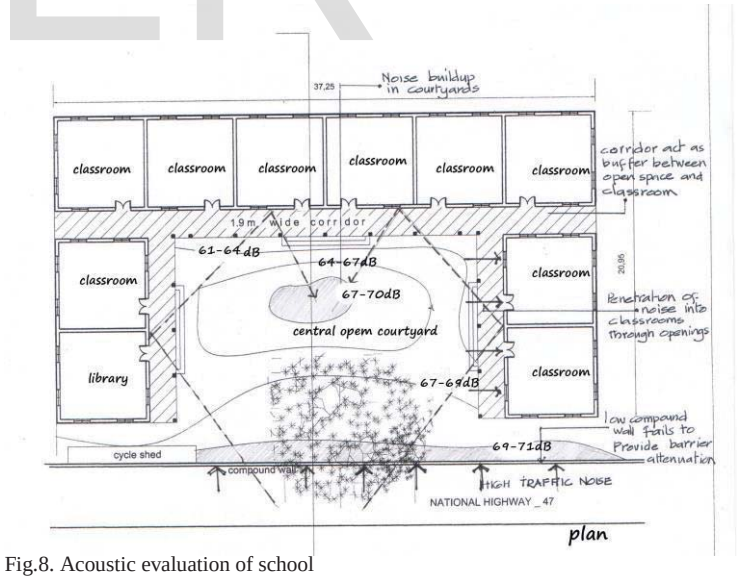


Fig.8. Acoustic evaluation of school

The methodology of noise mapping in built up areas by measuring the noise levels on a grid system was adopted

[21]. The contours were categorized at 3 dB interval on a horizontal plane. The barrier attenuation offered by the compound wall with respect to distance was measured. A section indicating the noise levels with respect to distance is shown in *Fig.8*.

High noise level was recorded at the center of the courtyard. The arrangement of classrooms around an open courtyard directly facing the road confined the traffic noise, causing a buildup of sound energy [22]. The low height of the compound wall offered very less noise reduction. The isolated trees near the wall did not provide any acoustical shielding.

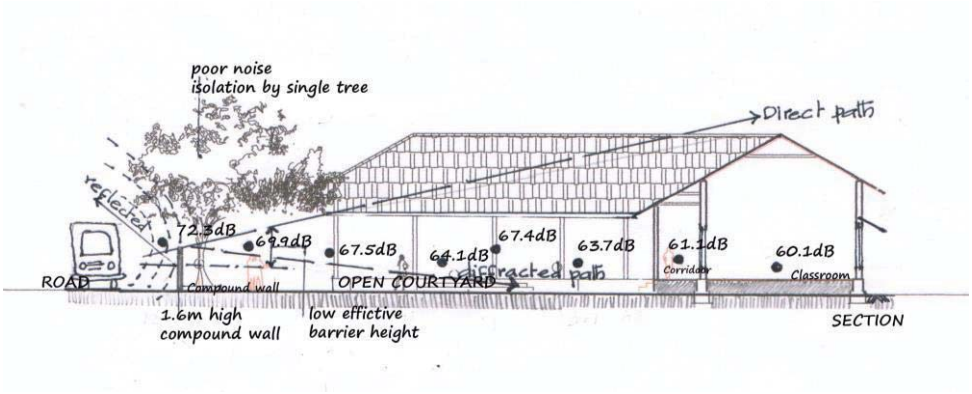


Fig.9. Low barrier attenuation offered by compound wall

A detailed investigation was made on the internal ambient noise levels in all classrooms. The mean sound levels were calculated for each room. The sound spectrum of the maximum sound levels at different positions was superimposed on the family of Noise Criteria (NC) Curves and the single value of NC Curve was obtained. The obtained curves were compared to the acceptability parameter which establishes the range NC35- NC40 as the NC curve for comfort in classrooms. The NC obtained for noise level of a classroom and corridor is shown in *Fig.9*. The frequency analysis of the measured sound levels in classroom, corridors, outside and inside the school compound was carried out to identify the frequency which had the maximum sound levels.

It was observed that the noise levels exceeded the limit of 40-45 dB determined by the standards in all cases.

Noise levels above 60dB exceed the normal speaking voice level by 5 dB, impairing the listener‘s attenuation [23]. The sound level measurement taken during the class hour was 64.5dB indicating the stress on the vocal chords of teachers resulting in fatigue. With regards to the sound levels listed in the *Table.5*, it can be concluded that the classrooms are not comfortable acoustically. In addition to the traffic noise, the noise from the play area located centrally contributed to the increase of sound level inside the classroom. It was also observed that walls of few classrooms were not constructed to the full height. The noise and the voice of the teacher from the adjacent classrooms interfered with the normal functioning of the classrooms.

TABLE 5. SUMMARY OF NOISE LEVELS IN CLASSROOMS.

Sound levels in decibels			***Noise Criteria Curves***	***Recommended NC Curve***
Occupied classrooms	Windows open	66.7	55	*NC35-NC40*
	Windows closed	59.8	45	
Inside classroom with teacher speaking		64.5	50	
Inside classroom with students in silence		60.1	50	
In empty classroom with classes going on in adjacent class rooms		62.2	45	
Corridors	While classrooms are occupied	64.5	50	
	While classrooms are un occupied	61.6	45	

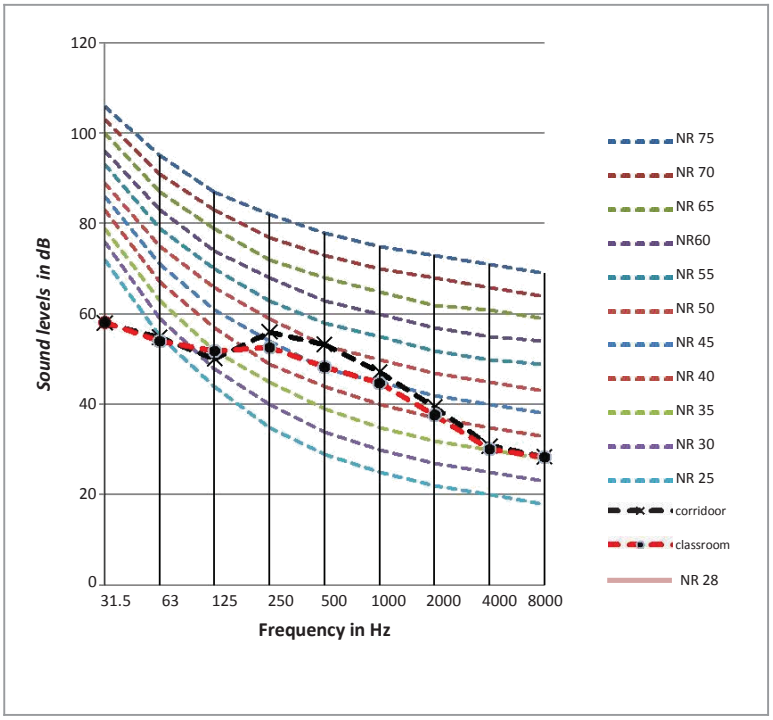


Fig.10. Sound spectrum of corridoor and a classroom superimposed on NC curves.

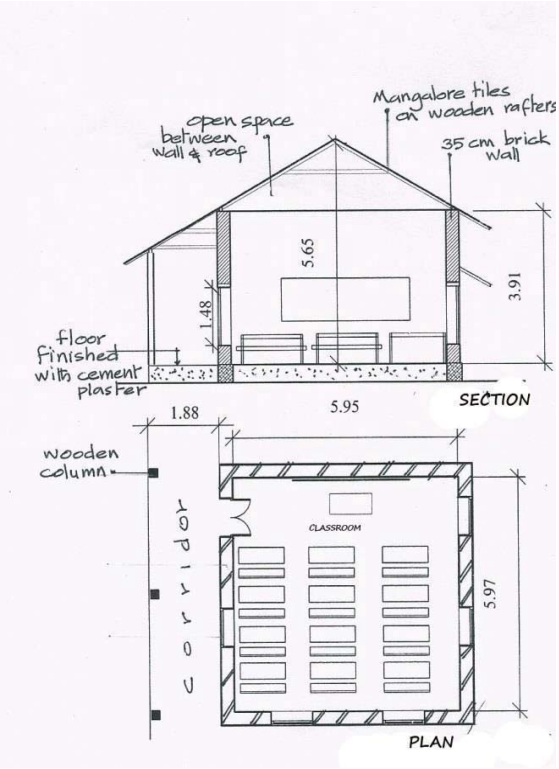


Fig.11. Detail drawing of aclassroom.

B. Measurement of Reverberation Time

Summary of the reverberation time measured in 5 classrooms at 1000 Hertz frequency, along with the classroom dimensions are shown in *Table 6*. The classrooms are built without any acoustical treatment. The openings above the walls in these classrooms increased the total absorption resulting in low RT. The lack of absorbing materials inside the classrooms was evident in classrooms where the opening above the wall was closed.

TABLE. 6. TYPE OF ARRANGEMENT OF CLASSROOMS ALONG THE CORRIDOR

class room	*Length (Meters)*	*Breadth (Meters)*	*Area (square meters)*	*Volume (cubic meters)*	*Reverberation Time*
C1	5.96	5.73	34.15	164.77	1.12
C2	5.96	5.98	35.52	173.69	1.23
C3	5.97	5.97	35.64	170.18	1.18
C4	5.97	5.98	35.70	167.79	1.0
C5	5.96	5.97	35.58	167.04	1.92

C. Measurement of sound insulation

The methodology specified in National Building Code of India Section-4 (Specification of sound insulation) was adopted for the measurement of sound insulation. The standardized level difference, referred as `Dnt' which specifies the sound insulation between rooms was calculated for the wall between classrooms and the wall separating the classroom and corridor. The _Dnt' was compared with the minimum recommended sound reduction.

The calculated standardized level difference D*nt* of classroom was 20.6dB. This is low when compared to the recommended minimum sound reduction of 35 dB between classrooms. The recommended minimum sound insulation for walls separating classroom and corridor is also 35 dB, but the measured value is only 28.8dB. The low values contribute significantly to the noise transmission between the classrooms and from the corridor.

VI. CONCLUSION

The present study, which is the first of its kind in Kerala, evaluated the acoustic parameters-background noise and RT in 10 vernacular schools located in Kollam district. The measured background noise and RT are compared with the recommended values prescribed by Indian standards and was found high. The findings support the strong need to enforce regulations in Kerala building rules to meet the acoustic comfort standards in schools. The planners have an important role while preparing the Master plan to ensure that areas under educational use are zoned in relatively quiet areas.

The detailed investigation proved that the classrooms in vernacular schools are not acoustically comfortable. The high background noise in classrooms was mainly due to the intrusion of noise through the openings and poor insulation of materials used. The design layout of the school which encloses a courtyard space confined the traffic noise increased the noise buildup. A preferred layout would be to locate the courtyard such that the building shields the traffic noises. Low acoustical insulation of walls and lack of good absorbing materials inside the classrooms increased the RT in classrooms. The design of school investigated is one of the typical designs popularly seen in many regions of the state. Thus the acoustic deficiencies are likely to be repeated, impairing the acoustic comfort of a large student population of the state. Achieving acoustically comfortable environment in schools through the use of appropriate materials will increases the efficiency and the physiological well-being of the students and teachers. The study strongly support the need for intervention by architects and designers at the initial stages of designing the layout and choosing of appropriate building materials which are more absorptive, especially in classrooms to achieve an acoustically conducive environment for learning.

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