Acoustic Comfort of Schools in Tropical Humid Climate

Jolly John, Asha Latha Thampuran, B. Premlet

Abstract - This paper reports the investigation on acoustic comfort of school buildings in tropical warm humid climate. In this type of climate the intrusion of external noise into the classrooms along with cross ventilation is unavoidable. Studies have been carried in 30 secondary schools located in Kollam district of Kerala in India. The two important acoustic parameters viz., background noise and reverberation time which affect the acoustical comfort were measured on site, in the school environment and a few selected classrooms in all schools. The measured values were compared to the acoustical recommendations of Bureau of Indian standards. The acoustical study on one of the schools is presented in detail. The study reveals a strong need of improving the acoustical comforts in school environments and classrooms. The study also reveals that a simple treatment to the ceiling and walls could improve the acoustic comfort in classrooms.

Keywords: Acoustic comfort, background noise, reverberation, ambient noise level, sound insulation, tropical climate

I. INTRODUCTION

Education of every citizen is essential to all modern societies [1]. Formal education takes place in classrooms where there is intense verbal education between teachers and students and among the students. The efficiency of the learning environment depends largely on the measure of the acoustic conditions of the classrooms [2]. Children spend almost 12% of their effective time inside classrooms, more time than any other building environment other than home [3].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 [1]-[11]. Extensive work in this area has been reported by PHT Zannin and DCCK Kowaltowski, in Brazil [4]-[6]. A medical report in U.S.(Niskar etal, 2001) reports that 12.5% of school aged children have hearing loss caused by excessive noise. Poor acoustic condition in classroom increase the strain on teacher‟s voice as most teachers find it difficult to cope with high noise levels. Influence of noise and its perception by students and teachers has been another focus of study by researchers [7]-[9]. In a survey (Smith etal..1998), 32% of the teachers reported having occasional voice fatigue, and 20% reported they had 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 main objectives of this paper are-

a) To evaluate the existing acoustic environment in the schools and assess how the existing design of school buildings confirm to the acoustical recommendations of National Building Code of India.

b) To quantify scientifically the acoustic parameters (noise levels, Reverberation Time (RT), sound insulation) by taking of onsite readings and explain its influence on acoustic comfort in classrooms through a detailed study in one school.

A. Educational scenario in Kerala

The educational scenario in Kerala is well advanced than all other states in India. The development of education over the years has been tremendous. Kerala is the most literate state in India with the literacy rate is 93.6% [13]. The school educational sector is conducted in four different stages primary, secondary, High school and higher secondary (introduced in 1990-91). The 2011-census data reports that there are 12,644 schools in Kerala of which 93 % are in the Government/Aided sector. The total number of student population (age group 14 – 18 years) is 4.4 million [14], which is about 1/8th of the total population of Kerala. Addressing any issue related to student population therefore has a very strong impact on the entire society in the state.

B. Influence of climate on school building design in Kerala

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 tend to 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 type of arrangement ensures thermal comfort. Koenisgsberber clearly mentions that there will be conflict between thermal and aural requirements especially in humid climates where the buildings require openings; therefore it cannot effectively control noise penetration [15].

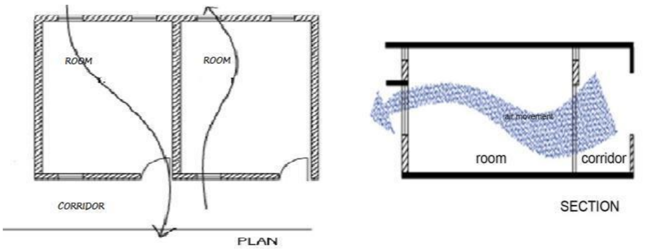

Fig. 1 Typical arrangement of rooms in tropical humid climate to promote cross ventilation

Manuscript published on 30 April 2015.
***** Correspondence Author (s)
Jolly John, Department of Architecture, TKM College of Engineering, Kollam, India.
Asha Latha Thampuran, Director, Mohandas College of Engineering Trivandrum, India.
B. Premlet, Department of Physics, TKM College of Engineering, Kollam, India.

C. Regulation on school building design in Kerala

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 that can be related to acoustic comfort is the minimum distance of 6 meter 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] mentioned later in this paper is the only specified standards in India.

II. STUDY AREA

All the evaluated schools are from Kollam district of Kerala state, which is located in the southern part of India. The locations of these schools vary with respect to noise source. Some of them abut the national or state highways, few of them are located away from highways, but they can be approached by public transport while others are in areas which are relatively quiet and can be approached only by private vehicles. For the convenience, the school in the study area has been classified under three categories;

I. Schools abutting National or State highways (Noisy area)

II. Schools abutting road approached by public vehicles

III. Schools abutting roads approached by private vehicles only (relatively quiet area)

All the schools surveyed are low rise buildings, either single storied, double storied and a few three storied.

Description of the school studied in detail

Fig. 2.a. photograph of the school taken from main entry

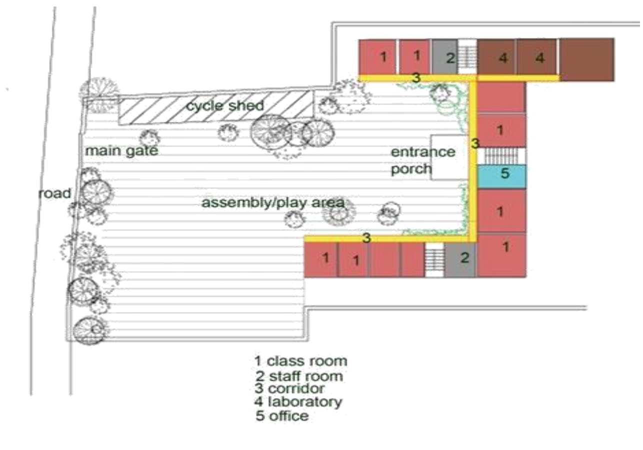

Fig. 2.b Layout of the school

The particular school under study (Fig.2.) is located in Kollam district falls in the second category. The school has strength of 1200 students with 53 teachers. The classrooms in the school are disposition along a 2 meter wide corridor (Fig.3.) in 3 floors. This is one of the typical layouts of school design seen in Kerala. 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 classrooms measuring 6m×9m×3.6m accommodates 60 students and those measuring 6.2m x 6.2x 3.5m accommodates 40 students. The walls are built with cement blocks plastered with cement mortar; flooring in cement concrete finished with cement mortar. The roof was of reinforced cement concrete in the ground and first floor. The second floor has the roof of galvanized iron sheets with plywood ceiling.

III. METHOD OF STUDY

A. Preliminary investigation

The preliminary investigation was carried out in 30 secondary government schools by recording the ambient background noise levels outside and inside all the school compounds. The ambient noise levels inside three unoccupied furnished classrooms of each school were measured and the average was taken. 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 RT inside three unoccupied furnished classrooms in all the schools was recorded. All measurements were taken on school working days, without any typical noises such as rain, thunder or strong winds. The sound pressure levels were measured using (Bruel and Kjaer) BK 2250. In all situations the continuous equivalent sound levels *LAeq* has been measured along with its range of variation *LAmax* and *LAmin* for a duration of 3 minutes each, at three points and the average was taken.

B. Detail investigation of one school Background noise in school environment and classrooms

A noise map of the school environment was prepared to investigate the noise condition and suitability of positioning of school building in the site acoustically. The methodology of noise mapping in built up areas by measuring the noise levels on a grid system has been adopted. On site measurements of background noise in the school environment was measured at 50 grid points marked in the ground. The sound pressure levels *LAeq* was measured positioning the sound level meter in the grid points. The points having the same range of readings were joined to obtain the equal noise contour map. The contours are categorized at 5 dB interval on a horizontal plane. No software was employed for the mapping. The noise level outside the school compound and the abutting road was measured at a distance of one meter from the compound wall to assess the surrounding noise interference. The sound attenuation offered by the compound wall and trees in the site with respect to distance was measured.

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ISSN: 2249-8958 (Online), Volume-4 Issue-4, April 2015

The background noise levels inside twenty four classrooms (eight in each floor of the school building) was measured at three spots positioned at front row, center and last row. The background noise level was measured in empty classrooms with classes going on in the adjacent classrooms. The noise level was measured in the same classroom with adjacent classrooms empty. This was done to study the disturbance caused by the neighboring classrooms. The background noise levels along the corridor, staff rooms, laboratories, computer room and library was also measured. The frequency analysis of the measured sound levels in classrooms and corridors was carried out to identify the frequency which had the maximum sound level. The sound spectrum of the maximum sound levels at different positions was superimposed on the family of Noise Rating curves (NR) and the single value of NR was obtained [17]. The sound pressure levels were measured using (Bruel and Kjaer) BK 2250 and the frequency analysis was done using BZ - 7223 software [18]. In all situations the continuous equivalent sound levels *LAeq* has been measured along with its range of variation *LAmax* and *LAmin* for a duration of 3 minutes each at three points and the average was taken.

C. Measurement of reverberation time

The RT was measured inside furnished unoccupied classrooms at three different points and the average value was taken. The door and windows were kept open while the measurement was taken to ensure the physical comfort. The measurement was then transferred to the computer using qualifier software (BK7831) from Bruel and Kjaer which computed the reverberation time (T60 value) for each evaluated frequency. This procedure was repeated for all classrooms in which RT was measured. Three types of roofing material; cement concrete, galvanized iron sheet, and GI sheet plywood ceiling were used for classrooms. The RT values for each classroom was measured and compared.

D. Measurement of sound insulation

The methodology specified in National Building Code-2007 Section-4 (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 mentioned below, for the wall between classrooms and the wall separating the classroom and corridor. The „Dnt" was compared with the minimum recommended sound reduction. The wall of the classroom is constructed with cement blocks plastered with cement plaster and lime washed. The wall separating the classroom and corridor has a wooden door and a window which is permanently open.

$$Dnt = L_S - L_R + 10 \log \left(\frac{T}{T_0} \right)$$

L_S = Noise levels in source room

L_R = Noise levels in receiving room

T = RT of room

T_0 = 0.5 s (reference value)

The pink noise generated by the BK 2250 sound level meter was amplified by the BK 2734 amplifier and distributed throughout the classroom using BK 4292 omnidirectional dodecahedron sound source. The sound level was then measured in the source room, receiving room and corridor. The RT of the receiving room was also measured. The „Dnt" was then manually calculated.

IV. RESULTS AND OBSERVATIONS

A. Sound levels in school environment and classrooms

The range of ambient noise levels outside the schools ranged from 71.5dB to 88.1dB for school abutting the national or state highway (category I), while for schools located in areas approached by public vehicles (category II) the range was between 65.6dB to 77.1dB and for schools located in quite areas accessible by private vehicles (category III) ranged from 60.2dB to 71.5dB. The US department of Transportation specifies the maximum noise level of 70dB for highways abutting schools [19]. As there is no recommended standard for noise levels for road way for various land-use categories in India, the same has been compared with that of the standard stipulated in United States and was found high for category I. The range of ambient noise levels inside the schools ranged from 66.4dB -78.3dB, 61.2dB – 67.3 dB and 51.7dB - 64.6dB for category I, II, and III respectively. No standard has been specified in India regarding the outdoor ambient noise level in schools. Hence the same has been compared with international standards (LAeq=55dB) [20] and background noise levels in the category I, II was found high and satisfactory in category III.

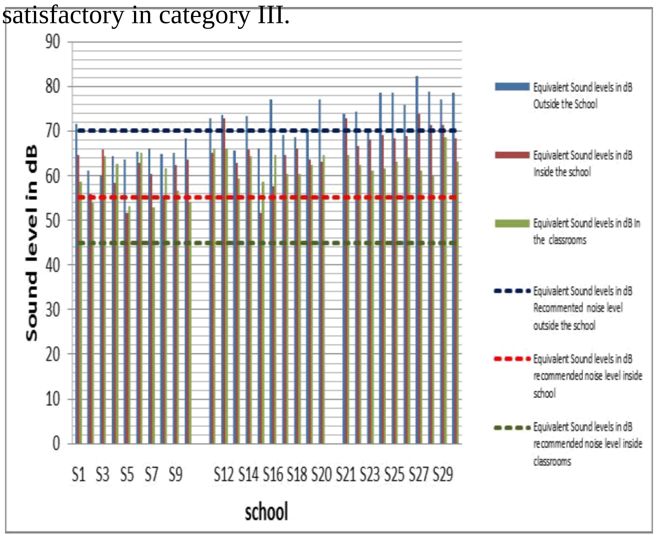

Fig. 3 Measured sound levels of 30 schools located in Kollam

Fig.3 shows the measured sound levels in 30 schools located in Kollam. It was found that the background noise levels in the classrooms of all the schools was above 40-45 dB, which is the recommended Indian standard as per NBC -2007 for noise level in classrooms. The range of ambient noise levels in unoccupied classroom with windows closed did not show a marked variation among the three categories, (Table. I) however the range of ambient noise levels in unoccupied classrooms with windows open was found much higher in category I.

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Table. I Measured Background noise levels (dB) in school environments

Category	Noise level outside the school (dB)	Noise level inside the school (dB)	Noise level inside unoccupied school classrooms with windows closed (dB)	Noise level inside unoccupied classrooms with windows open (dB)	Noise level inside occupied classrooms with windows (dB)
I	71.5 – 88.1	66.4 – 78.3	52.5 - 65.3	59.8 – 68.6	61.2 – 68.5
II	65.6 – 77.1	61.2 – 67.3	53.3 – 56.5	58.4 – 66.2	58.2 – 68.5
III	60.2 71.5	51.7 – 64.6	51.3 – 61.9	53.1 – 64.4	51.5 – 64.3

In 76.2% of the furnished un-occupied classrooms, the measured RT at 1000 Hz was above the range 0.75- 1.2, which is the recommended standard for RT specified in NBC. In 16.9% of the classrooms RT varied between 1.2-1.5 seconds, 59.3% above 1.5seconds and 5.08% below 0.75 seconds.

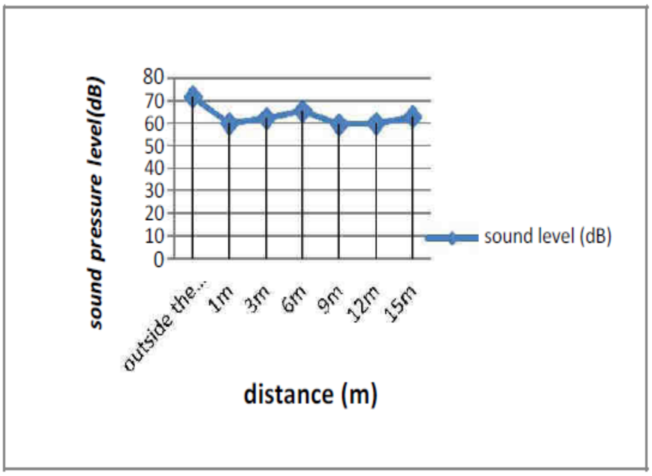

Fig. 4 Noise attenuation offered by the 1.7 m high compound wall of the school

In the school studied in detail, the background noise level of roadway abutting the school compound measured 72.9dB and the background noise inside the school compound 60.9dB. Both the values are above the recommended standards, The noise attenuation offered by the compound wall at every 3 meters from the 1.7 meter high compound wall is shown is Fig.4 The graph shows that compound wall acts as a noise barrier offering a good attenuation of 10 dB.

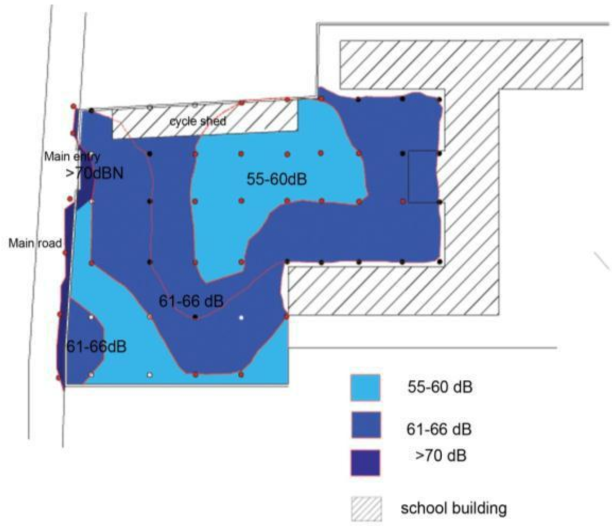

Fig. 5 Noise contour map of school site

The noise contour map (Fig.5.) prepared shows that the noise level reduced initially, near the compound wall, but gradually increased with distance towards the school building. The least sound level (55-60 dB) was observed towards the center portion of the site. This area has sufficient buffer from the traffic noise and is away from the disturbance of the school. The mango trees planted very close to the cycle shed also contributed to the noise reduction. As the school building is located more than 30 m from the road, the traffic noise did not interfere with the background noise in the classrooms of the school. All the classrooms open into the corridor which surrounds the central open area of the school. Layouts with the open space enclosed by hard wall surface will intensify the noise build-up [21]. Hence this layout design of the school will not contribute to any reduction in the background noise in classrooms.

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Table. II Mean equivalent noise levels (dB) measured at different locations in the school.

Location in school	Ground floor		First floor		Second Floor		Obtained NR value	*A dB
	occupied	unoccupied	occupied	unoccupied	occupied	unoccupied		
Classroom	64.8	57.1	63.2	59.8	62.8	55.6	NR-45	35
Corridor	66.39	60.2	66.3	58.7	62.9	58.2	NR-50	45
Science labs	63.3	61.1	64.1	62.3	65.8	59.2		40
Computer lab	-	-	65.3	62.4	-	-		40
Office	-	-	65.1	62.6	-	-		40
Stair area		60.3	68.2	56.6	65.5	60.9		45
Staff room	63.1	62.2			55.4	54.1		40
Library	60.4	59 dB	-	-	-	-		35

Table. III Recommended background noise levels 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**	**"**	**2007**	**40-45**

Summary of the obtained mean background noise level measured for various rooms in the ground, first and second floor of the school building is shown in Table.II. Table.3 gives the recommended background noise level in classrooms specified by different countries [22]. The measured noise levels were compared to the comfort and acceptability parameter of NBC-2007. It was found that the background noise levels in classrooms in all the floors exceeded the recommended standard of 40-45 dB. With the maximum equivalent noise levels and corresponding frequencies the Noise Rating values were obtained. The obtained noise rating was NR 45 for unoccupied classrooms and NR50 for unoccupied corridor, while the accepted range is NR 35[17].

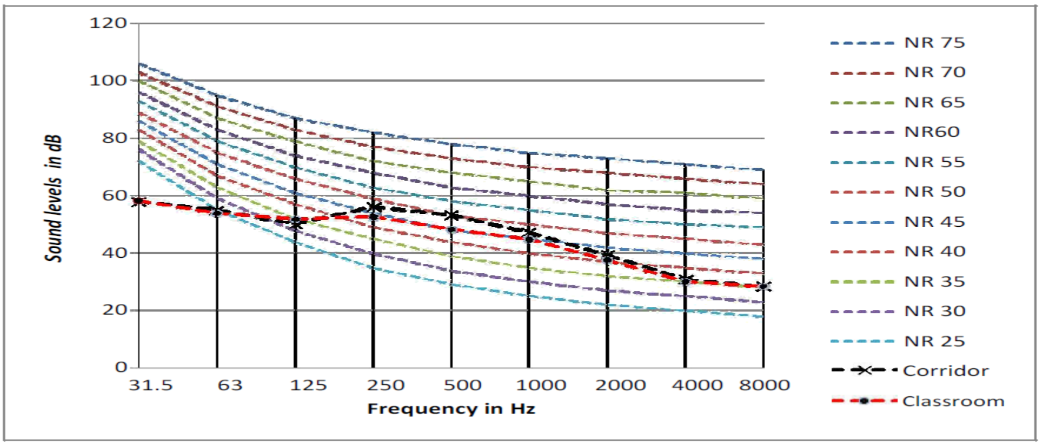

Fig. 6 Noise spectrum of unoccupied classroom and corridor super imposed on noise rating curves

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Fig.6 shows the sound spectrum of the sound level in an unoccupied classroom and corridor superimposed in NR curves to obtain the single number to the noise spectrum. As per Indian standards, there are no recommended noise levels for rooms other than classrooms in school, hence the same has been compared with values recommended in Building Bulletin-93 [22],[23]. All the measured values are found above the specified standard values. The frequency spectrum of the noise level measured in classrooms showed the highest noise levels in the octave band of 500Hz-1000Hz, which corresponds to speech frequency. It was also observed that the noise levels were higher in the first floor when compared to the ground and first floor. This was mainly due to the plants and small trees planted close to the corridors which act as noise barrier. The average sound level along the corridor was 3 dB higher than the sound levels in the classrooms. The background noise level measured in empty classrooms with classes going on in the adjacent classrooms was 64.6 dB, while the noise level was measured in the same classroom with adjacent classrooms empty was 56.9dB. In both situations the background noise level inside the classroom was above the recommended standards. Another finding was that the noise from other classroom was the main source responsible for background noise in the observed classroom. This also indicates the lack of proper insulation by the walls. None of the classroom windows have shutters, therefore the outdoor noise interfered into the rooms. The window and door along the wall separating the classroom and the corridor provide good ventilation but promote the entry of noise into the classroom.

B. Reverberation Time in classrooms

Table. IV Reverberation time measured in classrooms

Class room	Floor	REVERBERATION TIME in Seconds(T60)		
		500 Hz	1000Hz	2000Hz
C1	Ground	2.53	2.29	1.99
C2	Ground	2.1	1.88	1.67
C3	Ground	2.51	2.36	1.9
C4	First	1.78	1.56	1.45
C5	First	1.67	1.67	1.67
C6	First	1.63	1.55	1.45
C7	Second	1.48	1.39	1.33
C8	Second	1.41	1.36	1.36
C9	Second	1.34	1.27	1.18
C10 (without roof)	Second	0.09	0.76	0.7

Table.V Reverberation time limits 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**	**0.75-1.2**	**0.75-1.2**

Summary of the reverberation time measured in ten classrooms at frequencies 500 Hz, 1000Hz and 200 Hz in different floors of the school are shown in Table.IV. The measured reverberation time is higher than the recommended limits indicated in Table.V [22], [23]. The high reverberation time indicate the lack of absorbing materials inside the classrooms. High reverberation time increases the background noise and hampers the speech intelligibility in classrooms. Fig.7. shows the comparison of RT in classrooms with different ceiling materials. It is observed that the RT in the second floor was much lower than ground and first floor. This is mainly due to the difference in the ceiling material employed. Plywood has a higher absorption coefficient when compared to cement concrete and hence provided better absorption in the classroom. The measured RT in the classroom without roof was found very low.

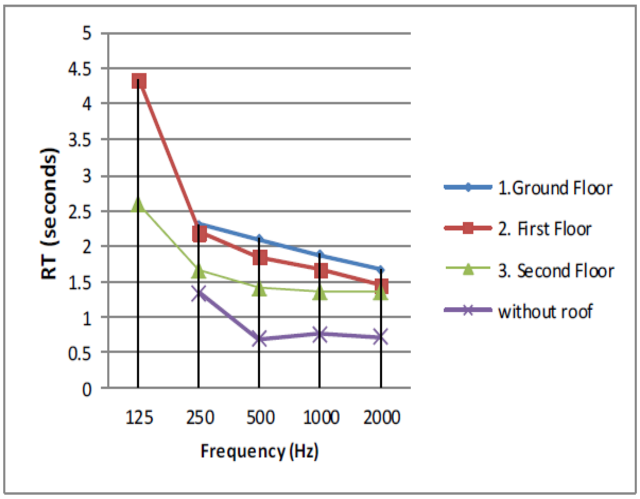

Fig.7 Comparison of measured reverberation time

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1&2 - Reinforced cement concrete roof with cement plaster

3 - False ceiling of ply wood (4 mm thick) below galvanized iron sheet roof.

The calculated standardized level difference D*nt* of classroom is 27.7 dB. 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 35 dB, but the measured value is only 20.1 dB. The low values contribute significantly to the noise transmission between the classrooms and from the corridor.

V. CONCLUSION

The present study, which is the first of its kind in Kerala, evaluated the acoustic parameters-background noise and RT in 30 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. In the detailed investigation it was verified that all the classrooms are not acoustically comfortable. The high background noise of classrooms was mainly due to the intrusion of noise through the open windows and ventilators. The design layout of the school which encloses a courtyard space did not offer any noise attenuation. Low acoustical insulation of walls and lack of good absorbing materials in the classrooms increased the RT in classrooms. The high RT also significantly increased the interior noise levels in classrooms. The classrooms with plywood ceiling showed better reverberation time. This implies that simple treatments to the ceiling could significantly improve the RT in room. The design of school investigated is one of the typical design 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 cost effective methods and 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.

ACKNOWLEDGMENT

The authors extend sincere gratitude to All India Council for Technical Education (AICTE No: 8024/MOD-23/2011-12) and Kerala State Council for Science, Technology & Engineering (KSCSTE) for funding this project.(No: EPP/15/2012). The authors also extend sincere gratitude to Ms.Renjini S.L. for the help rendered in the conduct of this investigation.

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