Indian Journal of Engineering & Materials Sciences
Vol. 28, October 2021, pp. 462-471

Thermal and acoustic performance of cement fibreboard and bamboo buildings

Siddharth Singh[a*], Ajay Chourasia[b], Ravindra Singh Bisht[a] & Sameer Yadav[a]

[a]Acoustics Instrumentation and Mechanical Systems Group, CSIR- Central Building Research Institute, Roorkee 247 667, India

[b]Structural Engineering Group, CSIR- Central Building Research Institute, Roorkee 247 667, India

Received: 11 September 2020; Accepted: 8 September 2021

The present study evaluates the thermal and acoustic performance of building constructed from aerated concrete-cement fibreboards and bamboo composite. The thermal, humidity, ambient, and indoor temperature parameters are analyzed for a 24-hours cycle from April to May and December to January. The average temperature plot shows the maximum indoor temperature does not exceed 28-32 $^{\circ}$C for April to May and 12-16 $^{\circ}$C for December to January for both the buildings. Thermal admittance is observed as 7.3 W/m^{2}K and 12 W/m^{2}K for cement fibreboard and bamboo composite buildings respectively. Outdoor to indoor noise reduction (OINR) values at frequencies ranging from 80 Hz to 4000 Hz are noted and analysed. The maximum noise isolation provided by cement fibreboard and bamboo composite walls are found to be ~40 dBA and 35 dBA at 500 Hz. With proper ventilation and avoidance of direct sunlight in the room, a comfortable atmosphere can be achieved for these buildings.

Keywords: Bamboo building, Cement fiberboard, Thermal performance, Thermal admittance, Outdoor-indoor noise, Noise isolation

1 Introduction

Masonry and concrete are the traditional wall construction methods in the housing sector. However, these methods are very time consuming and require a lot of workforces on site. In recent times, lightweight materials viz. porous concrete, cement fibreboards, gypsum wallboards which come under drywall construction technology are gaining much attention worldwide for various building constructions viz. houses, offices, schools, and hospitals, etc. These construction techniques facilitate time-saving, less manpower, material requirement, and ease of construction at the actual site[1-5]. In drywall construction techniques, porous concrete based cement fibreboard is speedy and efficient construction. Drywall provides safety and adequate strength as compared to conventional masonry brick walls[5].

The existing wallboards in the market are usually made of cement, fibres with 5-20 weight percent of cement and water. Asbestos based cement boards are very commercial and economical in use, but they face problems with environmental and human health. Being carcinogenic in nature, these asbestos-based fibers find restricted to use in many countries. As a replacement, cellulosic fibers are gaining a lot of attention due to environmentally friendly property. Among this fiber category, bamboo fibers and cereal (rice) straw are the most commonly used in the manufacturing of cement boards. The cement fibreboard is an appropriate substitute for natural wood and wood-based products as it is made from forty percent of recycled content. These wall panels offer optimized drywall solution techniques by facilitating rapid construction with maximum space utilisation, thus maintaining the solid effect of a conventional brick or block walls. These fibreboard walls are cost-effective, energy-efficient, have structural quality, durable, and lightweight. They also provide high thermal and acoustic insulation and are economical as compared to conventional construction techniques with less carbon footprint during the manufacturing and construction of the buildings[6,7].

Apart from traditional building construction materials, bamboo as a construction material is gaining wide attention in India. As per the current Indian scenario, the bamboos account for total of 12.8 percent of the total forest land cover. The majority of the bamboo production in India is credited to northeastern states, namely Arunachal Pradesh, Assam, Mizoram, Meghalaya, Sikkim, Nagaland, and Tripura. Around 66 percent of the bamboo stock in India is concentrated in the above mentioned northeastern states. According to a report published by International Network for Bamboo and Rattan

*Corresponding author (E-mail: siddharthsingh@cbri.res.in)

(INBAR, 2005), a total of 145 species belonging to 23 genera were reported to be found in India. The hilly northeastern States of India accounts for nearly 90 percent of bamboo species. Some of the bamboo species found in India are Bamboosa balcooa, Bamboosa bambos, Arundinaria gracilis, Arundinaria maling, Arundinaria racemosa*,* etc.

At the specific site, being a natural locally available material, bamboo can be a potential construction material that has a low value of thermal conductivity (0.55 to 0.59 W/m K.) as compared to cement mortar and concrete structures. Bamboo in the construction sector will also help the locals in improving their socio-economic status. Few literatures have studied the bamboo and its thermal performance in the wall structures[8-13].

2 Materials and Methods

2.1 Construction materials

The satellite image of cement fibreboard and bamboo building site at CSIR-CBRI Roorkee, is shown in Fig. 1. The walls of the cement fibreboard building of ground plus one (G+1) storey comprises of 4 mm thick fibre cement boardsand aerated cement concrete sandwiched in between cement boards. The total area of G+1 storey building is 1100 sq. ft. The boards used in wall construction are light in weight, easy to carry and install at the actual construction site. These boards are moisture, fire and impact, and all-weather resistant. The jointing of multiple boards for complete wall construction was done by making a paste of fly ash and sodium silicate in 1: 15 proportion weight as a jointing agent[5]. The individual board, including the aerated concrete, is provided with a tongue and groove joints for multiple jointing of the boards facilitating in fast construction. Figure 2 shows the jointing of cement boards used in drywall construction and directional faces of the building.

The bamboo building of G+1 storey was constructed from *Bamboosa balcooa* bamboo species. Beams and columns have been constructed using same bamboo species, having an average outer diameter of 80 mm. The bamboo was first treated with a borax solution to provide a good life span to the structure with safety against termites, humidity and adverse weather conditions. Walls of the structure have been made using split bamboo stripes and bamboo boards. The structure, after completion, was given a finished look by application of cement plaster of 3 inches over steel wire mesh on the outer walls. The inner walls and false ceiling of the bamboo building consist of laminated plywood of 10 mm thickness. The stairs and steps were also made from bamboo materials. Figures 3 and 4 show finished bamboo house with directional faces and its interiors.

2.2 Thermal measurement

The constructed drywall of cement fibreboard building was tested for temperature difference for outside and inside wall surfaces, ambient and inside room temperature, on the ground plus storey building. Table 1 and 2 show the physical properties of the cement board and bamboo walls and their related thermal conductivity values.

The instrument used for wall temperature measurement was an infrared thermometer Fluke 64 MAX having a temperature range of -30°C to 600 ºC with an accuracy of ± 1.5 ºC. According to guide for heat insulation of non-industrial buildings

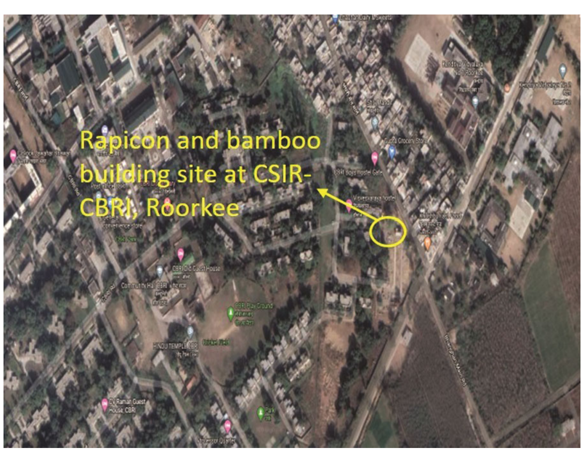

Fig. 1 — Satellite image of the building site.

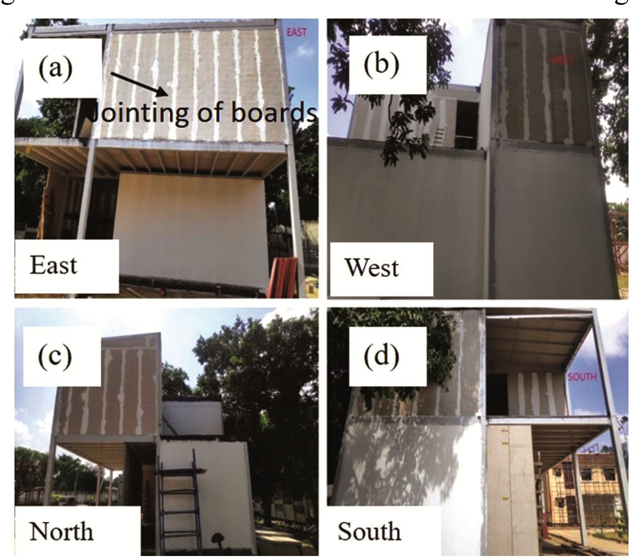

Fig. 2 — Directional faces of cement fiber board building.

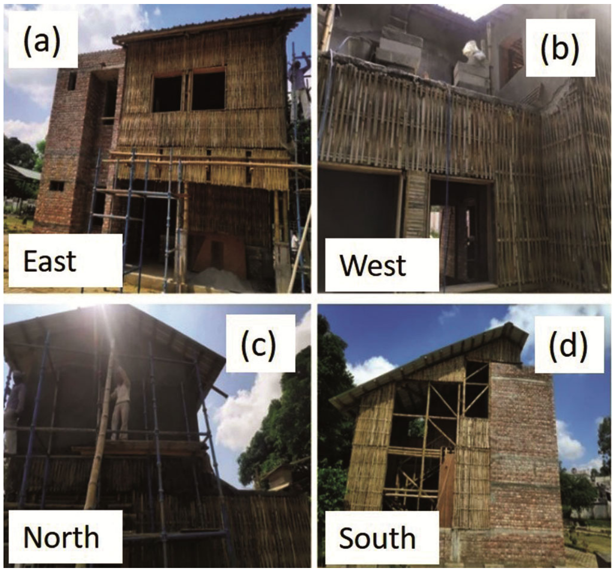

Fig. 3 — Directional faces of the bamboo building.

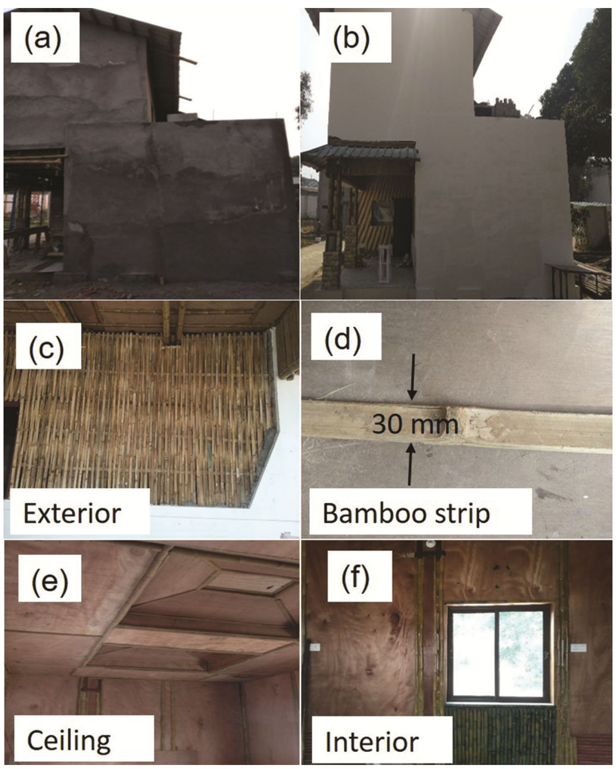

Fig. 4 — (a), (b) Mortar finishing of bamboo building, (c) exterior wall of bamboo building, (d) bamboo strip dimension, (e) ceiling, and (f) ply wood-based interior.

IS 3792 – 1978, no heating or cooling aids were used during the measurement. The wall and inside temperatures and relative humidity were recorded at a 1-hour interval for 24-hours. The average of the data plot has been plotted and analyzed for various thermal parameters.

Table 1 — Physical properties of cement fibreboard walls and related thermal conductivity values[5]

Physical parameters	Values
Temperature and humidity	41 °C 17 % R.H
Wall construction	Cement fibreboard, 75 mm thickness
Length and width	3000 mm and 600 mm
Density	892 kg/m^3
Total wall thickness	75 mm
Total area	1100 sq. ft.
Thermal conductivity	0.14 W/ m. K
Test location	Roorkee, Hot and Arid zone.
Coordinates	29.87 °N, 77.88 °E
Altitude	268 meters

Table 2 — Physical properties of bamboo strips wall and related thermal conductivity values

Physical parameters	Values
Temperature and humidity	41 °C 17 % R.H of April to May
Wall construction	Bamboo strips, 10 mm thick
Density	600-750 kg/m^3
Total wall thickness	176 mm
Room area	3 m x 2.6 m
Thermal conductivity of bamboo strips	0.11- 0.15 W/ m. K
Thermal conductivity of plyboard	0.12W/ m. K
Thermal conductivity of air	0.02W/ m. K
Thermal conductivity of mortar	0.5 – 1.2 W/m.K

The thermal transmittance (U-value) measurement of cement fibre board walls were measured by Testo 635 U-value probe meter. The measurement is based on the formula which can be described as:

$$U = \alpha \frac{T_{in} - T_{surface,in}}{T_{in} - T_{out}} \quad \ldots(1)$$

where, α is 7.69 W/m^{2}K, T_{in} inside room temperature, $T_{surface,in}$ is inside room surface temperature, T_{out} is outside ambient temperature.

2.3 Acoustic isolation measurement

Sound level meter Class I, CESVA SC-420 was used for measuring the outdoor-indoor noise for cement fibreboard and bamboo building. A sound source of continuous audible frequencies over the range of 80-4000 Hz was used. A multi-face amplifier was used to amplify the noise of interested frequency to an average level of 100-115 dBA. Table 3 and 4 show the acoustical parameter details of cement fibreboards and bamboo material with instrumental details.

The daytime illuminance level was measured by lux meter, which has a range of 20 to 2,00,000 lux level and an accuracy of ± 3 percent of the reading.

The meter has a working temperature and humidity in the range of 0-40°C and up to 80 percent relative humidity level.

Table 3 – Acoustical parameter details of cement fibreboard and instrumental details[5].

Physical parameters	Values
Temperature and humidity	42 °C 19 % R.H for April to May
Sound transmission class for 75 mm thickness	40 dB
Ambient noise at the time of testing	60 to 70 dB
Measuring range of sound level meter	30 dBA to 130 dBA
Accuracy	± 1.1 dB at 1 kHz
Resolution	0.1 dB
Operating condition	0 to 40 °C, 10-80 % R.H

Table 4 — Acoustical parameter details of bamboo stripes.

Physical parameters	Values
Temperature and humidity	42 °C 19 % R.H for April to May
Sound transmission class for 10 mm thickness	20 dB at 500 Hz
Ambient noise at the time of testing	60 to 70 dB

3 Results and Discussion

3.1 Thermal analysis

Figure 5 shows the average surface wall temperatures of all the directional faces of cement fibreboard building viz., East, West, North, and South for the month of April to May month. From the plot, it is evident that outside wall temperature increases and reaches a maximum of 35-40°C for East, West, and South-facing walls at 1100 and 1600 hours and gradually decreases afterward. The inside wall temperature of all the directional faces does not exceed 32 °C maximum during the daytime period and a minimum of 22°C in the night time for the 24-hour period cycle. Figure 6 shows the temperature plot of the cement fibreboard building for the December to January month. From the plot, it is evident that the maximum temperature of outside walls reaches up to 16-20°C during the daytime and a minimum of 8-10ºC in the night hours. The inside wall temperature varies from a maximum of 12-15ºC in the daytime and reaches to a minimum of 10-12ºC in the night-time for 24- hour cycle.

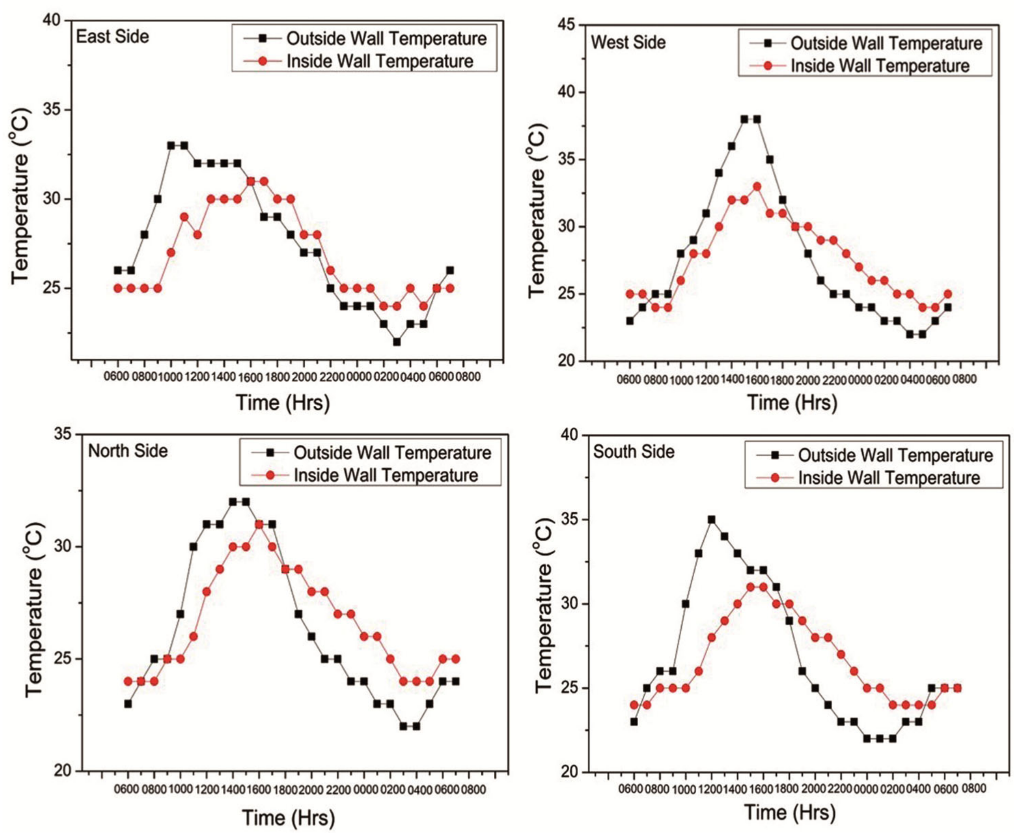

Fig. 5 — Average wall temperature variation for cement fibreboard building facing towards East, West North, and South side for April to May month.

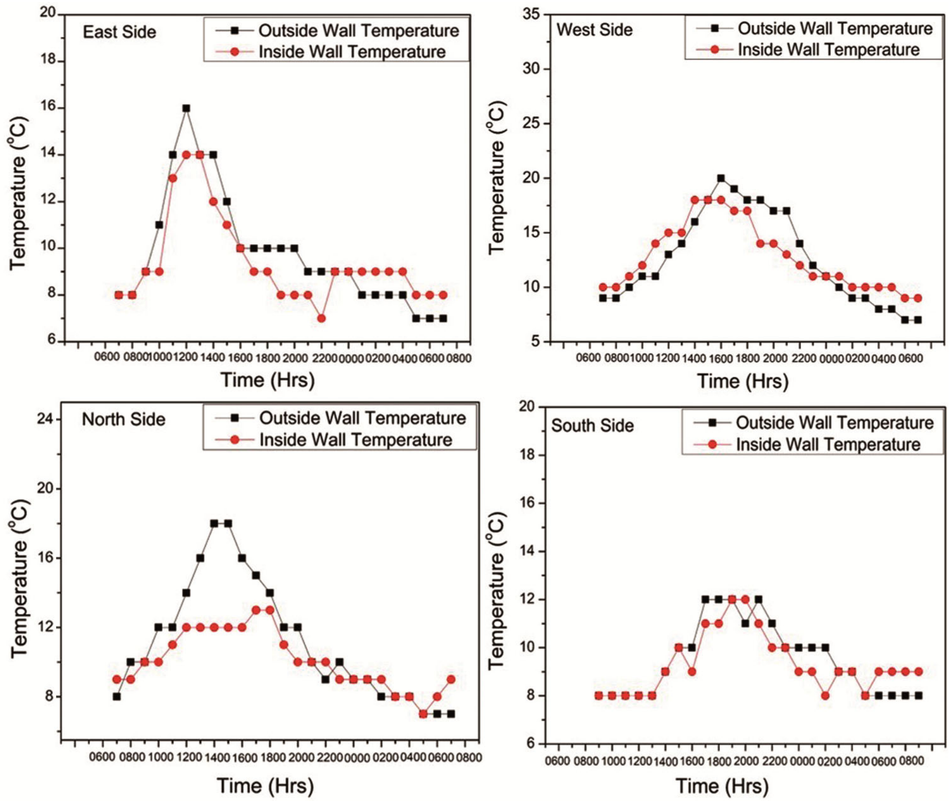

Fig. 6 — Average wall temperature variation for cement fibreboard building facing towards East, West North, and South side for December to January month.

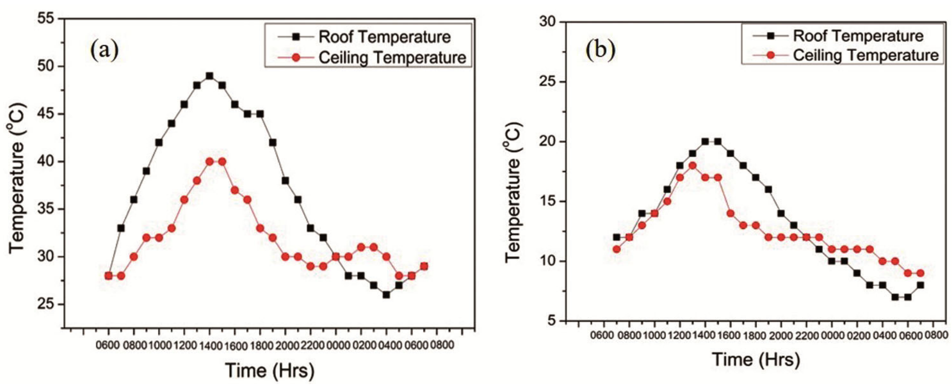

Fig. 7 — Roof and ceiling temperature variation for cement fibreboard building for (a) April to May, and (b) December to January month.

Figure 7 shows average roof temperature plots for the April to May and December to January period of cement fibre board building. From the plot, it can be observed that during April to May period, the temperature of the metallic sheet as rooftop reaches as high as 55-60°C in the daytime and a minimum of 25°C in the night time. The ceiling temperature reaches up to 32°C and a minimum of 28-30°C in the day and night time, respectively. Whereas, in the December to January season, the roof temperature reaches 20°C and 7-10°C in the day and night hours. The ceiling temperature reaches to a maximum of 15-18°C in noon time and 10-12°C in the night hours.

Figure 8 shows the average temperature plot for multilayered bamboo walls for April to May month. From Fig. 8, it is evident that the maximum outside temperature for bamboo building reaches up to 35- 38 ºC and ~25-27°C for interior side of the walls. The temperature curve follows an approximate sinusoidal nature. The bamboo wall comprises of multilayered structure with cement plaster, bamboo strip, air gap and plywood as layer components. The schematic of the bamboo wall is

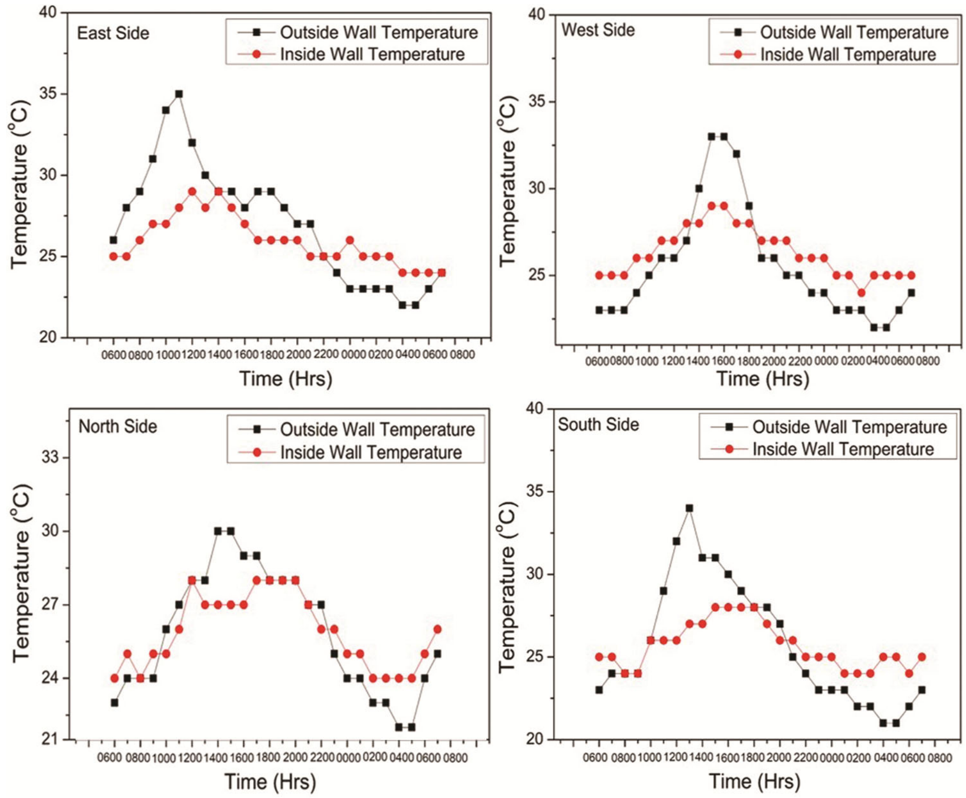

Fig. 8 — Average wall temperature variation for bamboo building facing towards east, west north, and south side for April to May month.

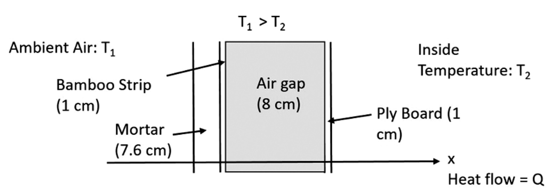

Fig. 9 — Schematic of the bamboo wall.

shown in Fig. 9, along with the thickness of different layers.

Figure 10 shows the temperature plot of the bamboo building for December to January month for all the directional faces viz. east, west, north, and south. The temperature plot shows the outside temperature plot reaches to a maximum of 18°C in the daytime and a minimum of 6-8°C in the night hours. Whereas, for the interior walls, the maximum temperature attains a maximum value of 15°C and a minimum of 8-10°C in day and night time, respectively. Roorkee comes under the composite climate region, which has both extreme summer and winter climate. This extreme weather condition is visible in both summer and winter plots of both the buildings.

The maximum temperature difference between outside and inside temperature for both buildings for the April to May period is around 10-15°C. The aerated cement concrete layer sandwiched between fiber cement boards has a large number of pores. These pores are responsible for exhibiting good thermal insulation because of air entrapment inside the pores. Whereas, large air gap and low *k*-value of bamboo strips of the bamboo wall also provide good thermal insulation from outside high temperatures. From the average summer temperature plots of both the buildings, it can be observed that inside wall temperatures are slightly less for bamboo buildings as compared to cement fibreboard buildings. This may be attributed to the reason of the large air gap in the bamboo wall structure, which helps in low thermal conductance of outside heat to inside. The inside ambient temperatures of both the buildings range from 28-32°C in daytime and 24-27°C in the night hours.

Figure 11 represent the average roof and ceiling temperature for bamboo building. From the Fig. 11 it can be seen that due to metal sheet as roof material the temperature reaches upto 60°C in the summer (April to May) season while the ceiling temperature attains a maximum temperature of 30-32°C. Whereas, for the winter season (December to January), the ceiling temperature reaches a maximum of 15 °C and a minimum of 10 °C in day and night time, respectively.

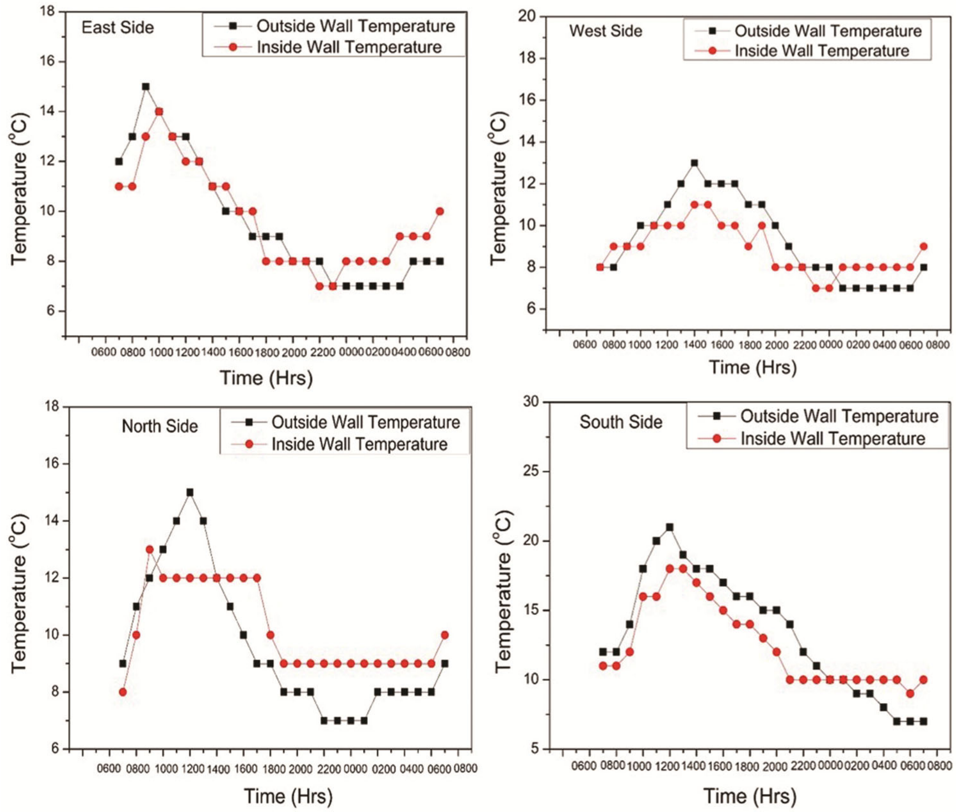

Fig. 10 — Average wall temperature variation for bamboo building facing towards east, west north, and south side for December to January month.

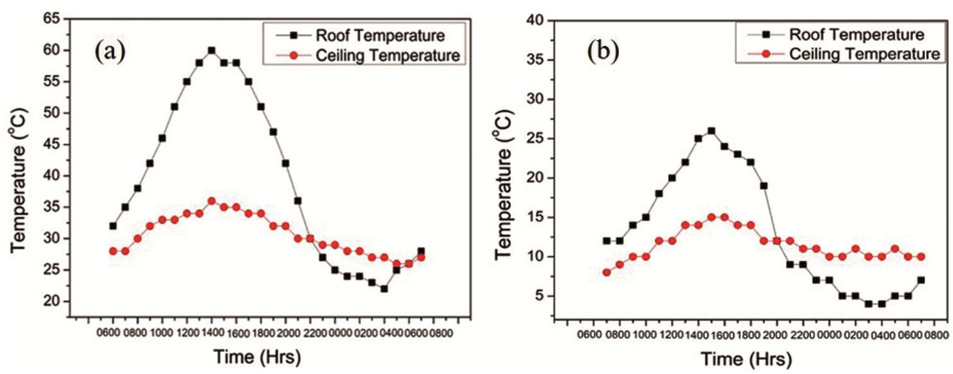

Fig. 11 — Roof and ceiling temperature variation for bamboo building for (a) April to May month and (b) December to January month.

The heat transfer mechanism between the outdoor atmosphere and walls of cement fibreboard building is assumed to be one-dimensional and non-steady-state, i.e., transient state.

The one-dimensional (1-D) transient heat conduction may be written as[7].

$$\rho c_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial x^2} \qquad \ldots(2)$$

where, k is the thermal conductivity, ρ is the density, and C_p is the specific heat capacity of the building wall materials.

The temperature (T) is the function of time (t) and distance (thickness x).

The Eq. 2 can be rewritten as:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \qquad \ldots(3)$$

where, α is the thermal diffusivity and is defined as k/ρ. C_p expressed in m^2/sec. The thermal diffusivity may be defined as rate at which thermal disturbance propagates and is a thermos-physical property of the material. The thermal transmittance (U-value) of cement fibreboard and bamboo

Table 5 — Various thermal parameters of cement fibreboard and bamboo building walls

	Time lag (hrs)	D. F.	Thermal damping (%)	Thermal admittance (Y) (W/m^{2}K)	U value (W/m^{2}K)	Thermal Resistance (m^{2}K/W)	TPI
Cement fibreboard wall	2	0.5	16	7.3	1.9-2.5	0.5	25
Bamboo wall	4	0.38	20	12	1.5-1.7	0.62	25

buildings and other thermal parameters are shown in Table 5.

Time lag and decrement factors are critical thermal performance characteristics that influence the heat storage capabilities of any materials. Time lag (Φ) is the time difference between the temperature maximum at the outside and inside when subjected to periodic conditions of heat flow (IS 3792-1978), and decrement factor is the ratio of the maximum outside and inside surface temperature amplitudes.

The time lag can be defined as[7]:

$$\Phi = t_{T_{in(max)}} - t_{T_{out(max)}} \quad \dots(4)$$

where, t [$T_{in\ (max)}$] and t [$T_{out\ (max)}$]are the time of day when the inside and outside surface temperatures reach maximum.

Decrement factor is defined as:

$$DF = \frac{T_{in(max)} - T_{in(min)}}{T_{out(max)} - T_{out(min)}} \quad \dots(5)$$

where, $T_{in(max)}$, $T_{in(min)}$, $T_{out(max)}$ and $T_{out(min)}$ are maximum inside surface temperature, minimum inside surface temperature, maximum outside surface temperature and minimum outside surface temperature of wall under consideration.

Thermal damping or decreased temperature variation is a characteristic dependent phenomenon based on the thermal resistance of the material used in the structure. It can be written as

$$D = \frac{T_o - T_{in}}{T_o} \times 100 \quad \dots(6)$$

where, T_o and T_{in} are maximum outside and inside wall temperatures, respectively.

The thermal performance index (TPI) of a building depends on heat gained by the building structure through a steady-state and periodic part.

TPI may be defined as: $T_{is} - 30 \times 12.5$ …(7)

where, T_{is} is the maximum peak inside surface temperature.

3.2 Thermal admittance calculation for cyclic temperature variation

Thermal admittance (Y) is a measure of a material's ability to absorb heat energy and release it over a period of time. This is an indicator of the thermal storage capacity (thermal mass) of a building or wall material. Thermal admittance is expressed in W/(m^{2}K), where the higher the admittance value, the higher the thermal storage capacity of the wall material. The large value of thermal admittance (Y) indicates lower temperature fluctuations inside the buildings. Typical admittance values are based on a 24-hour temperature cycle. The thermal admittance of the cement fibreboard wall has been calculated by the transmission matrix method in MATLAB coding.

One dimensional heat transfers through the slab thickness in the direction normal to its surfaces, the cyclic heat fluxes q_i and q_o occurring at the two surfaces of the slab can be written as a function of the surface temperature in the following form[14,15]:

$$\begin{matrix}\theta_{si} \\ q_{si}\end{matrix} \text{(cyclic)} = \begin{bmatrix} z_1 & z_2 \\ z_3 & z_4 \end{bmatrix} \begin{matrix}\theta_{so} \\ q_{so}\end{matrix} \text{(cyclic)} \quad \dots(8)$$

The elements of the transmission matrix can be calculated as follows:

$$z_1 = z_4 \cosh(t + i\, t) \quad \dots(9)$$

$$z_2 = \frac{\sinh\,(t+it)}{\xi\,(1+i)} \quad \dots(10)$$

$$z_3 = \xi(1 + i)\sinh(t + i\, t) \quad \dots(11)$$

where, i is the imaginary part, t is cyclic thickness and ξ is the thermal effusivity, L is the slab thickness, and the period P of the cyclic energy transfer. Both cyclic thickness and thermal effusivity can be written as:

$$t = \sqrt{\frac{\pi}{P.3600} \cdot \frac{\rho.c}{\lambda} \cdot L^2} \quad \dots(12)$$

$$\xi = \sqrt{\frac{2\pi.\lambda.\rho.c}{P.3600}} \quad \dots(13)$$

ξ is thermal effusivity in J. m^{-2}. K^{-1} s$^{0.5}$, ρ is the density of the material, c is specific heat capacity in J. Kg^{-1}. K^{-1} and P is the number of period hours.

The transmission matrix Z of the multilayered wall is obtained through the product of the matrices related to each layer, including the transmission matrix containing the film thermal resistances:

$$\begin{bmatrix} z_1 & z_2 \\ z_3 & z_4 \end{bmatrix} = \begin{bmatrix} 1 & R_{si} \\ 0 & 1 \end{bmatrix} \prod_1^n \begin{bmatrix} z_1 & z_2 \\ z_3 & z_4 \end{bmatrix} \begin{bmatrix} 1 & R_{so} \\ 0 & 1 \end{bmatrix} \quad \dots(14)$$

The thermal admittance function Y can be written as $\frac{Z_4}{Z_2}$ (W/m^{2}K), R_{so} and R_{si} are film thermal resistances.

For multilayer wall panels, a similar approach is adopted for the calculation of transmission matrix parameters described in Eq. 8. Due to multi-wall layers, thermal admittance is evaluated by MATLAB coding, and the result is summarized in Table 5.

3.3 Noise isolation analysis

Regarding noise isolation testing of cement fibreboard building, the noise source of frequency range 80-4000 Hz of 100 dB is created outside, and the indoor noise level is measured. Figure 12 shows the sound isolation of outdoor to the indoor noise level of cement fibreboard building. According to the national building code of India (NBCI) the optimum noise level values for apartments and homes is 35-40 dB[16,17]. From Fig. 13 it is evident that the noise isolation value at 500 Hz is 40 dB. Whereas for bamboo building, the noise isolation at 500 Hz is around 35 dB and 65 dB inside the building under stairs and porch area under rainfall condition on metal sheets, as shown in Fig. 13. According to ASTM E 1332, the outdoor-indoor sound attenuation rating of bamboo and cement fibre board building calculated as 40 dB and 34 dB respectively.

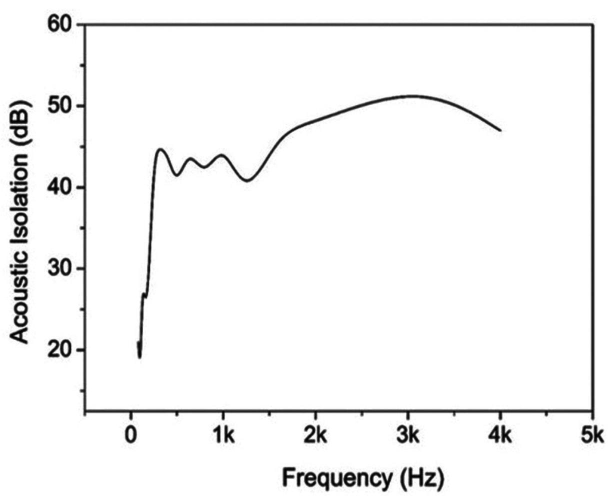

Fig. 12 — Noise isolation of cement fibreboard building.

Sound isolation (transmission loss) depends upon surface density, thickness, and damping of the material. High dense and stiffed material shall have more sound isolation as compared to porous materials. The cement fiber boards have low density but the total wall finishing is almost leak-proof, which prevents the noise leakage inside the buildings. The noise isolation of wall material is directly related to stiffness, Young's modulus, and thickness of the material and is mentioned in detail elsewhere[18].

The day time illuminance measurement inside both the buildings is done at various locations and the illuminance values are shown in Table 6. From the Table 6, it can be noticed that the illuminance values at the ground floor, stairs, kitchen, and in lavatories are above 200 lux. According to NBCI 2016, the illuminance level inside the residential apartments should be greater than 200 lux.

Table 6 — Indoor illuminance level of various locations in fibreboard and bamboo building

	Cement fibreboard building	Bamboo building
	Illuminance level (lux)	
Ground floor	345	340
Kitchen	435	420
Lavatory	210	200
Stairs	1470	1250
First floor	490	460

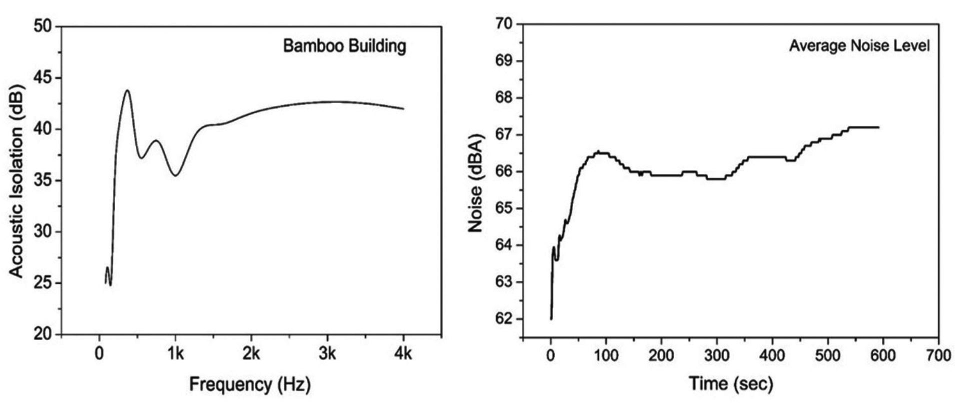

Fig. 13 — Noise isolation curve for mortar finished bamboo wall and corrugated metal sheet as a roof under simulated rainfall condition of 150 mm/hr.

4 Conclusion

The thermal and acoustic properties of cement fibreboard and bamboo buildings have been studied and presented. The thermal performance of the cement fibreboard building exhibits good thermal insulation in the April to May period with outside and inside temperature is 45 and 30°C respectively. The bamboo building also shows good thermal insulation in the April to May period with an outside temperature of 40-45 °C, interior wall and indoor temperature being in the range of 27-30 °C. Whereas, in the December to January, with the outside temperature falling below 10 °C, the inside temperature lies in between 12-16°C in the day time and 8-10 °C in the night hours. The U value lies in the range of 1.9-2.5 W/m^2K and 1.5-1.7 W/m^2K for cement fibreboard and bamboo composite buildings respectively. The noise isolation study shows 40 dB and 35 dB transmission loss for cement fibreboard and bamboo building, respectively. The outdoor-indoor sound attenuation rating of bamboo and cement fibre board building calculated as 40 dB and 34 dB respectively. The daytime indoor illuminance values are well in accordance with the prescribed NBCI values. With proper noise reduction techniques like proper sealing of door and window frames and sound insulation materials, the optimum values may be achieved.

Acknowledgments

The authors are grateful to the Director, CSIR-Central Building Research Institute, Roorkee, for the encouragement during the research work and permitting to publish the paper. Authors would also like to thank Dr. S.K Panigrahi, for guidance. Authors are also grateful to Mr. Naman Garg and Mr. Rajith Patel (MAHE, Manipal Institute of Technology) data collection and analysis.

References

1 Wu R, Dai S, Jian S, Jun H, Tan H, & Li B, *J Clean Prod*, 9 (2020) 123416.
2 Ali M, Li X, & Chouw N, *Materials & Design*, 44 (2013) 596.
3 Ma S, Bao P, & Jiang N, *Applied Sciences*, 10(6) (2020) 1976.
4 Shukla A K, & Maiti P R, *In Advances in Structural Engineering and Rehabilitation*, (2020) 15.
5 Readymade walls, A revolutionary concept. Everest Walls.
6 Števulová N, Hospodarova V, Václavík V, & Dvorský T, *In Key Engineering Materials*, 838 (2020) 31.
7 Balaji N C, Mani M, & Reddy B V V, International Building Performance Simulation Association *(IBPSA),* (2013) 151.
8 Bamboos in Meghalaya, Published by Forest and Environment Department, Government of Meghalaya (http://megforest.gov.in/activity_bamboo_resource.)
9 Bamboos of Mizoram, Published by Environment and Forest Department Government of Mizoram, Aizawl (https://forest.mizoram.gov.in/page/bamboo-resources- in-Mizoram.)
10 Loushambam R S, Singh N R, Taloh A, & Mayanglambam S, *Indian Journal of Hill Farming*, 30 (2017) 181.
11 The India State of Forest Report FSI (Forest Survey of India) (2011).
12 The India State of Forest Report FSI (Forest Survey of India) (2015).
13 NMBA, Arunachal Pradesh. National Mission on Bamboo Applications Arunachal Pradesh (http:// arunachal pradesh.nic.in).
14 Marletta L, Evola G, Guiga M, & Sicurella F, IBPSA-ITALY, (2013) 59.
15 Mohammad S, & Shea A, *Buildings*, 3 (2013) 674.
16 National Building Code of India, Bureau of Indian Standards 2016 Volume 1.
17 National Building Code of India, Bureau of Indian Standards 2016 Volume 2.
18 Peng L, *Advanced High Strength Natural Fibre Composites in Construction,* (2017) 1.