Experimental and Theoretical Performance Evaluation of a Solar Passive Featured Envelope Building in Composite Climate

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Abstract: The performance of School of Energy and Environmental Studies (SEES) building a solar passive envelope building at Indore India has been analyzed by experimental measurements of air and surface temperatures . For the analysis the data for peak winter (December) and peak summer (June) months only was used. Further from the building, data for two rooms in south block (a classroom and library) and two rooms in north block (environment lab and class room) facing opposite to each other were used to compare the thermal performance of south and north units. The surface temperatures of library were also used to measure the thermal time lag due to the hollow wall. Thermal simulation and analysis package TRNSYS was used to simulate the building for air and surface temperatures and the results are validated using the measured data. It has been found that in the month of June the minimum surface temperature occurred at 5.00am in the morning while, the minimum ambient temperature was recorded at 6.00am and in the month of December the minimum of both surface temperature and ambient temperature occurred at 6.00am in the morning. It is also found from that a time lag of about 4 hours between the maximum of the outer and inner surface of the south wall of library during the month of June and a time lag of 2 hours between the minimum temperatures of the outer and inner surface of the wall was observed during the month of June..

Keywords: TRNSYS, Time Lag, Surface temperature, Air Temperature

1. Introduction

Modeling and simulation are now important engineering techniques in the fields of building and building system design and operation. This is further necessitated by the emergence of thermal performance standards of building in many countries and building codes and building guidelines for energy efficient buildings. In India too recently a building code, ECBC (Energy Conservation Building Code) [1] and GRIHA, (Green Rating for Integrated Habitat Assessment) [2] were released and so simulation is viewed as a viable tool for building design and environmental engineering .In the current context, modeling and simulation are used to predict the performance of a building or its systems in order to support design decisions. The building in question may be an existing structure, a proposed modification of an existing structure, or a new design. School of Energy and Environmental Studies (SEES) building, was designed and constructed incorporating various passive features. The building was used to validate the available computer model of building simulation by comparing the measured performance of the school building with the simulated results obtained from the model. A whole building simulation model TRNSYS (Transient system simulation) was chosen for the simulation work. TRNSYS has been in use worldwide both by the academicians and professionals for its power and capabilities including the simulation of solar and other dynamic systems. TRNSYS has modular structure, where the user specifies the building components and the manner in which they are connected.

1.1 Building Design

The building of the School of Energy and Environmental Studies Building was designed with specific passive features relevant to the composite climate of Indore and was constructed and completed in the year 2000. The building form is elongated rather than compact which has an advantage of better daylighting and ventilation. The entire building is oriented in geographical East-West direction (figure2) which in addition to the simpler design of control elements for the solar radiation gives the building an additional advantage over the prevailing easterly winds. The overhangs in the north and south windows are optimally designed keeping in mind the solar path. In the south windows horizontal overhangs are provided which cut off the direct sun rays entirely in summer season as the sun's altitude is higher in summers and allow the direct sun rays in winter season as the sun's altitude is lower in winters .In the north windows, a combination of overhangs and fins are provided to cut off the direct sun rays during mornings and evenings as the sun's altitude is lateral during this period. The windows are divided into three parts. The top part acts as a light shelf in combination with the overhang below it that is glazed with ceramic tiles. The light shelf distributes daylight deep into the interior. The middle part of the window provides daylight at the task level and the lower part provides outside view that helps the user of the building in releasing the stress produced due to work. The windows in combination with the light wells, light shelves and light shafts admit sufficient daylight to illuminate the working areas of the building during daytime and thus reduce the consumption of electricity for artificial lighting to almost zero. Only a few openings are provided in the east and the west facades for eliminating the glare and heat associated with these orientations. The envelope walls of the building have rat trap bond arrangement in which a hollow space is created between two brick layers; this thermally isolates the inner environment from the extremities of the outer environment. Solar chimneys have been constructed to produce stack pressure differences in the rooms connected to it to augment natural ventilation. Louvers in the room opening of the solar chimney have been provided to control the night/day ventilation rates as per requirements of the season.

1.2 Temperature Monitoring Methodology

High end and generic Data Acquisition Systems (DAQ) were employed for the physical monitoring of the air and surface temperatures in the SEES building. The DAQ consisted of Field-Points, which provided the facility of the distributed and networked I/O hardware that can be conveniently configured using the software LabView (Virtual Instrument Engineering Workbench) a graphical programming language. Air temperature (indoor and surface) measurements were taken at various locations in the building using RTDs with the Field- Point FP-1000/1001 system. The sensors were suspended from the centre of ceiling at a distance of 0.3m from the ceiling. These Field-Points mounted on universal terminal bases were connected via Serial Bus (RS-485) [3].The sensors used for the measurement of surface temperatures were buried up to a depth of 2mm at the surface and shielded from direct exposure with the help of matching cement plaster and finishing ensuring the accurate measurement of the temperature at the surface. Figure- 1 shows the Field-Point network node installed in the office of SEES building.

Figure 1 Field point network node in the office of SEES building.

Figure2 . Building Design.

From the building, data for two rooms in south block (a classroom, CLASS_S and library, LIBRARY) and two rooms in north block (environment lab, ENVLAB and classroom, CLASS_N) facing opposite to each other were used to compare the thermal performance of south and north units. The classrooms are being used for lectures, the library for reading and the environmental lab for experiments. The lab also contains chemicals and chemical instruments. The inner and outer surface temperatures of the south wall of the library were used to measure the thermal time lag and damping due to the hollow wall. . Figure-3 shows the location of the sensors indicated by square box and figure 4 shows the overhang and window details.

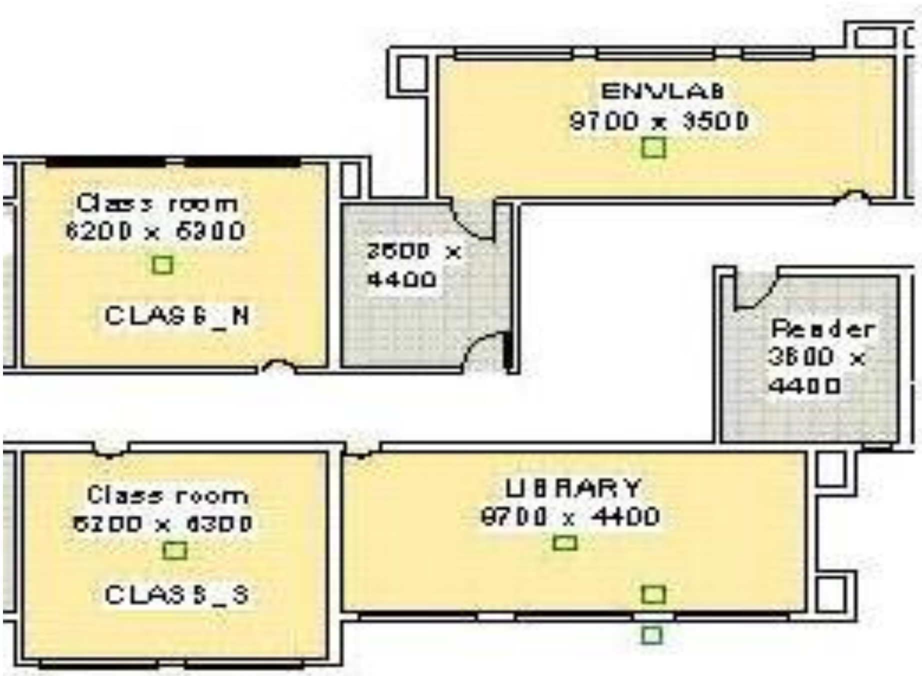

Figure 3 The location of sensors with the North and South blocks of study.

Figure 4 View showing overhang and window details

2. Results And Discussion

The performance of SEES building was analyzed by experimental measurements of air and surface temperatures. The DAQ had recorded the measurements at an interval of 15 minutes. These values were then converted to hourly measurements by determining the average of four values recorded during each hour. These were further converted to monthly average measurements for each hour by determining the average of each hour values of the days of month. For the analysis the data for peak winter (December) and peak summer (June) months only are presented here.

2.1 Simulation And Validation

Thermal simulation and analysis package TRNSYS [5.4] (Transient System Simulation) was used to simulate the building for air and surface temperatures and the results are validated using the measured data. The solar radiation data for Indore have been taken from handbook of Mani and Rangrajan[5.5].

2.1.1 Input Data For Sees Building

The input data required by TRNSYS for the simulation of the rooms in South and North blocks includes the following information.

City Indore

Latitude 22.720N

Longitude 75.800E

Altitude 567m

2.1.2 Construction Details

Outer wall: Plaster (0.025m), Brick (0.115m), Cavity (0.15m), Brick (0.115m), Plaster (0.025m).

Inner wall: Plaster (0.025m), Brick (0.115m), and Plaster (0.025m).

Floor: Stone (0.025m), Concrete (0.050m), Sand Gravel (0.300m).

Roof: Plaster (0.025m), Concrete (0.100m), Plaster (0.025m).

2.1.3 Areas Of Different Zones

The areas of simulated rooms, Thermo physical properties of materials and the other relevant parameters used are listed in tables 1, 2 and 3 respectively.

Table 1 Wall, window and floor /roof areas

Zone Name	Floor/Roof Area m^2	Wall areas m^2				Window areas m^2	
		South	West	North	East	South	North
ENVLAB	33.95	29.10	10.50	29.10	10.50	-	9.38
Class_N	32.86	18.60	15.90	18.60	15.90	-	7.00
Class_S	32.86	18.60	15.90	18.60	15.90	7.00	-
LIBRARY		29.10	13.20	29.10	13.20	11.07	-

Table 2 Thermo physical properties of building materials [3], L thickness of layers (m)

Layer	Conductivity, k kJ/h m K	Specific Heat Capacity, Cp kJ/kg K	Density, d Kg/m^3	Resistance (L/k) m^2 K/W
Plaster	1.80	1.00	1300.00	0.100
Brick	3.02	1.00	1700.00	0.274
Cavity(Air)	0.0257	1.005	1.205	0.036
Cement Concrete	7.56	1.00	2400.00	0.048
Stone	2.50	0.90	2600.00	0.036
Sand Gravel	2.52	1.0	1800.00	0.429
Plywood	0.54	1.20	800.00	0.253

Table 3 Values of other relevant input parameters used for simulation

S. No.	Quantity		Value
1.	Inside heat transfer coefficient		11kJ/(h.m^2.K)
2.	Outside heat transfer coefficient		64 kJ/(h.m^2.K)
3.	Heat gain by each occupant		120W
4.	Occupancy	ENVLAB	5
		LIBRARY	5
		Class_N	10
		Class_S	10
5	Occupancy timings		8am to 6pm

The measured monthly average of hourly values of the air and surface temperatures recorded during the months of June and December are given in tables 4, 5 and the corresponding simulated values are given in tables 6 and 7 respectively.

Table 4 Monthly averages of measured inside air, ambient and surface temperatures (o C) in June.

Time	CLASS_N	CLASS_S	ENVLAB	LIBRARY	LIBRARY WALL INSIDE SURFACE	LIBRARY WALL OUTSIDE SURFACE	AMB
0:00	28.5	30.6	30.0	32.2	31.5	27.0	27.0
1:00	28.3	30.4	29.8	31.9	31.3	26.7	26.6
2:00	28.0	30.0	29.5	31.6	31.1	26.3	26.1
3:00	27.7	29.7	29.2	31.3	30.9	25.9	25.6
4:00	27.6	29.8	29.0	31.1	30.6	25.8	25.2
5:00	27.3	29.6	27.8	30.4	30.4	25.7	24.1
6:00	27.2	29.4	26.7	29.1	30.2	26.0	23.6
7:00	27.6	29.3	26.3	28.8	30.1	26.5	25.1
8:00	27.3	29.5	26.5	28.9	30.2	27.9	26.7
9:00	27.6	30.0	27.2	28.7	30.3	29.4	28.5
10:00	27.9	30.9	28.5	29.6	30.7	31.7	30.1
11:00	28.4	31.5	29.0	31.4	31.1	32.8	31.3
12:00	28.7	32.0	29.9	31.1	31.5	33.2	30.7
13:00	29.1	32.3	30.4	31.9	31.9	34.4	31.5
14:00	29.3	32.5	31.0	32.7	32.4	35.1	31.4
15:00	29.5	33.0	31.5	32.8	32.8	35.0	32.0
16:00	29.8	32.8	31.8	33.2	33.1	34.4	30.2
17:00	30.3	32.5	31.5	33.2	33.3	33.9	30.6
18:00	30.4	32.3	31.8	33.0	33.3	32.6	30.6
19:00	30.3	32.2	31.2	32.7	33.2	31.4	29.6
20:00	30.0	32.0	30.7	32.5	33.1	30.3	28.8
21:00	29.8	31.9	31.0	32.3	33.0	29.1	27.9
22:00	29.6	31.6	29.7	31.9	32.9	28.7	27.6
23:00	29.3	31.2	29.5	31.5	32.7	28.3	27.3

Table 5 Monthly averages of measured inside air, ambient and surface temperatures (o C) in December.

Time	CLASS_N	CLASS_S	ENVLAB	LIBRARY	LIBRARY WALL INSIDE SURFACE	LIBRARY WALL OUTSIDE SURFACE	AMB
0:00	20.9	23.0	22.0	23.0	26.6	20.1	18.1
1:00	20.8	22.8	21.6	22.9	25.7	19.4	17.8
2:00	20.6	22.3	21.4	22.7	25.6	18.6	17.1
3:00	20.4	22.2	21.4	22.5	24.9	17.9	16.2
4:00	20.1	21.8	21.0	22.2	24.5	17.3	15.5
5:00	19.7	21.9	19.9	21.3	24.0	16.7	14.0
6:00	19.5	21.3	19.6	20.8	23.1	15.8	13.8
7:00	19.2	21.0	19.5	20.9	23.4	16.5	14.6
8:00	19.1	21.7	19.3	21.1	22.0	19.0	16.2
9:00	19.1	22.3	19.4	21.8	23.2	25.1	18.6
10:00	19.2	23.0	20.0	22.5	23.5	30.3	20.9

11:00	19.6	23.8	20.3	23.2	23.9	34.3	21.7
12:00	20.9	24.0	22.0	23.4	24.6	37.0	22.2
13:00	21.3	24.9	21.8	23.8	26.0	37.5	22.7
14:00	22.4	25.7	22.7	25.7	26.8	39.6	25.4
15:00	22.4	25.7	22.9	26.1	29.3	38.7	25.7
16:00	22.4	25.6	23.1	25.7	28.6	36.3	24.8
17:00	22.3	25.3	23.1	25.2	28.0	32.6	23.0
18:00	22.2	25.3	22.0	25.0	28.5	29.3	21.8
19:00	22.2	25.2	21.9	24.7	28.0	27.0	20.8
20:00	22.0	25.2	21.7	24.5	27.7	25.2	20.1
21:00	21.9	25.1	21.6	24.3	27.3	23.7	19.6
22:00	21.8	25.0	21.5	24.3	27.3	22.5	19.3
23:00	21.4	24.0	21.1	23.7	26.9	22.1	19.0

Table 6 Monthly averages of simulated inside air and surface temperatures (o C) in June

Time	CLASS_N	CLASS_S	ENVLAB	LIBRARY	LIBRARY WALL INSIDE SURFACE	LIBRARY WALL OUTSIDE SURFACE
0:00	29.2	31.4	31.9	32.4	31.7	28.2
1:00	29.3	31.0	31.5	33.0	31.5	27.7
2:00	29.0	30.7	31.2	32.7	31.3	27.2
3:00	28.7	30.4	30.8	32.0	31.0	26.7
4:00	28.4	30.1	30.0	31.6	30.8	26.2
5:00	28.0	29.8	28.1	31.4	30.6	25.8
6:00	27.8	29.5	28.0	30.4	30.4	26.2
7:00	27.7	29.4	27.0	29.3	30.3	27.1
8:00	27.7	29.4	27.7	29.4	30.1	28.6
9:00	27.9	29.5	28.5	29.9	30.1	30.4
10:00	28.7	30.4	29.9	30.6	30.4	32.2
11:00	29.3	31.1	30.7	31.5	30.8	33.8
12:00	29.9	31.6	31.5	32.3	31.0	35.2
13:00	30.7	32.4	32.0	32.7	31.4	36.3
14:00	31.3	33.0	33.0	33.7	31.8	37.1
15:00	31.9	33.7	33.4	34.0	32.2	37.4
16:00	32.0	34.1	33.4	34.0	32.7	37.2
17:00	32.7	34.4	33.4	33.7	32.9	36.2
18:00	32.2	33.8	33.2	33.7	33.3	34.6
19:00	32.0	33.6	33.0	33.4	33.3	32.9
20:00	31.8	33.4	32.6	33.4	33.2	31.3
21:00	31.4	33.1	32.0	33.1	33.1	30.3
22:00	31.1	32.8	31.5	32.7	32.9	29.6
23:00	31.0	32.4	31.6	32.3	32.6	29.0

Table 7 Monthly averages of simulated inside air and surface temperatures (o C) in December

Time	CLASS_N	CLASS_S	ENVLAB	LIBRARY	LIBRARY WALL INSIDE SURFACE	LIBRARY WALL OUTSIDE SURFACE
0:00	21.3	22.7	21.2	23.5	25.0	19.5
1:00	20.9	22.2	20.8	23.3	24.6	18.7
2:00	20.5	21.8	20.4	23.3	24.1	17.9
3:00	20.1	21.3	20.0	23.0	23.6	17.3

4:00	19.8	20.9	19.7	22.7	23.1	16.8
5:00	19.4	20.5	18.9	21.8	22.6	16.3
6:00	19.1	20.2	18.6	21.0	22.1	15.9
7:00	18.8	19.9	18.4	20.6	22.0	18.1
8:00	18.6	19.9	18.0	21.2	22.1	21.4
9:00	18.7	20.1	18.2	21.8	22.6	26.0
10:00	19.7	21.2	19.4	23.0	23.4	31.3
11:00	20.4	22.2	20.4	23.5	24.4	35.7
12:00	21.0	23.0	21.1	24.8	25.4	38.9
13:00	21.7	23.9	21.9	25.9	26.2	40.7
14:00	22.3	24.6	22.4	26.7	26.8	41.0
15:00	22.9	25.3	23.0	27.2	27.2	39.9
16:00	23.4	25.7	23.4	27.4	27.3	37.4
17:00	23.7	25.8	23.5	27.3	27.2	34.3
18:00	23.0	25.1	22.6	26.6	26.9	30.2
19:00	22.6	24.6	22.0	25.7	26.5	26.0
20:00	22.4	24.2	21.7	25.0	26.2	24.0
21:00	22.0	23.8	21.2	24.3	26.0	22.6
22:00	21.6	23.3	20.8	23.7	25.6	21.4
23:00	21.2	22.8	20.4	23.1	25.3	20.4

It is seen from these tables, that the measured values of the external temperature of the wall can go to 39.6 0 C in peak winter while it reaches to 35.1 0 C in peak summer. In summers during the day time, the highest value of monthly average of hourly values of room air temperature of 32.0 OC and 31.8 OC were observed in library and south class room respectively which are higher than comfortable temperature of 30 O C [6, 7] in tropical climates, while in the environmental lab and north class room, the highest value of monthly average of hourly values of room air temperature of 30.3 OC and 29.1 OC respectively were recorded which are nearer to the comfortable temperature. The temperatures in library and south class room are higher mainly because of their south exposure. The fluctuations of the order of 3.2 OC between the maximum and minimum air temperatures in both the class rooms were found equal mainly because of the equal floor and window areas while in the environmental lab and in library the fluctuation in the room air temperatures were found to be 5.5 OC and 4.4OC respectively. Though the window to floor area ratio of library is higher than the environmental lab the observed fluctuations in the environmental lab, were found to be higher because of the exposed west wall. In winters during the day time, the monthly average of hourly room air temperature of 24OC was observed in the library while, the average room air temperature of 24.3OC was observed in south class room which are within the comfortable range. In the north class room as well as the environmental lab, an average room air temperature of 21OC and 21.5OC respectively was observed. The fluctuations between the maximum and minimum room air temperatures of north class room, Environmental lab, south class room and Library were observed to be 3.3OC, 3.8OC, 4.7OC, and 5.3OC respectively. The south rooms have higher fluctuations because of the fact that the sun moves towards south façade during winters.

A comparison of measured and simulated hourly values of inner and outer surface temperature of the south wall during the month of June is shown in figure 5.The comparison of measured and simulated hourly values of inner and outer surface temperatures of the south wall during the month of December is given in figure 6.

The comparison for measured and simulated hourly values of room air temperatures in the library during the month of June is given in figure 7. The corresponding comparison of the measured and simulated hourly values of room air temperature in the library during the month of December is shown in figure 8.Similar comparison for the hourly values of room air temperature in the environment lab, south class room and north class room during the month of June are given in figures 9, 10 and 11 respectively and during the month of December are given in figures 12, 13, and 14 respectively.

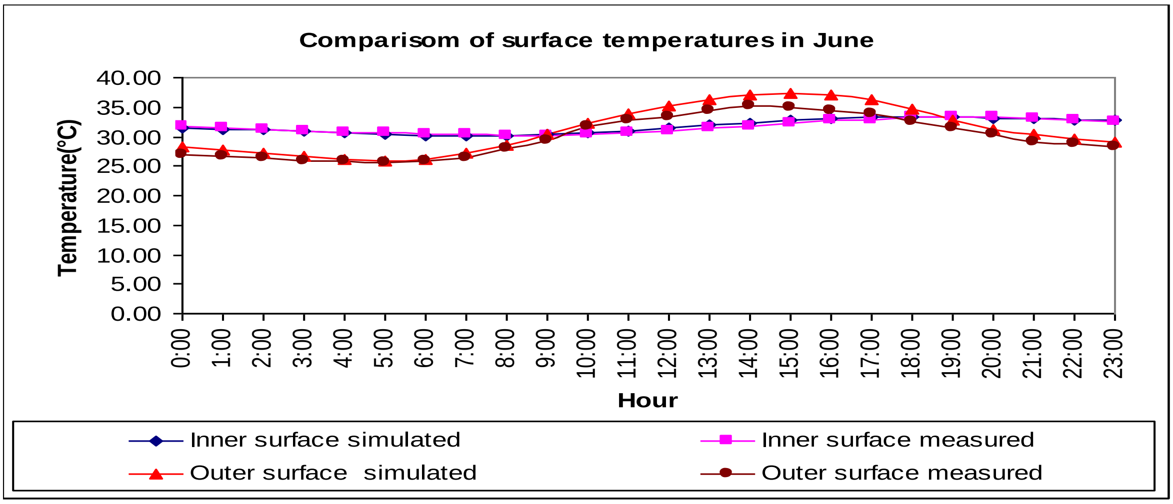

Figure 5 Comparison between measured and simulated surface temperatures of South wall (library) in June

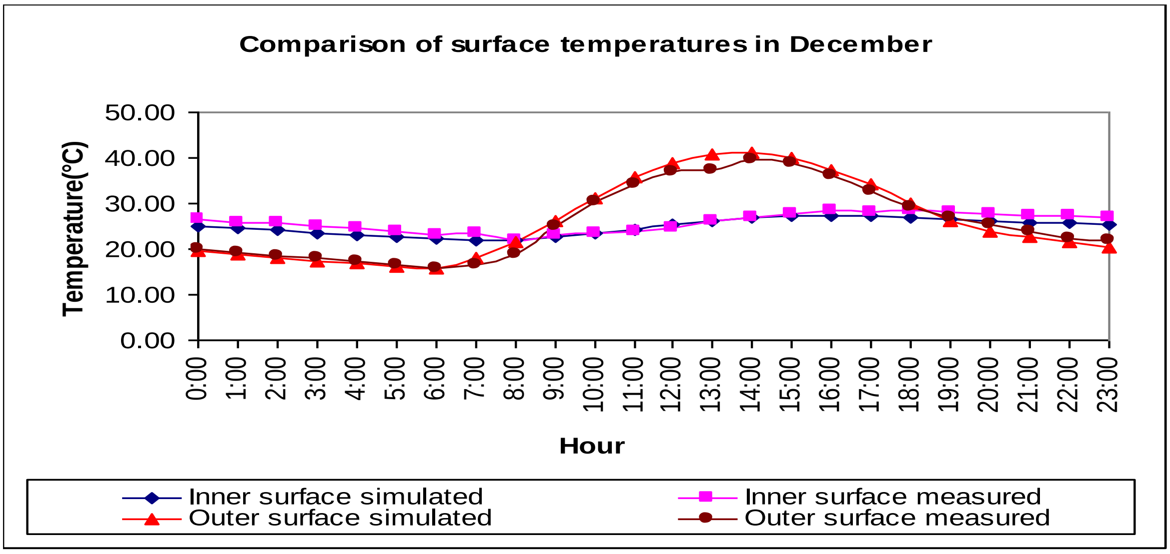

Figure 6 Comparison between measured and simulated surface temperatures of South wall (library) in December

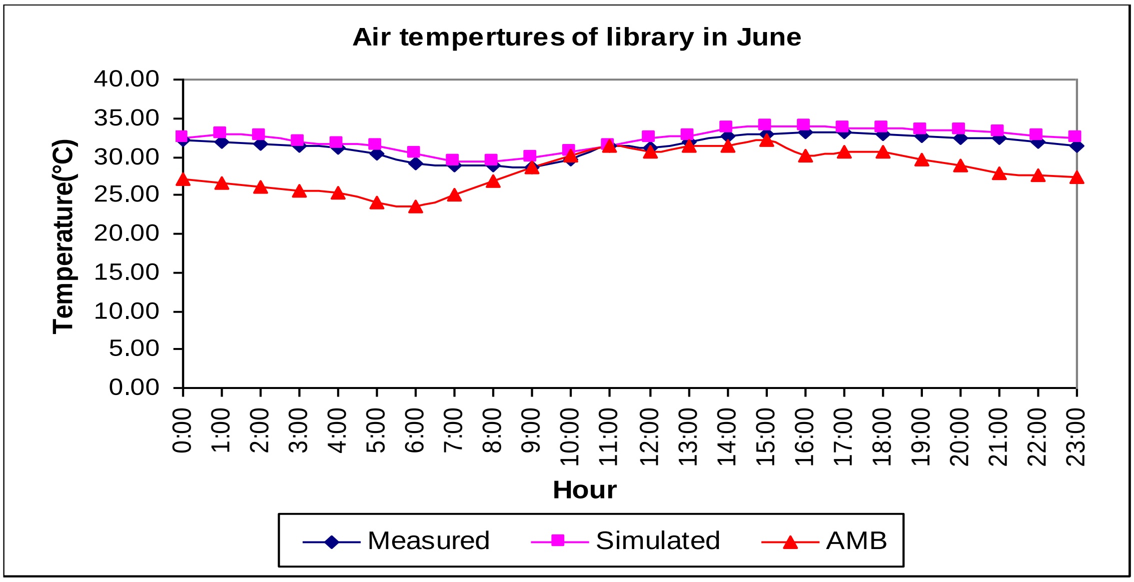

Figure 7 Comparison between measured and simulated air temperatures of library in June

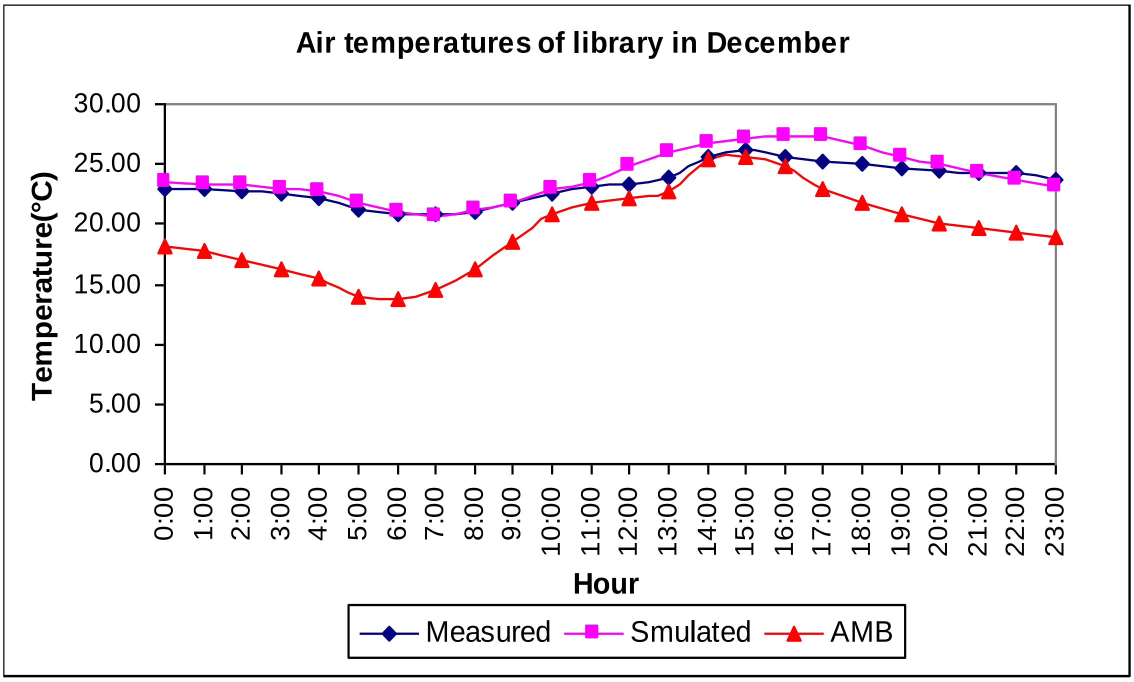

Figure 8 Comparison between measured and simulated air temperatures of library in December

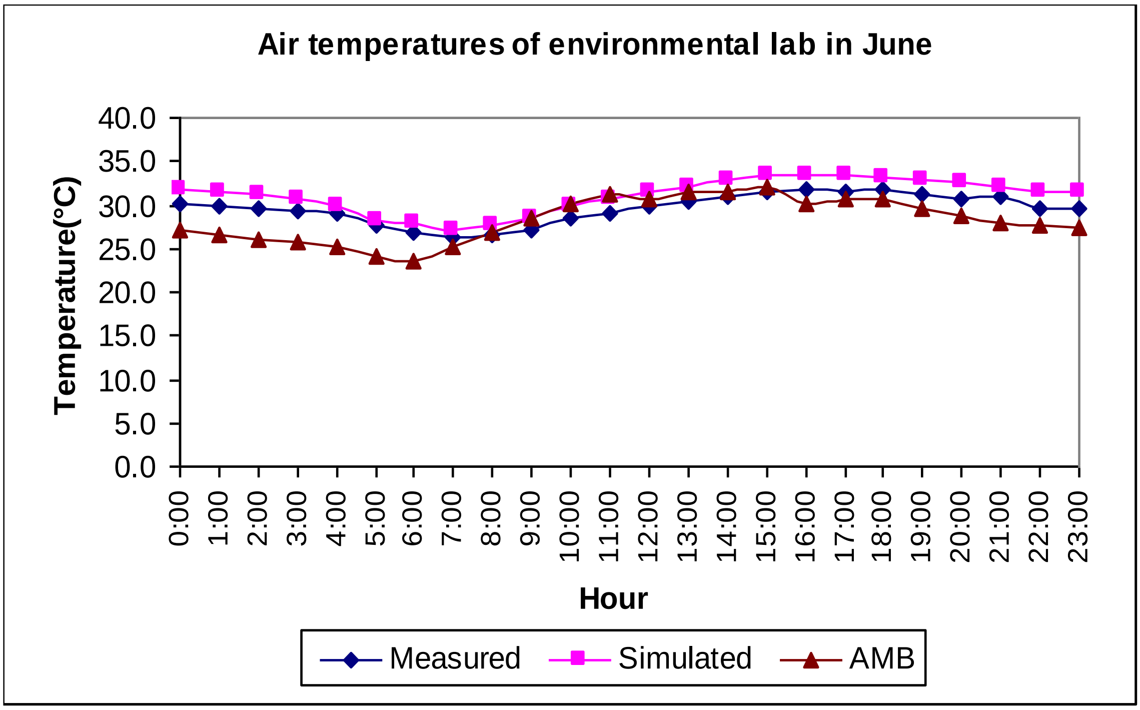

Figure 9 Comparison between measured and simulated air temperatures of environmental lab in June

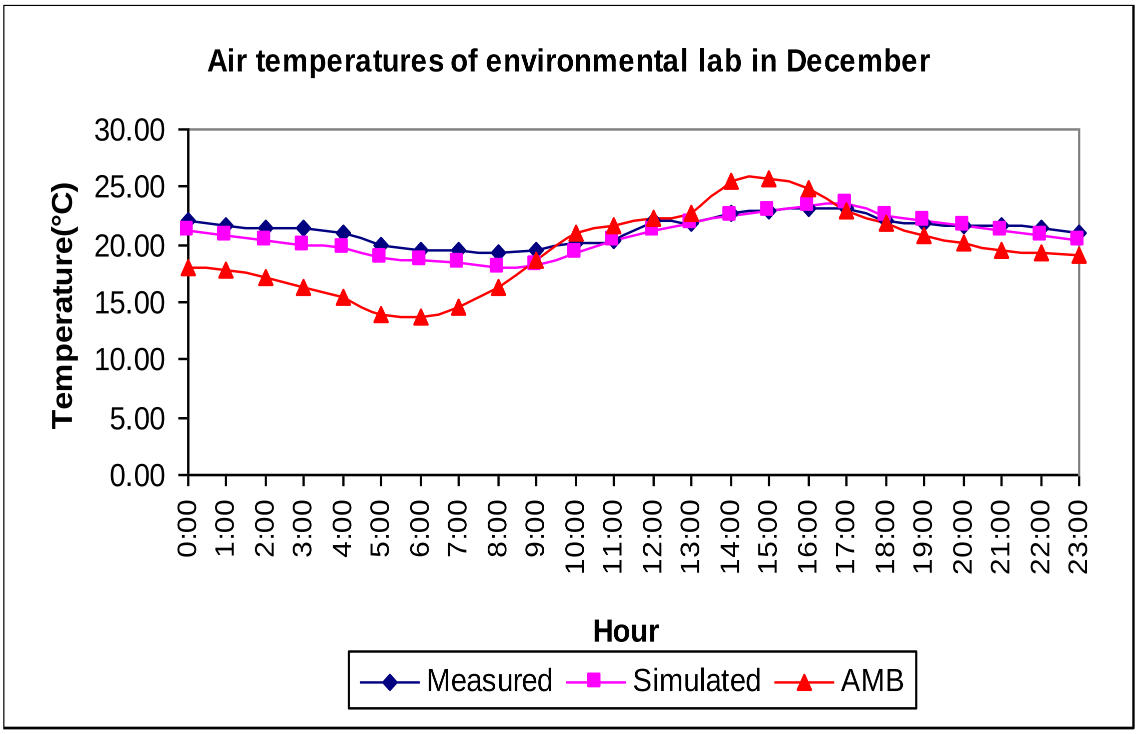

Figure 10 Comparison between measured and simulated air temperatures of environmental lab in December

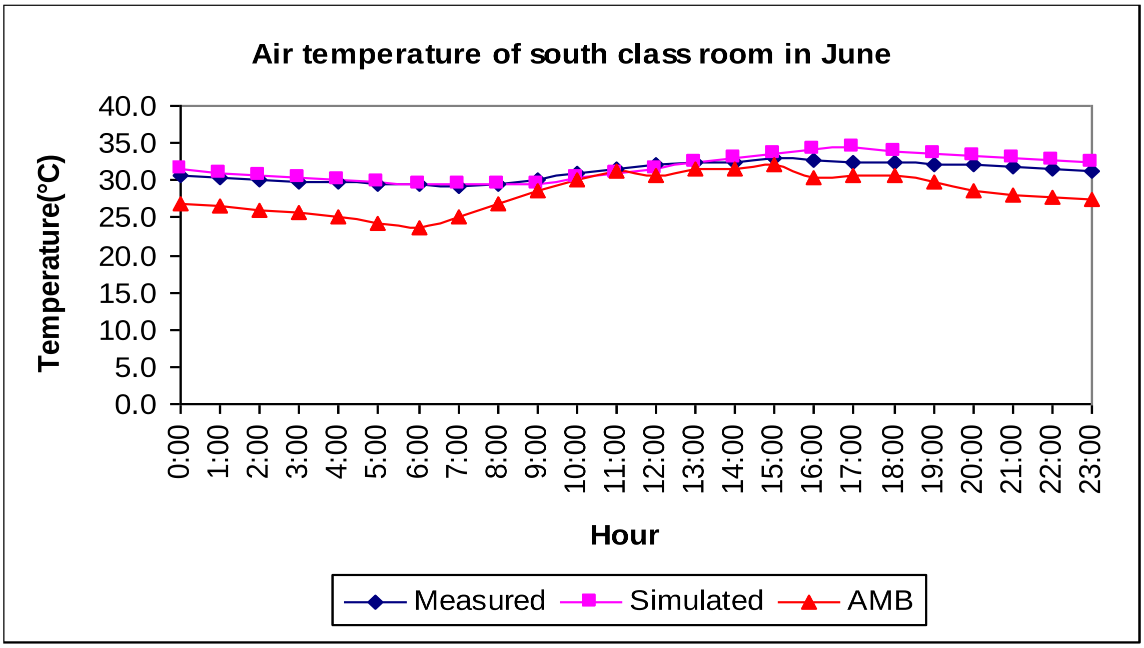

Figure 11 Comparison between measured and simulated air temperatures of south class room in June

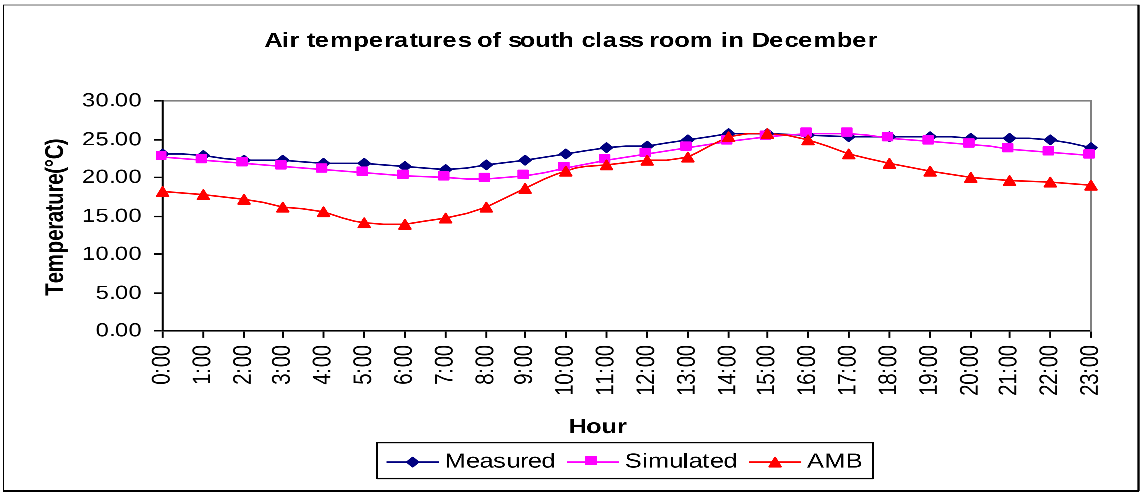

Figure 12 Comparison between measured and simulated air temperatures of south class room in December

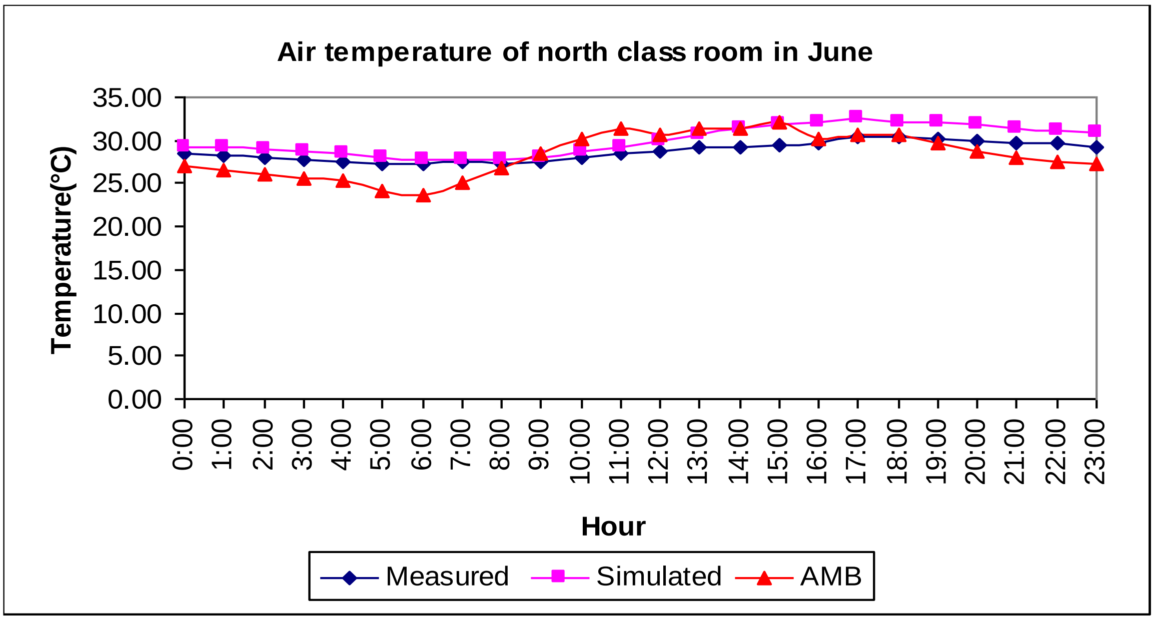

Figure 13 Comparison between measured and simulated air temperatures of north class room in June

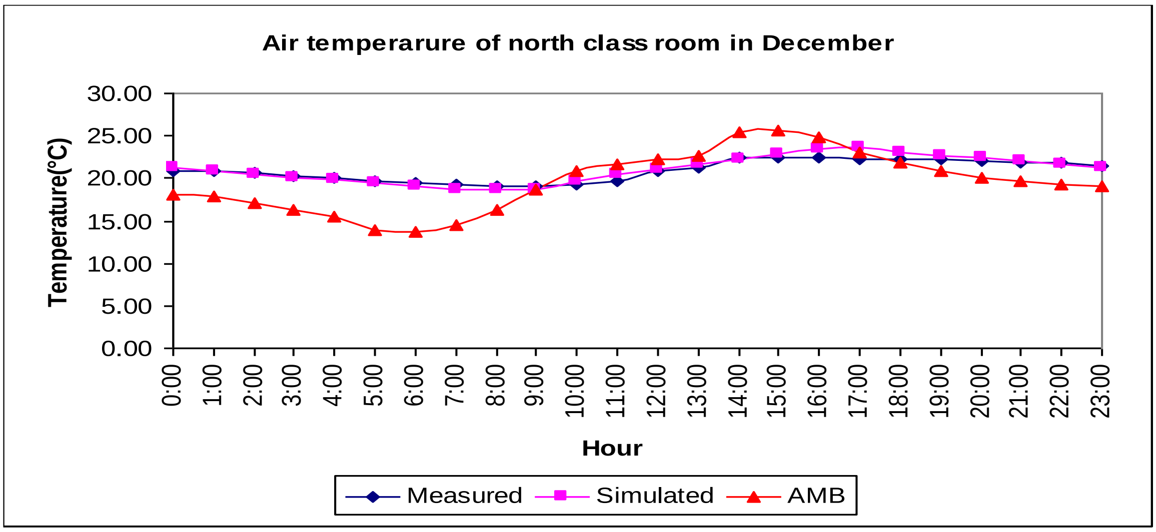

Figure 14 Comparison between measured and simulated air temperatures of north class room in December

It can be observed from the above figures that the measured and simulated temperature profiles match within 20 C. The coefficient of correlation, for all the cases as seen from these figures lies between 0.92-0.99.

The solar radiation and ambient temperature data was taken from recorded values averaged over last twenty years [5], the agreement between the measured and simulated temperatures may be considered to be good. It must also be mentioned that the openings of the doors and occupancy during the measurement period was not strictly controlled which would also contribute to the some difference observed between simulated and recorded values of the temperature.

3. Conclusions

Thermal performance of a passive solar building with surface and air temperature measurements between college hours of 8am to 6pm has been analyzed. A time lag of 6 hours between the peaks of walls has been observed. Thermal simulation and analysis package TRNSYS has been used to simulate the building for air and surface temperatures and the results are validated using the measured data. It has been observed that the north classroom has temperatures lower than south classroom in summers and vice versa in winters. In composite climates, where summer and winter seasons touch extremes, it is not possible to bring the temperatures in comfortable range in all the orientation rooms. Hence, it can be concluded the rooms in north block are within the comfortable range in summers and the rooms in south block are within the comfortable range in winters

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