International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 6, June - 2013

Simulation And On-Site Measurement Methods To Study Thermal Performance Of Rural Mud Hut In Humid Sub-Tropical Climate: A Case-Study In Jharkhand, India.

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Abstract:

The existing realities of the mud house with respect to its ability to providing thermal comfort to occupants are studied. How the areas in which thermal performance is unsatisfactory and can be improved has been suggested. Various parameters have been considered in the study of the existing mud house like roof and wall insulation, direct and indirect heat gain, ventilation, and orientation. As a tool for studying the thermal comfort conditions inside the mud house and in order to simulate different thermal conditions, the software 'Autodesk Ecotect Analysis' is used. The different sources of heat gain during summer and heat loss during winter are pinpointed through detailed analysis. On-site measurements are used to validate building simulation results and to draw some inferences about thermal behaviour of dwelling units.

Keywords: mud-house, thermal-performance, Simulation.

1.0 Typical Existing Vernacular Mud Huts in Jharkhand in rural and suburban areas

1.1 Size & Layout

Since the Iron Age, Jharkhand has been a land of thirty different tribes on the Chotanagpur plateau. Before British colonization in 1870, Jharkhand had an agrarian society. Huts made of mud walls and thatched roofs were the standard construction. Along with a thermally-responsive construction, the architecture of Jharkhand also responded to interactive social life by creating community courtyards. (Das & Pushplata, 2005).

An average hut measured approximately 5 to 6 meters (15 to 18 feet) long and 3 to 4 meters (10 to 12 feet) wide (Dhar, 1992). The huts vary in size. There are also a considerable number of larger huts that extend up to 12 to 14 meters in length and 8 to 9 meters in width. The walls are usually thick ranging between 450 mm-500 mm. **(Figure 1)**

These huts are arranged in a linear pattern along the main street of a village, usually amidst a group of bamboo trees. The houses are normally surrounded by a fence made of bamboo, shrubs, or twigs that defined the boundary between the public street and the semi-public courtyard area in front and at the rear of the hut. This open-to-sky courtyard acts as a prime space for the house, especially during the day in winter and in the evenings in summer.

The Cob method & Wattle and Daub method is the most commonly used in Jharkhand huts. The huts were made of local materials. Timber, bamboo, clay, straw, cow dung, and a special variety of grass were used to build houses (Dhar, 1992). The walls were made of a special type of mud obtained by souring earth by adding vegetable waste and leaving it to mature. The decaying waste produced tannic acid and other organic colloids, greatly improving the mud's plasticity (Cooper & Dawson, 1998). This mud was then mixed with cow dung, chopped straw, and gravel or stones to make the raw material for the walls to improve its tensile strength. The pitched roofs are made of burnt clay tiles.

In the Middle East fibrous ingredients like straw are used to improve tensile strength of mud bricks. Binici et al (2007) investigated the thermal isolation and mechanical properties of fibre reinforced mud bricks as wall materials. The fibre reinforced mud bricks fulfil the tensile strength, compressive strength and heat conductivity requirements of the ASTM (American Society for Testing & Materials) standards. Further, as per Binici's study, Mud bricks with plastic fibres showed a higher compressive strength than those with straw, polystyrene and without any fibres. Basaltic pumice as an ingredient was found to decrease the thermal conductivity coefficient of fibre reinforced mud bricks.

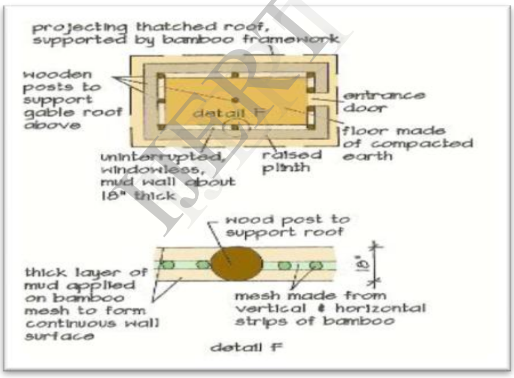

Figure 1: *Mud wall with wooden-posts of typical hut –plan & detail (Reproduced from Dhar, 1992)*

1.2 Studied Hut

The studied hut is located in Mesra village, 16 kms from Ranchi, the capital of Jharkhand, a state in eastern India located on the Chota Nagpur plateau region. It is a state which is rich in its forest and mineral resources. In fact, the word Jharkhand in Sanskrit means the 'Land of Forest bushes'. Ranchi has a Sub-Tropical Humid type of climate as per Koppen's Classification of Indian Climates**. (Figure 2)**The external mud walls of the studied hut are 450 mm and the internal walls are 250 mm. The studied mud house has its longer side oriented along East-West Axis. The two doors are placed in the northern side. The two small void like openings are placed on the southern wall. It measures 14 meters in length by 8 meters in breadth. **(Figures 3 & 4)** Mesra, (near Ranchi) lies at latitude of 23.4 degrees north and the longitude passing through it measures 85.3 degrees east. Ranchi has a hot summer

(April, May, and June), monsoon with heavy rains (July-September), moderate autumn (October), moderate spring (March) and cold to very cold winter (November, December, January and February.)

Figure 2: *Climatic Zones of India by Koppen (Source: www.ijlct.oxfordjournals.org)*

Days are hot, and nights are cool in summer; heavy rains occur during monsoon; and in winter, both days and nights are cold.

According to Brown and DeKay (2001), the main strategies to create comfort in this climate include:

Summers:

Use evaporative cooling.
Protect against summer heat gain.
Keep the sun out in summers to reduce heat gain and glare.
Flatten day-to-night temperature swings to reduce cooling in summers.
Use vegetative cover to prevent reflected radiation and glare.
Expand use of outdoor spaces during the night.
Night time flush ventilation to cool thermal mass.

Winter:

Let the winter sun in to reduce heating needs.
Protect from cool winter winds to reduce heating.
Expand use of outdoor spaces during the day.

Spring:

Use natural ventilation to cool in spring.

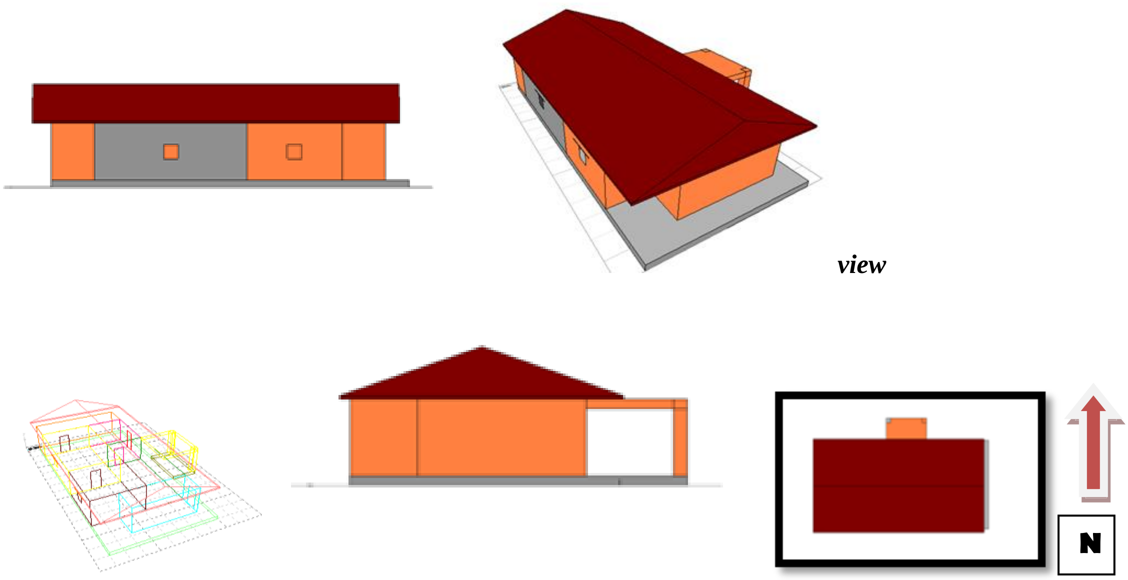

Figure 3: *Studied Hut (clockwise from top left: front elevation, view, plan, side elevation & wire-frame model)*

Figure 4: *Photographs of the studied hut (Photographs by Author)*

The Model House under study has been divided into two zones – the **north-zone (ZONE 2)** and the **south zone** (**ZONE 1**) for more specific study. Also, for further detailed study, **one room in the south zone**, which is used as a sleeping room at night, is subjected to further detailed study to analyse its thermal behaviour. **(Figure 5)**

ISSN: 2278-0181
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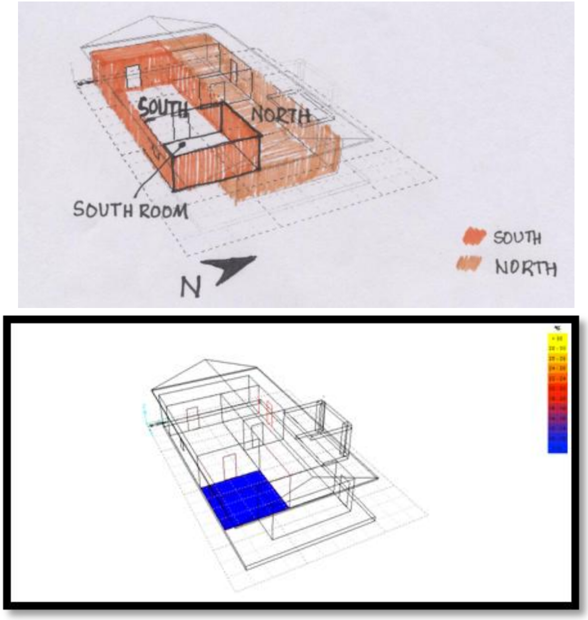

*** blue region shows south zone room.**

Figure 5: *Demarcating south and north zones.*

2.0 On-site measurements

The on-site temperatures inside the mud house are taken, on one of the hottest days, one of the coldest days and one of the windiest days. This is done to validate simulation results and to study the thermal conditions inside the dwelling unit.

The room chosen for taking temperatures is the sleeping room in the south zone of the hut.

Fig 6a ***Fig 6b***

Figure 6a: *Raytek Gun*. (Source: www.lasertools.com.au/images/raytekmt6.jpg)

Figure 6b: *Magnetic Compass*

2.1 Raytek handheld infrared thermometer :

A Raytek thermometer (see Figure 6a) was used to record temperature instantaneously on different surfaces.

2.2 Magnetic compass:

Orientation of the house under investigation was identified. A magnetic compass corrected for declination was used to determine the orientation of the building. (Figure 6b)

2.3 Temperatures taken during one of the hottest days of the year:

In South Zone Room. (inside hottest period)

HOURLY TEMPERATURES - Tuesday 29th May
Zone: south room
Avg. Temperature: 34.2 C (Ground 23.6 C)

HOUR	INSIDE (C)	OUTSIDE (C)	TEMP.DIF (C)
00	34.7	32.1	2.6
01	34.7	30.8	3.9
02	34.7	29.6	5.1
03	34.7	28.8	5.9
04	34.7	27.2	7.5
05	34.6	28.4	6.2
06	34.6	30.2	4.4
07	34.6	32.8	1.8
08	34.6	35.0	-0.4
09	34.6	37.2	-2.6
10	34.6	38.6	-4.0
11	34.6	40.0	-5.4
12	34.6	40.9	-6.3
13	34.6	41.6	-7.0
14	34.6	41.4	-6.8
15	34.6	40.8	-6.2
16	34.5	39.4	-4.9
17	34.5	37.9	-3.4
18	34.4	36.0	-1.6
19	34.5	34.6	-0.1
20	34.8	33.2	1.6
21	34.9	32.6	2.3
22	34.8	32.0	2.8
23	34.8	31.8	3.0

Table 1: Hourly Inside and OutsideTemperatures measured in south zone room,29th May

ANALYSIS: In summer, inside remains cooler than outside during day-time, after 8 AM in the morning. This can be attributed to thermal time-lag of heat-conductivity of mud. The mud stores the heat gained during day-time and dissipates it gradually after 8 PM at night, after getting heated from 7 AM to 5 PM in summer (with peak heat gain during 10 AM in the morning to 4 PM in late afternoon), thereby demonstrating a thermal lag of more than 8 hours.

Inside Temperature is less than outside temperature from 8 AM in the morning to 7 PM at night during summer.

KEY OBSERVATIONS: Mean temperature inside the hut during summer which remains at constant between 34.7 to 34.9 degrees Celsius needs to be decreased for better thermal comfort inside.

The above data taken matches with the simulation results derived from Ecotect Software for the same room on 29th May.

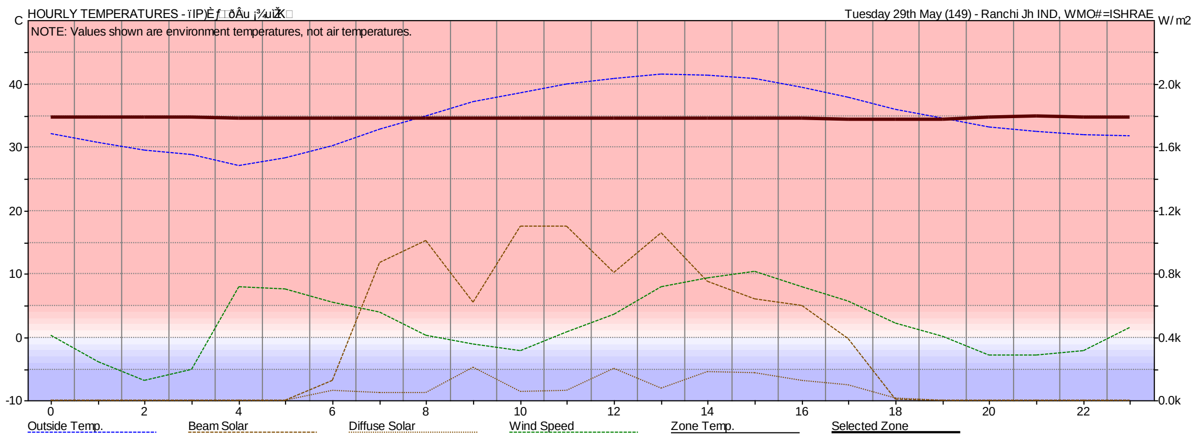

Table 2: Ecotect simulation result : hourly temperatures : south zone room, 29th May

HOURLY TEMPERATURES - Tuesday 29th May.

2.4 Temperatures taken during one of the coldest days of the year. *(in the coldest period)*

HOURLY TEMPERATURES - Thursday 4th January
Zone: south room, Avg. Temperature: 14.3 C

HOUR	INSIDE (C)	OUTSIDE (C)	TEMP.DIF (C)
00	15.2	11.4	3.8
01	15.2	11.2	4.0
02	15.0	9.2	5.8
03	15.0	8.4	6.6
04	14.8	6.8	8.0
05	14.8	7.3	7.5
06	14.8	8.9	5.9
07	14.8	10.8	4.0
08	14.9	13.3	1.6
09	15.1	15.4	-0.3
10	15.1	17.2	-2.1
11	15.3	18.0	-2.7
12	15.2	18.6	-3.4
13	15.2	18.6	-3.4
14	15.1	18.7	-3.6
15	15.0	18.2	-3.2
16	14.8	17.6	-2.8
17	14.6	16.2	-1.6
18	14.6	14.9	-0.3
19	14.7	13.4	1.3
20	14.7	12.6	2.1
21	14.9	11.9	3.0
22	15.3	11.6	3.7
23	15.2	10.8	4.4

Table 3: Hourly Inside and OutsideTemperatures measured in south zone room, 4th January

OBSERVATIONS: As seen in the summer-time case constant inside temperatures inside the room are maintained in spite of fluctuating outside temperatures. The heat stored during day is released at night in winter which offsets the dip in night temperatures outside to some extent. This is again due to the thermal lag in the conduction of heat gained in daytime by the mud walls.

However, the temperatures inside should ideally be increased by a small amount to ensure better thermal comfort for the inhabitants of the hut.

The above data taken matches with the simulation results derived from Ecotect Software for the same room on 4th January 2012.

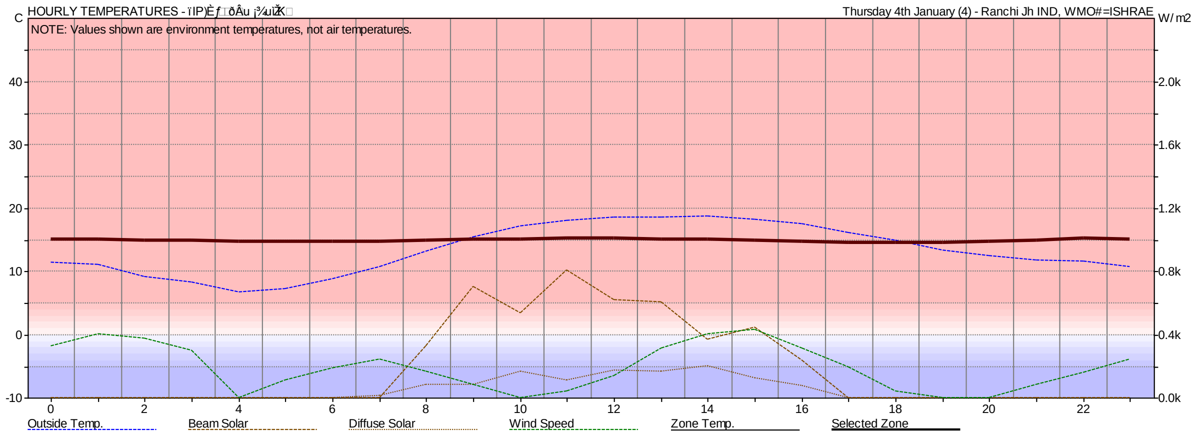

Table 4: Ecotect Simulation Result: hourly temperatures, south zone room, 4th January.

2.5 Temperature measurements taken during one of the windiest days of the year (in windiest period of the year as per past 10 years data)

HOURLY TEMPERATURES - Friday 27th July

Avg. Temperature: 24.7 C

HOUR	INSIDE (C)	OUTSIDE (C)	TEMP.DIF (C)
00	27.4	24.3	3.1
01	27.3	24.4	2.9
02	27.3	24.0	3.3
03	27.3	23.9	3.4
04	27.2	22.4	4.8
05	27.0	22.7	4.3
06	27.1	23.1	4.0
07	27.1	23.6	3.5
08	27.1	23.9	3.2
09	27.5	24.0	3.5
10	27.6	24.0	3.6
11	27.7	24.0	3.7
12	27.4	23.9	3.5
13	27.6	24.0	3.6
14	27.5	24.1	3.4
15	27.6	24.1	3.5
16	27.4	24.0	3.4
17	27.2	23.8	3.4
18	27.1	23.5	3.6
19	27.1	23.2	3.9
20	27.1	23.0	4.1
21	27.2	23.0	4.2
22	27.3	23.0	4.3
23	27.3	23.1	4.2

Table 5: Hourly Inside and OutsideTemperatures measured in south zone room, 27th July

ANALYSIS & OBSERVATIONS: On data collected during the windiest day, wind speed reduces exterior temperature but not internal temperature to that extent, which remains at a constant of near about 25 degree Celsius, about 1 degree to 2 degrees more than the outside temperature.

For ideal thermal comfort the temperature can be reduced by 1 to 2 degrees more by allowing more amount of air into the house in windy periods, which is not happening now.

Thus more of the exterior wind needs to be channelled in to the interior, necessitating more ventilation. Venturi Effect can be utilized during these high wind velocity times and otherwise too when wind velocity is average through small openings, keeping the openings closed during periods when wind movement is absent or negligible.

The typical rural huts of Jharkhand, as has been mentioned earlier incorporate cluster type of planning, so these clusters can be slightly modified to allow each individual dwelling unit to catch as much wind as possible, which can bring down summer temperatures to more comfortable levels**. (Figures 7, 8, 9, 10 & 11)** An air speed of 0.5m per second equates to a 3 degree drop in temperature at relative humidity of 50 per cent and a maximum DBT of 40 degree Celsius.

Figure 7: *Courtyard type planning in clusters in studied hut.*

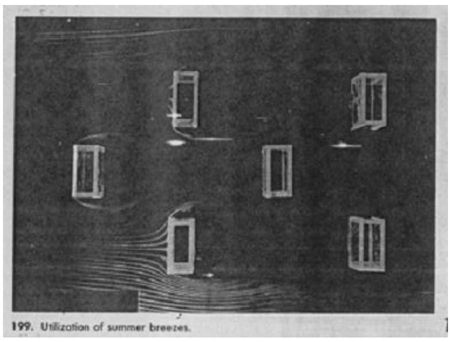

Figure 8: *Probable arrangement of huts in a slight variation of the already existing courtyard type planning to channelize cooling breezes in summer.*

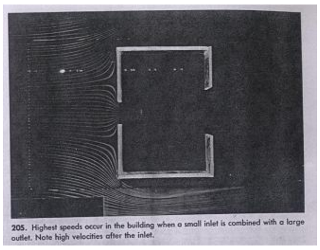

Figure 9: *Venturi Effect to facilitate wind circulation inside hut. Small inlet opening, large outlet.*

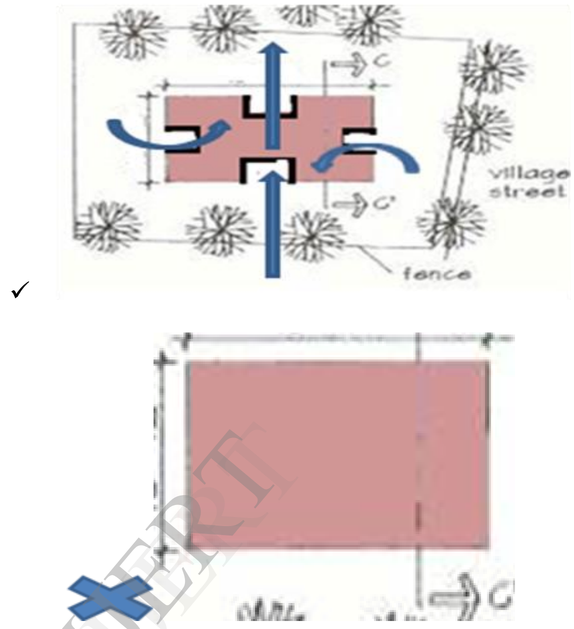

Figure 10: *Recessed porch provides ventilation for inner area of house*

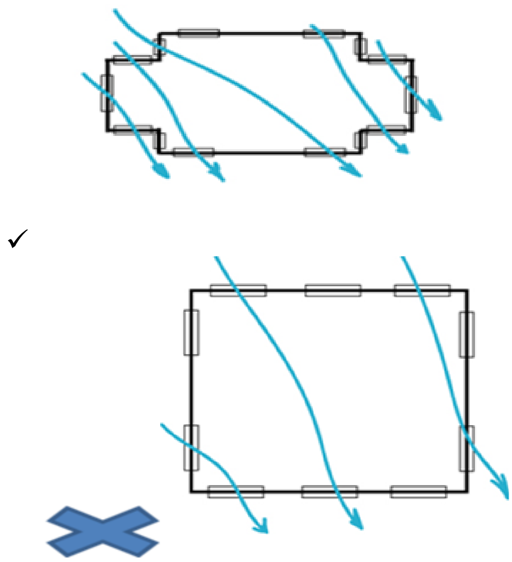

Figure 11: *increased airflow through the home is possible by substituting the simple "box" design for one with more corners in it. This will allow greater airflow through the home.*

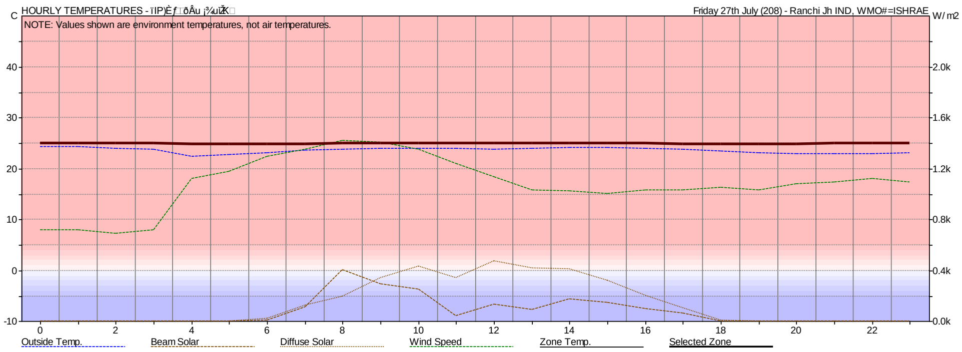

Table 6: Ecotect Simulation Result: hourly temperatures, south zone room, 27th July

The above measurements taken matches with the simulation results derived from Ecotect Software for the same room on 27th July2012.

Now that on-site measurements have been taken and the results tallied with those which have resulted out of software simulation results, we need to investigate as to what exact reasons are causing the summer temperature to remain high inside, above the comfort level and what is causing the winter temperatures to remain slightly lower than the desired comfort level. Answers as to where are the exact areas where heat is been undesirably gained and lost are sought through Ecotect Software Simulation Analysis.

3.0 Ecotect Software Simulation Analysis

We begin with inter-zonal heat gains and losses. Inter-zonal heat gains and losses, refers to the heat exchange considering the inside of the dwelling unit as a zone and the outside atmospheric surroundings of the dwelling unit as another zone. A study of the inter-zonal heat gain/loss in both Zone 1 (Southern Zone) and Zone 2 (North Zone) shows the following results.

3.1 Hourly Gains, Zone 1, i.e. South Zone.

3.1.1 PEAK SUMMER CONDITION

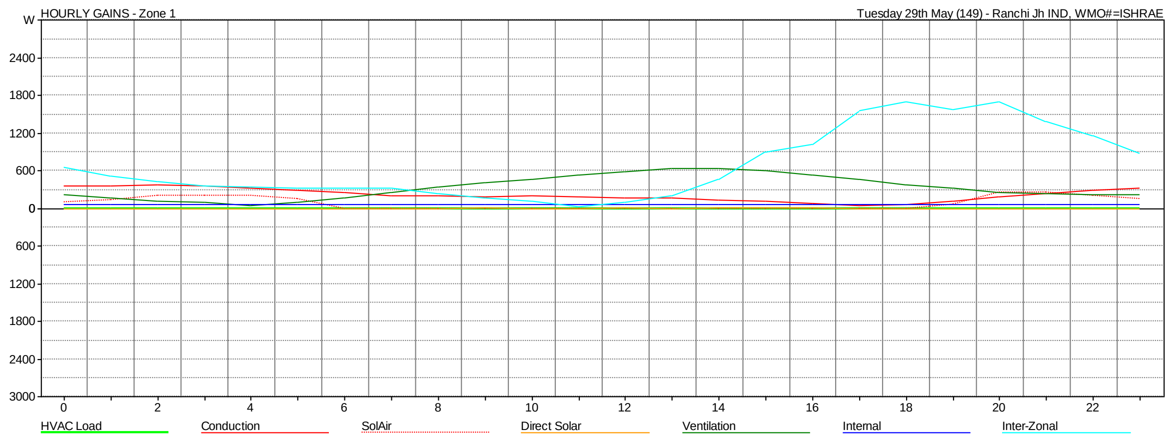

Table 7: Different sources of hourly heat gains,South Zone, 29th May-Ecotect Simulation

Inter-zonal heat gain is most during 4:00 PM in late afternoon to 9 PM at night, resulting in increased temperature inside the hut, ranging from 1063 watt to a maximum of 1711 watts (at 7 PM in the evening). This needs to be rectified and roof and wall insulation improved.

Heat gains through ventilation are another cause of substantial heat gain.

3.1.2 AFTER ROOF INSULATION: In simulation taken after providing insulation to the roof with gyproc/glasswool/rockwool, Peak Hour Heat Gain reduces from 1711 Watts to 1187 Watts. Total heat Gain in summer reduces from 16640 Watts to 12565 Watts.

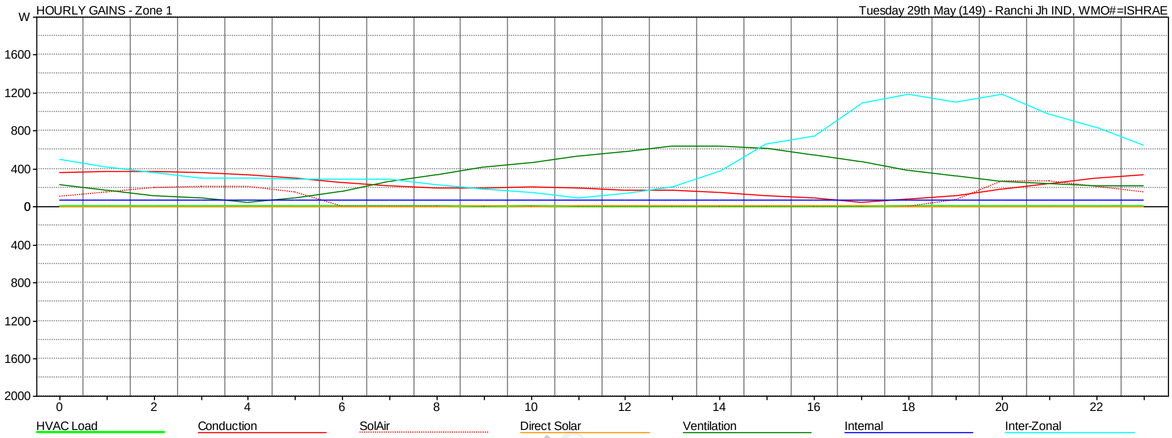

Table 8: Different sources of hourly heat gains,South Zone, 27th May-Ecotect Simulation-after roof insulation.

3.1.3 PEAK WINTER CONDITION

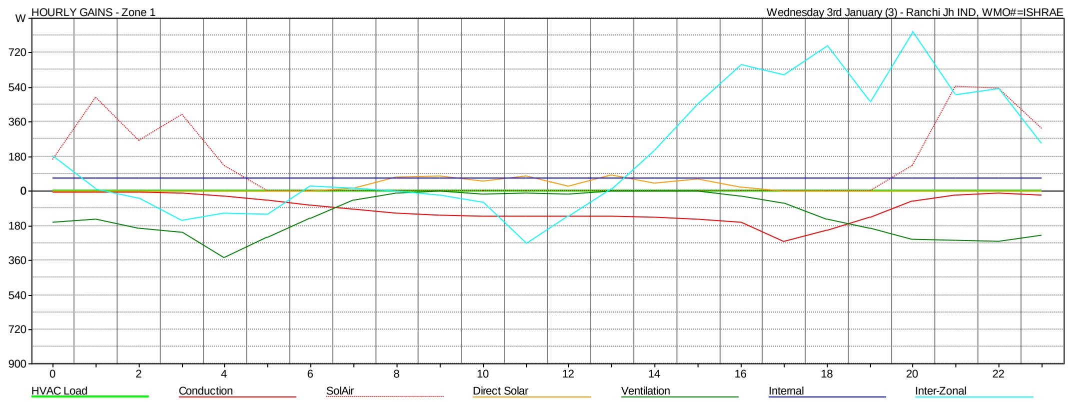

Table 9: Hourly heat gain/loss during peak of winter-South Zone-Ecotect Simulation

In winter, heat is lost between 1 AM at night to 2 PM in the afternoon, and a maximum heat-loss of 270 watts at 11 AM in morning.

Ventilation heat loss is another major reason of heat loss in winter.

3.1.4 AFTER ROOF INSULATION:

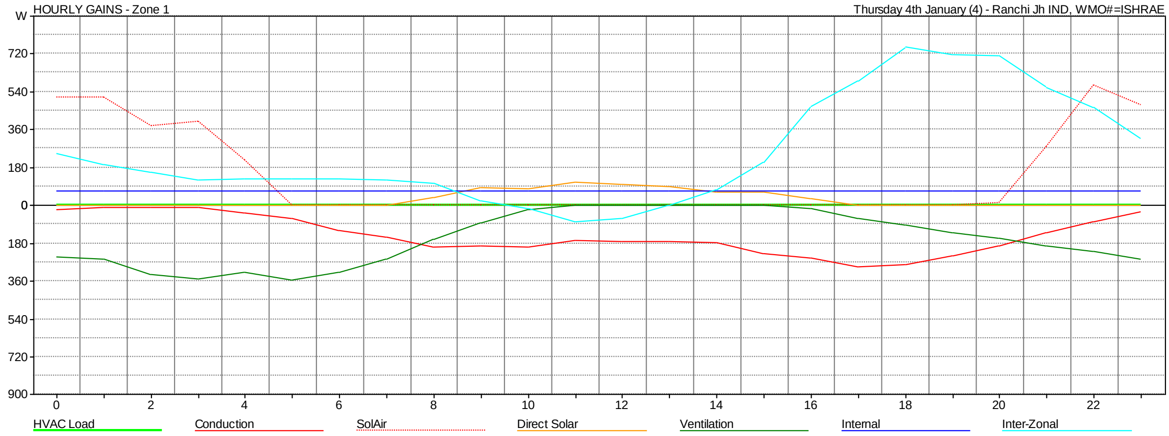

Table 10: Hourly heat gain/loss during peak of winter after roof insulation-South Zone-Ecotect Simulation

Heat loss in winter reduces from peak hour heat loss of 270 Watts to a maximum peak hour loss of 79 Watts.

3.2 HourlyHeat Gain, Zone 2, i.e. North Zone.

3.2.1 PEAK SUMMER CONDITION

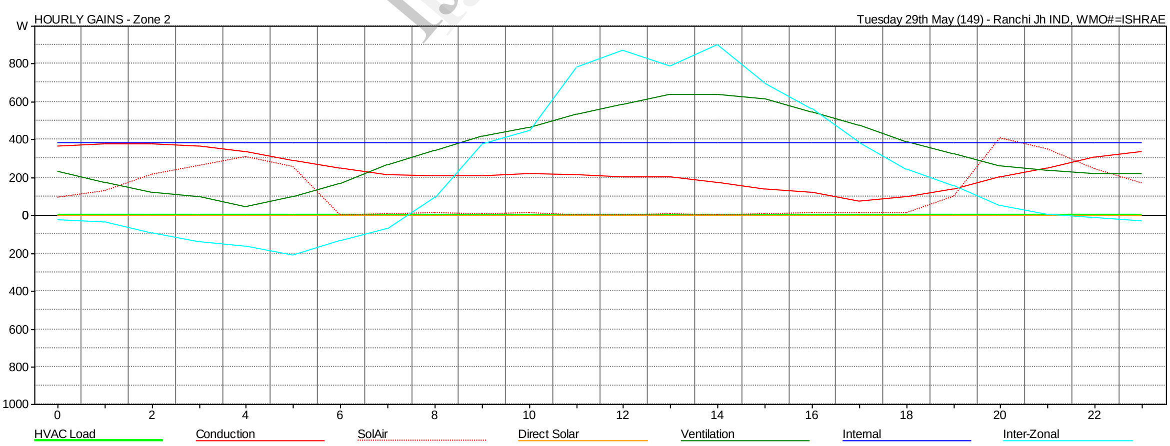

Table 11: Hourly Heat Gains-North Zone, 29th May-Ecotect Simulation

Main sources of heat gain in north zone on a typical day in peak summer are through ventilation heat gains, building fabric/skin heat gain and inter-zonal heat gain.

Other than roof-insulation, building skin also requires further insulation to reduce heat gain through building fabric.

3.2.2 AFTER ROOF INSULATION:

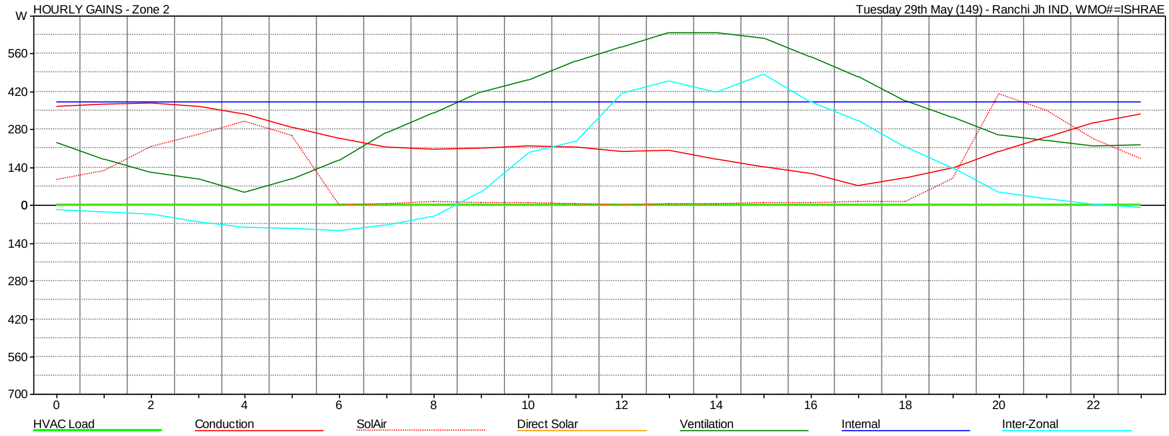

Table 12: Hourly Heat Gains after roof insulation-North Zone, 29th May-Ecotect Simulation

After Roof insulation with rockwool/glasswool/gyprock, peak hour inter-zonal heat gain comes down from 900 Watts to 481 Watts in summer on the hottest summer day (peak summer temperature day) and total diurnal heat gain through inter-zonal gains comes down from 5451 Watts to 2856 Watts.

3.2.3 PEAK WINTER CONDITION

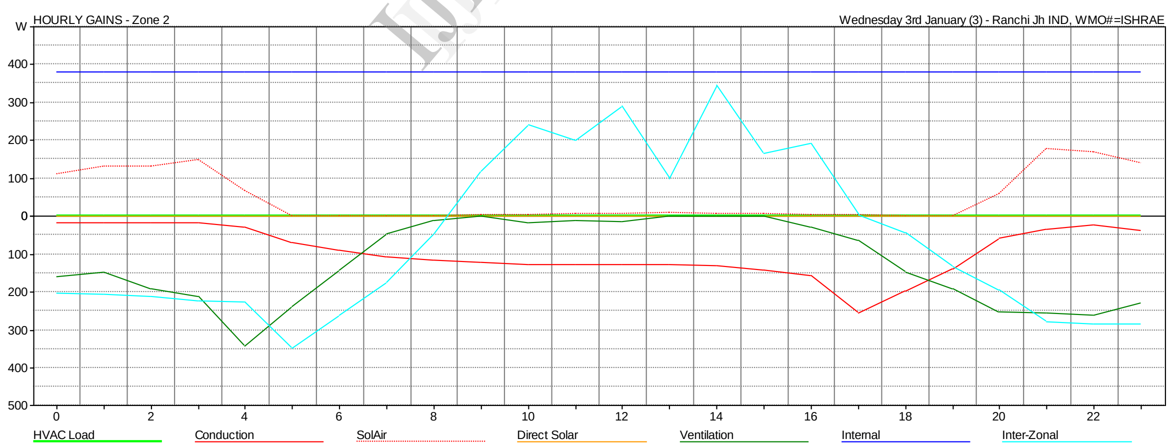

Table 13: Hourly Heat Gains/losses -North Zone, Peak Winter-Ecotect Simulation

Main sources of heat loss in winter are, in descending order: ventilation heat loss, inter-zonal heat loss and heat loss through building fabric/skin.

Other than roof-insulation, building skin also requires insulation to reduce heat loss through building fabric.

3.2.4 AFTER ROOF INSULATION -

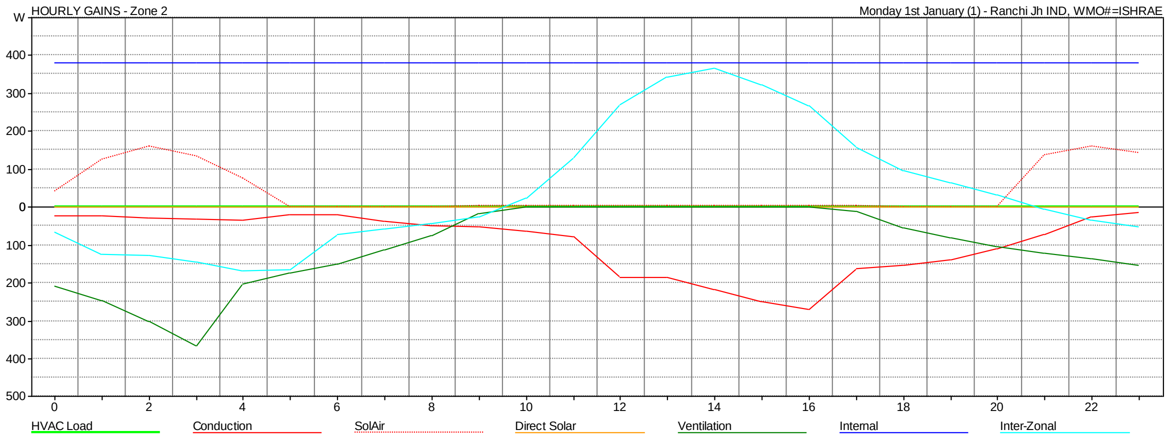

Table 14: Hourly Heat Gains/losses after roof insulation -North Zone, Peak Winter-Ecotect Simulation

Amount of Heat loss on peak winter day decreases considerably. (From peak hour heat loss of about 348 Watts to 160 Watts). (**Figure 12**)

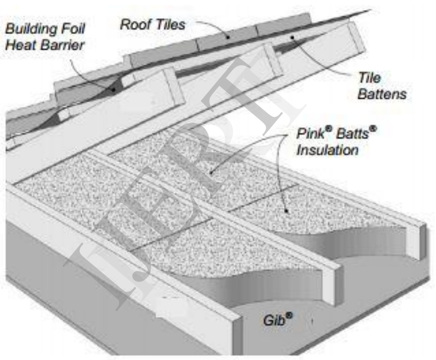

Figure 12: *Probable insulation using gypsum/gyprock/glasswool in clay tiled pitched roof.*

3.2.5 Time during which Inter-zonal Heat Gain happens in South Zone

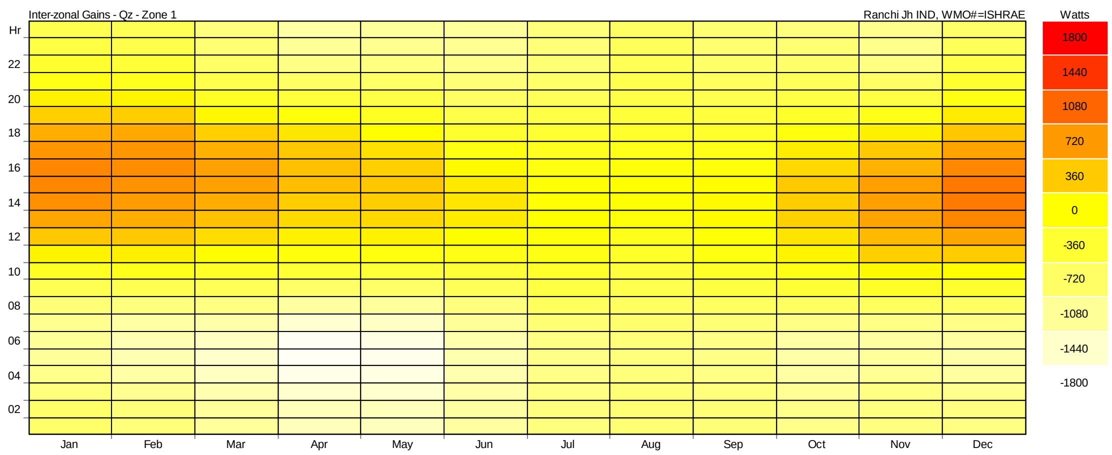

Table 15: Winter-time effective inter-zonal heat gain in Zone 1, viz. South Zone

In South Zone, peak amount of heat gain that occurs in winter is actually desirable.

3.2.6 Time during which Inter-zonal Heat Gain occurs in Northern Zone

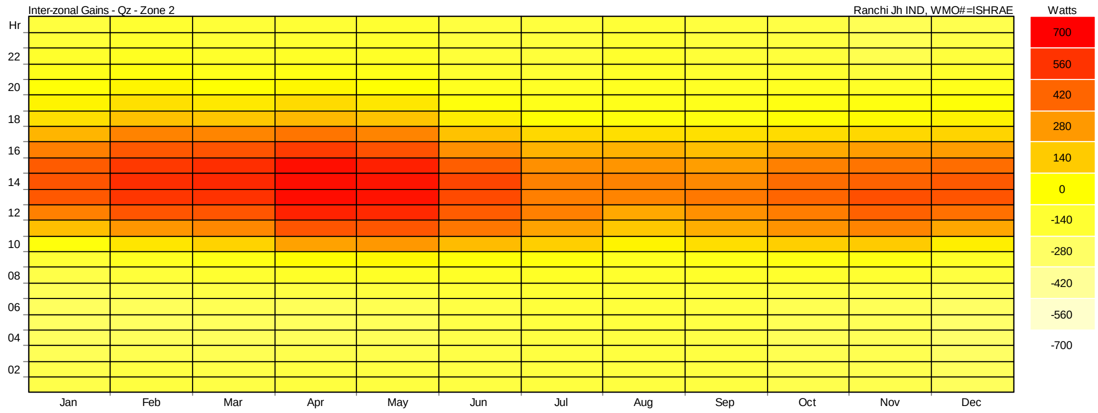

Table 16: Time during which Inter-Zonal heat gain occurs in Zone 2, viz. Northern Zone

In the Northern Zone, this graph shows that inter-zonal heat gains occur at the worst possible time, afternoon and late afternoon, especially pronounced in April and May. Steps should be taken to reduce this.

3.3 Ventilation Gains: South Zone

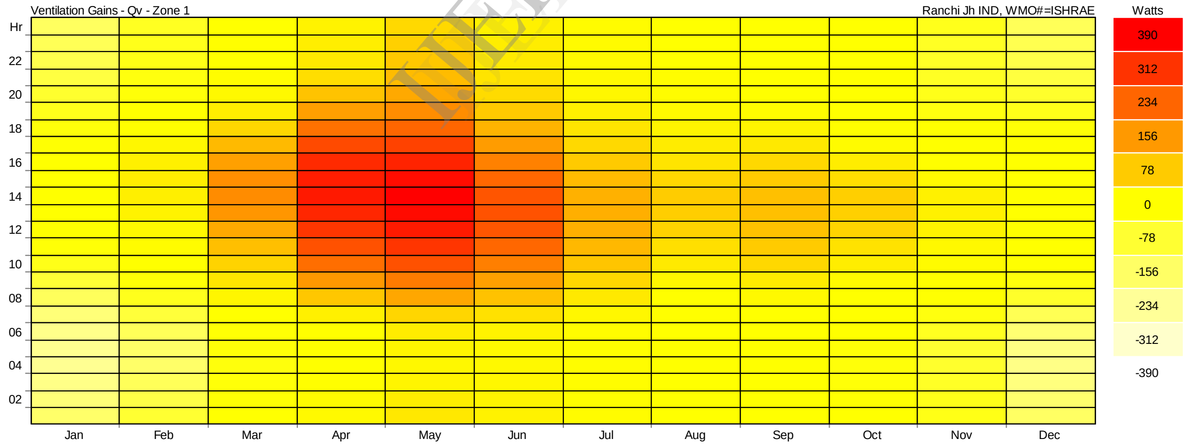

Table 17: Ventilation Gains: South Zone

Ventilation heat gains in South Zone are mainly from 10 AM in the morning to 5 PM in the evening from April to June. Thus, external windows need to be kept closed during this duration in the peak summer months of April, May to June.

3.3 Ventilation Gains: North Zone

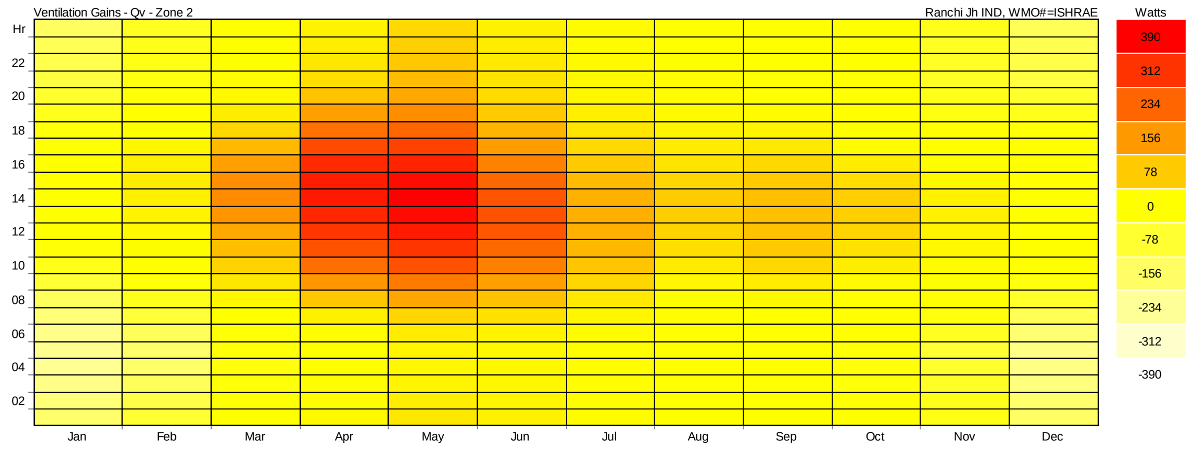

Table 18: Ventilation Gains: North Zone

Primarily in April, May and June heat gain is maximum, in between 10 AM in the morning to 4 PM in the afternoon. Windows to be closed during that time.

3.4 Building Fabric Heat Gains: South Zone

In South Zone Sleeping Room, the heat gains through building fabric are as follows:

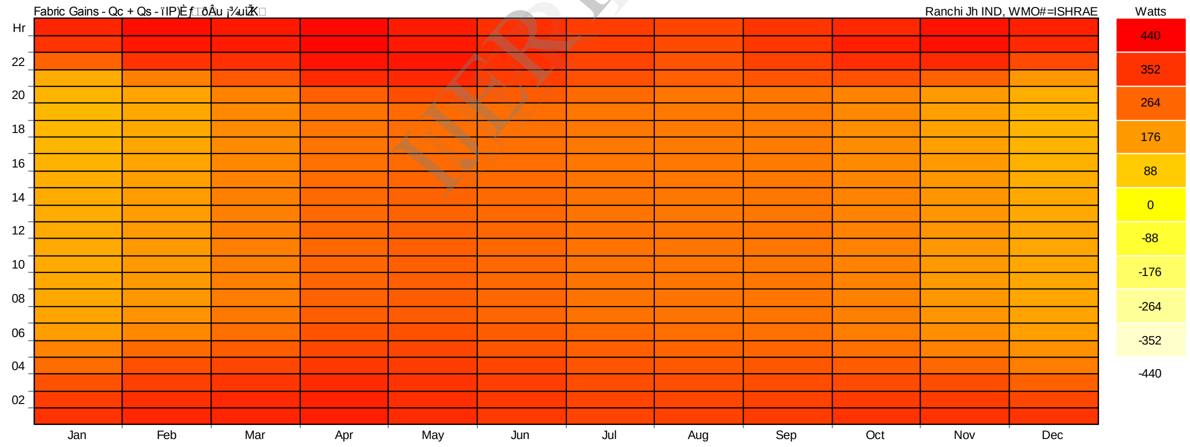

Table 19: Building Fabric Heat Gains: South Zone

This shows that heat gains from the building fabric, due to both external temperatures and incident solar radiation; occur mainly from about 10 PM at night to 4 AM in morning in winter. It also shows that summer gains occur from about 10 PM at night to 3 AM in the morning in a pronounced way and throughout the day from 4 AM to 10 PM at night in a less pronounced way. This is mainly because the sun rises earlier in summer and spends longer time heating up the east wall and due to the thermal time-lag factor of mud.

3.5 Indirect solar Gain: South Zone

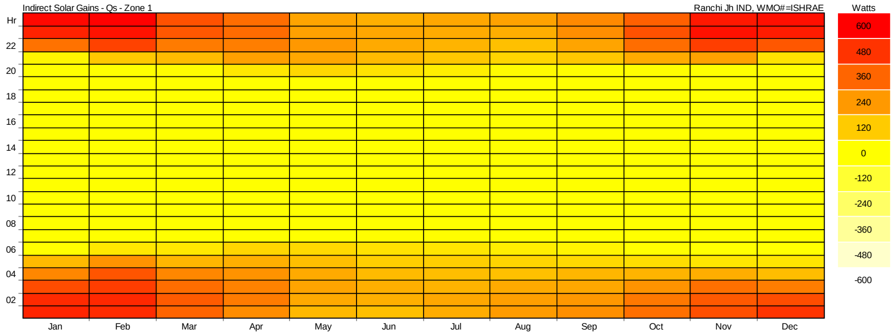

Table 20: Indirect solar Gain: South Zone

The above suggests that some form of temporary summer-time shading on the east side is required, but something that doesn't adversely affect morning winter gains. (**Figure 13**) **Indirect solar gains** can be controlled by shading the east and west walls, or by using a white colour external finish on facade.

3.6 Indirect solar Gain: North Zone

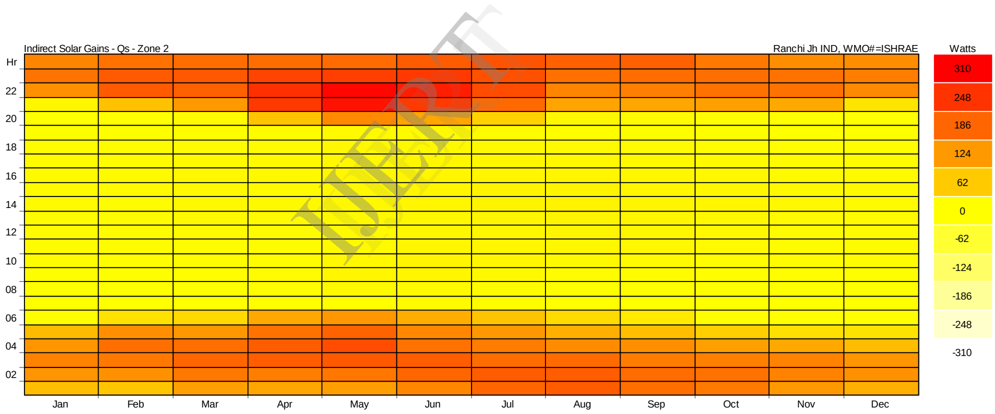

Table 21: Indirect solar Gain: North Zone

3.7 direct solar Gain: South Zone

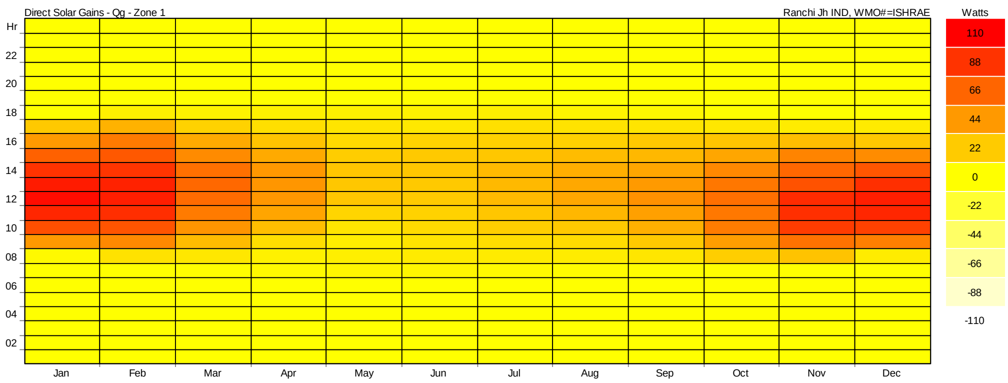

Table 22: Direct solar Gain: South Zone

No shading on Southern walls needed. Only shading of south window with sun shade is required. South wall is contributing to winter time heating.

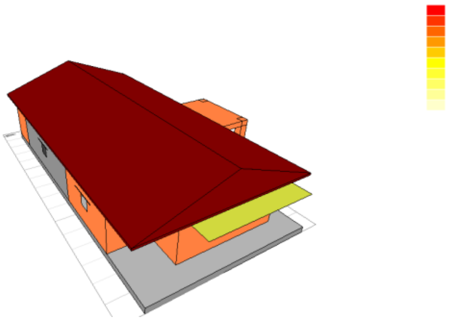

Figure 13: *Probable removable in winter shading options on east wall.*

3.8 Discomfort degree hours-measurement in terms of thermal comfort –Zone 1 and Zone 2.

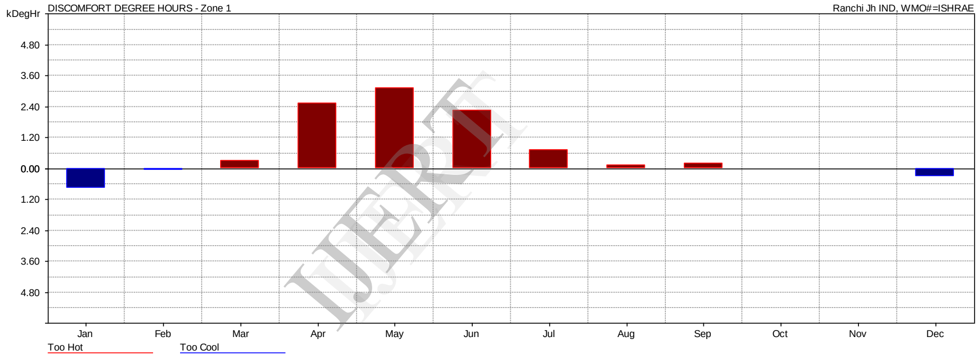

Table 23: Discomfort degree hours-measurement in terms of thermal comfort ,Zone 1

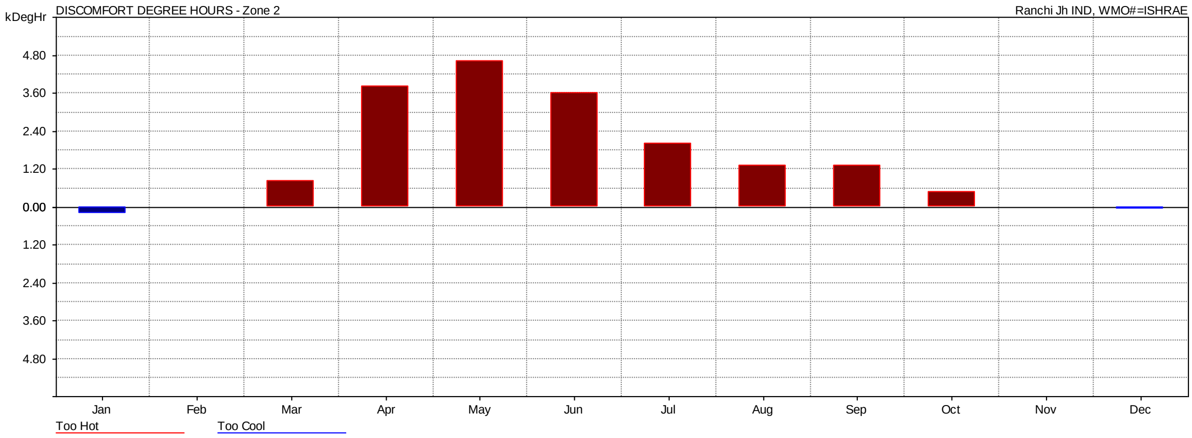

Table 24: Discomfort degree hours-measurement in terms of thermal comfort ,Zone 2

Observations: Discomfort Degree Hours is more in South Zone (Zone 1) in winter than that in the North Zone, whereas discomfort degree hours is slightly more in North Zone(Zone 2) in summer than that in the South Zone. Thus it necessiates more winter heating through passive design methods in the Southern side in winter and more shading in the northern side in summer.

3.9 Heat Gains Breakdown - Zone 1(summer time)

FROM: 1st April to 30th September

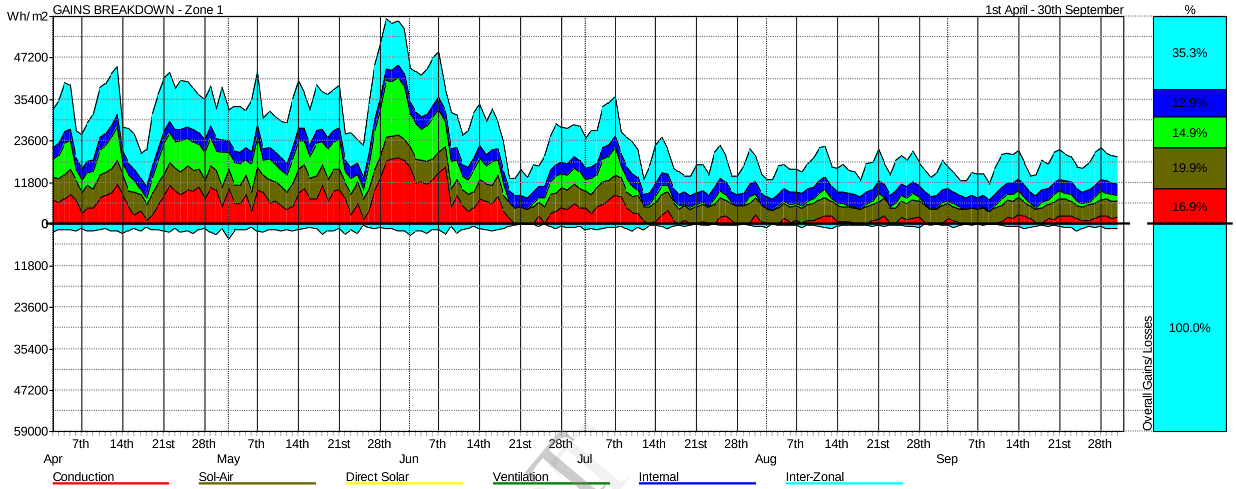

Table 25 a: Heat Gains Breakdown – South Zone, 1st April to 30th September

Dwelling Unit Heat Gain:

CATEGORY GAINS

FABRIC	16.9%
SOL-AIR	19.9%
VENTILATION	14.9%
INTERNAL	12.9%
INTER-ZONAL	35.3%

Table 25 b: Heat Gains Breakdown - 1st April to 30th September (South Zone)

The above table summarizes the main causes of heat gain in summer time, out of which inter-zonal heat gain is the major heat gain. Sol-Air heat gain, heat gain through external building walls and heat gain through ventilation are other major sources of heat gain.

3.10 Heat Gains/Losses Breakdown - Zone 1(winter time)

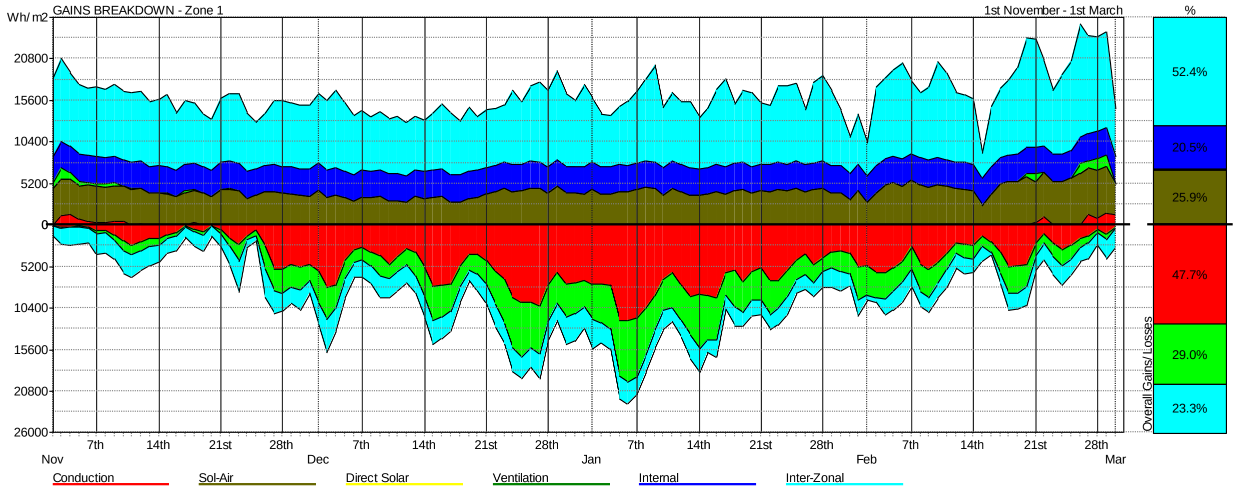

Table 26a: Heat Gains/Losses Breakdown- South Zone-1st November to 1st March

GAINS & LOSSES BREAKDOWN - Zone 1(winter time)

FROM: 1st November to 1st March

CATEGORY	LOSSES	GAINS
FABRIC	47.7%	0.6%
SOL-AIR	0.0%	25.9%
SOLAR	0.0%	0.0%
VENTILATION	29.0%	0.6%
INTERNAL	0.0%	20.5%
INTER-ZONAL	23.3%	52.4%

Table 26b: Heat Gains/Losses Breakdown- South Zone-1st November to 1st March

In winter, Inter-Zonal Heat Gain is the primary cause of heat gain. Whereas, with respect to heat loss during winter, main heat loss is through building fabric, that is building skin. Thus to minimize winter time heat loss, it is required to properly insulate building external walls.

3.11 Simulations showing the existing temperature levels in the south side sleeping room at different times.

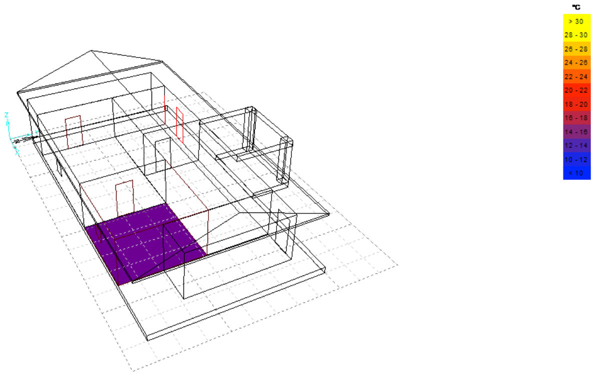

***Figure 14a**: 6 am on 5 January – 14-16 degree Celsius (south side sleeping room)*

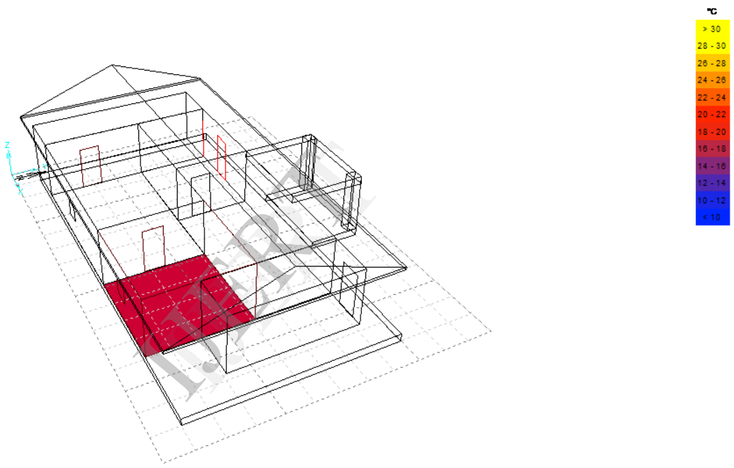

***Figure 14b:** 5 Jan. 12 noon – 16-18 degree Celsius.*

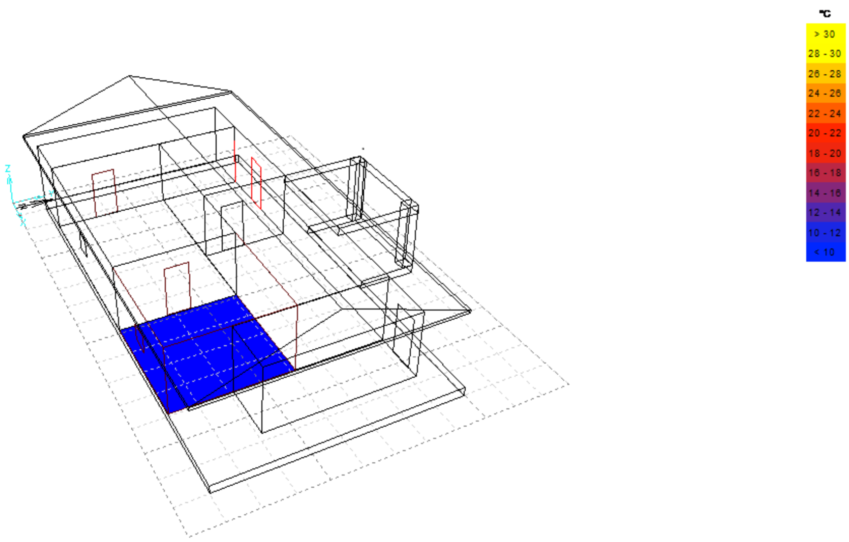

***Figure 14c:** 11:45 PM, near midnight, 5 Jan- 12 degree Celsius*

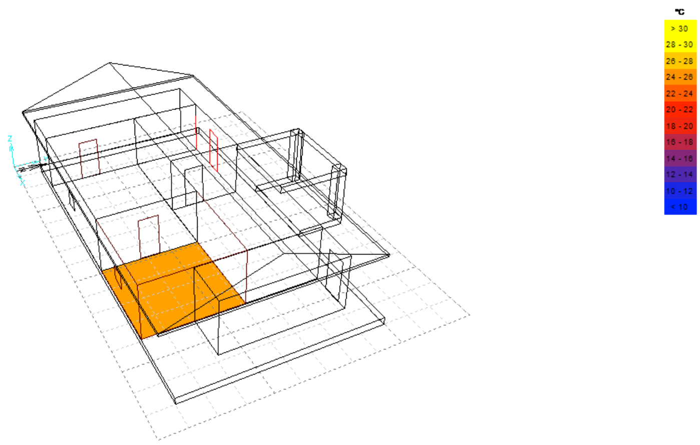

Figure 14d: 17 April 12 Midnight – 24-26 degrees celsius

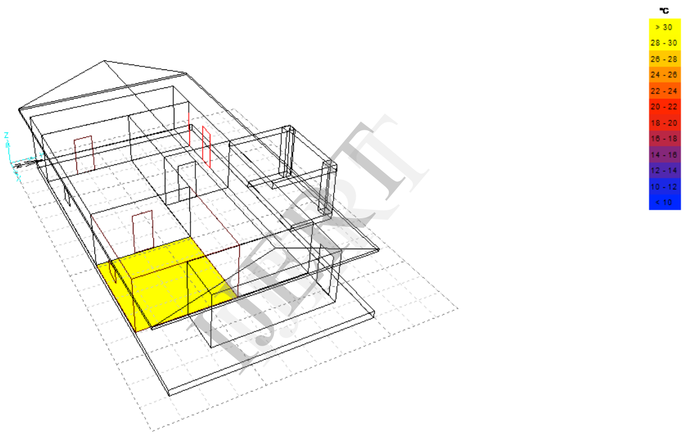

Figure 14e: 15 May 10 PM-32 degrees celsius

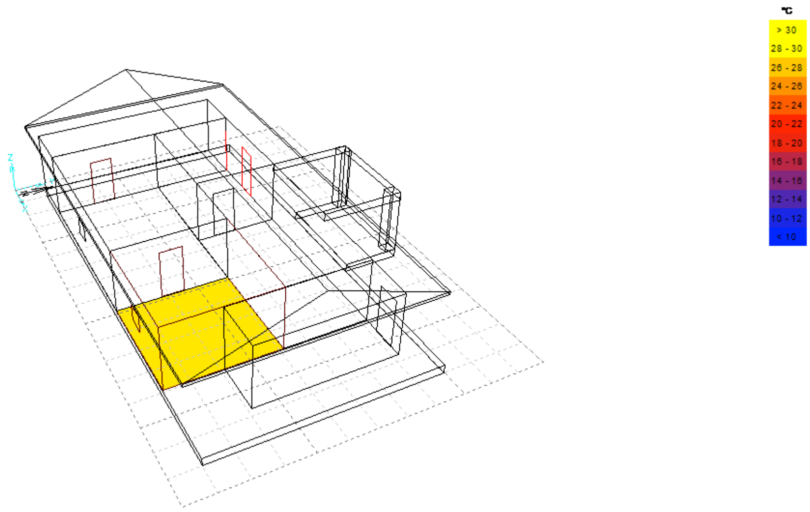

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Figure 14f: July 12 Noon-32 degree Celsius

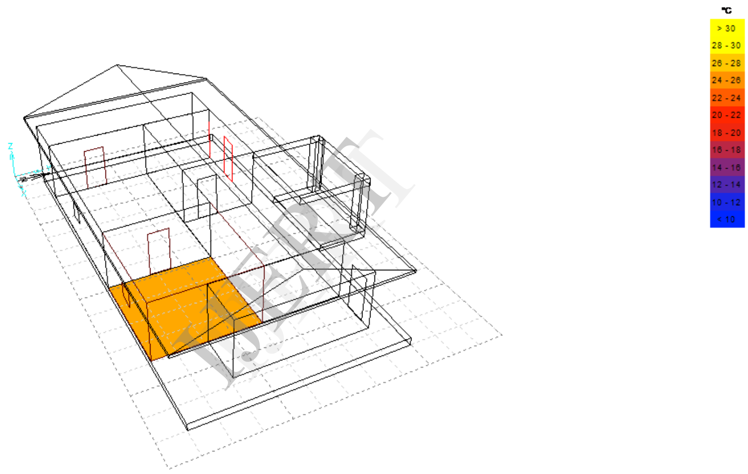


Figure 14g: 1 oct 12 noon- 24 to 26 degree Celsius

3.12 Thermal dissatisfaction percentages

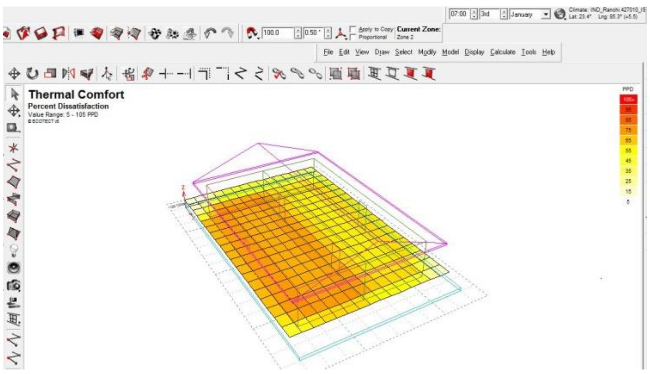


Figure 15a: Thermal dissatisfaction percentages, 7 AM, 3rd January

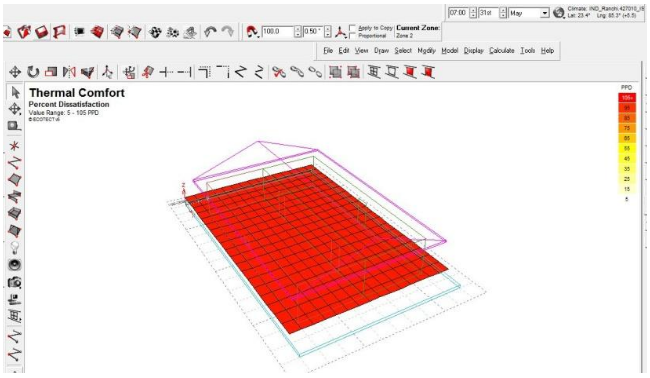


Figure 15b: Thermal dissatisfaction percentages, 7 AM, 31ST May

Observations: In peak winter southern zone of dwelling unit more comfortable than northern zone at 7 AM in the morning.

Also, in extreme summer both parts of the house is equally uncomfortable at 7 AM in the morning.

4.0 Some other general parameters based on which comfort conditions inside hut can be improved are listed below other than the specific factors identified in studied hut:

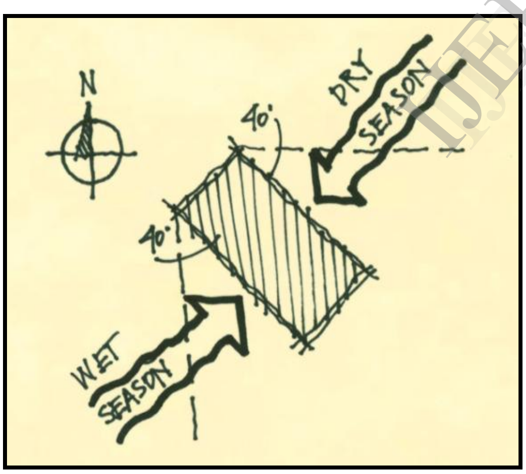
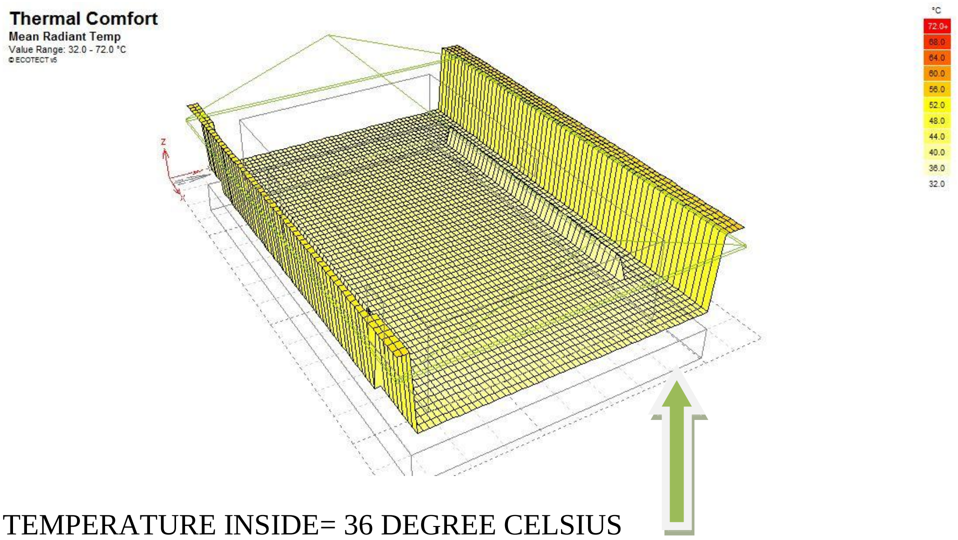


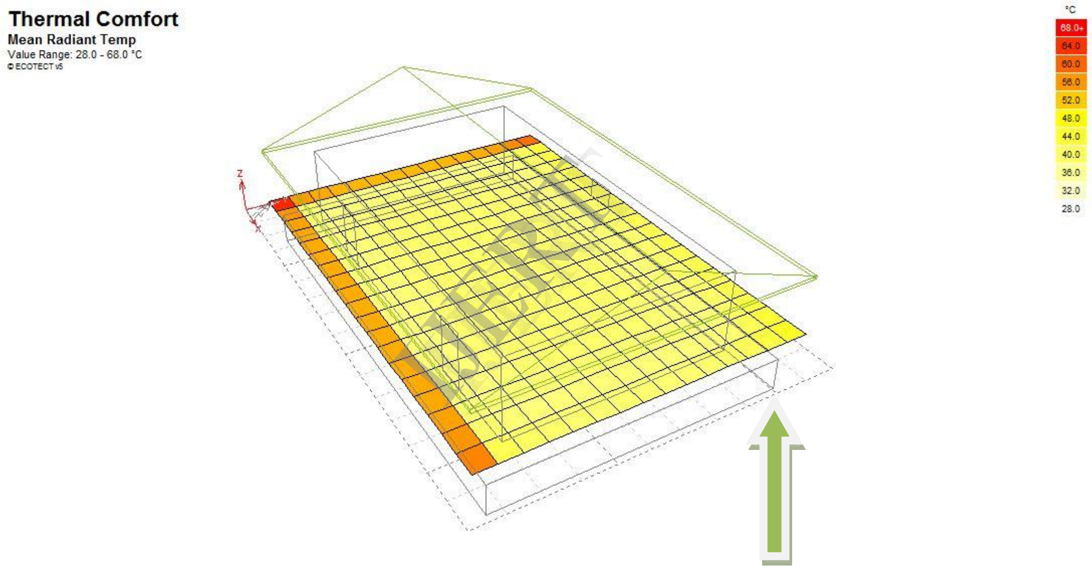
Figure 16: *Ideal orientation in Indian conditions*

4.1 Ideal Orientation**:** Ideal orientation in Indian conditions for sub-tropical /composite climatic conditions for least summer heat gain and maximum winter heat gain, along with proper ventilation is as shown in the figure with longer side aligned along north-west, south-east making an angle of 45 degrees with the east-west axis. (**Figures 16 & 18**)



TEMPERATURE INSIDE= 36 DEGREE CELSIUS

Figure 17: *Ecotect software analysis of simulated study-hut – Mean radiant temperature (Thermal Comfort) inside mud hut at 12 Noon, 1st June. East-West Orientation of house.*



TEMPERATURE INSIDE = 34 DEGREE CELSIUS (2 degree Celsius lesser than when oriented in East-West direction as studied hut is oriented)

Figure 18: *Ecotect software analysis of simulated study-hut – Mean radiant temperature (Thermal Comfort) inside mud hut at 12 Noon, 1st June longer side orientated along NW-SE direction, at an angle of 45 degrees to the East-West Axis.*

4.2 Low Surface Area to Volume Ratio**:** In composite or sub-tropical humid type climate the S/V ratio should be as low as possible as this would minimize heat gain.

The Surface Area to Volume Ratio can be reduced by using a domical or vaulted roof over a circular plan. A domical roof and vaulted roof would further reduce direct heat gain. A vault roof mud-house with roof made of stabilized mud blocks (composition: soil, sand, lime/cement and water) would be very helpful in creating better thermal comfort. The vault would also induce better convective air movement thereby cooling the internal space. Square building forms also result in lower Surface Area to Volume Ratio.

The annual heating and cooling energy saving potential of a vault roof mud-house was determined as 1481 kW h/year and 1813 kW h/year respectively for New Delhi composite climate. The total mitigation of CO_2 emissions due to both heating and cooling energy saving potential was determined as 5.2 metric tons/year. A vaulted roof would also increase the attic area, which can act as a thermal buffer and help in thermal insulation both during summer and winter.

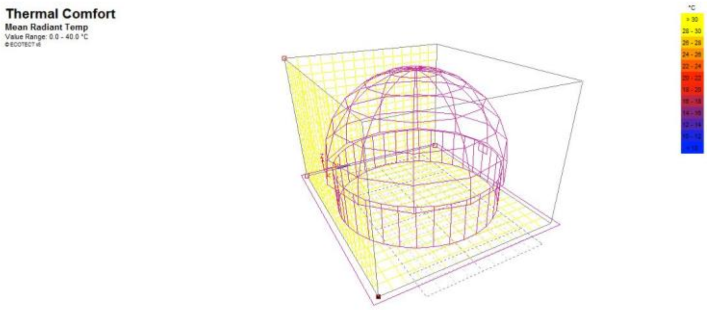


Figure 19: *Improved thermal comfort in vaulted roof building with circular plan made of stabilized mud blocks (composition: soil, sand, lime/cement and water)*

Figure 20: *Vaulted roof building made of stabilized mud blocks*

Source: Arvind Chel,G.N.Tiwari(2009), Case study of vault roof mud-house in India, Thermal performance and embodied energy analysis of a passive house, Energy, Volume 86, Issue 10, October.

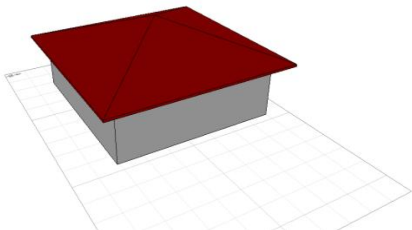


Figure 21: Square building forms also result in lower Surface Area to Volume Ratio.

***4.3 Ventilation*:** The portion through which cool air at night could come in at the top portion of the roof and through which warm air can go out by convective process has been blocked in this particular hut due to rain water coming inside the hut during rains. This causes lack of ventilation in summer and convective air flow at evening and night. A probable solution is to let the openings remain and cover them by bamboo mesh like surface to stop rain water coming in monsoons. **(Figure 22 and 23)**

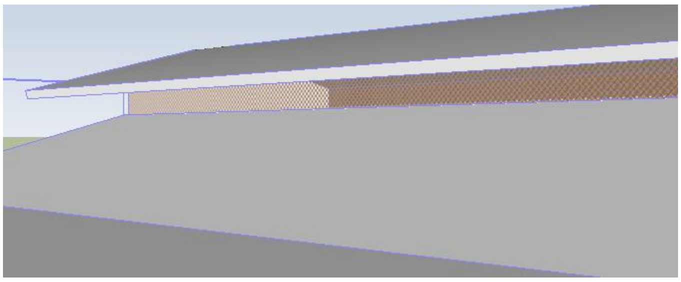


Figure 22: *Extended Eave projection & bamboo meshing to prevent rain ingress & allow ventilation*

Figure 23: *Suggested modifications for causing internal air flow*

4.4 Building Materials: The building material for the walls is mud and the roof material is Mangalore Tiles. The U value for mud is 3.44 W/sq m K & the U value for Mangalore Tiles is 3.1 W/sq m K.

Analysis: Though U value of Mangalore/Clay Tiles and *khapra* used is not that high, the insulating property of thatch is much more, as its U value is even lesser. So in summer, it keeps the inside of the hut even cooler than clay tiles do. The disadvantages associated with thatch use can be mitigated with modern day industrially improved thatch use.

Modern day thatch treated and improved industrially can also be used for mass use in rural areas, being low cost and having very good thermal properties. Thatch is a natural reed and grass which, when properly cut, dried, and installed, forms a waterproof roof. The most durable thatching material is water reed which can last up to 60 years. A water reed thatched roof, 12 inches thick at a pitch angle of 45 degrees meets the most modern insulation standards. The U-value of a properly thatched roof is 0.35 W/sq m K, which is equivalent to 4 inches of fibreglass insulation between the joists. Only in the last decade have building codes begun to demand this level of roof insulation. Yet, thatch has been providing insulation since much longer.

5.0 OUTCOMES

The Mud house studied reinforced the fact that mud as a building envelope keeps the inside of the hut cooler in summer than outside and warmer than outside in winter. However the cooling effect of these traditional mud houses can be further improved and thermal comfort conditions inside the huts improved by proper design considerations. The study brings out the following facts:

1. Arrangement of huts in a slight variation of the already existing courtyard type planning to channelize cooling breezes in summer is required. To encourage air circulation inside the dwelling unit through venturi effect it is desirable to have small inlet opening and bigger outlet opening.

2. Recessed porch provides ventilation for inner area of house.

3. Increased airflow through the home is possible by substituting the simple “box” design for one with more corners in it. This will allow greater airflow through the home. But at the same time, care must be taken to ensure that surface-volume ratio remains relatively less. Square with corners cut in cruciform shape will work well.

4. Proper insulation of roof causes marked decrease in heat gain in summer and heat loss in winter. Roof can be insulated using gyprock, glasswool or gypsum in clay tiled pitched roof.

5. Shading west and east walls will reduce heat gain in summer to a large extent. Temporary summer time shading of east wall will be beneficial.

6. No shading on Southern walls needed. Only shading of south window with sun shade is required as South wall is contributing to winter time heating.

7. South side window opening needs to be closed in between 12 Noon and 4 PM in the afternoon during summer to reduce heat gain through ventilation as illustrated by Ecotect Simulations.

8. Indirect solar gains can be controlled by shading the east and west walls, or by using a white colour external finish on facade.

9. More winter heating through passive design methods in the Southern side of the dwelling unit is necessary in winter and more shading in the northern side in summer is necessary.

10. To minimize winter time heat loss, it is required to properly insulate building external walls.

11. Improved thermal comfort is possible in vaulted roof building with circular plan made of stabilized mud blocks (composition: soil, sand, lime/cement and water) as per Ecotect Simulation Analysis.

12. Mean radiant temperature inside mud hut at 12 Noon on 1st June with longer side orientated along NW-SE direction, at an angle of 45 degrees to the East-West Axis is 2 degree lesser than same dwelling unit oriented along east-west axis under similar conditions as per Ecotect Simulation Analysis.

6.0 ACKNOWLEDGEMENTS

The authors wish to acknowledge help of Mr Dipon Bose (third year B.Arch student, BIT, Mesra, Ranchi) for helping carrying out measurements in mud-house.

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