Testing and quantifying the thermal performance of various Roof Sections for building heat gain by live Case studies

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Abstract : Roof is a most important building element not only for aesthetics or shelter but also for thermal performance of building and also create habitable environment below the structure for the users. If we consider climatic parameters, it increases the complexity to design the roof because roof plays a major part for heat gain inside building. The thermal performance of a roof is difficult to analyze because it is constraint by complex different parameters of climate Ex. Solar Radiation, cloud condition, Wind etc…

Designers consider lot of parameters to design roof for an example, materials, texture, form of roof, context amalgamation and structures, but considering the thermal performance of roof becomes very difficult because thermal properties of designed roof materials are not ready available. For understanding of thermal performance of roof building has to go for simulation process through the simulation we can identify the heat gain by the designed roof section. It has been proved that simulation data is not as accurate as really time reading because of climate change. This research focus on testing and quantifying the thermal performance of roofs based on live roof sections reading considering the existing parameters of climate of Indian cities. This Research helps designers to understand the thermal performance of roof and also to refer roof sections for building design.

Keywords: Solar Heat gain Coefficient (SHGC), U-value, Reflective Index, R-value, Heat Gain.

1. Introduction

The Thermal Performance of a building depends on a large number of factors. They can be summarised as (i) design variable (geometrical dimensions of building elements such as walls, roof and window, orientation, shading devices etc.): (ii) material properties (density, specific heat, thermal conductivity, transmissivity, etc.): (iii) weather data (solar radiation, ambient temperature, wind speed, humidity, etc.): and (iv) a building's usage data (internal gains due to occupants, lighting and equipment, air exchanges, etc.) (Energy conservation Building Code, 2017)

A block diagram showing various factors affecting the heat balance of a building is presented in Fig.1.

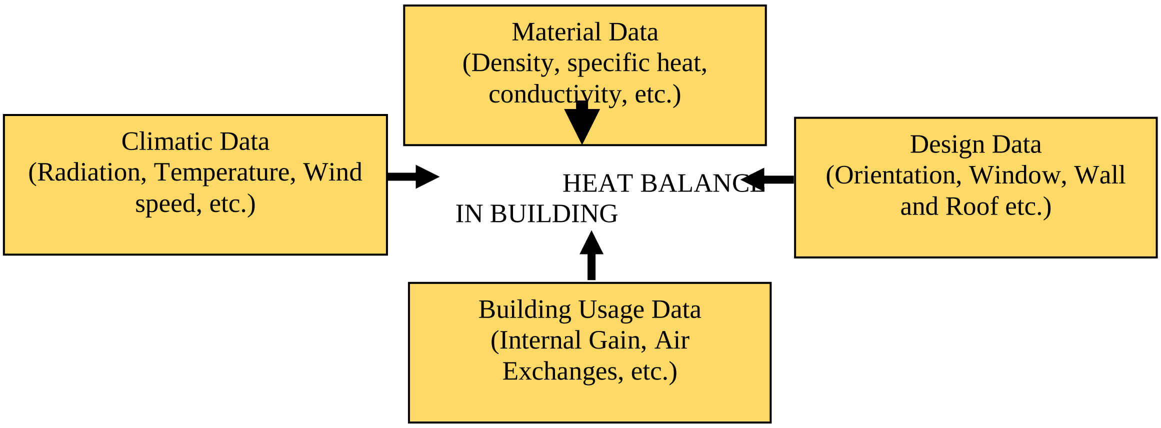

Figure 1 Heat Exchange In Building

The influence of these factors on the performance of a building can be studied using appropriate analytical tools. Several techniques are available for estimating the performance of buildings. They can be classified under steady state methods, dynamic methods and correlation methods. Some of the techniques are simple and provide information on the average load or temperature, on a monthly or annual basis. Others are complex and require more detailed input information. However, the letter perform a more accurate analysis and provide results on an hourly or daily basis. (Energy conservation Building Code, 2017)

To understand the process of heat conduction, convection and radiation occurring in a building, consider a wall having other surface ne surface exposed to solar radiation and the other surface facing a room. Of the total solar radiation incident on the outer surface of the wall, a part of it is reflected to the environment. The remaining part is absorbed by the wall and converted into heat energy. A part of the heat is again lost to the environment through convection and radiation from the wall's outer surface. The remaining part is conducted into the wall: where it is partly stored- thereby raising the wall temperature- while the rest reaches the room's interior surface. The inner surface transfer shown in Fig.2 same thing happens in the case of roof and unfortunately roof plays an important role in heat gain of the building. Studying the radiation, I found out that the horizontal radiation is mostly high so roof is the major part to be treated. (Beauro of energy efficiency, 2010)

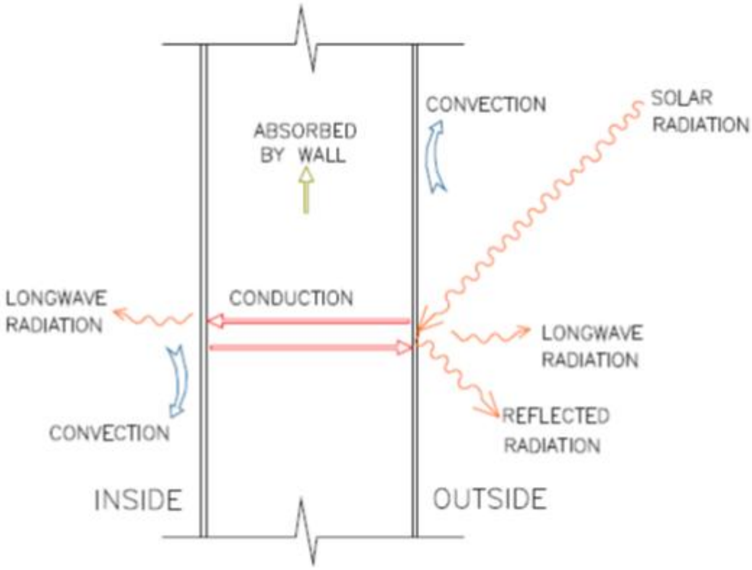

Figure 2 Heat Transfer process occurring on the wall

Such Heat transfer processes affected the indoor temperature of a room and consequently, the thermal comfort experienced by its occupants. Thus, a knowledge of the fundamentals of heat transfer and solar radiation would help in understanding the underlying processes that take place in a building and its interaction with the external environment.

2. Case Studies:

For studying the thermal performance of the roof live case study was conducted to obtain the information needed for pursuing the objective of the research are given hereunder:

Sr.No.	Name of the Building	Type of Roof
1.	Office building, Hyderabad	Cool roof
2.	Ottawa, Canada Campus	Green Roof
3.	Model Sample	Ballast Roof
4.	Model Sample	Roof Pond
5.	ITC Mughal hotel, Agra	Green roof
6.	TCI office building, Delhi	Green roof
7.		White reflected coating
8.		Insulated roof with reflected tile
9.	IISC campus Bangalore	Integrated Solar panel roofing
10.		Jack arch roof
11.		Stabilized soil block roof
12.		Filler slab
13.		Adobe block roof
14.		Broken China mosaic tile roof
15.		Vault roof with SSB block

Table 1 List of case stydies for live section

2.1 Case Study: Office Building Hyderabad (Thermal Performance of cool roof paint:

Building Type- Office Building

Location- Hyderabad

Climate- Composite

Building Parameters: The complex houses two near-identical buildings- this facilitated the study through ensuring identical parametric values for floor area, number of floors, roofing material and system, occupancy and schedules, and cooling systems. This is a two-storey building with a roof area of 700m. The roof of one building was coloured black and white reflective coating was applied to the roof of the other building. (BEE, 2010)

Monitored Data: Weather towers, temperature sensors, current transducers, and data-loggers continuously monitored the weather, energy-use, and temperature data for two buildings. The data points monitored weather conditions, building temperatures, and energy use.

Weather: Outdoor temperature, Relative Humidity.

Energy Use: Whole building electricity use, Cooling energy use.

Building Temperatures: Surface Temperature, Heat flux through roof, Roof underside temperature.

Conclusion: The average summertime daily roof surface temperature was reduced by 20-degree C. Cooling energy savings due to roofing (from grey concrete to white roof coating) can vary largely, for example, ranging from approximately 15% to 20% during hot summer days.

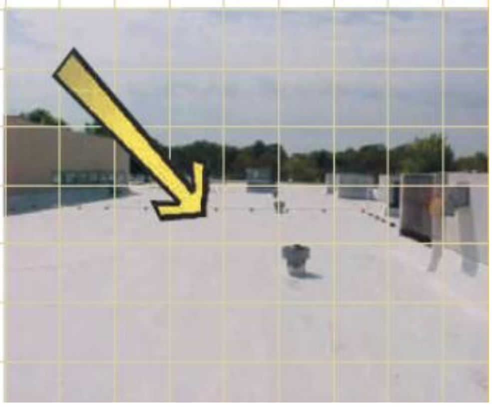

Figure 3 Third coat of Cool roof

Figure 4 Roof with first coat of cool roof paint

2.2 Case Study: Ottawa Campus Canada: (Thermal Performance of Green Roof): Building Type- Institutional Building Location- Ottawa Canada

Climate- Cold and sunny

Building Parameters: NRC has constructed the filed roofing facilities at its Ottawa campus in Canada. It provides an experimental roof area of about 72 sq.m. (800sq.ft) and can represent a low slope industrial roof with a high roof-to-wall ratio. The roof is divided into two equal areas separated by a median divider: a generic extensive green roof was installed on one side and a modified bituminous roofing assembly was installed as a reference on the other side. The surface of the roof membrane (on both roof sections) is covered with light grey coloured granules, which is intended to avoid the extreme colours of a reflective white membrane or a dark built up roof surface. While the green roof have the same basic components up to the membrane level, it incorporates additional elements to support plant growth. Figure 1 Shows the components and configurations of the two roofing systems. In the first year of the study (2001), a wild flower meadow was established in the garden and in the second year (2002), common lawn grass (Kentucky blue grass) was planted. (baskaran, 2015)

Both the green roof and the roof reference roof are instrumented to measure the temperature profile within the roofing system, heat flow across the system, solar reflectance of the roof surface, soil moisture content, microclimate created by the plants, and storm water runoff (figure 1). The local meteorological data such as temperature, relative humidity, rainfall and solar radiation are monitored continuously by a weather station located at the median divider on the rooftop and an additional weather station situated approximately 50m (160ft) from the site. All sensors are connected to a data acquisition system for monitoring.

Conclusion: An exposed roof membrane absorbs solar radiation during the day and its temperature rises. The extent of the temperature increase depends on the colour of the membrane. Light colour membranes are cooler because they reflect solar radiation but dark colour membranes are hotter because they absorb much of the solar radiation. Result shows that the roof membrane on the reference roof experienced much higher temperatures than that on the green Roof. The membrane on the reference roof absorbed the solar radiation and reached close to 70°C in afternoon. However, the membrane on the green roof remained around 25°C.

Observation from the filed roofing facility showed that a generic extensive green roof with 150mm (6in.) of growing medium could reduce the temperature of the roof membrane significantly in the summer. The exposed roof membrane on the reference roof was recorded to reach over 70°C in the summer but that under the green roof rarely reached over 30°C. Also the green roof modified the temperature fluctuations the roof membrane experienced, especially in the warmer months. The median daily temperature fluctuation of the membrane on the reference roof in spring and summer ranged from 45°C, however, the green roof reduced the temperature fluctuation to 6°C. The green roof also significantly moderated the heat flow through the roofing system in the warmer months.

Temperature Greater than:	Reference Roof		Green Roof		Ambient	
	No. of Days	% of Days	No. of Days	% of Days	No. of Days	% of Days
30 degree C	342	52	18	3	63	10
40 degree C	291	44	0	0	0	0
50 degree C	219	33	0	0	0	0
60 degree C	89	13	0	0	0	0
70 degree C	2	0.3	0	0	0	0

Table 2 Temprature data reading

	Reference Roof	Green Roof	Reduction
Heat Gain	19.3 kWh/m2	0.9 kWh/m2	95%
Heat Loss	44.1 kWh/m2	32.8 kWh/m2	26%
Total Heat Flow	63.4 kWh/m2	33.7 kWh/m2	47%

Table 3 Heat gain Heat loss calculation

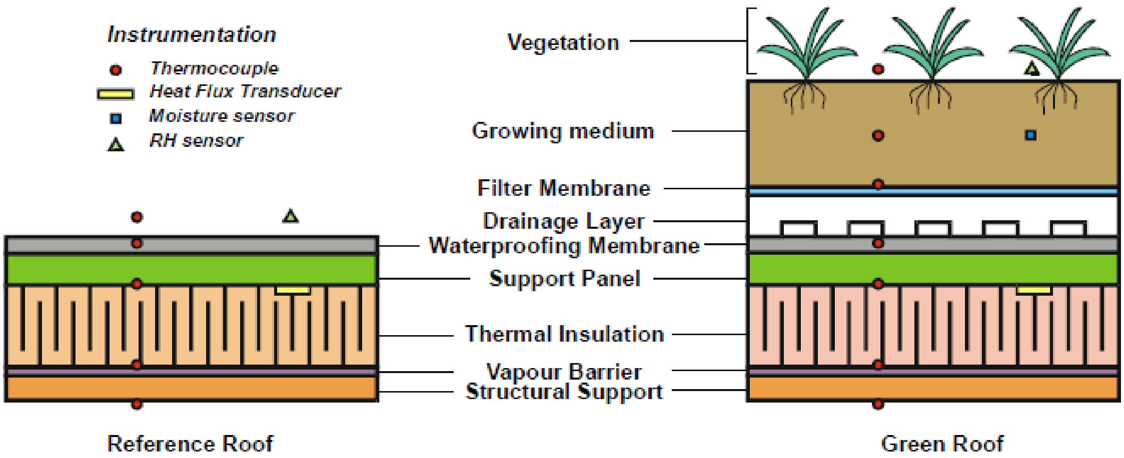

Figure 5 Green roof section

2.3 Case Study: Evaluating the energy performance of ballasted roof systems
Building Type- Sample Roof (physical Model of roof created)
Location- EAST Tennessee yielded
Climate- cold and sunny

Building Parameters: Three full years of continuous monitoring in the mixed climate of East Tennessee yielded data to compare the energy performance of six ballasted systems and a system with an exposed black membrane to that of a system with an exposed white membrane. Heat fluxes through the insulation in each test section were used to obtain the annual cooling and heating loads due to unit area of each system. (Andre o. desjarlais, 2007)

Conclusion:

• The cooling loads for the heavy and medium stone-ballasted and uncoated paver-ballasted systems were approximately the same as for the white system.

• Cooling loads for the light weight stone systems were slightly larger than for the white system but significantly less than for the black system.

• Cooling loads for coated pavers with heavy and medium loading showed cooling loads significantly less than for the white system.

• Only the cooling load of the white system showed significant effects of weathering, which was complete by the start of the second year of the project.

• Heating loads for the ballasted systems showed random variation as loading increased and type changed. Except for the heavy weight stone system, they were about the same as for the white system.

• The heavy weight stone system showed slightly less heating load than the black system but this is considered an anomaly due to rain effects.

• All evidence on clear days of diurnal behaviour showed the heavy weight stone and uncoated paver systems performing equally due to the same thermal mass despite different solar reflectance. An effort was made to model heat flow through the ballasted systems with transient heat conduction alone, using the program STAR. STAR has successfully modelled non-ballasted systems in past projects and did so again in this project. Trial-and-error was required to duplicate diurnal variation of measured membrane temperatures and insulation heat fluxes on clear days for the ballasts. Effective thermal conductivities 34% to 74% of measured values resulted for the stone and paver systems. Specific heats were close to literature values. With these properties:

• The predicted cooling loads showed the same variation with ballast loading and type as the measurements.

• Predictions of cooling loads were made using the procedures of the DOE Cool Roof Calculator for higher levels of roof insulation and more severe cooling climates than for the measurements.

• Ballasted systems performed relative to white systems like they did in the measurements.

• Contrary to the measurements, these properties predicted heating loads for the conventional ballasts much smaller than heating loads for the white system.

• Heating loads for the coated pavers were predicted well but coated pavers are not commercially available systems. High effective thermal conductivities and unrealistically low specific heats still did not yield heating loads like the measurements. It is concluded that transient heat conduction alone is not adequate to predict heating loads for ballasts.

Type of Roof	**Heat flux Btu/h.sqft**	**Membrane temperature deg. F**	**Heat flux W/sqmt. K**	**Membrane temperature deg C**
Bare black EPDM	17.5	146	55.2	63.33
Bare white TPO	3	86	9.46	0
10lb/sqft	8.5	103	26.81	39.44
10lb/sqft	7	95	22.08	35
10lb/sqft	4.5	90	101..57	32.2
Under uncoated pavers	4.6	91	103.37	32.77

Table 4 Ballast roof reading data

2.4 Case Study: Evaluating the energy performance of roof pond system

Building Type- Sample Roof (physical Model of roof created)

Parameters: Based on appropriate input data, the model computes the following of time:

1. Interior DBT for a comparable reference building having no roof pond;
2. Auxiliary heating and cooling to maintain interior DBT within comfort conditions for the reference building;
3. Interior DBT for a reference building having a total thermal mass equal to that of the Roof-Pond Building;
4. Pond water temperature for the roof-pond building assuming optimal operation of the roof pond;
5. Interior DBT for the roof-pond building assuming operation of the roof pond;
6. Auxiliary heating and cooling required to maintain interior DBT within comfort conditions in the Roof-Pond Building.
7. Solar savings fraction for the roof-pond building over the period of study.

Conclusion:

The study provides a basic for comparative evaluation of roof pond performance. The reference building has a thermal mass equal to the building thermal mass (excluding the thermal mass of water) of the roof-pond building. The overall thermal transmittance (the average

e "U-Value") of the reference building is set to be appropriate insulation of buildings given the severity of the winter climate.

A Building with a well-insulated inoperative roof pond, allows the program user to isolate the effects of the large thermal mass introduced by the water in a roof pond from the energy collection and dissipation functions the pond.

Applying to the roof-pond building are the heart of the program output. They is conditioned by it. The overall thermal behaviours of roof pond and of the interior space that is conditioned by it. The overall thermal transmittance of the roof-pond building is set to be consistent with that of the reference building except for the roof area represented by the pond itself.

Finally determine the auxiliary heating and cooling energy consumption in the operative roof-pond building and compare them to the corresponding quantities for the reference building using the concept of solar saving fraction.

Typical output is shown in the diagram that follow.

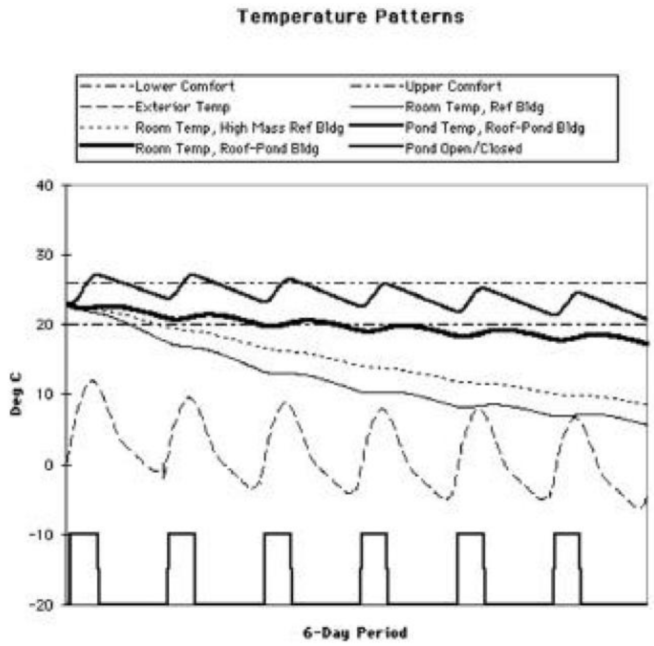

Figure 6 Roof Pond data reading

2.5 Case Study: Evaluating the energy performance of TCI Office Building (Thermal performance of insulated roof with reflective tiles)

Building Type: Office Building

Location: Delhi

Climate: Composite

Building Description: A prototype of the modern city office, the design of the building is based on traditional inward looking house (Haveli Plan). All materials used in the building are indigenous and attain a new aesthetic in the contemporary from. The orientation of the building is determined by the site and entrance contains a panted and shaded forecourt. The internal spaces orient around the central court which helps shade and facilities stack ventilation and reduce artificial lighting.

Roof Description: The heavy mass construction is insulated from the outside by 25mm thick polyurethane foam protected by a dry red- stone slab cladding. The roof has a 35mm thick insulation with a reflective glazed tile paving cover to minimize the sol-air temperature on the surface and white painted roof.

2.6 Case Study: ITC MUGHAL HOTEL

Thermal performance of green roofs/white reflective coating/ terracotta tile roofing with insulation:

Building Type: Hotel Building

Location: Agra, Uttar Pradesh

Climate: Composite Climate

Building Description: Sprawled over 35 acres of luxurious gardens, and in close proximity to the Taj Mahal, ITC Mughal, A luxury hotel in Agra is fitting tribute to the great Mughal builders of the past. The only Indian hotel to have won the prestigious Aga khan Award for its excellent representation of Mughal Architecture, it now boasts of a brand new Royal Mughal suites. This Luxury hotel in Agra comprises of 233 opulent rooms and suites, recreating a paradise for the contemporary mogul-full of splendor and perfection which was the hallmark of the Mughal dynasty.

Roof: Insulated roof white coating, green roof, and terracotta tile roofing with insulation has been applied in the building.

Temperature Reading:

1. Green roof gives 24° Temperature inside.
2. Tile roofing with insulation roof 25 deg. Temperature.
3. Roofing with terracotta tile insulation was 30 deg.
4. White paint roofing with insulation was giving 26 deg.
5. Reception was room was having air conditioning unit.
6. Reception waiting, lounge, beer bar have AHU system.
7. Golf club dinning was naturally cooled.
8. Passage corridor was having insulated roofing.
9. Natural therapy was having green roof with water body acts like an evaporative cooling tower.
10. Some area of building is white painted and insulated covered with the false ceiling.

2.7 Case Study: IISC CAMPUS BANGALORE

Thermal performance of Vault/ SSB/Jack Arch/Solar panel etc. Roofs:

Building Type: Institutional Building

Location: Bangalore

Climate: Moderate Climate

Conclusion: Reading at different time indoor and outdoor temperature:

Bangalore case study	Indoor temperature	Outdoor temperature
vault roof	20	28
filler slab with SSB block	24	28
filler slab with SMB block	22	28
composite jack arch RC panel	27	28
composite jack arch with decorative clay tile ceiling	26	28
Reinforced tile jack arch roof ceiling	24	28
solar panel integrated	32	28

Table 5 Different roof sections at IISC

3. Results:

Sr.No	Name of the Building	Type of Roof	Results	Methodology
1.	Office building, Hyderabad	Cool roof	20 degree reduction	Infrared thermometer
2.	Ottawa, Canada Campus	Green Roof	18-20-degree temp. Fluctuation in summer and winter	Infrared thermometer
3.	Model Sample	Ballast Roof	8 degree temperature fluctuation	Infrared thermometer
4.	Model Sample	Roof Pond	10-20 degree temperature Difference depending upon the Ambient temperature	Infrared thermometer
5.	ITC Mughal hotel, Agra	Green roof	10 degree temp. Fluctuation in Summer.	Infrared thermometer
	ITC Mughal hotel, Agra	Tile roofing with insulation roof	6-8 degree	Infrared thermometer
6.	TCI office building, Delhi	Green roof	12 degree	Infrared thermometer
7.		White reflected coating	18 degree	Infrared thermometer
8.		Insulated roof with reflected tile	8-12 degree	Infrared thermometer
9.	IISC campus	vault roof	8 degree difference	Infrared thermometer

10.	Bangalore	filler slab with SSB block	4 degree difference	Infrared thermometer
11.		filler slab with SMB block	6 degree difference	Infrared thermometer
12.		composite jack arch RC panel	1 degree or no difference in temp.	Infrared thermometer
13.		composite jack arch with decorative clay tile ceiling	2 degree or no differ.	Infrared thermometer
14.		Reinforced tile jack arch roof ceiling	4 degree difference	Infrared thermometer
15.		solar panel integrated	Increase 4-6 degree temp.	Infrared thermometer

Table 6 Table showing details of temperature difference for each roof section

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