Quantifying Thermal Performance of Roof In Composite Climate

Ar.Monica Sharma[1], Ar.Piyush Pant[2], Ar.Sonika Sharma[3]
[1, 2, 3]Acharya NRV School of Architecture, Bangalore

Abstract- *The thermal performance of an in-service roof is difficult to analyse because it is dominated by complex time-varying boundary conditions at the outer surface. The different calculator has been built by the researcher to evaluate the energy saving from the roof. No calculator has been formed to quantifying the thermal performance of the roof. This research is evaluating the thermal performance of the different roof section and quantifying heat flow from per square meter area of the roof. Composite climate is critical climatic condition for designing any building because of its extreme condition and roof plays an major part for heat gain inside building. This research helps designer to choose any roof section for composite climate. Research is compared on the numerical solutions with live reading and literature case study to evaluate the absolute thermal performance by the roof.*

Keywords- Thermal Performance, Energy Saving, Heat transfer, U-Value, R-Value

I. INTRODUCTION

The thermal performance of a building refers to the process of modelling the energy transfers between a building and its surroundings. For a conditioned building, it estimates the heating and cooling load and hence, the sizing and selection of HVAC equipment can be correctly made. For a non-conditioned building, it calculates temperature variation inside the building over a specified time and helps one to estimate the duration of uncomfortable periods. These quantifications enable one to determine the effectiveness of the design of a building and help in evolving improved designs for realising energy efficient buildings with comfortable indoor conditions. The lack of proper quantification is one of the reasons why passive solar architecture is not popular among architects. Clients would like to know how much energy might be saved, or the temperature reduced to justify any additional expense or design change. Architects too need to know the relative performance of buildings to choose a suitable alternative. Thus, knowledge of the methods of estimating the performance of buildings is essential to the design of passive solar buildings. Various heat exchange processes are possible between a building and the external environment Heat flows by conduction through various building elements such as walls, roof, ceiling, floor, etc. Heat transfer also takes place from different surfaces by convection and radiation. Besides, solar radiation is transmitted through transparent windows and is absorbed by the internal surfaces of the building. There may be evaporation of water resulting in a cooling effect. Heat is also added to the space due to the presence of human occupants and the use of Lights and equipment. The interaction between a human body and the indoor environment is shown in Fig1 (koenigsberger, 2010).

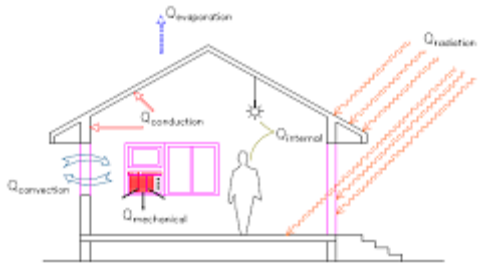


Figure 1 Heat Exchange Process between a building and the external environment

The thermal performance of a building depends on a large number of factors. They can be summarised as (i) design variables (geometrical dimensions of building elements such as walls, roof and windows, 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.).A block diagram showing various factors affecting the heat balance of a building is presented in Fig2.

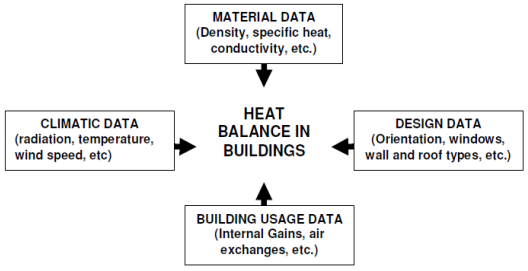


Figure 1 Thermal Simulation flow paths of a building

Same fundamental applies to the roof heat transfer procedure which plays an important role in heat gain of the building. Studying the ration, I found out that the horizontal radiation is mostly high so roof is the major part to be treated. Such heat transfer processes affect 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.

II. HEAT TRANSFER

The human body was considered as a defined unit and its heat exchange processes with the environment were analysed. The building can similarly be considered as a defined unit and its heat exchange processes with the out-door environment can be examined

a) Conduction of heat may occur through the walls either inwards or outwards, the rate of which will be denoted as **Qc** (convective and radiant components in the transfer of same heat at the surfaces are included in the term: transmittance)

b) The effects of solar radiation on opaque surfaces can be included in the above by using the sol-air temperature concept, but through transparent surfaces (windows) the solar heat gain must be considered separately. It may be denoted as **Qs**.

c) Heat exchange in either direction may take place with the movement of air i.e. ventilation, and the rate of this will be denoted as. **Qv**.

d) An internal heat gain may result from the heat output of human bodies, lamps, motors and appliances. This may be denoted as **Qm**.

e) Finally, if evaporation takes place on the surface of the building (e.g. a roof pool) or within the building (human sweat or water in a fountain) and the vapours are removed, this will produce a cooling effect, the rate of which will be denoted as **Qe**.

The thermal balance, i.e. the existing thermal condition is maintained if:

$$Qi + Qs + Qc + Qv + Qm - Qe = 0$$

If the sum of this equation is less than zero (negative), the building will be cooling and if it is more than zero, the temperature in the building will increase (koenigsberger, 2010).

III. ANALYSIS TOOL

Manual calculation, calculator for thermal performance, energy modeling by energy simulating software (ECOTEC) etc. Tools are used for analysis of collected data and information.

3 (a) Cool roof calculator

There are different type of calculator available on web to evaluate the thermal performance of roof , designed by different intitute for evaluation here I have used to different calculator for analyzing the roofing thermal performance are**:**

1. Cool roof calculator
2. CARBSE calculator
3. ORNL calculator
4. Energy Star Calculator

3 (b) Manual calculation

Manual calculation was done with the help of heat flow formula and temperature difference mathematical formula.

FORMULA FOR HEAT FLUX CALCULATION

$$q=U[(Ta-Ti)+aG/Ho$$

FORMULA FOR TEMPERATURE DIFFERENCE

$$T=qx \; X \; l/k$$

Energy simulation software
Ecotec software used to simulate the building case for analysing the heat gain.

IV. CASE STUDIES

4 (a). Literature Study- Literature study was conducted for four building and four typology was studied.

LITRETURE CASE STUDY				
Sr.No.	Name of Building	Location	Type of Roof	Tem. difference
1	Office Building	Hyderabad	Cool Roof	15%-20%
2	NRC Ottawa Campus	Canada	Green Roof	47%
3	Oak Ridge National Laboratory	Knoxville	Ballast roof	34%-74%
4	Residential		Roof Pond	20%-34%

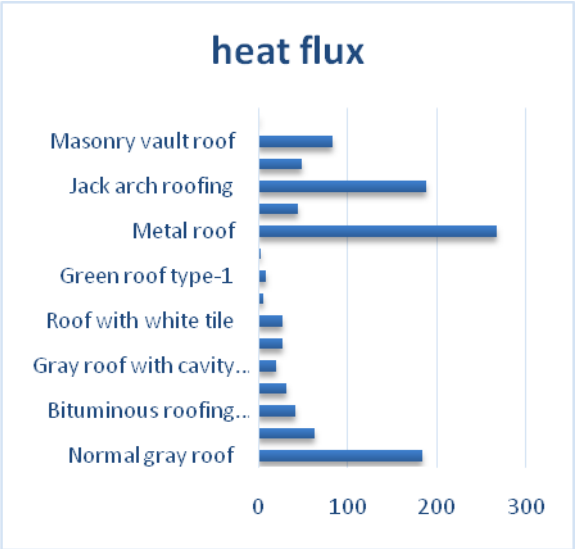
4 (b). Live case studies- Three project was studied live and the multiple type roof typology of the section

LIVE CASE STUDY				
Sr.No.	Name of Building	Location	Type of Roof	Tem. difference
1	TCI Office Building	Delhi	Insulated	30%-40%
2(a)	ITC MUGHAL	Agra	Green Roof	55%
2(b)			cool roof	30%
2©			insulated	30%-40%
3(a)	IISC Campus	Bangalore	vault roof	12%-15%
3(b)			filler slab with SSB block	18%-20%
3©			filler slab with SMB block	10%-16%
3(d)			composite jack arch RC panel	8%-10%
3 €			composite jack arch with decorative clay tile ceiling	6%-12%
3(f)			reinforced tile jack arch roof ceiling	6%-12%
3(g)			solar panel integrated	nill

V. FINDINGS

Comparative Analysis Of Different Roof And The Maximum Benefits Which Can Achieve By Roof.

These are the different roof section used in roof designing have different heat transfer characteristic. Which has given hereunder:



After analysing all these roof section roof pond, acoustic tile roofing, green roof and thatch roof gives best thermal performance. Metal roof is very bad in thermal performance filler slab is good when there is air cavity in the slab. Masonry vault roof is good with high reflected coating.

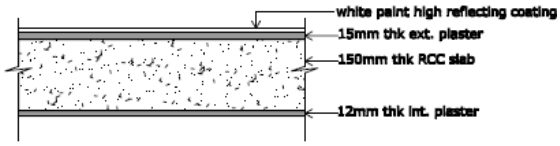


Figure 2Elbedo Coated RCC roof

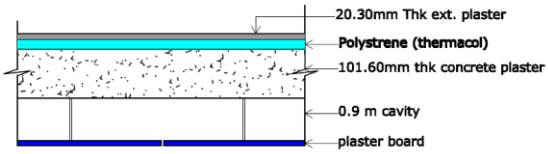


Figure 4 roof with cavity

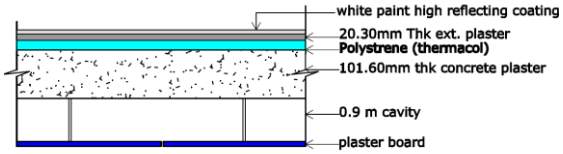


Figure 3 cavity roof with reflected coating

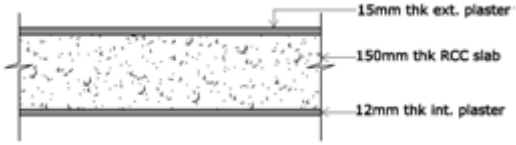
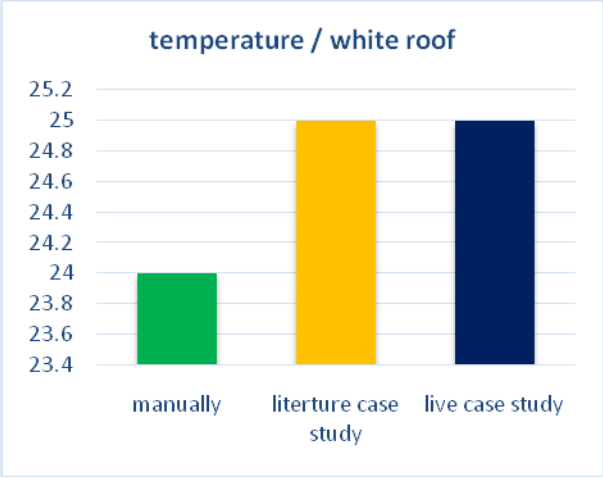


Figure 6 conventional RCC roof

Other derived option for reducing internal heat gain from gray roof

These options are applicable to the RCC roof to make it more thermally comfortable it is tested that if the white paint is applied, it reduce heat flow by 65% of total heat gain and adding insulation reduce 75% and adding cavity reduce 90% in total heat gain.

Normal grey roof	150mm thk RCC slab + 12mm thk internal plaster+ 15mm thk external plaster with grey coating	0.33	3.03	184.34w/sqmt. K
Normal grey roof with white paint	white paint + 150mm thk RCC slab+ 12mm thk internal plaster + 15mm thk external plaster with grey coating	0.33	3.03	63.57w/sqmt. K
Grey roof with cavity and insulation	101.60mm thk concrete slab + 20.30mm plaster on upperside expanded polystrene (thermacol) + cavity 0.9m + plaster board	1.618	0.618	31.44 w/sqmt. K
Grey roof with cavity insulation and white painted at top	white paint + 101.60mm thk concrete slab + 20.30mm plaster on upperside expanded polystrene (thermacol) + cavity 0.9m + plaster board	1.618	0.618	19.12w/sqmt. K



Bituminous roofing with insulation

Bituminous roofing with insulation has good thermal performance. Cork gives best thermal insulation with compare to other insulators.

Bituminous roofing with insulation	Reinforced concrete slab, 100mm screed 63-12mm, 3 layer bitumenous felt as above- with insulation on the screed	0.298	3.35	128.70w/sqmt.K
	25mm cork	0.925	1.08	41.49w/sqmt. K
	50mm straw or wood wool slab	0.885	1.13	48.41w/sqmt. K
	two 12 mm fiberboard	0.8	1.25	48.02w/sqmt. K
	127mm to 76mm aerated concrete	0.735	1.36	52.24w/sqmt. K
	127mm to 76mm foamed slag concrete	0.68	1.47	56.47w/sqmt. K

Different types of tile roofing system and their characteristic of heat transfer

Mostly used technique is tile as an cooling technique out of china mosaic tile, white tile and acoustic tile , acoustic tile give best thermal comfort inside building. It gives 3% of grey roof. China mosaic tile give 15% and white tile give 14% of grey roof.

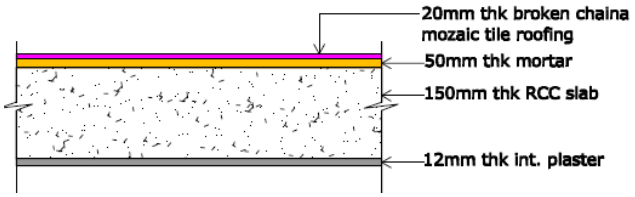


Figure 4chaina mosaic tile roofing with flat surface

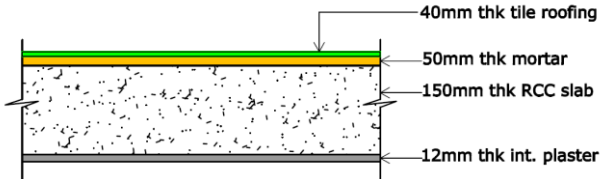


Figure 5 insulated tile roofing

Broken china mozaic terracing	20mm thk tile+ 50mm thk insulation+150 mm rcc slab+10mm thk plaster	1.7687	0.57	27.09w/sqmt. K
Roof with white tile	40mm thk tile+ 50mm thk insulation+150 mm rcc slab+10mm thk plaster	1.795	0.55	26.61w/sqmt. K
Accoustic tile flooring	30mm thkaccoustic tile+ 150mm thk RCC roof + 10mm thk plaster	5.48	0.182	5.57w/sqmt. K

Filler slab

Stabilized mud block gives better thermal insulation and it is cheaper compare to bricks and other masonry blocks.

Filler slab	120mm thk RCC slab with foamed slag aggregate + different thkfilling material	R-value	U-value	Heat flow
	mangalore tile roofing (single tile) 15mm thk	0.72	1.38	**66.76w/sqmt. K**
	mangalore tile roofing (double tile)30 mm thk	0.748	1.34	**64.82w/sqmt. K**
	Roofing with stablized mud block 75mm thk	1.102	0.907	**43.88w/sqmt. K**
	burnt clay brick roofing (double) 75mm	0.56	1.786	**86.4w/sqmt. K**
	fly ash brick (75mm thk)	0.811	1.23	**59.5w/sqmt. K**
	hollow concrete block 75mm	0.571	1.751	**84.71w/sqmt. K**
	hollow clay tile block 75mm	0.624	1.603	**77.55w/sqmt. K**

Metal roof

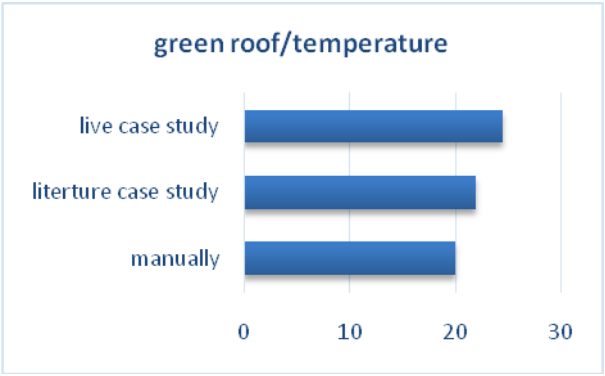
Aluminium metal roof is mostly used because of its easy construction and less labour cost. But it gives bad thermal comfort inside the building as evaluated it increase the heat gain inside. But if the aluminium roof is painted white with high reflective coating it reduce by 60%. Which have great impact on temperature as calculated temperature reduce by 20 deg.

Metal roof	76.2mm thk steel roof	0.2	5	**266.83w/sqmt . K**
Metal roof with white paint	white paint + 76.2mm thk steel roof	0.2	5	**104.9w/sqmt. K**

Green roof

Heat flow through green roof and if the insulation thickness has increase heat flow goes reduce. It is best suitable roof option for composite and hot and dry climate. Best aesthetic and thermal comfort.

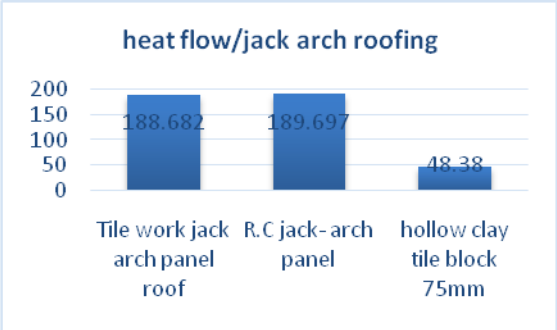
Green roof type-1	240 (140+ 100)mm thk of polyfoam, eco roof board extra and 40mm screde, 150mm thk concrete 13mm plaster	7.142	0.14	**8.37w/sqmt. K**
Green roof type-2	130 (100+60)mm thk of polyfoam, eco roof board extra and 40mm screde, 150mm thk concrete 13mm plaster	4	0.25	**14.96w/sqmt. K**



Jack arch roofing

Bad in thermal comfort and useful in an moderate climate. Hollow clay tile block is better in thermal comfort with compare to R.C and tile jack arch.

Jack arch roofing	Tile work jack arch panel roof	0.2564	3.9	**188.682w/sqmt. K**
	R.C jack-arch panel	0.255	3.921	**189.697w/sqmt. K**
	hollow clay tile block 75mm	1	1	**48.38w/sqmt. K**



Masonry vault roof

It is mostly used and traditional roofing technology. It gives better thermal performance but it is wisely used technology with appropriate material selection. It is calculated if the masonry vault is painted white it give better thermal performance and reach to thermal comfort.

Masonry vault roof	75mm thkssb block	0.291	3.43	**82.972w/sqmt. K**
Masonry vault roof with white paint	white painted + 75mm thkssb block	0.291	3.43	**35.984w/sqmt. K**

Roof pond and tensile roof

Roof pond	5cm insulation + 0.6m air cavity + 0.3m water + 150mm rcc slab	25.218	0.0396	**0.83w/sqmt. K**
Tensile roof	Acrylic Sheet 5mm thk + 0.9m air cavity + 50mm thkpolyutherine foam	36.92	0.027	**1.06w/sqmt. K**

VI. CONCLUSION

Roof is the mazor component in heat gain of building. High reflected coating reduce heat gain upto 50% of normal RCC roof. In bituminous roof wood wool and cork has a better insulators for bituminous roofing have low heat transfer. Among all tile roof acoustic tile give low heat transfer. In filler slab stabilized mud block is the better option to have as an filling material it reduces heat flow upto 80% .Jack arch is not a better option for roofing without insulation. Hollow clay tile gives better thermal performance due to air cavity in between. Now metal roof is available with high reflected coating it is suitable for large span areas. Masonry vault with reflected coating give good thermal performance. Roof pond is the best option out of all studied roof option due to its low heat transfer property. Composite climate has extreme conditions for that green roof , acoustic tile roofing , thatch roof and roof pond are the best option to design and it has a beat thermal performance . Other roof section also reduce heat gain and helps to reduce internal heat gain.

REFERENCES

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