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COMPARATIVE STUDY OF DIFFERENT ROOF COMBINATIONS IN PAKISTAN HEAT CONDUCTION RATE AND COST ANALYSIS OF DIFFERENT ROOF MATERIALS IN PAKISTAN

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Abstract
Building cooling and heating consumes a sizable fraction of the total global energy, therefore, the energy efficient building is a dire need to save a significant amount of electricity consumption. A roof is the element of building which is exposed to solar radiations directly, therefore, dissipation through roofs is higher. In present era, roof is built from reinforced cement concrete (RCC) because of satisfactory mechanical properties of RCC. Although, heat conductivity of RCC is higher which gives rise to transmission of heat through the rooftops composed of RCC, to resist this heat an RCC roof is insulated with Marble and Polyurethanes in Pakistan. In this study, equivalent thermal conductivities, temperature reduction ability, heat transfer rates and overall cost of three roof combinations have been analysed. The hot plate guarded method and Fourier law was employed to determine thermal conductivity of distict roofing materials, and heat transfer rates through roof combinations. The construction cost and energy saving cost of each roof combination were found through market survey and Hourly Analysis Program (HAP). The experimental outcomes proved that the rate of heat conduction declined by 8.1% and 84.2% with combination B (RCC insulated with marble) and C (RCC lined with marble and polyurethane), respectively, in contrast to an RCC roof. The construction expenditure of combinations B and C has been enhanced by 15.7 % and 22.5 %, respectively, additionally, energy saving cost of roof combinations B was 73 PKR and energy saving cost of C was 364 PKR. Finally, the temperature reduction capability of roofs A, B, and C in degree centigrade (°C) were 5.70, 6.58, and 11.94, correspondingly. However, combination C proved to be efficient heat insulation roof. The study was conducted to determine suitable insulation material for an RCC roof and its influence on over all cost and heat dissipation.

INTRODUCTION

One of the leading electric energy consumers, which consumes around fifty percent of global energy, is refrigeration and air conditioning equipments [1]. Over 50% of the world's power is already utilized for buildings, and global warming will make this sector much more burdensome [2]. In urbanised and developing states, housing, markets, and government buildings use roughly 40% of the world's total electrical energy. According to current forecasting, by 2040, developing nations could use up to 65% of the world's electricity [3]. Up to 60% of the nation's energy is used by arid and hot regions like Saudi Arabia to control indoor comfort temperatures in buildings [4]. In Pakistan, the building cooling accounts for greater than fifty percent of all total energy use, and it is on a rise due to global warming and urbanization [5]. About fifty percent of the entire heat dissipation from and to the outside environment is caused by heat transfer through the opaque building envelope [6]. The primary structural component of a building that dissipates the majority of the heat within is a roof, and an RCC roof can have an outside temperature of up to 65°C [7]. Currently, most of the roofs are made up of RCC, therefore, building consumes 50% raw materials of the world [8]. Thermal conductivity of RCC is more than other materials cork, foamed concrete, polyurethane, clay [9]. The interior temperature of the structure rises as a result of the stronger heat conductivity of RCC, which necessitates the use of air conditioning and refrigeration equipment with greater capacity and energy requirements. This device's enhanced use is wholly dependent on nonrenewable energy sources. Nevertheless, the substantial sum of heat transfer through the roof can be compromised with the adoption of the insulation approaches. The decrease in heat transfer rate lowers the temperature inside, which also lowers the need for power and carbondioxide emissions into the enviroment [10]. A rigid foam polyurethane's thermal conductivity can be reduced from 45miliiwatt/mK to 22.7 milliwatt/mK which is equal to $1/75^{th}$ of the thermal conductivity of concrete [11]. A study was conducted on three insulation materials i.e glass wool, extruded polystyrene and polyurethane. The finding of research recommended the polyurethane to be the best thermal insulation material for cold places of Pakistan [12]. Concrete has a higher specific heat than other building materials in comparison, which could lead to increased electricity consumption and the development of urban heat islands [13]. These concrete roofs significantly contribute to the urban heat island (UHI) consequence by radiating heat into the surroundings [14]. The air temperature in urbanized cities is 10°C higher than in nearby rural surrounding as a result of this urban island [15-18]. According to a case study, concrete's thermo behaviour directly influences a building's energy needs in terms of cooling load [19]. In order to implement the cool roof strategy in Pakistan, the RCC roofs are insulated with Poly ninyl chloride , Ziarat white marble, polyurethane spray in expanded form, polyurethane foam (PU foam), extruded polystyrene foam ,thermol leaf, concrete tile, artifical tile, and jumbolon-board [20]. The experimental results suggested that the quantity of heat conducted per second was declined by 11.8% with marble and by 84.3% with marble and polyurethane compared to RCC [21]. A research was conducted on athermal behaviour of a RCC roof insulated with artificial marble (tile), it was found that reduction in heat transfer rate of this roof was up to 17% [22]. The findings of the study revealed that polyurethane reduced 60-62% electricity consumption by a building [23]. A study was conducted in Iraq and revealed that the rate of heat transfer was lowered when concrete roof was insulated with air, sand , cork tiles and cork [24]. A study on energy efficient building probed the electrical power savings connected to the deployment of retrofitting precautions on Irish household buildings results revealed that when compared to a pre-retrofitted building, it may conserve up to 45% of electricity utilization and 29% of CO_2 emissions [25]. Energy efficiency techniques can cut flat energy use by 51.3% to 54.2%, according to a Taiwanese study [26]. Another study reported that the use of thermally insulated roofs might reduce electrical energy consumption by up to 25% [27]. According to a study on cool roof technologies, 295000 Kwatthr units of electricity of worth 59 euros, can be saved yearly, resulting in a 136000 metric tonne reduction in the amount of CO_2 emitted into the atmosphere [28]. The metal roof sheet includes phase change materials to enhance heat performance and electrical power conservation [29]. Because foamed concrete's heat conductivity is dependent on density, heat transfer from light weight concrete is significantly reduced because of voids present in it when the mass density of foamed concrete is 180 kg/m^3 at standard temperature and pressure [30]. Another research study found that roof coatings minimise heat conduction through the rooftops [31]. Like other natural or synthetic materials, heat-resistant materials exhibit temperature dependence that changes from substance to substance, and heat conductivity increases as temperature rises [32]. The mathematical relation of temperature with heat conductivity is linear for a number of materials. However, few materials exists in the world that d not express a linear connection between temperature and heat conductivity, such as blown foam insulations [33]. An experimental finding demonstrated that the effectiveness of rigid polyurethane sheets is determined by operating temperature value and PCM thermal behaviour rather than quantity of integrating phase change material [34]. The thermal conductivity of hollow concrete blocks made with marble debris will suffer [35]. According to study results conducted on modern building's roof in Malayesia, white roof tiles decrease the average temperature of the roof's exterior upto 16 °C and that results in annual energy savings of up to 13.14% because the white colour reflects all the solar radiations falling on it [36]. Experiments have shown that the top of the roof should be covered with material with higher thermal conductivity for more effective insulation [37]. The thermochromic building envelope had a positive and considerable influence on local thermal comfort conditions, according to a CFD simulation-based study [38]. Low thermal diffusivity and conductivity of the Mangalore pattern tile prevent heat loss from or to the building surroundings [39]. The temperature of the roof surface can be lowered through the application of cool roof techniques by 1.4°C to 4.7°C [40]. A research was conducted on temperature reduction ability of RCC, results revealed that temperature reduction by rcc roof was 6.6 °C [41]. The most common approaches to determine a material's heat conductivity are the heat flow metre and the guarded hot plate ways [42]. The infrared thermometer is easier to use than a conventional thermometer and offers quick and convenient measurement. The study of infrared thermometer design therefore has significant theoretical and practical implications [43]



Fig.1 a- RCC roof **Fig.1b- Roof combination A** **Fig.1c- Roof combination B**

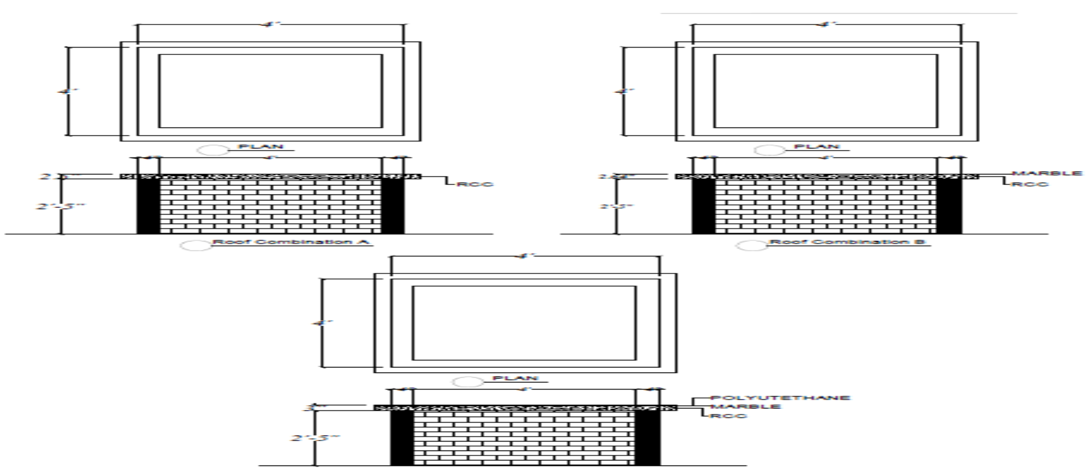


Figure 2 Plans of roof combinations drawn by Autocad

The higher thermal conductivity of the RCC roof results in more heat transfer to or from the RCC structure. By lining RCC roofs with materials that perform better in terms of thermal insulation, heat transfer through RCC roofs can be reduced dramatically. Numerous research are done on the mechanical features of RCC roofs around the world, however, there is few researches were conducted on thermal properties of RCC [44]. Heat rates of transfer through concrete roofs lined with clay, wooden sheet, gypsum plaster, and chemical films have been measured in Pakistan and other Middle Eastern nations. This experimental study was perfomed on three roof combinations A, B, and C that are often utilised these days. In this experimental study, Marble and polyurethane were lined on RCC roof for heat insulation purpose The objectives of this research were to determine temperature reduction ability, equivalent thermo conductivities, heat transfer rates, construction costs and energy saving costs of all roofs and suitable roof type was acknowledged based on the heat transfer rate, construction cost and energy saving cost.

1. Research aim and methodelogy

The materials chosen for the current experimental study are marble and polyurethane, which are commonly used on RCC roofs as heat insulators in Pakistan. Each building material has a different thermal behaviour. The materials used in this research are described in full in Table 1. By evaluating thermal conductivities, temperature reduction ability and heat transfer rates of different roofing materials' thermal behaviour have been assessed. The cost of roof combinations has been analyzed on the basis of construction cost and energy savig cost. The suitable roof has been recommended by analyzing over all cost and thermal behaviour. These roof types are represented in figure 1 a, b, and c as RCC roof, an RCC roof lined with marble (roof combination A), and an RCC roof insulated with marble and polyurethane (roof combination B). The plans of all roofs were drawn by AUTOCAD which was denoted by Figure 2. The model roofs, which measure 4 feet by 4 feet and have different depths as illustrated in Table 1. These roofs were constructed in Pakistan and were open to sky.

Table 1: Details of chosen Roof Combinations

S.NO:	Materials	Width (cm)	Length (cm)	Depth (cm)	Code
1	Reinforced cement concrete	121.92	121.92	6.5	A
2	RCC lined with Marble	121.92	121.92	7.3	B
3	RCCinsulated with Marble and Polyurethane	121.92	121.92	9.1	C

A heat conduction unit was used to compute heat conductivity that consists of temperature sensors and a heater with a known power. It is designed on the basis of law of heat conduction given by Fourier, it is also referred to as the hot plate guarded approach. The thermo conductivity of pure RCC, marble piece, and polyurethane (PU) foam was determined using a conduction unit designed by Hilton manufacturer and depicted in figure 3. This heat conduction unit is placed in the refrigeration laboratory, mechanical department QUEST Nawabshah. The acceptable size of the specimen in the test section of said equipment is a cylinder of diameter 25 mm and length 30mm. The sample of RCC, Marble, and polyurethane of the required geometry and size are constructed and placed in the test bed of the device to compute the heat conductivity of each roofing material.

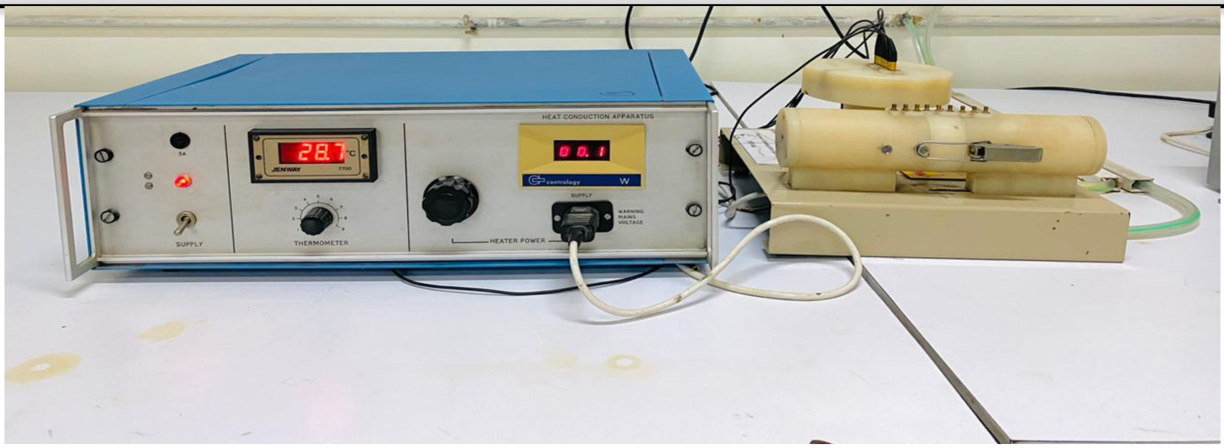


Fig.3- Hot plate guarded heat conduction unit

The technical details of conduction unit are illustrated in Table

Table 2: Details of Heat Conduction Unit

Model name	Description
Heat conduction unit Manufactured by Hilton limited	Heat conduction unit determines the heat conductivity (K) of solid material. This deviceincludes • Heat input section with an heater of known rating. • Temperature detectors. • Heat sink portion with surface water cooling • The test section of diameters 25mm and 30 mm in length.
Heater	0 to 100000 mWatt

The law of heat conduction was employed to determine the thermal resistivity of roofs and rate of heat transmission through sample rooftops.

The mathematical model derived from Fourier law of heat conduction was applied to the composite slabs (roof samples B and C) to assess their equivalent thermal resistance. $\text{Thermal resistance}_{eq} = \frac{x_1}{K_1} + \frac{x_2}{K_2}$

(1) [37]

The rate of heat flow through roof combinations were analyzed by using following equation of Fourier law of heat conduction.

$Q = KeqAdT/dx$

(2)

The temperature of the roof's inner and outside surfaces is determined by an infrared thermometer. The infrared thermometer is a well-known tool used in hot, industrialised areas all over the world. The specification of infra red thermometer is described in table

Figure 4 Infrared thermometer

Table 3: Details of Monitoring Equipment

DT-8859 high-temperature infrared thermometer	Infrared Thermometer includes I.K-class thermocoupleS I.Strong hard casing I.Universal serial board 1.0 /.Computer interface wire
Temperature range	-50 0C to 1600 0C
Device accuracy	<-10 0C: +3 0C, - 3 0C

2.1 Simulation Heat Transfer Analysis using Hourly Analysis Program

HAP is Hourly analysis program which is simulation tool used to compute the cooling load of a building. This computer scheme also decides the capacity and size of Air conditioning device. Hourly Analysis Program version 4.90 was employed to analyze the heat dissipation through RCC roof, roof combination A and B. Energy saving cost by all roof combinations were calculated based on previous simulation result of HAP.

2.2 Cost Analysis

Cost analysis of each roof combination is done based on data obtained through a market survey. The rate of each roofing material is inquired from different markets of different cities. Based on the market survey, the average price of the roof is taken into account.

3. Results and Discussions:

The three model roofs (A,B &C) were built in Nawabsha which were exposed to solar radiations directly for

experimental study. Thermol conductivity, heat cond uction rate, and temperature reduction capability, construction cost and energy saving costs of each roo f combination were computed.

3.1 Analysis of thermal conductivity & thermal resistivity

The heat conductivity of individual constituents of roof was assessed empirically employing aforesaid heat conduction unit. These roof constituents were put in the test section of heat conduction unit to evaluate the material's thermo conductivity. The heat resistivity of samples A, B, and C were assessed from mathematical model of fourier law.

$$R_{th} = \frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3} +, \dots, + \frac{x_N}{K_N}$$

(3) [37]

Where x= Thickness of individual roof material

K= Heat conductivity of individual roof material

The experimental findings of heat conductivity, depth and heat resistivity are mentioned in Table 4.

Table 4- The heat Conductivity, depth and thermal Resistivity of Roof Combination Materials

S.NO	Materials of roof combination	Depth (cm)	Heat conductivity (milliWatt/mK)	Heat resistivity (K/Watt)
01	RCC	6.35	1700	0.0373
02	Marble	0.8	2000	0.004
03	Polyurethane foam	1.8	4.5	3.99
04	Roof combination A	6.37	1707	0.0373
05	Roof combination B	7.17	17400	0.00412
06	Roof combination C	7.35	167	0.441

3.2 Determination of temperature reduction

An infrared temperature detector was used to determine the interior surface temperature as well as the external surface temperature of roof samples three times daily, i.e., in the morning at 10:00 am, during the afternoon at 1 p.m., and the evening at 4:00 p.m. between the dates of 4 June of 2022 and 2 July 2022.

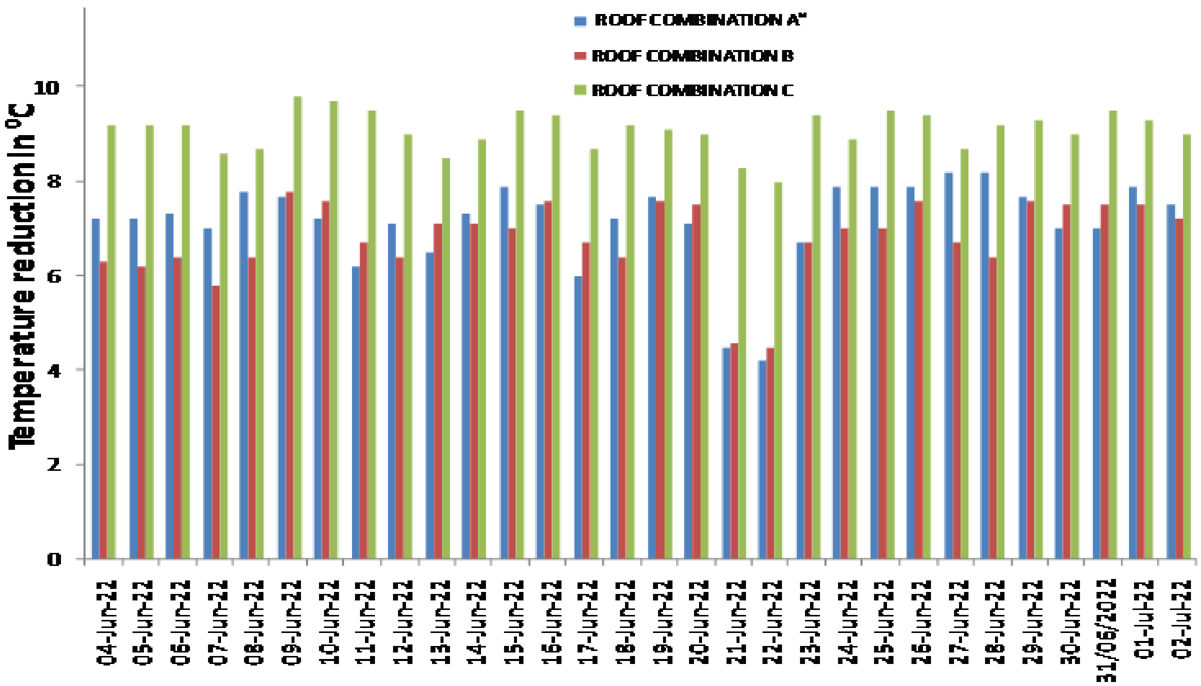
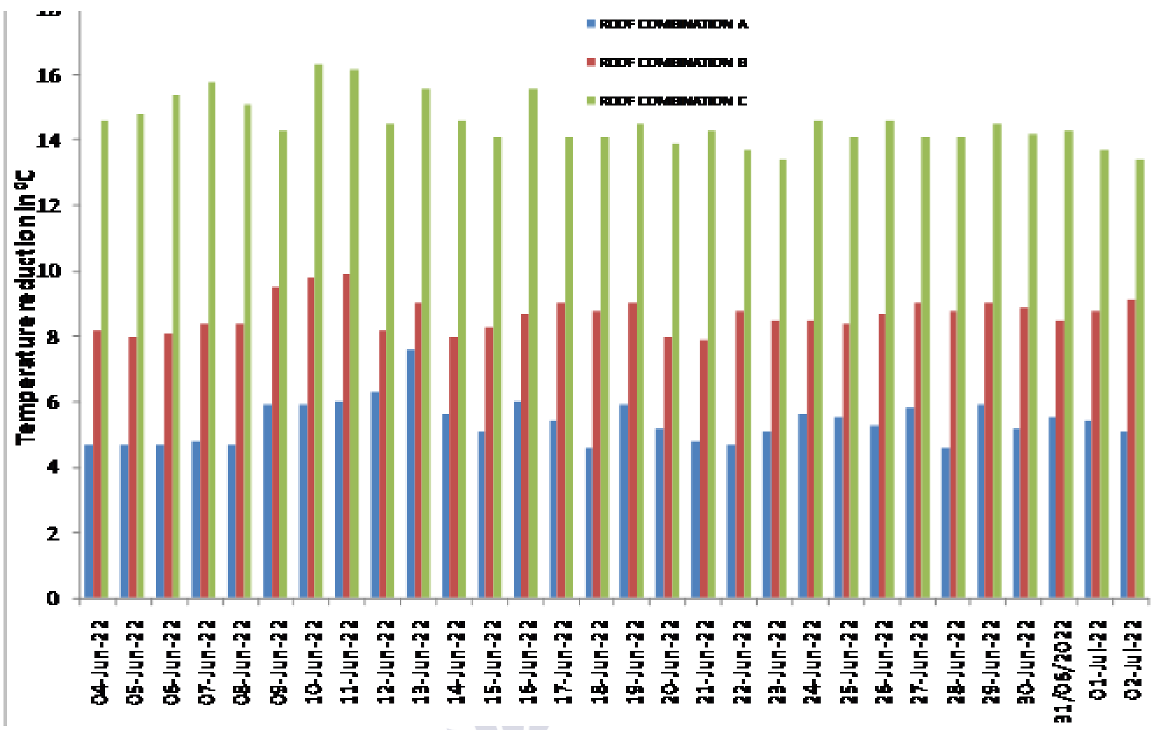


Fig.5- Temperature reduction of roofs A, B &C at 10:00 AM

Fig.6- Temperature reduction of roof combinations A, B &C at 01:00 PM



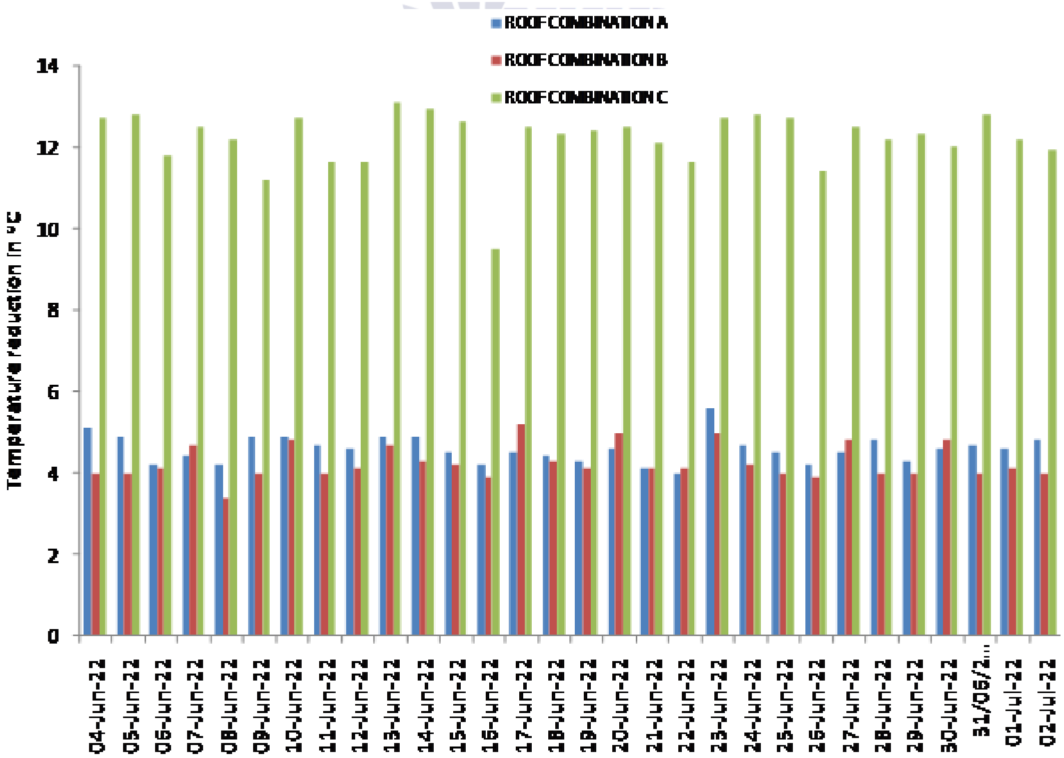


Fig.7- Temperature reduction in roof samples A, B &C at 04.00 PM

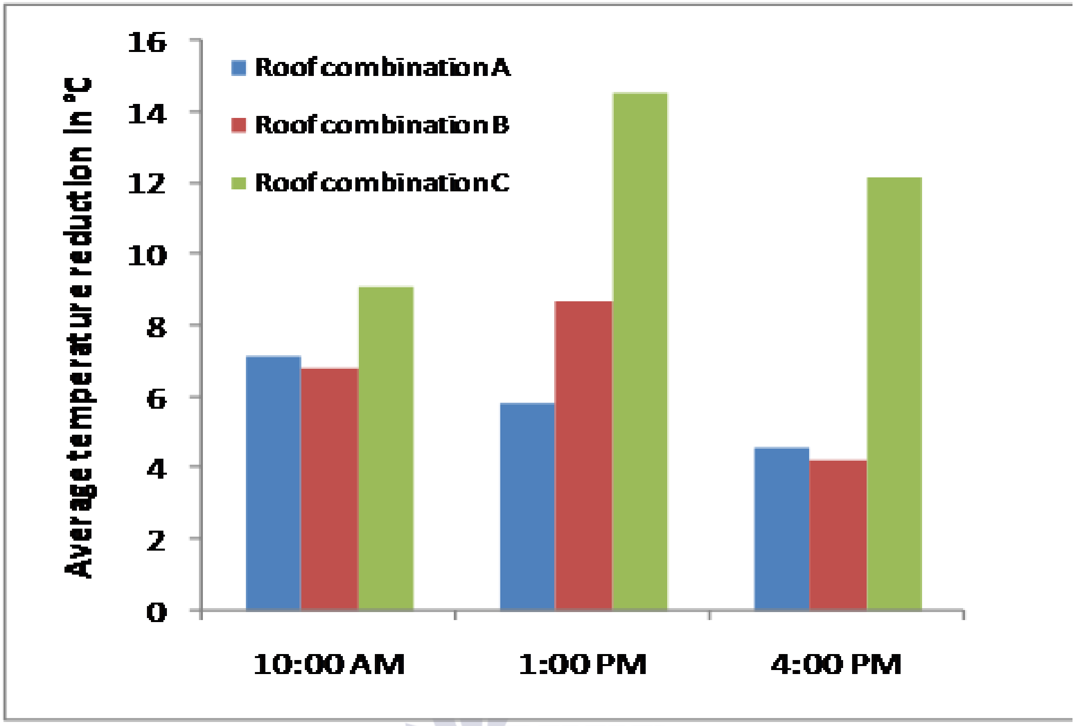


Fig.8- Average Temperature reduction of roof s A, B &C

The daily temperature reduction for each roof combination is illustrated in Figures 5, 6, and 7, which is the difference of the external surface temperature and the inside surface temperature measured at 10 AM, 1 PM, and 4 PM, accordings, from the fourth of June to the second of July, 2022.

At 10:00 AM, 1:00 AM, and 4:00 PM, Figure 8 shows the mean temperature drop of roof models (A, B, and C). Figure 9 shows that the average temperature reductions caused by combinations A, B, and C were 5.70°C, 6.58°C, and 11.94°C accordingy.

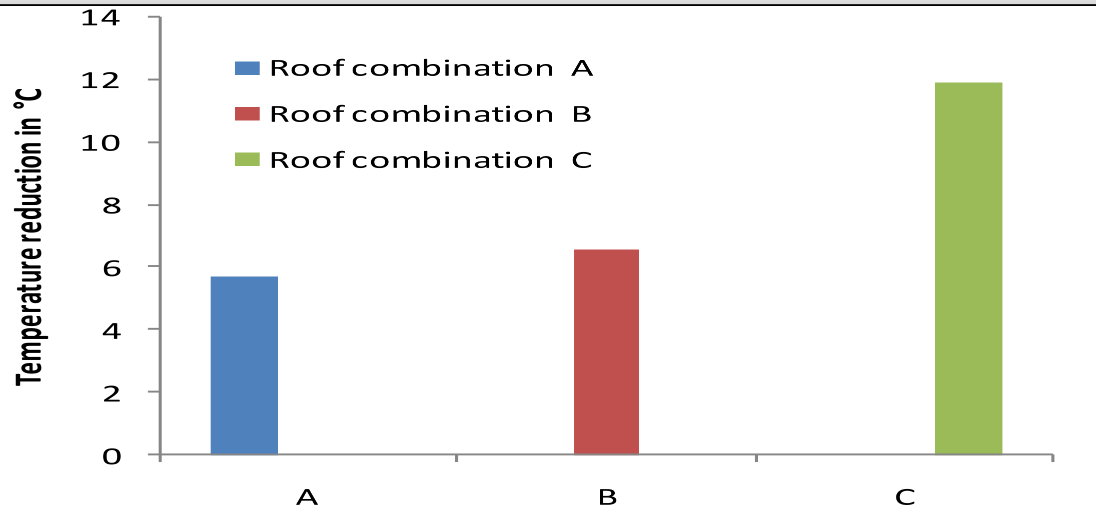


Fig.9- Average Temperature reduction in roof combinations A, B &C

The results revealed that reduction in temperature is higher in case of roof combination C and is mimimum in roof combination A. The Roof combination C proved to be a higher temperature reducing ability compared to roof combinations B and C.

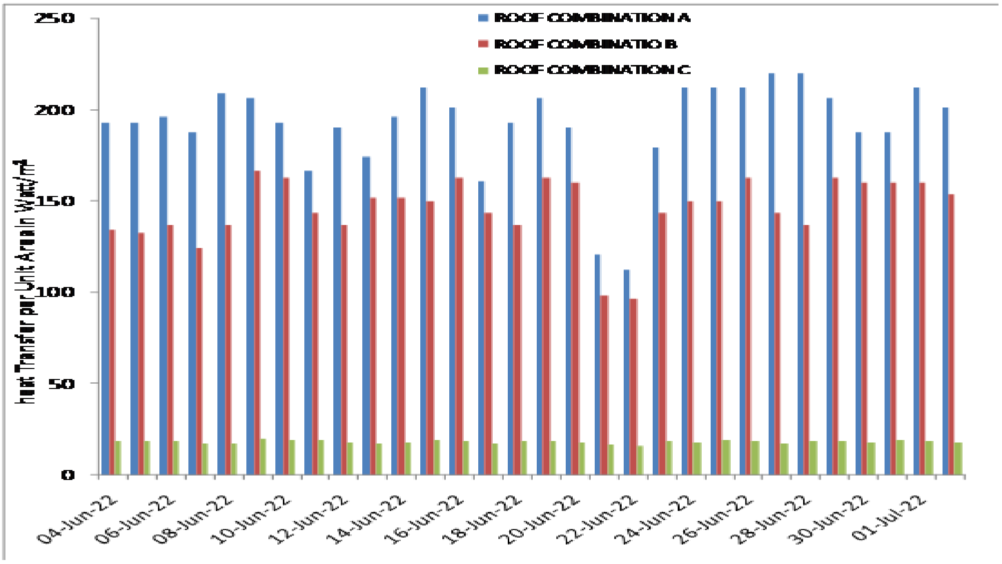
3.3 Analysis of heat transfer rate

Heat transfer rates through roof samples A, B & C were calculated from the law of heat conduction relation i-e

$$Q = \frac{KAdT}{dx} \quad (3) \quad [37]$$

From 4 June 2022 to 2 July that year, the rate of heat conduction for each roof sample was investigated on three separate occasions daily, i.e., in the morning at 10 am, the afternoon at 1 pm, and the evening at 4 pm. In this experimental study, it was found that roof C is the better roof to stop the heat from atmosphere to inside enviroment, which in turn reduces the electricity need and size of cooling device. The amount of heat transfer per unit area through roof combination C was smallest , and through combination A was most rapid.

Fig.10- Heat transfer rate per unit area in roof combinations A, B &C at 10.00 AM



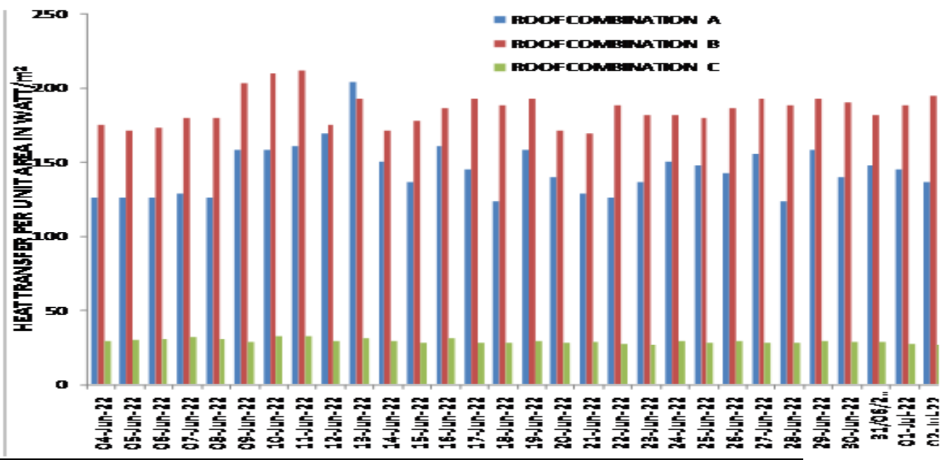


Fig.11- Heat transfer rate per meter square area of roof combinations A, B &C at 01.00 PM

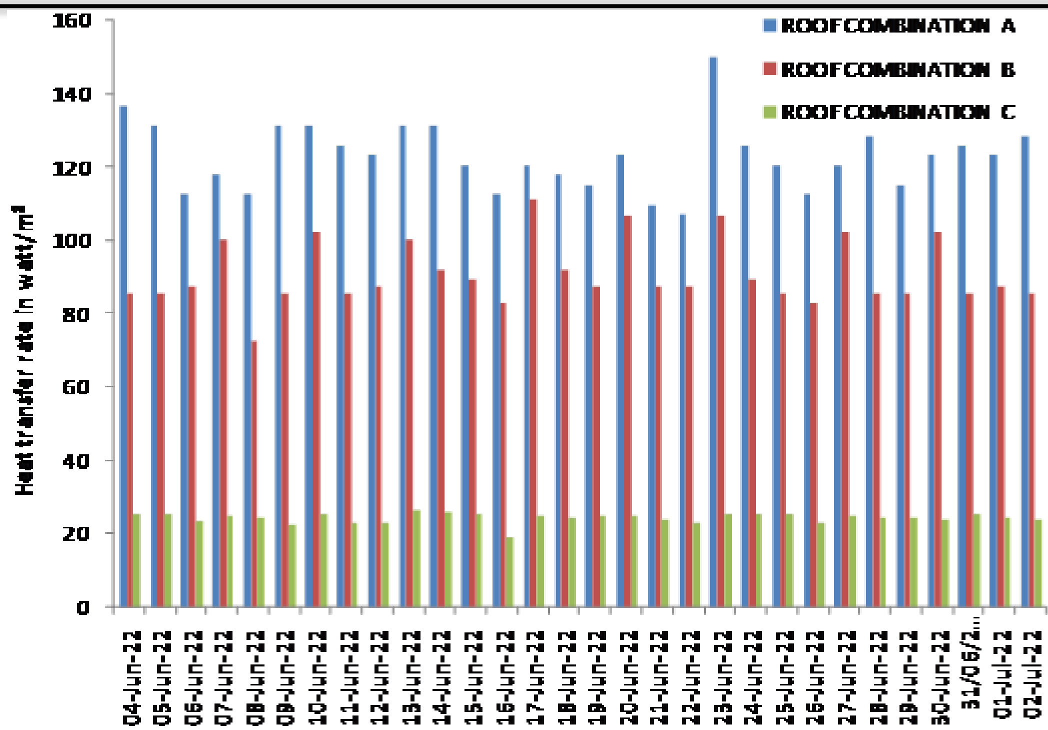


Fig.12- Average heat transfer rate per square meter o area of combinations A, B &C

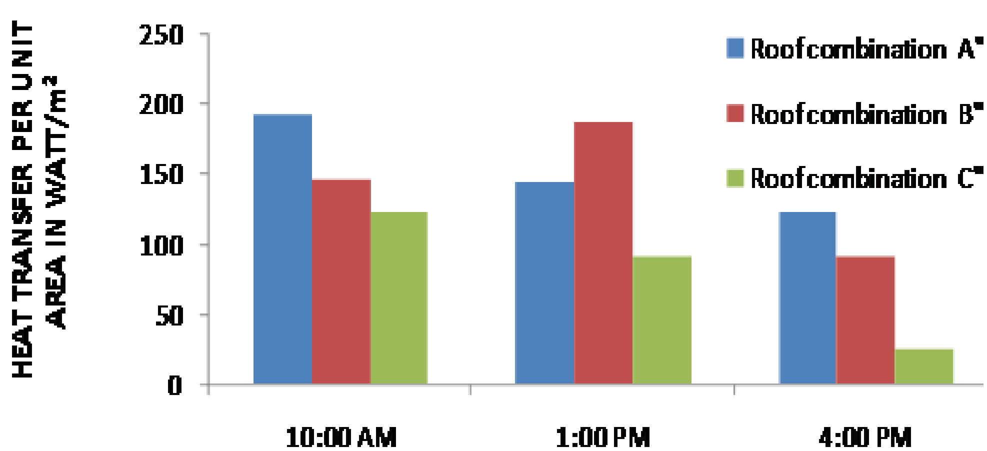


Fig.13- Average Heat transfer rate per unit area in roof combinations A, B &C at 10.00 am

Figures 10 to 12 illustrate the rate of heat dissipation per square meter area through each of the roof samples A, B, and C during 10:00 AM, 1:00 PM, and 5:00 PM, accordingly, between the fourth of June and the 2nd of July, 2022. The mean heat transfer rate per square meter area for roof combinations A, B, and C at 10:00 AM, 1:00 PM, and 4:00 PM is illustrated in Figure 13.

Fig.14- Average Heat transfer rate per unit area in roof combinations

01:00 pm & 04:00 pm

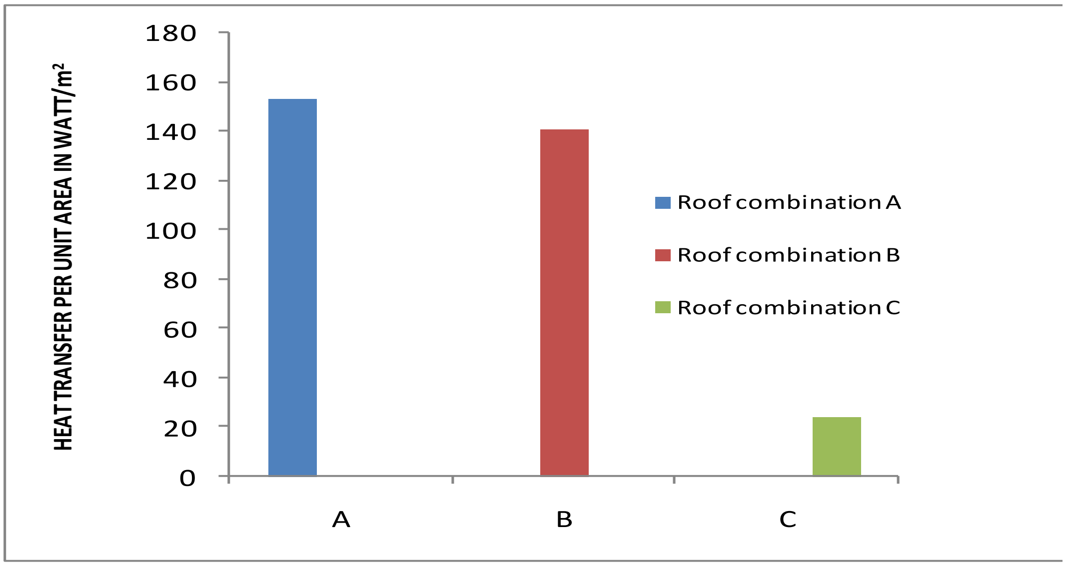


Figure 14 depicts the average heat transfer rates in watt/m^2 for combinations A, B, and C, which were 153, 140.6, and 24 correspondingly. In comparison to roof combination A, roof combination B can minimise heat dissipation per square foot of roof by 84.4%. In terms of cooling and heating load, roof combination C can reduce building energy use by 8.1%.

3.4 Heat Analysis through Hourly Analysis Program

Heat rate was also analyzed using Hourly analysis program HAP.
HAP is the computer scheme which is used to estimate the capacity of heating and cooling device required by each roof combination A, B & C. Total cooling load of roof combination A, B and C are estimated 0.7 KW, 0.6 KW, 0.2 illustrated in Table 5.

Table 5: The Cooling Load Requirement by Each Roof Combination Obtained through Hourly Analysis Program

Roof Combination	A	B	C
Estimated Cooling load using HAP in KWatt	0.7	0.6	0.2

3.5 Energy Running Cost of Roof Combinations

The energy consumption by each roof combination was found by Hourly Analysis Program (HAP). It was estimated that rating of air conditioning devices for roof combination A, B and C is 0.7 KW, 0.6 KW and 0.2 KW respectively. The energy utilization in 24 hours, electricity units consumed and running costs are illustrated in Table 4.7.

Table 6: Energy Running Cost of Roof Combinations

Roof Combination	Rating of Air Conditioning Device in KWatt	Energy Consumed in 24 hours in Kwatt.hr	Running Cost in PKR	Energy saving cost
A	0.7	16.8	510	-
B	0.6	14.4	437	73
C	0.2	4.8	146	364

It was analyzed that energy running cost is higher in case of roof combination A and least in roof C, therefore, combination C has been declared efficient roof combination as per energy saving.

3.5 Construction cost:

Roof combinations RCC roof, A , B & C were constructed from different materials; each material's cost and required quantity are illustrated in Table 7, 8 and 9 and presented in Figure 15 graphically. The area of each roof combination is 4 ft by 4 ft, and the depth of the roof is 2.5 inches.

Table 7: Construction Cost of Different material used in RCC roof

S.No	Material	Quantity	Cost in PKR
Roof combination A	Steel bars 12mm	19.2 KG	4800
	Labor	100 per square ft	1600
	Cement	0.75 bags	750
	20 mm Aggregates	3.30 ft^3	500
	Sand	1.67 ft^3	500
	Total		8150

Table 8: Construction Cost of Different material used in Roof combination B

Roof combination B	Steel bars 12mm	19.2 KG	4800
	Labor	100 per square ft	1600
	Cement	0.75 bags	750
	20 mm Aggregates	3.30 ft^3	500
	Sand	1.67 ft^3	500
	Marble	40 per square ft	640
	Extra concrete	10 per square ft	160
	Extra labor cost	30 per square ft	480
	Total		9430

Table 9: Construction Cost of Different material used in Roof combination B

Roof combination C	Steel bars 12mm	19.2 KG	4800
	Labor	100 per square ft	1600
	Cement	0.75 bags	750
	20 mm Aggregates	3.30 ft^3	500
	Sand	1.67 ft^3	500
	Marble	40 per square ft	640
	Extra concrete	10 per square ft	160
	Extra labor cost	30 per square ft	480
	Polyurethane foam	35 per square ft	560
	Total		9990

It is found that the construction cost of combination C is more than 22% as compared to Combination A, whereas the construction cost of combination B is 16.3% more than combination A.

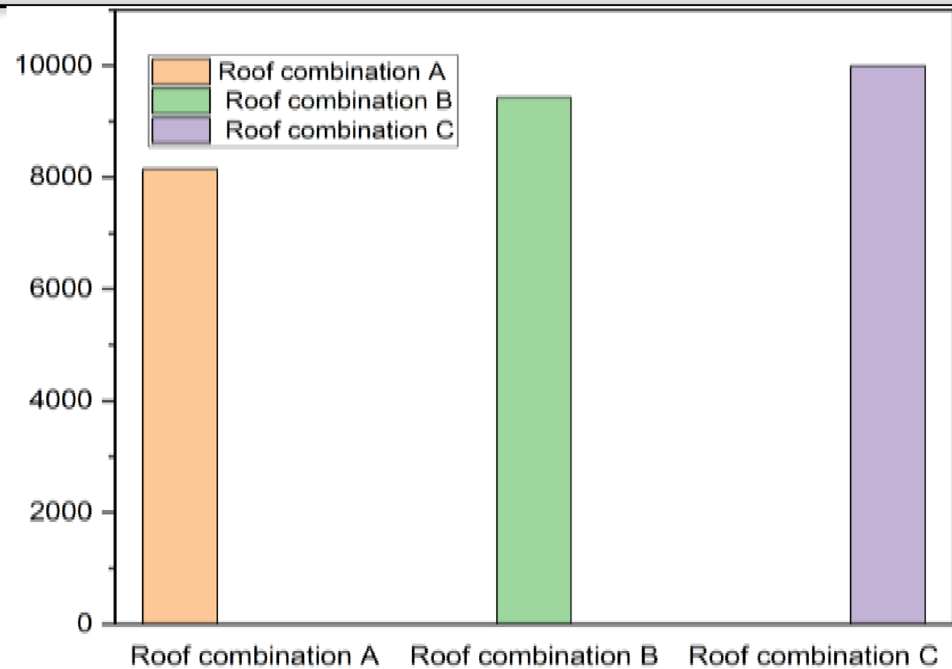


Figure 15: Construction cost of roof combinations A, B & C in PKR

4 Conclusions

In this research, three roof samples namely A, B and roof C were chosen for comparative analysis of thermal behaviour. The roofs were built in Nawabshah and were open to the Sun radiations directly. The cross sectional area of all roof combinations is 4 ft by 4 ft, however, the depth of roof A, B and C is 6.5 cm, 7.3 cm and 9.1 cm, respectively. The height of all roof combination from ground level is 76.2 cm. An examination of the thermal characteristics of the distinct roof combinations has been performed from 04 June 2022 to 02 July 2022. The rate of heat transfer, temperature reduction ability and construction cost of each roof combination have been analyzed and a suitable roof combination has been determined. The Fourier law of heat conduction was used to compute the flow of heat conduction per second. The construction cost has been assessed through a market survey and the temperature reduction ability of each roof was determined by an infrared thermometer. The results of conducted study shown that rate of heat conduction was decreased by 8.1 % and 84.4 % with the adoption of marble and combination of marble and polyurethane, correspondingly, incmparison with the concrete roof without insulating roof material. The temperature reduction ability of roof combinations A, B & C in degree centigrade (°C) was 5.76.58, and 11.94, correspondingly. Although, construction cost was increased compared to roof combination A. The Construction cost has been increased by 15.7 % and 22.5 % when using combination B and C compared to RCC roof. The results showed that roof combination C is recommended because its cost per unit reduction of heat is comparatively small. It is concluded that temperature reduction ability and construction cost of roof combination C is higher than roof A and B, however, heat transfer through roof C is much lower than roof combinationas A and B.

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