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Energy Performance of Conventional Residential Buildings of Kathmandu: A Case of Reflective and Insulated Roofs

Sajan Maharjan [a], Sanjaya Uprety [b]

[a, b] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
Corresponding Email: [a] mailsaajanmaharjan@gmail.com, [b] suprety.ioe.edu.np

Abstract

Buildings are composed of several fabrics that contributes in its thermal comfort and the energy consumption. Roof surfaces are one of largest parts of building envelopes that in constant exposure to the outdoor environment results in the phenomena of overheating of the rooms beneath the roof with constant penetration of solar radiation on outside fabric of roof surface. This paper intends to study the roof surfaces of Conventional Residential buildings in Kathmandu valley in the perspective of Insulation and reflective coatings. The thermal comfort with respect to the cooling and heating loads attained by the roofs were studied thereby resulting the impact and effects on the overall energy performance and energy demand caused by its structure and the construction material A survey to collect the data and perspective towards roof and the thermal comfort with respect to roof structure and its material during the construction was conducted to correlate the outcomes and results with the outputs of the typical prototype conventional residential building of Kathmandu during the course of simulation . In the course of the survey majority of respondent were in favor of cooling the rooms beneath the roof such that the roofs are mostly heated in the course of the year. The U-value and reflectance of the roofing materials were studied such that, the results in simulated scenario of green roof and the clay tile provision has come up to be the best deal by attaining the lesser overall energy consumption to maintain the thermal comfort as compared to the base scenario of the roof. Also Reflective Paint coating come out to be the better measure to reduce the cooling load of the rooms beneath the roof of Conventional Building in Kathmandu Valley.

Keywords

Thermal Comfort, Roofing Materials, Insulation, Reflective coatings, Cooling and heating load

1. Introduction

In the present scenario of Global energy issues, there has been a great concern on the energy optimization and savings on every sector of country. It is ubiquitous that Nepal is also been bothered by the energy issues, despite the fact of the remarkable efforts of government from delivering the electricity access with the restriction to only 6% in 2018 from 81% of people in 2000. [1].The concept of energy efficiency on residential dwellings can be a great approach towards saving energy. As to the reference [2] the total energy consumption by economic sector is 376.3 million Giga-Joule out of which the 80.36% of the energy consumption is been done by residential sector in Nepal. Reflective materials, when used on the roof, have become a well-known measure for reducing power usage from air conditioners (cooling loads) in buildings. Converting traditional roofs to reflecting cool roofs is one of the more straightforward retrofit options, as many of them are applied in the same way as regular paint. Reflective materials keep the roofs at a lower temperature than typical materials when exposed to solar radiation because of their strong solar reflectance and thermal emittance. [3]. It is typical to discover that while the sun's influence on the walls and windows is meticulously planned, nothing is done to reduce the effect of the sun on the roof, which is directly exposed to solar heat for the majority of the day. Heat gains and losses from roofs have a significant impact on indoor thermal conditions. There is no doubt that these issues can be addressed via thoughtful design and the provision of thermal insulation in some form or another. [4]. There has been a trend of conventional dwellings from constituting the roof of concrete and

CGI sheets with very fewer considerations on the energy consumption, interior comfort and its operational costs. As [5], states that the conventional building method has transformed from traditional mud and wood houses to cement concrete buildings, and it is understandable in today's context that Reinforced Cement Concrete (RCC) building construction is the conventional building construction, particularly within Kathmandu Valley. Roof surfaces are the primary recipients of solar heat in building structures with a high roof-to-wall area ratio, accounting for 5-10% of total building energy consumption and more than 40% of energy usage in top-floor buildings [6]. They are the portions of buildings that are most exposed to the sun during the summer season, and as a result, they are responsible for significant cooling loads, which can lead to overheating in the homes below the attics [7]. Overheating of roof increases the heat gain and likely disturbing the quality of life, interior environment and the comfort. The purpose of this study is evaluating the energy performance of roofs in conventional residential buildings in terms of heating and cooling load to attain sound thermal environment on the rooms beneath the roof of Kathmandu Valley.

2. Literature Review

The phrase "thermal comfort" refers to people's feelings about their surroundings, such as whether they are too chilly or too hot. Thermal comfort is difficult to quantify due to its subjective nature. It is determined by the following factors: air temperature, humidity, radiant temperature, air velocity, metabolic rates, and garment levels[8]. A conventional building is one that was constructed in accordance with the typical practice of a given nation during a specific time period. The energy consumed in buildings during their operational phase, such as heating, cooling, ventilation, hot water, lighting, and other electrical appliances, is referred to as operating energy. It can be represented in terms of either end-use or primary energy[9]. U-value (or thermal transmittance coefficient) is a measurement of how much heat passes through one square meter of a structure when the temperature on each side of the structure changes by one degree Celsius. The lower the U-value, the better a structure's thermal performance. The U-value is measured in W/m²K[10]. [11] has discussed the thermal conductivity of various materials as given in the table below:

Table 1: Thermal Conductivity of Material of roof

Material	Thermal conductivity (Watts/meter.Kelvin)
mortar	0.94 and 0.88 for outer and inner leaves (Watts/meter.Kelvin)
Concrete	0.2.3 for Rcc and 1.15 for Screed (Watts/meter.Kelvin)

In reference to [12] with the experiments and simulation carried out in Medan it was computed that the optimum performance was provided by a white painted metal roof with roof insulation. This was most likely related to the solar absorptance, visual absorption, and solar reflectance values. White-painted metal roofs have the lowest solar and visual absorption and the highest solar reflectance. This substance may absorb less solar energy and reflect more of it.as a result, the value of heat gains and HVAC load generated was was likely to be modest. The installation of insulation in the roof has a major impact as well as significantly reduces heat gains and HVAC loads. This is because the U-value of wood fiber being so low, at only 0.61 W/m²K. This indicates that the heat transmission was reduced resulting less heat gains. According to [13] , the under-roof temperature in one conditioned part of the shop with a plenum was decreased by around 22–28 Kelvin by retrofitting with a cool roof using reflective paint on a retail store. According to [14] lower radiation absorption and surface temperature result in lower heat transfers into the building, which reduces cooling energy consumption and peak power demand during the cooling season in conditioned buildings and increases thermal comfort in unconditioned structures throughout the summer. They also found that employing a cool roofing material for industrial premises in the Mediterranean region results in considerable sensible cooling energy savings of up to 42 percent. Those results were reached by employing the best cool roofing material on the market. In reference to [15] the results of the annual cooling loads for the first experimented building show a decrease of 18.8 percent after the cleaning of the cool roof, and a significant decrease of 72 percent after the application of the new cool coating. Additionally, the simulation result shows that after the cleaning of the roof, the annual heating penalty was reduced by 4.2 kWh/m², and after the implementation of the new cool roof results in a 1.76 percent reduction in yearly cooling load for the second building, whereas the heating penalty was 1% for the whole simulated year. [16] Measurements and simulation shows that when the heat transfer coefficient of the roof is less than 0.86 W/m.K for exterior insulation roofing, the change in energy saving rate is sensitive to the thickness of the insulation layer. When the thickness of the insulating layer increases, the change in energy saving rate is extremely minimal and the anticipated energy saving rate limit value is 40%. From the experimental study conducted in Cuernavaca, Morelos by [17] the traditional and green roof had a maximum interior surface temperature of 38.9°C and 25.5°C, respectively. In reference to [18] clearly indicates that Resistive insulation may be quite efficient at lowering soffit temperatures. Without insulation, the soffit temperature reached 42.8% of its maximum. This implies that the roof slab soffit can serve as a heated body, preventing the building from being used as a free-running structure with an adequate level of thermal comfort. Resistive insulation can have a considerable impact in lowering soffit temperature. The greatest recorded value was around 33.8°C for 25 mm insulation and 32.8°C for 50 mm insulation. The American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) initially acknowledged cool roofs on nonresidential and high-rise residential structures in ASHRAE Standard 90.1-1999. ASHRAE revised its criteria for low-rise residential structures in 2001 to credit cool roofs, and the changes were implemented three years later in ASHRAE Standard 90.2-2004: Energy-Efficient Design of Low-Rise Residential Buildings.[19]

3. Methodology

Initially a survey of 98 household was conducted on the perspective of roofing parameters , structures and occupants of the buildings of conventional residential buildings inside Kathmandu Valley. Before survey it was confirmed that about 98 household responses of survey would be enough to develop the level of confidence to bear with the certain uncertainty by the help of Rao software and to carry out further process in evaluation and analysis through simulations in virtual environment created for the prototype building in Ecotect Software. The margin of error was entered to be 5% whereas the level of confidence is maintained to be 90%.the population size of about 3.57 million projected by [20] is entered and response distribution among the questionnaire was maintained at 90Also field observations and data collections of a residential building was carried out and the data's surveyed information's were taken in other to relate them with the impact of the roof structures, their thermal performance, and the comfort level. A typical prototype residential building was prepared in a virtual environment of Ecotect Software to create the base case scenario such that it resembles with the construction technology, building materials and factors of thermal performance with the one that is been surveyed and examined. Then the models was subjected to various interventions on roof to examine the impact of its reflective and insulation property. The comfort level parameter of 18-22°C was also taken into consideration for the roofs beneath the roof. This parameter was established such that the cooling and heating loads are also keenly observed for the betterment of the analysis and to deliver the better interventions and ramification options and strategies to attain better thermal environment inside the room under the roofs.

4. Materials and data

The collection of climatic and weather data of past 2 years were done from hydrological and meteorological department, Nepal for the simulation processes. Weather files and other supplement files were generated from the weather oriented websites and are subjected for simulation according to the needed environment.

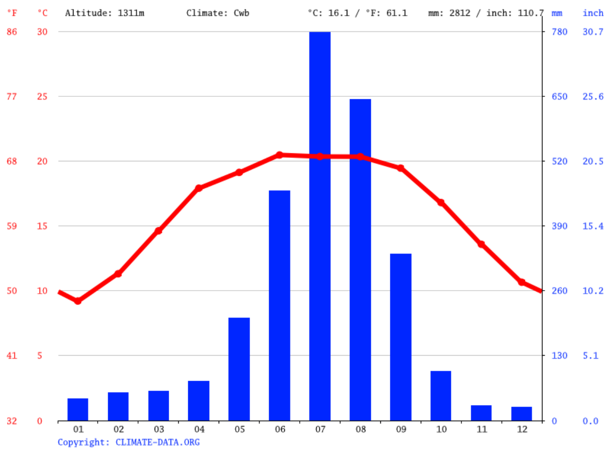

Figure 1: Monthly Weather Chart of Kathmandu Valley(source:climate-data.org.2021)

According to [20] the projected residential area in Kathmandu was computed to be around 16 thousand hectares. The increase in buildings and its area increases the urge in need of energy which in turn can reach into energy issues and energy crises Along with the issues the more the residential buildings with conventional structures the more the need of energy to balance out the thermal comfort inside the building with respect to the conventional roof surfaces.

Kathmandu valley is located 1311 meters above sea level. The climate here is moderate, with temperatures ranging from warm to cool. Summers in Kathmandu are significantly rainier than winters. The average yearly temperature is 16.1 degrees Celsius and annual precipitation totals to 2812 mm.The rainy season in Kathmandu is warm, humid, and partially overcast, whereas the dry season is pleasant and usually clear. Throughout the year, the temperature generally ranges from 37°F to 84°F, with temperatures seldom falling below 33°F or rising over 89°F. A data collection of residential buildings to set up the base parameter case on virtual environment of simulation software are collected as follows:

Table 2: Data Collection of one of the surveyed building

family size	5
Approx Monthly Electrical expense	1500-2500
Age of the House	more than 20 years
Roof Structure	flat surface
Level of roof	Double Terrace
Reflective and Insulated treatment on roof	No
Material of Roof	3mm Punning+38mm screed +150mm concrete slab+ 15mm cement plaster
rooms beneath the roof	puja room +bedroom+ toilet
No of People living beneath the roof	2
amount of time spend on rooms beneath the roof	10
Visitor Perception	hot
Active system of heating and cooling	No
Ventilation	yes
Area of roof	700 sq.ft (approx)
orientation of the building	south

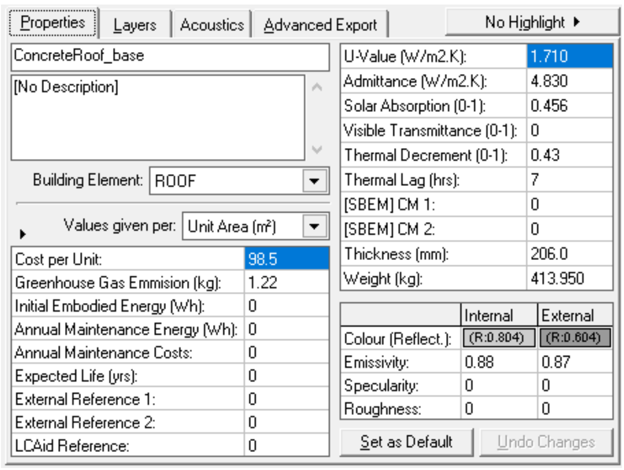

Figure 2: Thermal Property assignment of the material of the roof in the model for simulation (Ecotect)

In case of the data inputs in Ecotect software, the comfort thermostat level was assigned to be 18°C-22°C. The typical prototype building of conventional residence was established in Ecotect software with the roof zones to extract the cooling and heating loads of the rooms beneath the roof. The materials of the roof zone was also assigned as per the detail data collection of the residence during the survey. The roof zone were assigned to Thermal environment such that it computes the cooling and heating load. U-Value of the materials, Reflectance of the coatings in the exposed surface of the roof were assigned as per the default data of Ecotect Software and subjected to simulation for further analysis and discussions.

In the model the base case scenario was created first and then the series of interventions were done in respect to the insulation and reflective coatings. Four intervention cases were created and a combined case of reflective coatings and insulation was also established to analyze the impact of sole and integrated way of intervening the roof. The structure of roof were also established simultaneously to analyze the impact on thermal performance on heating load and cooling loads. Mostly in Nepal the traditional roofs are inclined 30 degrees to retain the roof and solar insulation. So the pitched roof of the simulated building was also subjected to the angle of 30 degrees. As a trend of 2.5 story residence houses are prevailing in Kathmandu valley, the model was also constructed in such way that it consists of upper and lower terraces. The windows of sizes 1800mm x 1200mm is established on the rooms beneath the roof. The vertical building fabric (wall) is assigned to be of Brick wall with plaster finish.

Scenario	Structure of Roof	Material for roof	Parameters
base roof Scenario	Flat	Intervention :3mm punning +38mm screed +150mm Concrete + 15mm plaster	Uvalue: 1.71 W/m2K Reflectance of reflective coating: 0.6
scenario 1	Flat	Intervention : Paint light color on sun exposed surface of Base roof scene	Uvalue: 1.71 W/m2K Reflectance of reflective coating: 0.7
scenario 2	Flat	Intervention: 25mm roof tiles + 38mm screed + 150mm concrete +15mm Plaster	Uvalue: 1.63 W/m2K Reflectance of reflective coating: 0.7
scenario 3	Flat	Intervention : scene 1+2	Uvalue: 1.63 W/m2K Reflectance of reflective coating: 0.7
scenario 4	Flat	Intervention : 75 mm ht green grass + 2mm waterproofing membrane +38mm screed + 150mm concrete +15mm Plaster	Uvalue: 0.42W/m2K Reflectance of reflective coating: 0.6

Figure 3: Scenario Intervention with different roofing material for simulation

5. Survey Results and Analysis

Among the survey of 98 conventional residence, the approximate monthly expenditure of most of the respondent is NRs 1500-2500. The 8.4% of the respondent are on one with the highest expenditure on the monthly expense on energy of the house.

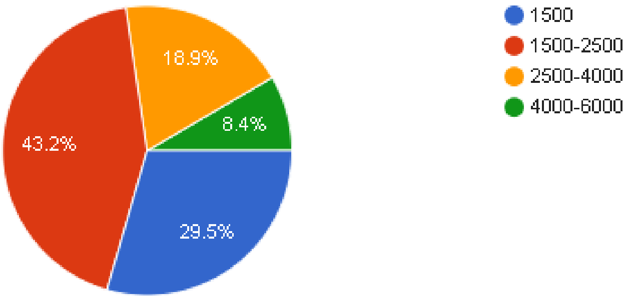

Figure 4: Pie-chart on Approximate monthly expenditure on electricity of Surveyed Buildings

Among the 92 responses on the structure of roof the majority people prioritizes the flat roof construction. This can suggest us that the people are more inclined to the economic way of constructing the roof. 17.4% of the people are the one with their house with combined roofing structure with the flat and pitched ones. Similarly 51.6% respondent have the house with the single terrace and 45.2% of the respondent has their home with 2 terraces in different levels. Normally the two terraces are located to the last two floors of the house.

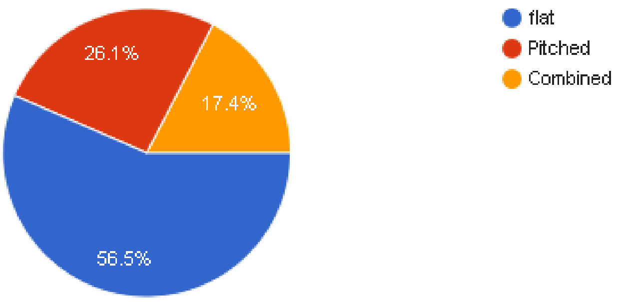

Figure 5: Pie-chart on Roof Structure of Surveyed Buildings

In present global world, there are variety of roofing materials that can be treated to achieve the insulation and reflection of the solar heat .majority of respondent believe in conventional concrete cement slab. The concrete slab may be the good option in structural point of view. 67 respondent has their roof treated with screed and punning whereas the 49 respondent has their roof treated with the tiles. Just 1 respondent has the wooden purlins with the tiles on his house.

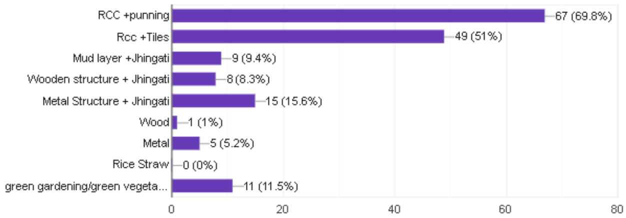

Figure 6: Graphical chart on the Roofing material of Roof of Surveyed Buildings

39.6% of the respondent feel hot during daytime living on the rooms beneath the roof whereas the 25.8% people have their thought on feeling hot during the evening time. This is due to the gradual heat transfer from roof media to the rooms beneath them and reaching the rooms on the time of evening and early night.

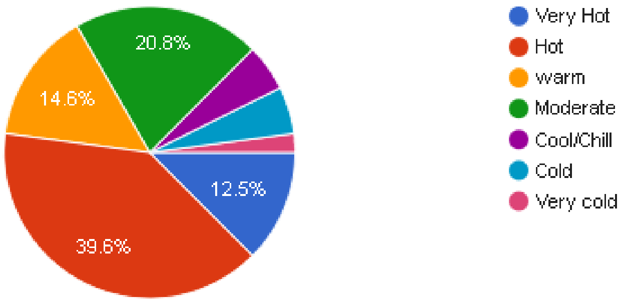

Figure 7: Pie-Chart on Occupant perception on living beneath the rooms of roof in Surveyed Buildings

6. Simulation Results and Analysis

A virtual environment of Kathmandu Valley is created using the weather file. An analogous surveyed building is established in the environment and the roofing parameters were analyzed and observed. A total of about 52 m2 building as collected from field measurement is established in Ecotect software and subjected to simulation process. The virtual model is maintained for dwelling criteria under the exact orientation of field measurement i.e. south orientation.

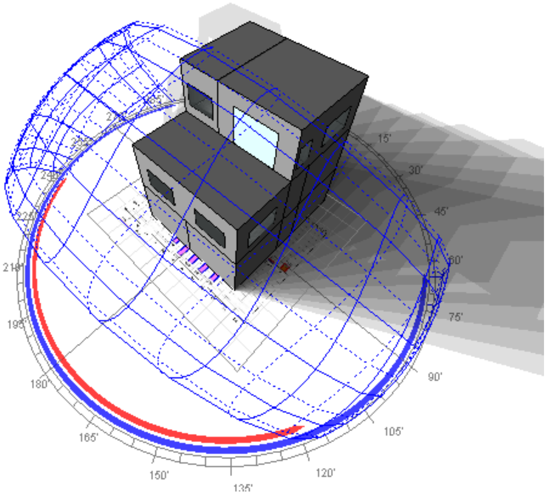

Figure 8: Ecotect Model of the Prototype Conventional Building of Kathmandu valley for Simulation

For the base case, as observed in the field the material were assigned with the managements of 3 zones, 2 below the upper terrace and one below the lower terrace. The monthly heating and cooling load are simulated to be around 686.3 KWh and 1108.6 KWh respectively. It is observe that the maximum cooling for the roof is required on 12th of May and maximum heating is required during the day of 29th of December. It is also observed that about 23% of the direct solar heat is received by the roof during 12pm on 2nd august.

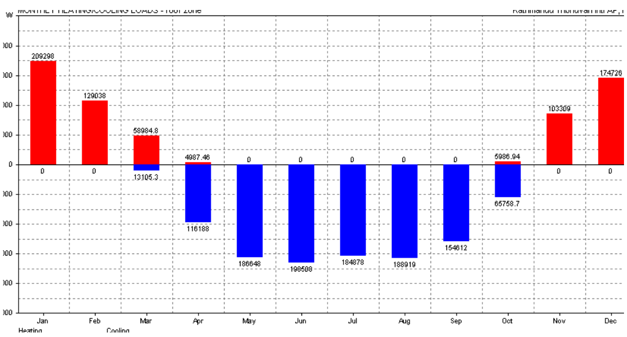

Figure 9: Energy Performance(Heating and Cooling load)of the Base case-Flat Roof

A comfort level of 18°C to 22°C is maintained in the thermal environment of the model. It is observed that the month of September was simulated to be the most discomfort month with 295 hours with the cooling load whereas the month of discomfort in the perception of heating load is December with total discomfort hours to be 303 hours. In the month of September 40.9% of the total hours are computed to be discomfort hours whereas 41.2% of the total hours of December are computed to be discomfort hours. The total percentage of comfort level in base scenario being 2927 hours in yearly calculation is calculated to be 33.2

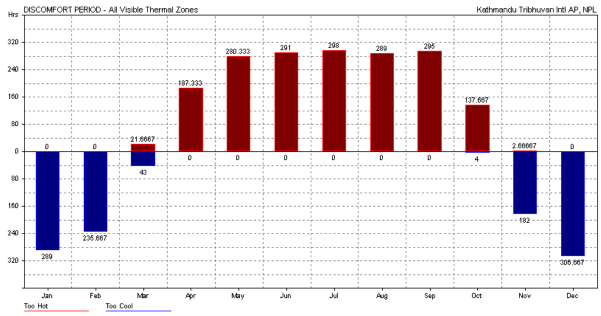

Figure 10: Monthly Discomfort Hours of Base Case Scenario-Flat Roof

Various interventions in flat roof surface of base case are carried out and different results are taken for analysis. A reflective coatings for base scenario is intervened in scenario 1 whereas the outside material of the roof is intervened in scenario 2 with the clay tiles of 25mm. also both the reflective and insulated properties are established in scenario 3. The case of green roof in scenario 4 is also established. With these interventions various results are obtained among them the cooling and heating loads are compared. The heating and cooling load of scenario 1 is obtained to be 713 KWh and 742 KWh. Relatively the cooling load is decreased up to 33% whereas the heating load is slightly increase by 4%. The restriction in transfer of heat with the provision of reflective treatment causes the heating load to slightly increase. The overall total load with the intervention in reflective coatings can result in decrease in load by around 18.9Similarly with the intervention of insulated clay tiles on the buildings as on scenario 2 can subsequently decrease the heating and cooling load by around 9.6% and 30.1% respectively. The total load decreased by 22.3% as compared to the base case scenario. An intervention of both reflective and insulated treatment is done in scenario 3 where the heating and cooling load are changed in an amount of 626 KWh and 705 KWh respectively. The change of total loads by this intervention is 1331 KWh from 1794KWh. Green roofs on other hand results the best performance of the roof as its U-value is relatively lower than that of the roofs previously discussed, the total load consumed by green roof with the U-value of 0.42 W/m2K as suggested by the Ecotect software is 171 KWh.

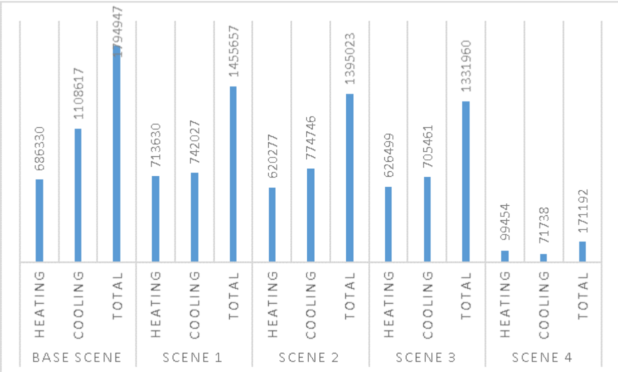

Figure 11: Energy Performance Comparison of Different scenario interventions in roof- Flat Roof

These interventions are also carried out in pitched roof surfaces. The maximum cooling load can be observed in the month of June whereas January has come up with the month of maximum heating load required. The results of the total loads in pitched roofs are relatively higher than that of the flat roofs. This is due to the increment in roof area from 52 m² to 68 m².

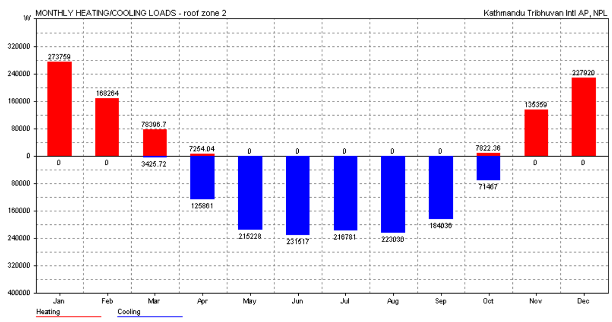

Figure 12: Energy Performance(Heating and Cooling load)of the Base case-Pitched Roof

The load consumed per unit surface area of pitched and flat roofs are 34.5 W/m² and 31.9 W/m². The pitched roof surface has relatively lower total load as compared to the flat surface. For pitched roof surface The heating and cooling load of scenario 1 is obtained to be 935 KWh and 875 KWh. Relatively the cooling load is decreased up to 31% whereas the heating load is slightly increase by 4%. The overall total load with the intervention in reflective coatings can result in decrease in load by around 17

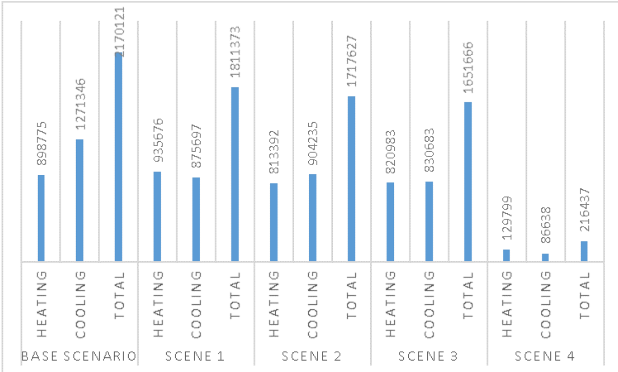

Figure 13: Energy Performance Comparison of Different scenario interventions in roof- Pitched Roof

Similarly with the intervention of insulated clay tiles on the buildings on scenario 2 can subsequently decrease the heating and cooling load by around 9.5% and 28.9% respectively. The total load decreased by 20.9% as compared to the base case scenario. An intervention of both reflective and insulated treatment is done in scenario 3 where the heating and cooling load are changed in an amount of 820 KWh and 830 KWh respectively. The change of total loads by this intervention is 1651 KWh from 2170 KWh. Green roofs intervention in scenario 4 consumes 129 KWh on heating load and 86 KWh in cooling loads. The intervention of green roof on the buildings on scenario 4 can subsequently decrease the heating and cooling load by around 85% and 93% respectively.

7. Discussions and Conclusion

Different cor-relational analysis were generated from the variables of the questionnaires during the survey. the output shows the significant relation of responses on cooling the rooms with respect to the functional spaces of the rooms beneath the roof. Respondent living most of the time beneath the roof constitutes the rooms like living room, bedrooms, kitchen in the building in upper floors whereas the occupant having their livable rooms in lower floors occupies the rooms beneath the roof lesser. It is also found that there is the relation between family size and the expenses on the electricity. the larger the family size the greater the expenses are seen on the correlation analysis between them variables.

The significant short dip of the cooling load in the moth of July can be observed on figure 9 and figure 12. the rainy season and cloudy sky can be the reason behind the dip seen during this month.The month of march, April and October suggests the transition of

heating and cooling loads due to the reason of major season change during those period of the year in Kathmandu valley.
Reflective Coatings of the roof delivers the energy performance better in terms of the cooling load that the heating load. The reason behind this might be the property of reflective coatings to only divert the solar radiation falling on surface of roof but not having the property of heat transfer through the surface of the roof. Also Green roofs and the integrated ramifications of reflective white paints and clay tiles were turned out to be the best way of managing the cooling and heating loads in the perspective of roofing treatment and balancing the thermal comfort inside the rooms beneath the roof surface to create sound thermal environment inside the building envelope.
Pitched and flat roof structures are the styles of building the roof. Pitched roofs on same plane constitutes larger surface area than that of the flat surface because of inclination which in turn consumes more energy by increasing the surface area. The pitched roofs are aesthetically pleasing and needs higher skilled person to construct and maintain whereas the roof of flat surface consumes lesser time and investment.Both the roof structures carries the valuable significance in terms of energy consumption , energy efficiency and architectural aesthetics. The pitched roof consumes the heat from sun radiation in discrete way as it has more than one or more surfaces whereas the flat roof surface has got only one surfaces and the rate of heat absorption and transfer is constant unless the shadows from adjacent object are observed. In Kathmandu valley the houses mostly consists of punning finish and fabricated tile finish which in turn consumes larger loads than that of the roofing materials with lesser U-value , better reflective properties and coatings . The concept of Green roofs with the provision of harvesting the crops can also be the better concept among the people of Kathmandu valley benefiting them with the crops and sound and thermal friendly rooms beneath the roof. This can be the sustainable approach towards attaining the energy efficient roof through lesser capital investment in terms of materials and technology.

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