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Thermal Energy Performance of a Residential Building with Respect to Walling, Roofing and Glazing Materials, For Present and Future Scenarios of Climate Change

Sama Sthapit [a], Inu Pradhan Salike [b]

[a] *Department of Applied Sciences & Chemical Engineering, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[b] *Department of Architecture, Pulchowk Campus, IOE, Tribhuvan University, Nepal*
[a] samasthapit@gmail.com

Abstract

Climate change is having a significant impact on Nepal's environment, people, and economy, and worsening existing social and economic challenges. Adaptation to climate change is a functional necessity and best way to protect building is to have distinct thermal boundary. Therefore, for any building, selection of suitable building materials during the design phase is important. This research focuses on evaluating and comparing effect of climate change in different types of wall, roof, and glazing envelopes in a residential house in Lalitpur for present and future scenarios of climate change. Ecotect has been used for the building simulation and analysis. Analysis have been done considering 4 different scenarios of walling materials, 4 different scenarios for roofing materials and 3 different scenarios for glazing materials. It was found that for walling material, AAC (Autoclaved Aerated Concrete Blocks); for roofing, Tile, air space, reflective foil, attic space, insulation, gypsum ; and for glazing, double glazed with argon were best in terms of thermal comfort.

Keywords

Climate change, Adaptation, building materials, present and future scenarios, Ecotect

1. Introduction

Nepal being listed as a least Developed country in the world it is hit hard by the adverse effects of climate change and the people of Nepal cannot afford the adaptive measures to fight against the Climate Change. Globally, Nepal is ranked fourth, in terms of vulnerability to climate change. Analysis of trends from 1971 to 2014 by the Department of Hydrology and Meteorology (DHM) indicates that the average annual maximum temperature has been increasing by 0.056 °C per year.[1]

The residential sector is now a significant environmental load with high related operational energy. Climate change is unavoidable and adaptation approaches to cope with future situations must be taken in consideration However, any climate adaptation strategy for dwellings must also be functional of adapting occupant requirements, influenced by new technologies.

The temperature of Nepal is warming at the rate faster than that of the global average[2]. Rising global temperatures trigger significant impacts on weather and climate. addressing the factors that contribute to climate change and minimizing energy consumption in buildings can have a positive impact on the thermal comfort of people living in them.

The building design code issued by the Government of Nepal does not address the issue of thermal comfort, which could be the reason the modern buildings built under the design code are performing poorly in terms of indoor thermal comfort[3].

Choosing the right building materials can play an important role in improving the thermal comfort of buildings and reducing their contribution to climate change. Factors to consider when selecting building materials are insulation, solar reflectance, thermal mass, sustainable sourcing and embodied carbon. Insulating a building can play a critical role in improving its energy efficiency, reducing energy consumption, and improving thermal comfort for occupants. Aspects of building insulation includes insulation type, location, R- value, u value, air sealing and vapour barrier.

This paper describes a series of field studies, literature and simulation analysis to improve the thermal performance of a residential building in the Lalitpur area.

Adaptation is a continuous process that requires a regular revision of development plans and policies as per the changing climate and socio-economic conditions[4].

2. Research Objectives

The general objective of the research to study the effectiveness of building envelope as insulating barrier for adapting climate change in residential building of Kathmandu.

Specifically, the objectives are:

- To study the heating and cooling load required to maintain comfort with respect to building materials.
- To analyse the effects of climate change in the energy performance of building.
- To study the energy performance for different combination of building materials with respect to current and future scenarios of climate change.

3. Literature Review

Temperature in Nepal's warm temperate climate does not fall down significantly during winter. Therefore, solar radiation combined with thermal mass of the building can retain the indoor temperature at a comfortable level.
Combined with the spatial design of a building, the design of a building fabric has a direct impact on the building's energy consumption. Hence, a proper envelope design is considered one of the passive design measures that should be applied in order to achieve energy conservation[5]. The required loads increase gradually with increasing the corresponding walls U-value, i.e. decreasing the thermal resistance of the wall materials[6]. Heating and cooling loads of buildings are gradually reduced, as the wall U-value is lowered[7].

Thermal transmittance (U value) of the burned brick wall (230mm) is 3.15 W/m^{2}k, not much very good but it can be improved with using the insulating material such as mineral wool, rock wool etc. Fly Ash, Autoclaved Aerated Concrete, Glass Fibre Reinforce Gypsum, Fly Ash Lime Gypsum comes under the criteria for sustainable building material[8]. For roof, performance of clay tiles is marginally better than that of cement fibre and its improvement can be achieved by using insulation[9].Selection of optimum glazing and ventilation system can reduce the energy consumption in the building. [10].Shading devices for windows are needed for the summer period[11]. The ASHRAE Standard 55-2004 recommends a temperature range of 20°C to 24°C in winter season and 22 °C to 26°C in summer season[12]. The purpose of this standard is to specify the combinations of indoor thermal environmental factors and personal factors that will produce thermal environmental conditions acceptable to a majority of the occupants within the space.

4. Methodology

This research follows the pragmatic research philosophy using both quantitative and qualitative approach. Methods used for this research are simulation and observation. Primary temperature data for the present climate scenario year 2022 were taken from DHM (Department of Hydrology and Meteorology, Nepal). Secondary data for future projected temperatures were collected from Climate Change Knowledge portal. Simulation was done using the data and analysis were done. Tools used are Ecotect, Weather data tool and Elements.

4.1 Study area

For modelling and analysis, a house in Sanepa was taken as a general model for simulation. A virtual model was generated using ecotect software. Analysis were done using different scenarios using different materials and climatic conditions. At present, most of the residential houses use bricks, concrete and single glazed windows. Hence similar house has been chosen for the base case. Geographically the site is located at 27° 41' 51.28" N/85° 21' 19.31" E at an elevation of 650 m above mean sea level. The Kathmandu Valley receives an average hour of sunshine of more than 6 hours per day from October to May, which is good for passive solar heating in the cooler months. [13]

4.2 Data Collection and Processing

Temperature data for the year 2022 were collected from DHM. From literature review, U-values for different materials were collected. Using Ecotect tool the annual load analysis for walling, roofing and glazing materials were carried out. Using the Climate Change Portal, the future temperature difference was calculated using the base temperature from DHM. Further analysis was done using ecotect and comparisons were made.

4.2.1 Analysis for walling materials

This analysis is done to determine which is an ideal walling material to maintain the human comfort level. It is determined by calculating the total heating and cooling load to maintain the comfort level. For this analysis 4 different scenarios are created and simulation was performed to calculate the annual heating and cooling loads. Roofing and glazing materials are made constant with variable wall materials listed as below.

Table 1: Scenarios for Wall

Scenario	Wall	Roof	Glazing
Base	230mm brick wall	Concrete with plaster	Single
1	Cavity brick wall	Concrete with plaster	Single
2	Hollow concrete block	Concrete with plaster	Single
3	Autoclaved Areated concrete	Concrete with plaster	Single

4.2.2 Analysis for Roofing materials

This analysis is done to determine which is an ideal roofing material to maintain the human comfort level. It is determined by calculating the total heating and cooling load to maintain the comfort level. For this analysis 4 different scenarios are created and simulation was performed to calculate the annual heating and cooling loads. Walling and glazing materials are made constant with variable wall materials listed as below.

Table 2: Scenarios for Wall

Scenario	Wall	Roof	Glazing
Base	230mm brick wall	Concrete with plaster	Single
1	230mm brick wall	Terra-cotta' attic space, timber film	Single
2	230mm brickwall	Ceramic tiles, 5mm thermal insulation, concrete slab	Single
3	230mm brick wall	Tile, air space reflective foil, attic space insulation, gypsum	Single

4.2.3 Analysis for Glazing materials

This analysis is done to determine which is an ideal glazing material to maintain the human comfort level. It is determined by calculating the total heating and cooling load to maintain the comfort level. For this analysis 4 different scenarios are created and simulation was performed to calculate the annual heating and cooling loads. Walling and Roofing materials are made constant with variable wall materials listed as below.

Table 3: Scenarios for Glazing materials

Scenario	Wall	Roof	Glazing
Base	230mm brick wall	Concrete with plaster	Single
1	230mm brick wall	Concrete with plaster	Double
2	230mm brick wall	Concrete with plaster	Double with argon filling

Using different scenarios for each analysis, the results are compared and ideal building materials for each three elements are determined. Based on the results the following cases are produced.
The above analysis gives results as follows:

Table 4: Best and Least Best materials

Material	Best	Least Best
Walling	Autoclaved Aerated Concrete	230mm Brickwall
Roofing	Tile, air space, reflective foil, attic space,insulation, gypsum	Concrete with plaster
Glazing	Double with argon filing	Single

For this scenario

Combining the best walling, roofing and glazing elements, best scenario is simulated and annual heating and cooling load is calculated.

Combining the least best walling, roofing and glazing elements, least best scenario is is simulated and annual heating and cooling load is calculated.

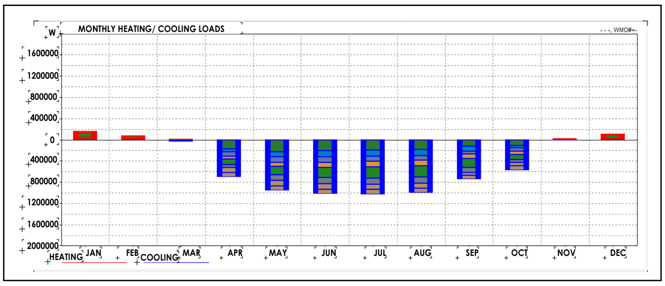

Figure 1: Annual Load using Best Case Scenario

Best case Scenario The best-case scenario was created using the materials which had good insulating properties with minimum annual load requirement. For walling, AAC Blocks. For roofing, Tile, air space, reflective foil, attic space, insulation, gypsum and for glazing, double glazed with argon filing.

For this scenario Heating Load is 401588 wh, Cooling Load is 6097666 wh and total load is 64,99,255 wh.

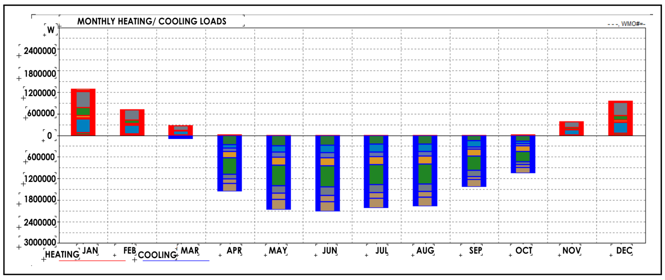

Figure 2: Annual Load using Least Best Case Scenario

Least Best case Scenario The least best-case scenario was created using the materials which did not had good insulating properties with maximum annual load requirement. For walling, 230 brick wall, for roofing, concrete roof with plaster and for glazing, single glazed window. For this scenario Heating Load is 3681077 wh, Cooling Load is 12361465 wh and total load is 160,42,542 wh.

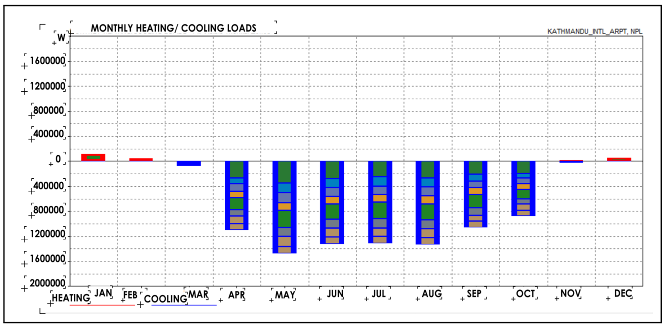

Figure 3: Predicted annual load for best case scenario for (2040-2059) SSP5-8.5

Predicted annual load for best case scenario for (2040-2059) SSP5-8.5 Annual load for the best-case scenario was calculated using the SSP5 – 8.5 for the year (2040-2059). Total heating load is 250282wh, cooling load is 8605205wh and total load is 88,55,487wh.

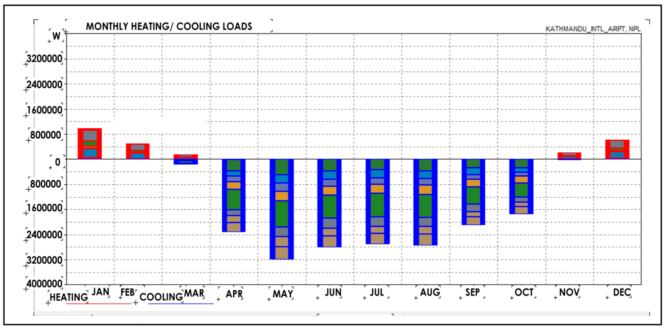

Figure 4: Predicted annual load for least best case scenario for (2040-2059) SSP5-8.5

Predicted annual load for least best case scenario for (2040-2059) SSP5-8.5 Annual load for the least best-case scenario was calculated using the SSP5 – 8.5 for the year (2040-2059). Total heating load is 2480146wh, cooling load is 17882076wh and total load is 2,03,62,222wh.

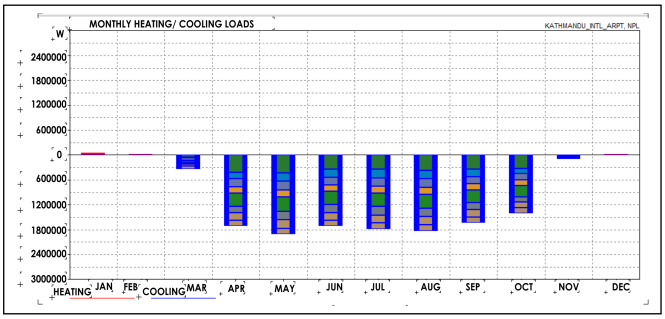

Figure 5: Predicted annual load for best case scenario for (2060-2079) SSP5-8.5

Predicted annual load for best case scenario for (2060-2079) SSP5-8.55 Annual load for the best-case scenario was calculated using the SSP5 – 8.5 for the year (2060-2079). Total heating load is 125652wh, cooling load is 12473753wh and total load is 1,25,99,405wh.

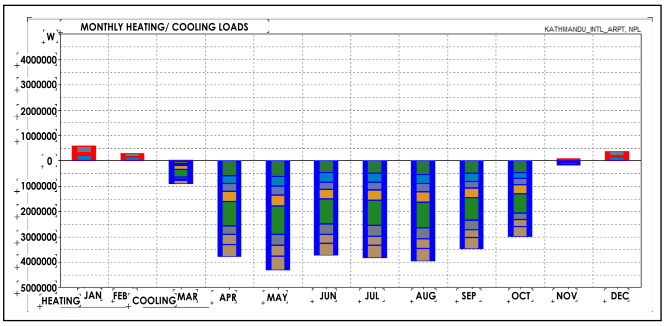

Figure 6: Predicted annual load for least best case scenario for (2060-2079) SSP5-8.5

Predicted annual load for least best case scenario for (2060-2079) SSP5-8.5 Annual load for the best-case scenario was calculated using the SSP5 – 8.5 for the year (2060-2079). Total heating load is 1408096wh, cooling load is 27307906wh and total load is ,87,16,002wh.

5. Result and Discussion

Table 5: Load Requirements

	2022	(2040-2059) SSP5-8.5
Best	64,99,255 wh	88,55,487 wh
Least Best	1,60,42,542 wh	2,03,62,222 wh

	(2060-2079) SSP5-8.5
Best	1,25,99,405 wh
Least Best	2,87,16,002 wh

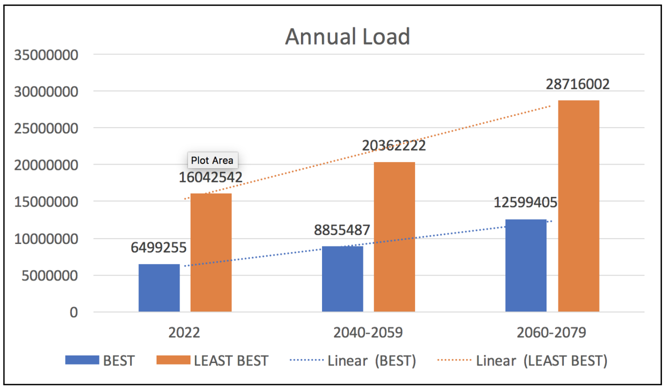

Figure 7: Annual Load for Present and Future Climate Scenario

Load Comparison for Present and Future climate change From the above result we can say that the total annual building load increases in the future scenario. Heating load can be seen decreasing while the cooling load is increasing significantly. Load difference between the best-case scenario and least best case scenario is more than double. So, it is recommended to use the suitable building materials which are thermally friendly for adapting the climate change effects i.e. for walling, AAC Blocks; for roofing, tile, air space, reflective foil, attic space, insulation, gypsum ; and for glazing, double glazed with argon.

Also, it is important for governing bodies to create policies and regulations that guide adaptation to climate change. Such policies can help ensure that necessary measures are taken to address the impacts of climate change and that vulnerable populations are adequately protected.

6. Conclusion

From the above analysis, we can conclude that for walling materials, AAC Blocks; for roofing materials, combination of tile, air space, reflective foil, attic space, insulation and gypsum; and for glazing materials, double glazing with argon filling are best among the selected building materials. Which can save the energy up to 9543287wh in present climatic scenario, 11506735wh in (2040-2059) and 16116597wh in (2060-2079) using SSP5-8.5. Result shows that with the increasing years the load required to attain comfort increases with the climate change, hence is important to incorporate suitable building materials. With climate change, heating load becomes significantly less important in better insulated buildings and therefore measures which reduce cooling load are more critical.

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