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Low-Cost Insulation for Energy Efficient Buildings in Terai Region of Nepal

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Abstract: There is a huge amount of energy savings potential in public building sector that has yet to be realized. By prioritizing energy efficiency in its own buildings and thus promoting the development of required knowledge in terms of new technology and construction methods, the public sector will lead the way in efforts to increase the rate of renovations. The low-cost insulation strategies and a comparison of cost with existing insulation materials has been described in this study. We have repeatedly faced energy crises and will continue to do so in the future if appropriate action is not taken in a timely manner. Properly implementing energy-saving initiatives in for achieving thermal comfort in buildings as well as reducing the energy costs would undoubtedly inspire the residential sector, resulting in significant reductions in energy usage. Simulations were carried out to study insulation layers on various building components like exterior walls, floor and roofs, generating different scenarios for a building as a base model, which were then compared and analysed to verify the literature used to develop the cases. The proposed recommendations, which have been validated, are certain to increase building energy efficiency, achieve thermal comfort in low cost than what is currently being used.

Key words: Buildings, energy, energy efficient, thermal comfort.

1. Introduction

Buildings are one of the major factors for global warming. It uses more than 40% of global energy and emits as much as one third of global greenhouse gas, both in developed and developing countries [1]. Recent report from Intergovernmental Panel on Climate Change (IPPC) predicts that the surface temperature of earth during 21st century is likely to rise a further 0.3 to 1.7 °C (0.5 to 3.1 °F) for their lowest emissions scenario and 2.6 to 4.8 °C (4.7 to 8.6 °F) for the highest emissions [2].

It is difficult to define or generalize the thermal performance of Nepalese building due to the irregularities in building construction geometry, materials used and cultural differences but if considered the indoor operative temperature and relative humidity levels in the building, perspective of comfort in accommodation can be drawn [3].

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Terai Region of Nepal is the hottest part of the country with average summer temperatures hitting easily above 35 °C and this creates a very uncomfortable environment for people residing in that part of the country. The Terai region of Nepal has longer summer season extending from Baisakh to Ashoj lasting six months and to tolerate the heat inside the buildings over there is a real challenge for the local people.

Here in this paper, we discuss about a problem which is specifically related to thermal discomfort inside the buildings in Terai region of Nepal and what can be done to overcome this discomfort and reduce the energy costs at the same time and hence solve the problem which has been persistently present over there for a long period of time.

The building design implementations which are based on the local climate for achieving the thermal indoor comfort that is required and which is attainable in the residential buildings by just tweaking the construction materials and methods.

The thermal comfort levels in the overheated periods mainly in the summer season create an unpleasant and uncomfortable indoor environment which has to be overcome by the means of new design methods which can be brought into practice and that will not only make the people feel much more comfortable inside but also reduce the overall energy consumption in the residential buildings.

2. Objectives

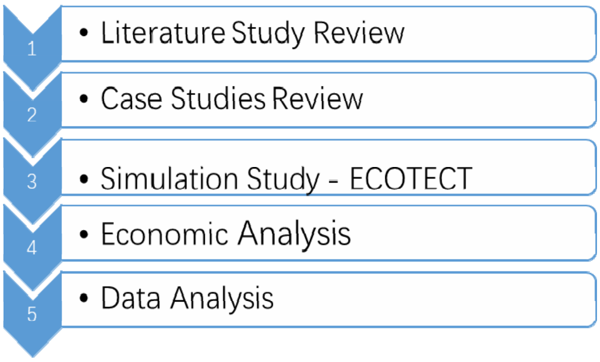
The main objectives of the study are as follows:

• To determine the effective high-performance insulation at low cost in Nepal.

• To compare the existing insulation prices with the proposed low-cost insulation.

3. Methodology

The methodology used in this based on simulation study and economic analysis. The flowchart of the project that has carried out is as shown below.



4. Literature Review

The traditional thermal building insulation materials and solutions of today have the drawback that they require rather thick building envelopes in order to meet the increasingly demanding thermal insulation requirements. Increasing the building envelope thickness up to between 400 and 500 mm, e.g., by use of mineral wool and similar insulation materials, forces new challenges both with respect to building physics and practice. In addition, such thick envelope structures are less cost-effective at locations where the area is restricted, i.e., by restrictions in physical dimensions or by high living area costs per square meter. Thus, with increasing thermal insulation, there is a strive to not increase the thickness of the building envelope substantially [4].

Reducing energy costs is one of the top reasons homeowners are reassessing the insulation in their homes. Whether building a new home, or renovating your current one, the selection of your insulation system warrants some serious attention. Adding insulation can offer you a lifetime of energy savings while improving the energy efficiency and comfort to your home [5].

Here, in this research we will find out ways of cost – saving insulation techniques that can be applied in the building envelope for reaching adequate thermal comfort for people residing in Terai Region.

4.1 Thermal Comfort

Thermal comfort is that condition of mind which expresses satisfaction with the external environment [6]. It varies from person to person and depends on various factors such as temperature, relative humidity, rainfall, wind velocity etc. of the place. Thermal comfort is the most important aspect for people when it comes to residing inside a building or living in a place.

A human body is very sensitive to temperature and it has a very narrow range where we can avoid thermal discomfort in turn avoiding heat or cold stress. Thermal discomfort is a major problem for people of all age groups, living in all regions of the country. Here in this research, we discuss about a problem which is specifically related to thermal discomfort inside the buildings in Terai region of Nepal and what can be done to overcome this discomfort and reduce the energy costs at the same time and hence solve the problem which has been persistently present over there for a long period of time. It is difficult to define or generalize the thermal performance of Nepalese building due to the irregularities in building construction geometry, materials used and cultural differences but if considered the indoor operative temperature and relative humidity levels in the building, perspective of comfort in accommodation can be drawn [3].

The building designs which are already being constructed or the building designs which have been understood to be the vernacular designs of the area are in practice over there for a long time now, but it still seems that there are no design implementations which are based on the local climate for achieving the thermal indoor comfort that is required and which is attainable in the residential buildings by just tweaking the construction materials and methods.

The thermal comfort levels in the overheated periods mainly in the summer season create an unpleasant and uncomfortable indoor environment which has to be overcome by the means of new design methods which can be brought into practice and that will not only make the people feel much more comfortable inside but also reduce the overall energy consumption in the residential buildings.

4.2 Insulation

Insulation is one of the most important, cost-effective, energy saving building materials in a home. In fact, without the insulation, some of the other energy-efficient components in a home won't perform as intended. Insulation is used as a thermal and acoustical solution in the walls, ceilings, floors, and attics of a home or every part of the building envelope.

Insulation keeps your home cooler in the summer and warmer in the winter. Insulation in a home saves energy and is perhaps the most cost-effective way to lower energy bills. Insulation reduces noise and adds to the quality and comfort of your home.

Insulation is of utmost importance not only in residential sector but also in commercial and industrial sector for meeting energy efficiency standards and maintaining a healthy environment.

Building components that need insulation varies from walls, ceilings, floors, attics and even interior rooms of the houses and their partition walls.

Some of them can be understood as shown in Figs. 1 and 2:

1. Exterior walls. Sections sometimes overlooked are walls between living spaces and unheated garages or storage rooms, dormer walls, and the portions of walls above ceilings of adjacent lowers sections of split-level homes.
2. Ceilings with cold spaces above, including dormer ceilings.
3. Knee walls of attic spaces finished as living quarters.
4. Sloped walls and ceilings of attic spaces finished as living quarters.
5. Perimeters of slabs on grade (not shown).
6. Floors above vented crawlspaces. Insulation may also be placed on crawlspace floors and walls (not shown).
7. Floors over unheated or open spaces such as over garages or porches. Floors over unheated basements. The cantilevered portions of floors.
8. Basement walls.
9. Band or header joists, the wall sections at floor levels.
10. Interior walls, ceilings and floors where sound control is desired (not shown).

The use of thermal insulation in building walls and roof does not only contribute in reducing the required air-conditioning system size but also in reducing the annual energy cost [7]. Focusing on this aspect, here in this study we aim to discover the right kind of insulation material that can be easily manufactured in our country and with a very low cost so that people residing in Terai Region of Nepal can easily afford that and use that insulation for achieving better thermal comfort in their houses during extremely hot climates in Summer.

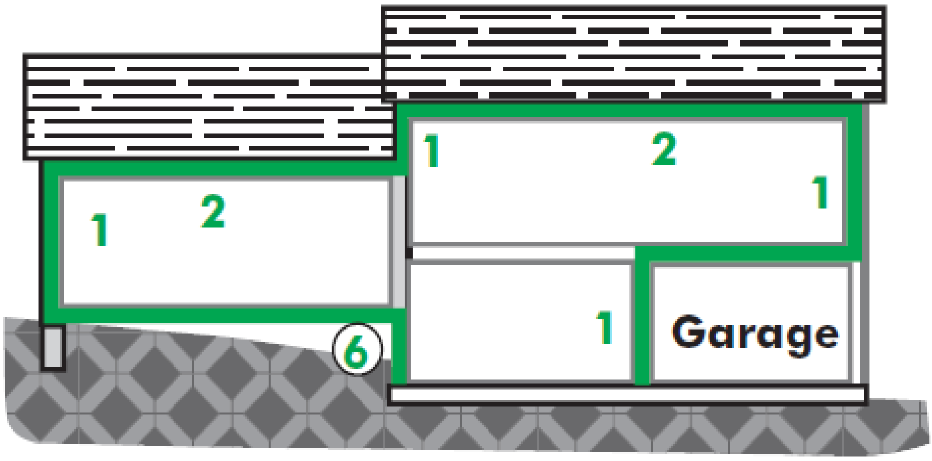


Fig. 1 Building components that need insulation - typical house -1 [5].

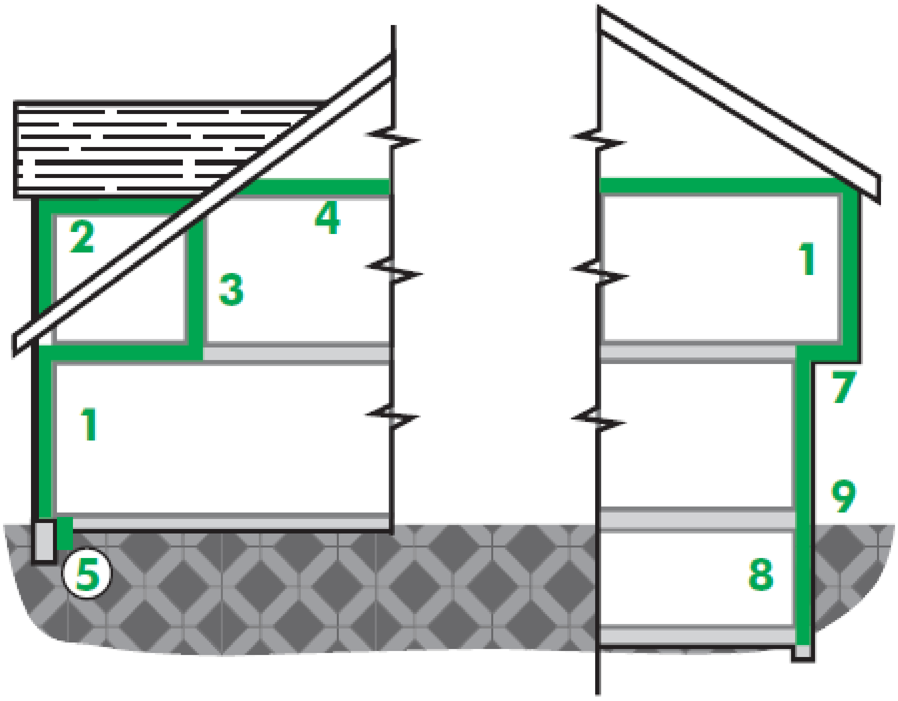


Fig. 2 Building components that need insulation - typical house -2 [5].

Mohammad S. Al-Homoud [7] emphasizes that Thermal insulation does not always have the same thermal effectiveness for all types of buildings. Its effectiveness and economic value can best be determined through life cycle cost (LCC) analysis, which is a function of the following:

- The building type and function.
- The climatic conditions at the building site.
- The type of insulation used.
- The cost of insulation (material and installation costs).
- The cost of energy (the value of energy saved).

4.2.1 Types of Thermal Insulation

Thermal insulators are those materials that prevent or reduce various forms of heat transfer (conduction, convection and radiation). Insulator resists the heat transfer from out to in or in opposite direction whether the environment temperature is high or low. There are many advantages of thermal insulation that isolates the building from the heat and reduces the energy consumption as well as the costs of air-conditioning operation.

To reduce the transmission of the heat, buildings must be isolated in order to protect it from heat loss in winter and heat gained in the summer. It is found that about 60% of heat losses directly through the ceilings and walls of the building and that about 15% through the glass and about 25% of the heat infiltrates through cracks, openings and doors [8].

Advantages of thermal insulation are as follows:

1. Reduce the amount of heat transmitted through the parts of the house.
2. Reduce the energy required for heating or cooling the house.
3. Make the internal temperature of the building stable, non-volatile.
4. Keep the temperature of the building elements stable thus long-time life.
5. Reduce energy bills.
6. Reduce the burning of fuel in power plants.
7. Reduce the emission of greenhouse gases.

4.2.2 Most Common Types of Thermal Insulators

1. **Cellulose**: which is made from wood or recycled paper and is characterized by its susceptibility to water and dust absorption.

2. Cork: This is taken from cork tree. It could be made industrial from petroleum product which is called the expanded polystyrene (EPS). It is found in the form of panels and used as thermal and acoustic insulators.

3. Glass wool: are widely used to insulate buildings, as well as boilers and reservoirs.

4. Rock wool: This material is used to isolate the buildings and storages.

5. Polyurethane: usually uses as insulated panel or foam to fill the cracks.

6. Polystyrene cork: both types, EPS and XPS.

7. Astrofoil (XPE) layers: consist of two aluminum foils and including air bubbles which are made of polyethylene materials. The aluminum layers reflect the solar radiations in the summer while the air bubbles reduce the heat transfer through the walls because of high air isolation. This material is a good insulator against the water and air leaks.

8. Polycarbonate panels: These sheets are lightweight panels, and are composed of several layers to be able to withstand the shocks with the presence of air cavities for the purposes of thermal insulation.

9. Reflective materials: such as aluminum panels, alu-cobond and reflective paints. These materials are used to reflect solar radiation on the exterior walls.

10. Fire retardant sheets: are wooden panels characterized by their ability to delay the fire growth in addition to the thermal insulation ability.

4.3 Thermal Conductivity

It is the property of a material to conduct heat. Heat transfer occurs at a higher rate across materials of high thermal conductivity than across materials of low thermal conductivity. Correspondingly, materials of high thermal conductivity are widely used in heat sink applications and materials of low thermal conductivity are used as thermal insulation. The thermal conductivity of a material varies with the temperature.

The reciprocal of thermal conductivity called thermal resistivity. There are a number of ways to measure thermal conductivity of a material using the conductivity meter aperture. The unit of thermal conductivity is (W/m·K).

Thermal conductivity values of various insulating materials:

Table 1 Thermal conductivity for common insulators.

Items	Materials	Thermal conductivity (W/mK)
1	Astro Foil (XPE)	0.08
2	Asbestos	0.12
3	Asphalt	0.69
4	Alucobond	0.15
5	Acrylic	0.2
6	Aerogel	0.02
7	Bitumen	0.17
8	Calcium Silicate	0.05
9	Cellulose	0.08
10	Coal	0.24
11	Cotton	0.04
12	Cork (EPS)	0.05
13	Ceramic Fiber	0.08
14	Engine Oil	0.15
15	Epoxy	0.35
16	Glass Fiber	0.03
17	Glass Wool	0.04
18	PVC	0.2
19	Paraffin Wax	0.25
20	Plywood	0.13
21	Polycarbonate	0.19
22	Perlite	0.05
23	Polystyrene (XPS)	0.08
24	Polyurethane	0.02
25	Rubber	0.35
26	Vacuumed Panel	0.007
27	Vermiculite	0.06
28	Wool	0.05

Table 2 Thermal conductivity for common metals.

Item	Material	Thermal conductivity (W/mK)
1	Aluminium (Al)	200
2	Bronze	110
3	Copper (Cu)	400
4	Iron (Fe)	80
5	Lead (Pb)	35
6	Silver (Ag)	450

Table 3 Thermal conductivity for common construction materials.

Items	Materials	Thermal conductivity (W/mK)
1	Basalt	2.3
2	Block (Hollow) – 20cm	0.5
3	Block (Hollow) – 15cm	0.6
4	Block (Hollow) – 10cm	0.7
5	Block (Solid)	0.9
6	Brick (Cavity)	0.4
7	Brick (Solid)	0.5
8	Concrete (Reinforced)	2
9	Concrete (Not Reinforced)	0.8
10	Cement Plaster	1
11	Clay	1.2
12	Dry Wall – 10 cm	0.3
13	Granite	3
14	Gypsum	0.8
15	GRC	0.9
16	Glass	1
17	Limestone	1.5
18	Mica	0.7
19	Marble	2.2
20	Porcelain	1.5
21	Sandstone	1.5
22	Sandwich Panel – 10 cm	0.04
23	Sandwich Panel – 5 cm	0.05
24	Thermostone – 20cm	0.3
25	Thermostone – 10 cm	0.4
26	Wood	0.15

Table 4 Thermal conductivity for common gases.

Item	Material	Thermal conductivity (W/mK)
1	Air	0.025
2	Argon	0.015
3	Bromine	0.04
4	Carbon Dioxide	0.014
5	Helium	0.15
6	Methane	0.03

5. Energy Modelling and Simulation

Energy modelling is the process of building computer models of energy systems in order to analyse them. Energy modelling is a virtual, computerized simulation of a building or complex that focuses on energy consumption and life cycle costs of various energy related items such as HVAC, lights, and hot water (Extergy, n.d.). Energy-modelling can be used to determine the best energy savings option, the best cost saving options, and the best carbon reduction options.

Autodesk® Ecotect® Analysis sustainable design analysis software is a comprehensive concept-to-detail sustainable building design tool (Mohammad Hossein, 2015). Ecotect Analysis offers a wide range of simulation and building energy analysis functionality that can improve performance of existing buildings and new building designs. Autodesk Ecotect Analysis is an environmental analysis tool that allows designers to simulate building performance from the earliest stages of conceptual design. It combines analysis functions with an interactive display that presents analytical results directly within the context of the building model.

Energy-analysis or energy-modelling is used to:

- Predict the monthly energy consumption and bills.
- Predict the annual energy cost.
- Annual CO_2 emissions.
- Compare and contrast different efficiency options.
- Determine life cycle payback on various options.

5.1 Model Plan – Sample Room

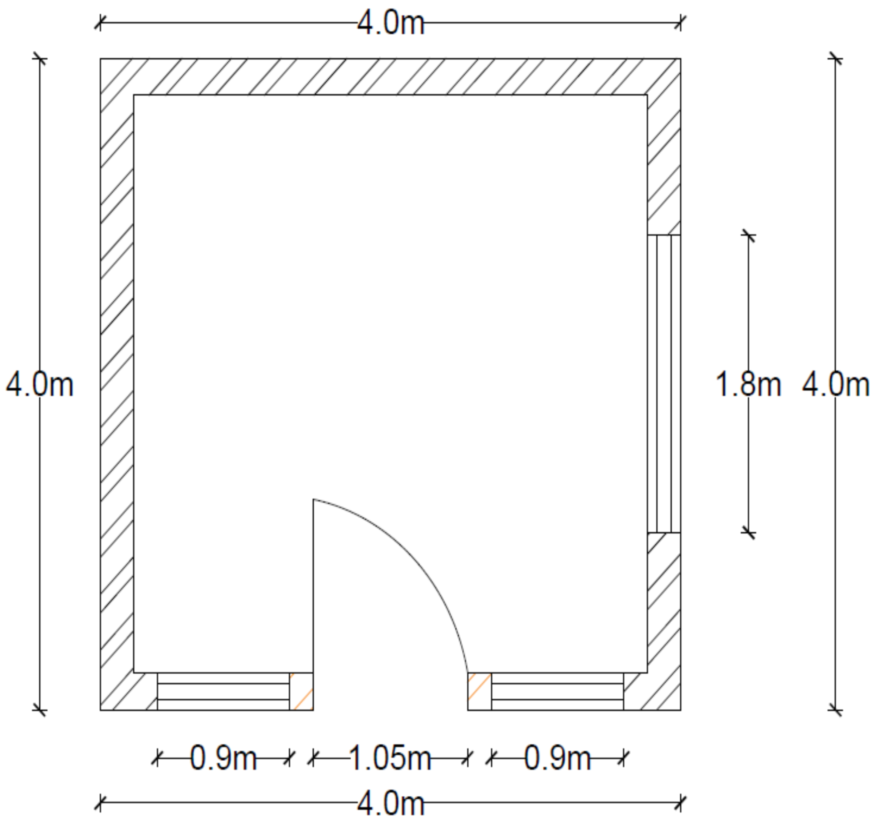


Fig. 3 Sample room plan - for energy analysis.

5.2 Model Inputs

A sample room was taken for study for the climatic condition of Biratnagar and it was analysed for effect of gains and losses through the building envelope components like walls, roofs and floor.

The general settings that were used are:

Inputs	Values
Clothing Level	1.0 Clo
Adaptive Temperature Range	18°C to 28°C
Lighting Level	300 lux
Internal Heat Gain	5 W/m^2
Latent Heat Gain	2 W/m^2
Air Change Rate	50 ACH – Cross Ventilated
Wind Sensitivity	0.25 – Reasonably Protected
Type of Ventilation	Natural Ventilation
No. of Occupants	2
Room Size	16 m^2
HVAC Type	Mixed Mode

Following cases were developed for impact of uninsulated sample room with high-cost insulation and the cost comparison of uninsulated sample room with low-cost insulation which has been proposed here in this report:

Case 1: No insulation.

Case 2: 50 mm XPS Insulation (walls, floor and roof).

Case 3: Green Ceiling (Alluvial Clay + Screed + Straw Thatch + Concrete + Plaster).

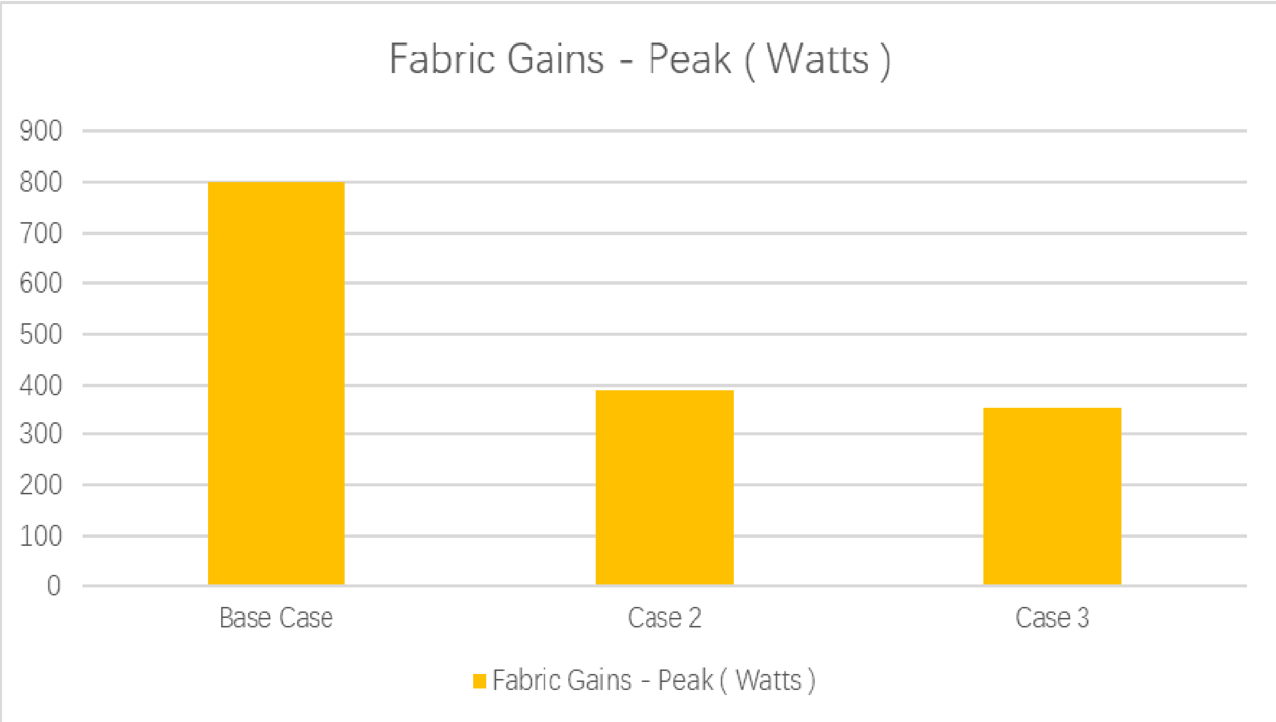
Walls (Plaster + Brick 230mm + Rice Husk + Mud Phuska + Saw dust + Plaster).

Flooring (Soil + Concrete + Mud Phuska) (All layers from Outside to Inside).

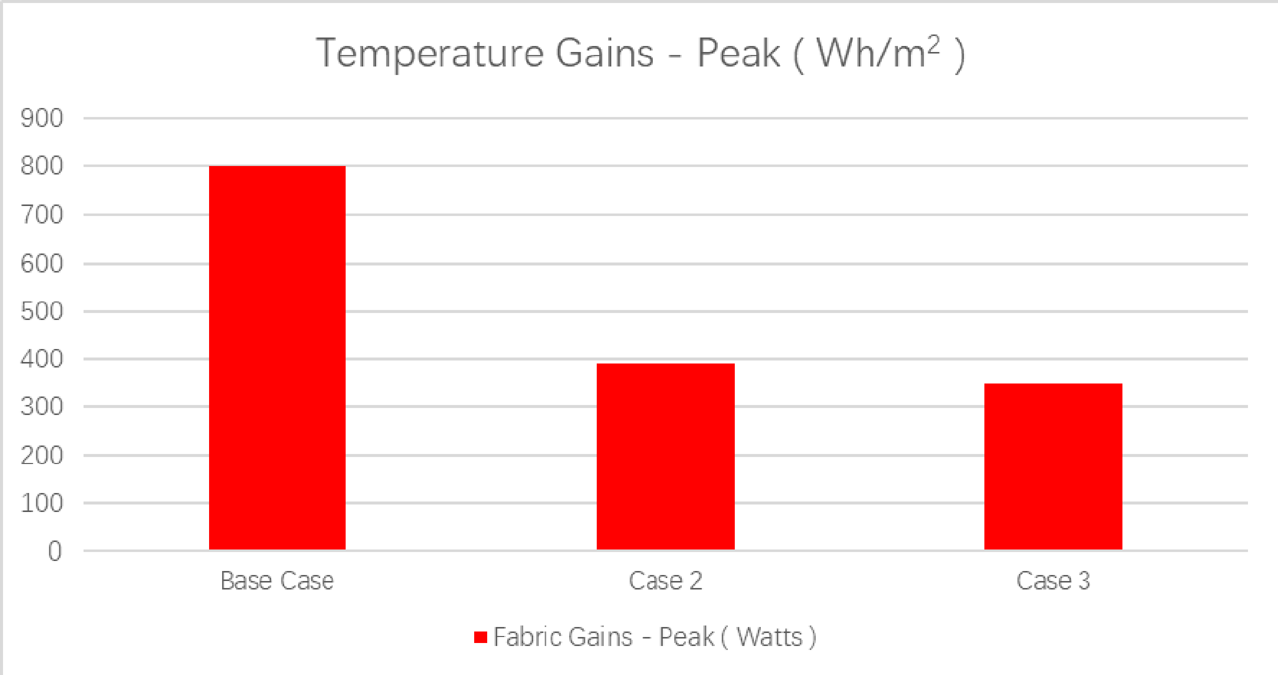
5.3 Results and Outputs

The major studies that were done in this report for the analysis of performance of the various common insulations were based on following studies:

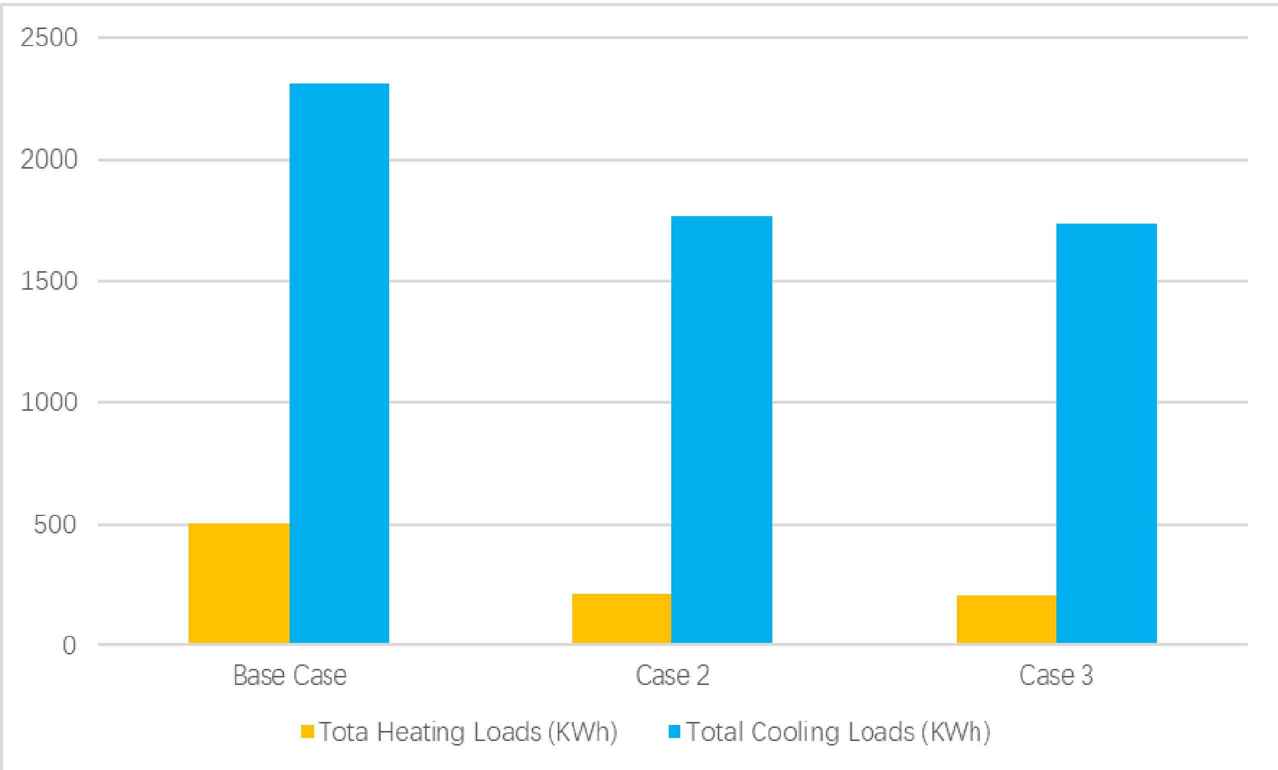
1. Fabric Gains Comparison



2. Temperature Gains Comparison



3. Heating and Cooling Loads Comparison



5.4 Cost Analysis

1. Expensive Insulation Rate Analysis

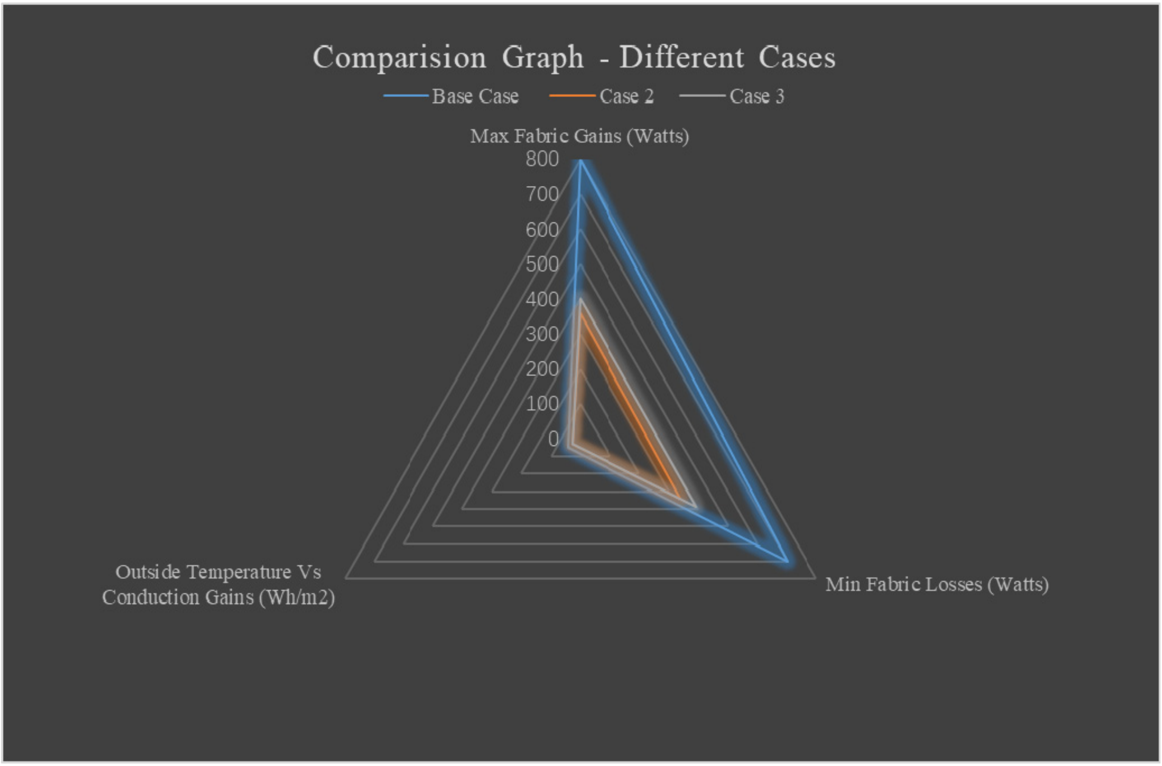
XPS Insulation : Thickness 50mm						
Name of Work : Installation of XPS Insulation Panels , fitting , fixing all.						
Unit: per m^2						
S.N.	**Description**	**Unit**	**Quantity**	**Rate NRs.**	**Amount NRs.**	**Remarks**
A	Labour Cost	md	0.02	1,080.00	21.60	
	Semi-skilled Labour	md	0.02	890.00	17.80	
	Sub Total 1				39.40	
B	Material Cost					
	XPS Insulation thickness 50mm	per m^2	2,250.00		2,250.00	Market Rate
	Sub Total 2				2,250.00	
C	Equipment Cost					
	3% of labour				1.18	
	Sub Total 3				1.18	
D	Other Cost					
	Damage Recovery (15% of Material Cost)				337.50	
	Sub Total 4				337.50	
E	Sub Total (A+B+C+D)				2,628.08	
F	Contractor's Overhead and Profit Cost (15%)				394.21	
G	Total (E+F)				3,022.29	per m^2

2. Low Cost Insulation Rate Analysis

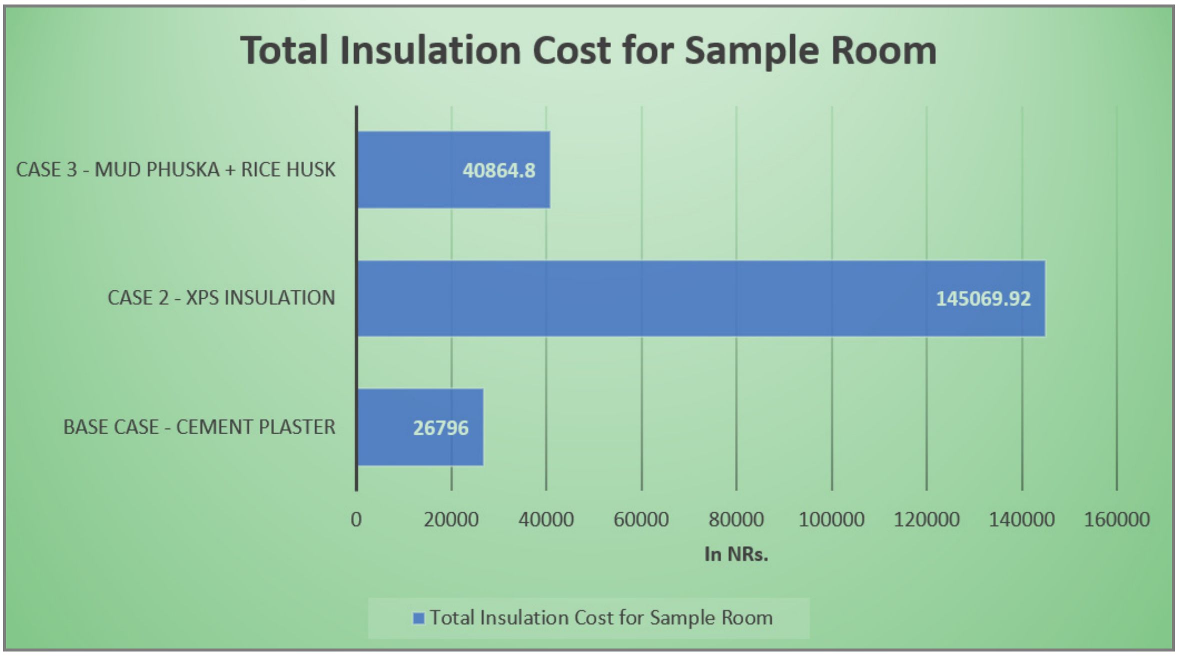
Mud Phuska + Rice Husk Insulation : 20 mm Thick						
Name of Work : Installation of 10mm Mud Phuska Layer , fitting , fixing all.						
Unit: per m^2						
S.N.	**Description**	**Unit**	**Quantity**	**Rate NRs.**	**Amount NRs.**	**Remarks**
A	Labour Cost	md	0.05	1,080.00	54.00	
	Unskilled Labour	md	0.05	790.00	39.50	
	Sub Total 1				93.50	
B	Material Cost					
	Mud Phuska Insulation : 10 mm thick	per m^2	410.00		410.00	Market Rate
	Rice Husk Insulation : 10 mm Thick	per m^2	150.00		150.00	Market Rate
	Sub Total 2				560.00	
C	Equipment Cost					
	3% of labour				2.81	
	Sub Total 3				2.81	
D	Other Cost					
	Damage Recovery (15% of Material Cost)				84.00	
	Sub Total 4				84.00	
E	Sub Total (A+B+C+D)				740.31	
F	Contractor's Overhead and Profit Cost (15%)				111.05	
G	Total (E+F)				851.35	per m^2

5.5 Comparative Analysis

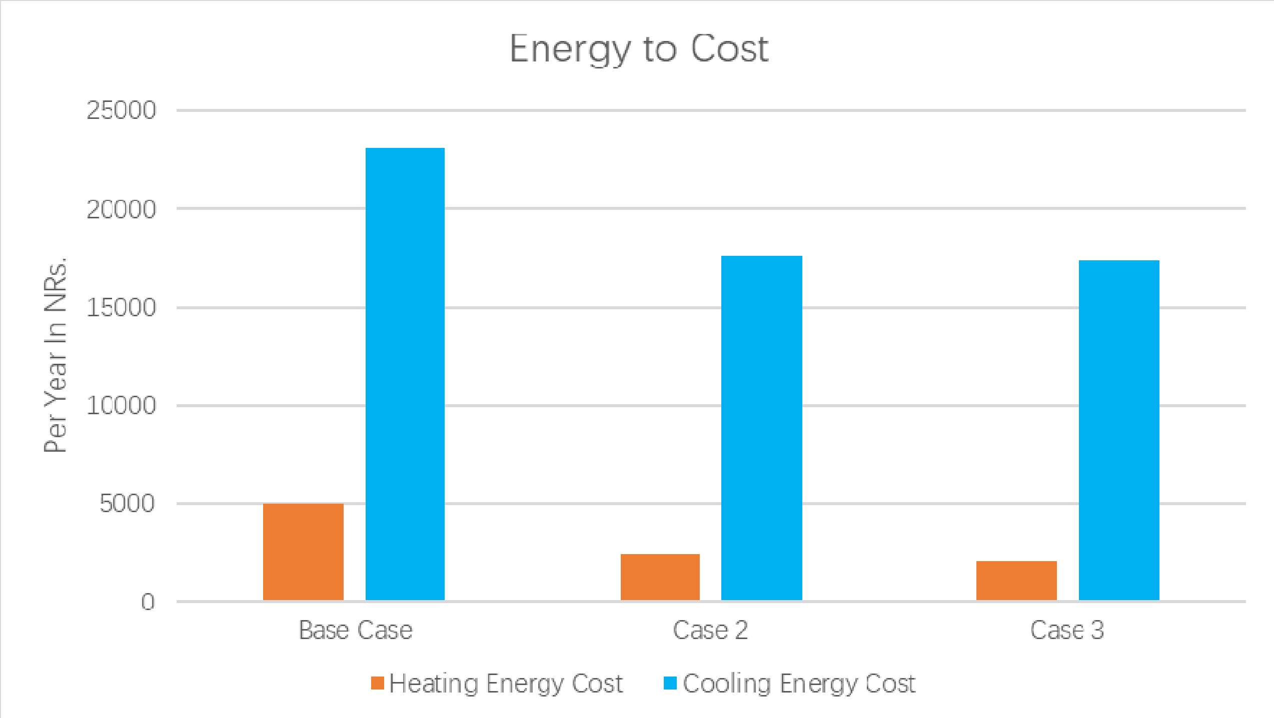
1. Energy Efficiency Comparison



2. Total Insulation Cost Comparison in Different Cases



3. Energy to Cost Equivalent Comparison (Assuming per Unit Cost – NRs.10)



6. Findings and Recommendations

The insulation plays an important role in the building energy performance as we have seen from this study. The XPS insulation is an expensive insulation method which enhances the thermal comfort but it comes at some cost as an initial investment.

The alternative insulation that we studied and found out here is the Mud Phuska plus Rice Husk insulation which is comparatively cheaper and produces almost identical results as XPS insulation.

The findings of the report can be as listed below:

The performance of a cheaper alternative to XPS insulation has been found out in the form of Rice Husk + Mud Phuska insulation which produces the identical results.

The fabric gains were reduced from a peak of around **800 Watts** in summer to around **400 Watts** which means there is a **50% reduction** in Peak Summer fabric gains or conduction gains.

The overall envelope conduction gains versus the outside air temperature in the base case was found to be around **44 Wh/m^2** and which was reduced to around **28 Wh/m^2** in both the insulation cases.

The overall cost difference in building a house without insulation and with an XPS insulation was found around Rs. 295182.

The overall cost difference in building a house without insulation and with a **low cost insulation (Mud Phuska+Rice Husk)** was found around NRs. 14,068 which is around at **89% reduced cost** than its counterpart **XPS insulation.**

Thus, the findings clearly suggests that the low-cost insulation works in favor as confirmed in Refs. [4, 7, 8] for both energy conservation, energy efficiency and as well as providing thermal comfort to residents of our country in a reasonable price. The low-cost insulation which has been proposed after the findings according to this study is Rice Husk (10mm) + Mud Phuska (10mm) insulation layers over the existing brick masonry which is being widely used and practiced in our country.

The people in our country have little or no idea about the energy efficiency methods or using insulation to achieve thermal comfort, hence this study will help them out reach to a conclusion of insulating their houses for achieving better thermal comfort along with saving energy cost. The above used insulation will be easier to develop and it can prove to be a low-cost insulation that we intended to find out through this study.

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