Proceedings of 13th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2023 Month: April Volume: 13

Eco-Friendly and Energy Efficient Building Technologies used in Houses of Mountainous Region of Nepal - Case in Rasuwa District

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Abstract
This study is about environment friendly and energy efficient building technologies in the mountainous regions of Nepal. The objective is to discuss eco-friendly and efficiency of several thermal comfort technologies for house owners of northern Nepal. There are many traditional and low-cost technologies to improve the thermal performance of buildings so that the inside temperature stays warm while outside temperatures are cold, especially during the winter months. The less warmth of temperature is lost from the inside of the building towards the outside of the building through exterior walls, roof, and floor (the less the house owner must heat the inside with heating sources like fire or others). Many of the heating sources consume significant amounts of energy resources and producing CO2 exhaust. Both traditional and modern house thermal comfort and energy efficient building technologies are listed and discussed in this article. Promoting suitable building technologies will ultimately help in reducing CO2 emission and help Nepal to contribute it's agreed long-term goal of limiting global temperature increase to reduce its destructive effects on communities around the world.

Keywords
Eco-Friendly, energy efficient, sustainable, buildings technologies, thermal comfort, mountainous region of Nepal

1. Introduction

There are a total of 364,120 households living across mountainous regions of Nepal. Due to the geography with its high altitudes the mountainous region in northern Nepal experiencing cold climates, especially during the winter months of November to February. 344,843 households (94.7%) in those areas are cooking and heating their houses with traditional firewood stoves [1]. The result of the deforestation is causing many environmental challenges including increase of carbon footprint, landslides hazards and others.

One of the key purposes of shelters and buildings is to provide thermal comfort to its inhabitants. Thermal comfort is important for the wellbeing, health, and performance of its inhabitants. Buildings in mountainous regions of Nepal can provide thermal comfort only if heated sufficiently and that heat is contained properly. The more the heat can be contained by the building the less it needs to be heated. That's where the phrase "thermal performance" of buildings is used. Thermal performance refers to "how well something maintains or stops heat from passing through it" [2].It is measured by the heat loss/transfer of the building. The main factors of the heat loss are convection, conduction, and radiation. Heat produced by the sunlight during the daytime can be gained by the building and on the other side can be lost from inside of the building during cold night-time temperatures. So, thermal performance is determined mainly by the heat gains or losses through various structural elements (walls, windows, and floors, internal heat loads, and ventilation rate) [3]. Building technologies that have good thermal performance is contributing to its energy efficiency as the house is using less energy to provide thermal comfort for its inhabitants.

Eco-friendly is the shortened form of "environmentally friendly". It is a term widely used in reference to living in a way that is not harmful for the environment we as humans live in [4]. In this study the term eco-friendly building technologies is understood as building technologies that are using natural based building materials compared to cement and chemically based building materials that are often produced with high levels of energy consumption and CO2 emission and therefore more harmful impact on the environment.

Nepal's CO2 emissions have been increasing significantly over the last years with yearly CO2 emissions of 7,833,787 tons in 2016. This was an increase of 10.1% from the previous year in 2015. Of those CO2 emissions 18.2% are produced in the sector of buildings through cooking and heating [1]. In Nepal, the residential sector alone consumes 89% of the total energy consumption [5]. Given the current scale of climate change many areas of our lives will be increasingly affected. This will mean households living in mountainous areas of northern Nepal will increasingly be affected by landslides, overflow from melting glaciers and other negative effects. According to the Paris Agreement that Nepal signed among other 192 parties in 2015, Nepal agreed to set a long -term goal to substantially reduce global greenhouse gas emissions to limit the global temperature increase in this century to 2 degrees Celsius while pursuing efforts to limit the increase even further to 1.5 degrees [6].

Therefore, actions must be taken on every level to cut unnecessary CO2 emissions while still ensuring a healthy life standard for everyone. That creates a need for energy efficient building techniques that are both cost-effective as well as sustainable. As Nepal prepares for the future many hydro power projects are being developed to use the great clean energy potential that this mountainous country has. This could lead to an easily accessible, cheaper, and cleaner way for houseowners across Nepal to cook and heat their buildings in future solely by electric energy. Much time and effort spent on collecting firewood can be used for other purposes of more comfortable and productive life. This, however, might also cause the main heat source of the wood fire stoves to be reduced to electric kettles and electric cooking stoves that will not increase the inside temperature as much during the winter months. To increase comfortable indoor temperatures the residential houses will benefit from thermal house insulation and energy efficient building technologies.

The objective of this study is to make a positive contribution to analyzing various alternative environmentally friendly house insulation and energy efficient building technologies that could reduce the carbon footprint while providing comfortable inside room temperatures for the households living across the mountain areas of northern Nepal. Houses in northern Nepal have a unique architectural and environmental setting that must be considered before introducing new building technologies. Not all modern thermal insulation material will be cost efficient since many of them would have to be imported. Therefore, nature based, and locally available thermal insulation materials are of great benefit and should be promoted for house owners in northern Nepal.

2. Methodology

Through field visits the traditionally used eco-friendly and energy efficient technologies have been assessed and listed. Additional new materials and technologies have been introduced and discussed through literature research, observation and interviews.

The methodology for the research has be conducted in following three steps:

1) Primary Data Collection: Assessment trips areas in Rasuwa district of Nepal have been conducted for technical assessments, collect photographs, data, and interviews with stakeholders in the field.

2) Secondary Data Collection: Additional data including existing literature, research studies, articles and reports have been collected and relevant parts mentioned in the previous chapter.

3) Documentation: The collected data will be documented and will be made available to Tribhuvan University and the wider research community.

3. Literature Review and Field Observation

This literature review and field observation section is divided into two parts. The first part is based on national literature and observations of existing building technologies used in mountainous regions of Nepal. The second section is based on international literature and recommendation of building technologies that could be used to increase the thermal performance of houses in mountainous regions of Nepal.

3.1 National/Regional Literature -Existing Building Technologies

There are numerous existing and traditionally used energy efficient building techniques that contribute to the rich cultural and architectural heritage of residential buildings across northern Nepal and some research has been done with guidelines for cold climate regions of Nepal [7].

3.1.1 Building Orientation and Openings

Most of the traditional residential houses observed have their openings towards the south elevation. The openings are found in the wooden front wall of the building. The other three outside walls are traditionally made up from wide dry-stone walls without any openings [8]. The window openings are traditionally kept small as they did not use glass materials. With the introduction of window glass openings became slightly bigger.

3.1.2 Livestock

Traditionally the livestock and animals have been kept in a ground floor below the house. The main floor being elevated from the ground helped to keep it dry and also utilized the generated heat from the animals as it rose into the living floor of the traditional mountain houses of central northern Nepal [9]. This building design and floor placement is highly energy effective throughout cold winter nights when the livestock stayed below the house as the animal provide a constant heat source.

3.1.3 Thermal Mass

Many traditional buildings have wide dry stone or mud walls. The walls themselves are functioning for the building as storage of heat energy as they warm up by the wood fire stoves for cooking in morning and evening in the inside of the building as well as from sun radiation on the outside of the building. The sun radiation in Northern Nepal has a long duration and intensity. The long duration comes from its location close to the equator and the dry season that has very little precipitation or sun blocking cloudy days. The intensity comes from the high altitude that has less atmosphere blocking the sun radiation on the house walls and roofs. Due to the intense sun light and cold temperature promising solar power plant projects have also been constructed in the similar climate areas of the high-altitude plateau of the Tibetan Autonomous Region of China [10].

3.1.4 Mud

Many traditional buildings across Nepal and in northern Nepal can be seen using mud masonry or rammed earth walls. Mud has a great density and therefore thermal capacity. It also is natural and locally available resource in most regions of Nepal. There is no industrial process with high energy consumption needed compared for example to cement and other industrial building technologies. There has been some research done on thermal performance of rammed earth and mud houses in Nepal [11, 12].

3.1.5 Cow Dung

Cow dung or Yak dung is a fascinating material that is being reused in northern Nepal for fuel of open fire stoves. As firewood can be not easily available and takes a lot of effort to collect in many areas of northern Nepal dried cow dung is an interesting natural alternative. It burns due to its inherent biogas what is a mixture of flammable gases that come from the anaerobic digestion of plant-based organic waste materials [13]. To dry the cow dung locals are used to plaster it on the outside walls of their houses. It works similar like mud plaster and prevents wind from blowing through the stone cracks and seals the outside walls. It also creates a thermal insulation layer on the outside of the dry-stone walls with a lower thermal conductivity (U-Value) as the natural stone walls. Thus, preventing heat from conducting from the stone wall to the outside air.

3.1.6 Wood

Wood has been observed as a natural building material with good thermal qualities that has been used traditionally in the southern outside walls of mountain houses in cold climate regions of central Nepal [9].The thermal conductivity for wood is comparatively low with 0,12-0,18 W/mK) [14]. If built properly it also seals of air tight to prevent cold wind from coming into the building or hot air from leaving the building. However, it is difficult to build the wooden wall with such air tightness with traditional tools and the reality is that many cracks and holes in the wooden walls cause unnecessary heat loss of the building. Additionally, the observed wood walls do not have the thermal mass capacity due to their thinness of 2-4 cm and therefore cannot store sufficient thermal energy during the day time and cools down during the cold nights rather quickly. The inside floors as well the furniture along the inside walls of the traditional houses have been built with local wood.

3.1.7 Straw

Straw has not been discovered much in residential buildings in mountainous regions of Nepal. However, thatched roofs made from straw are common in the lower altitudes of 1500-2500m in Western Nepal [11]. But it is also important to mention that thatched roofs have an increased fire hazard compared to other roof technologies. For this and other reasons residents have been continually transitioning to other roofing materials [15, 16].

3.2 International Literature -Recommended Building Technologies

After reviewing the national literature and discussing existing building technologies found in the mountainous regions of Nepal some recommendations based on international literature and field observations are made in the following sections.

3.2.1 Increased airtightness of building envelope

Generally, it has been observed that the building envelope (roof, walls, windows, doors) in houses across the mountainous regions of central Nepal shows many cracks and open connections where the air is able to flow easily through the envelope of the buildings. Therefore, the increase of airtightness of the building envelope is recommended to improve the thermal performance and comfort of the houses. Existing cracks can be filled and sealed properly to enclose the envelope and reduce the airflow.

3.2.2 Double glass windows

Most windows in the mountainous region of central Nepal are simple single glass windows made by local carpenters on site with manual tools and local timber. It is therefore recommended to use double glass windows to improve the thermal performance and comfort of the houses. For existing buildings, a second glass could be added to the existing wooden window frames and therefore increasing the thermal performance of the windows. Cracks in the window frames should be sealed with plaster, tape, silicone, polyurethane (PU) foam or other available materials. As the availability of aluminum and uPCV frame windows are increasing in urban areas of Nepal it is also recommended considering using industrialized quality windows.

3.2.3 Woven straw mats

"Gundri" is the Nepali name for traditional woven straw mats. They are locally made across the country and relatively inexpensive. The thermal conductivity of Gundri mats can be estimated similar to straw bales with 0.038-0.072 W/mK [17]. Due to the rise of warm, less dense air while the cooler, more dense air sinks down a significant amount of heat is loss through the ceiling and roof of a building. Most observed traditional Stone Masonry Mud (SMM) or Stone Masonry Concrete (SMC) structures in the mountainous region of central Nepal have pitched roofs covered with traditional stone shingles and nowadays more common CGI sheets. The attic spaces are used for storage or are partially empty. Therefore, thermal insulation of the attic space between the ceiling and the roof seems a very effective way to increase the thermal comfort of the buildings. Most ceilings are made with wood boards or plywood. Many cracks between the boards have been observed, so there is high airflow, and much heat is lost. Traditionally the open wood fireplace to cook and heat the house produced high volumes of smoke and therefore the ventilation through the roof was helpful to remove the smoke. However, it is becoming more common for houses to have fire stoves with chimneys that can ventilate the smoke out of the house more efficiently and it is likely that with increased access to electricity generated from hydropower many mountain houses in future will cook and heat the house purely by electricity. Therefore, it would be an important and simple first step to increase the air tightness and insulation of the roof and attic space of the buildings. Compared to foam mattresses, which are also widely available across Nepal, the traditional woven straw mats should be considered as the more sustainable and natural solution. The mats could be laid out to each other with an overlap of 10-30cm on all sides. The Gundri mats are normally woven with a thickness of 1-2cm per mat. Multiple layers of mats could be piled on top of each other to improve the U-Value of the ceiling even more. Additionally polypropylene tarpaulins could be laid out underneath the Gundri mats to increase the air tightness of the ceiling. Gundri mats would be preferred over loose straw as the risks of animal infestations of mice, rats, and others as well as fire hazard would be less compared to lose straw.

3.2.4 Cotton

Nepal is using cotton traditionally for making hand woven mattresses that are locally called "Sirak". The mats could be laid out as an insulation material between the ceiling and roof in the attic space. Cotton is locally available and is being recycled locally across Nepal. The blankets are normally made with a thickness of 3-5 cm. Multiple layers could be considered to increase the U-value of the ceiling. Cotton has a thermal conductivity of only 0.040-0.050 W/mK[17]. However, the cotton in form of a traditional "Sirak" is compacted more densely and will therefore have likely higher thermal conductivity than in loose form. The costs for the local cotton blankets are higher than straw mats. Therefore, it might be only cost efficient if the house owner has enough old or broken cotton blankets that are not used for bedding anymore.

3.2.5 Wool

Similar than cotton wool material could be used as an insulation material between the ceiling and roof in the attic space. Wool is locally available in mountainous regions from yaks, cows, goats, and sheep. Wool has a thermal conductivity of only 0.035-0.040 W/mK [17]. However, wool is very expensive and might therefore be not a cost-effective solution.

3.2.6 Reed

Reed is a material similarly like straw; however, reeds are thicker and stronger. They are used traditionally for roofing and as compounds of walls and floors in buildings in Europe and other regions across the world [18]. Reeds have a low thermal conductivity is 0.042-0.06 W/mK and have therefore good qualities to be used as a thermal insulation material [17]. In the mountain houses of northern Nepal, it could be used like straw as handwoven mats laid out in the attic space, between the ceiling and the roof. Reeds could also be used on the outside wall as an insulation layer between the masonry and plaster. In some parts of Nepal Reeds or Bamboo is on the outside wall under the plaster, however if the plaster layer is not done well rain and moisture can penetrate the reed layer and they will mold and get destroyed as they are not water proof. Therefore, they could also be used on the inside layer of the masonry wall and the inside plaster (or the plywood layer that some houses are using instead of inside plaster) where they are more protected from moisture. Optional the reeds layer could also be attached on inside wall without plaster to create a natural look of indoor rooms. In other countries reeds are also used as an insulation layer underneath the floor. However, if used unprocessed or not enclosed in plaster it also can increase risk of mice or other animal infestations as well as the fire hazard of the building.

3.2.7 Corncob

Corn cobs have been used as a natural insulator as a filling material for the external walls in ancient buildings in Portugal. Corn cobs have a similar microstructure and chemical composition as XPS insulation materials [19].Another research done in Malaysia by Sahat, Ahmad et al. in 2016 processed corn cobs into a 0.3m x 0.3m x 0.02m ceiling panels and concluded that indoor temperature was positively affected. They recommend corn panels suitable to be attached on ceilings rather than outside of walls because the corn panels are not water proof [20]. Corn cob boards have a thermal conductivity of 0.096 W/mK [17]. Applied to mountain houses in northern Nepal corn cobs could be used in the attic space between the ceiling and roof simply cut in small dice of 1-2cm and filled in a 10-20cm layer on top of the ceiling. However, in unprocessed form the corn cobs are likely to attract mice and other animals as well pose an added fire hazard. It is also possible to attach it on the ceiling in process forms of panels to reduce the mice problem, however there is no such product available on the Nepali market as of now.

3.2.8 Bamboo

Bamboo as well can be used as a natural insulation material for the building envelope. It's thermal conductivity ranges from 0.08 - 0.34 W/mK [17]. . Bamboo is widely available in Nepal and is traditionally woven into bamboo fiber mats of 1 cm thickness. Those could be used as an additional insulation layer in the attic space between the ceiling and the roof or on the inside of the masonry walls or underneath the wooden floor. The bamboo mats are not water proof so they should not be placed where they would be exposed to moisture. Because they are relatively thin it is recommended to use multiple layers to increase the insulation effect and reduce the U-Value of the envelope further.

3.2.9 Hemp

Hemp is similar than straw or reed a natural material than can be used in different ways for residential house construction [21]. Hemp has a thermal conductivity of 0.034-0.05 W/mK [17]. It can be used in unprocessed or woven form or as processed form. In processed form it can be mixed with a binder into a material similar than concrete. In this form it is also called Hempcrete. Hempcrete is claimed to be a good thermal insulator with a U-value of U= 0.27 W/m2K similar to lightweight concrete blocks. Hempcrete can sequester up to -16kgCO2e/m2 over its lifecycle. It is a bio-composite made from hemp shiv (the woody core of industrial hemp) with a lime-based binder (hydrated lime with natural hydraulic lime or ordinary Portland cement) [22]. Because the material is made from a plant-based compound caution needs to be heeded against water and rising damp levels. It can be used with lower density for walls and outside insulation layers or higher density for floors [23]. The strength of hempcrete was tested with "a mean compressive failure strength of 0.458 MPa for the 'wall' mix and a compressive stress at 10% relative to deformation of 0.836MPa for the 'floor' mix" [24]. Hempcrete is available and marketed in Nepal as ShivCrete by Shah Hemp Inno-Ventures located in Janakpur, Nepal [25].Since 2017 a total of 16 buildings have been constructed using Hempcrete in Nepal. 6 of those 16 houses have been constructed in mountainous regions of central Nepal in partnership of the Carbon Trading Project by the Germany based NGO called Atmosfaire [26]. One of the houses recently constructed in Tyangsapu, Rasuwa used hempcrete in the outside wall as an insulation layer between the stone masonry and the outside plaster layer. The outside wall was plastered with a clay-cement plaster to increase the water resistance on the outside wall. On the third story the hemp construction was even used to fill into the timber frame outside between the wide window openings without any supporting stone masonry wall. The other building used hempcrete on the inside of the wall between masonry and plaster as well as for the interior separation walls. According to an interview done with Diraj Shah, the owner of Shah Hemp Inno Ventures they have good experiences and local house owners have reported good thermal performance and insulation value. However no temperature data has been collected to confirm the thermal performance of

Hempcrete in Nepal. Costs are similar to brick wall with hemp shivs being sold at 1920 NPR per 12kg bag (120 liters) and lime being sold with 1000 NPR per 25kg bag. One 12kg bag of hemp shivs produce about 4.5 cubic feet of wall [27].

3.2.10 Other Materials

There are several other natural materials that have a low thermal conductivity and therefore are used as thermal insulators around the world. Some of them have been discussed above. Others have not been discussed (e.g., Flax, Cork, Cellulose, Bamboo fibers etc.) as they are not locally available and therefore would have to be transported a long distance to be used in the mountainous region of Nepal. Bozsaky has discussed them in his article of the Slovak Journal of Civil Engineering in 2019 and published following overview table of the materials and their thermal conductivity [17]

4. Case Study Hempcrete in mountainous region of central Nepal

Based on the findings of the literature review and field observation a case study has been chosen on the thermal performance three hempcrete buildings in Rasuwa, Nepal. The Outside-Inside Temperature will be measured for 10 days in during winter time and compared to conventional SMC and RCC buildings of the same area.

The thermal measurements will be taken with a digital thermometer also displaying time and relative humidity. The five thermometers that will be used have been calibrated in the same room and differences will be corrected to the data results afterwards. The thermometers will be installed in unheated rooms with windows to south orientation located on the ground or first floor. The thermometers will be installed indoors in a shaded area and outside at top of window in shaded area. After the thermometers will be installed the houseowners will read the thermometers and send a picture as a documentation every morning at 7am, midday at 1pm and evening at 8pm for 10 days.

The temperature data will be collected in following locations and buildings:

1) Namaste Guesthouse in Sherpa Gaun Village, Gosaikunda GP, Rasuwa (Hempcrete outside insulation, built in 2020)
2) Eco-Guesthouse in Thyangsapu Village, Gosaikunda GP, Rasuwa (Hempcrete inside insulation, built in 2020)
3) Everest Guesthouse in Mundu Village, Gosaikunda GP, Rasuwa (Hempcrete construction, built in 2020)
4) Hotel Panorama in Gumba Village, Gosaikunda GP, Rasuwa (SMC structure, built in 2016)
5) Super View Hotel, Kyanjin Gompa Village, Gosaikunda GP, Rasuwa (RCC structure)

5. Conclusion

There are several existing eco-friendly and energy efficient building technologies being used in the mountainous regions of Nepal. However, there are ways that the thermal performance of the buildings could be improved even more. Several recommendations using natural based and locally available building materials have been made and should be considered by homeowners in mountainous regions of Nepal. More research should be made on the prototype buildings using hempcrete as a relative new building technology. Therefore, the temperature data of three of the houses built with hempcrete will be collected, evaluated, and discussed. The findings of this data will help to evaluate the potential increase of thermal performance of buildings using hempcrete in mountainous regions of Nepal.

Acknowledgments

The authors express their sincere thanks to local partners for their assistance in the fieldwork.

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