Sustainable Housing Insulation for High-altitude Kyrgyzstan: A Technical Guide

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Abstract

Kyrgyzstan – a high-altitude and cold climatic Central Asian country, suffers from high residential energy consumption, especially in the rural housing sector. Due to the age of the building stock as well as lack of insulation, the energy consumption of Kyrgyz buildings is 3 to 5 times higher compared to European buildings. The implementation of thermal insulation is considered one of the potential measures for energy conservation. However, the local boundary conditions (especially low-income, remote locations, and lack of knowledge and awareness) do not allow local people to consider the insulation measures. There is a lack of scientific knowledge available about sustainable insulation of high-altitude rural Kyrgyz houses. Against this background, the presented research article provides comprehensive scientific information on sustainable housing insulation for high-altitude Kyrgyzstan. The research was carried out on three key dimensions; why (use insulation), which (insulation to use), and how (to use insulation) theoretically and technically. The necessary data was composed of the author's stay on site and literature review. Based on the three main research questions, why, how, and which, the article formulates a complete technical guide for sustainable insulation housing in high-altitude Kyrgyzstan.

Keywords: energy efficient house, high-altitude, sustainable, thermal insulation, cold climate, space heating

1. Introduction

1.1 Setting the scene: high-altitude rural Kyrgyz houses

The residential sector of Kyrgyzstan is considered the highest energy consumption among Central Asian countries. This is due to the existing housing conditions, lack of building insulation, and the age of the building stock. Due to the cold weather conditions, a typical Kyrgyz household spends a high portion (almost half of the income) of its budget on energy expenses (i.e., space heating). Eventually, this results in low thermal comfort and high energy consumption. This situation is very critical for high-altitude rural houses because more than 50% of rural houses were built from earthen materials during the Soviet era more than 30-50 years ago without proper building construction techniques and insulation dimensions (Mehta et al., 2021). These buildings are now in obsolete condition and do not provide minimum hygienic and comfortable living conditions. Fig. 1 represents the total final energy consumption by sectors in Central Asia and the residential buildings construction year to provide a full picture to the reader of the issue. This is expected to remain high unless the need for greater energy efficiency is fully realized and given due consideration during building construction and renovation.

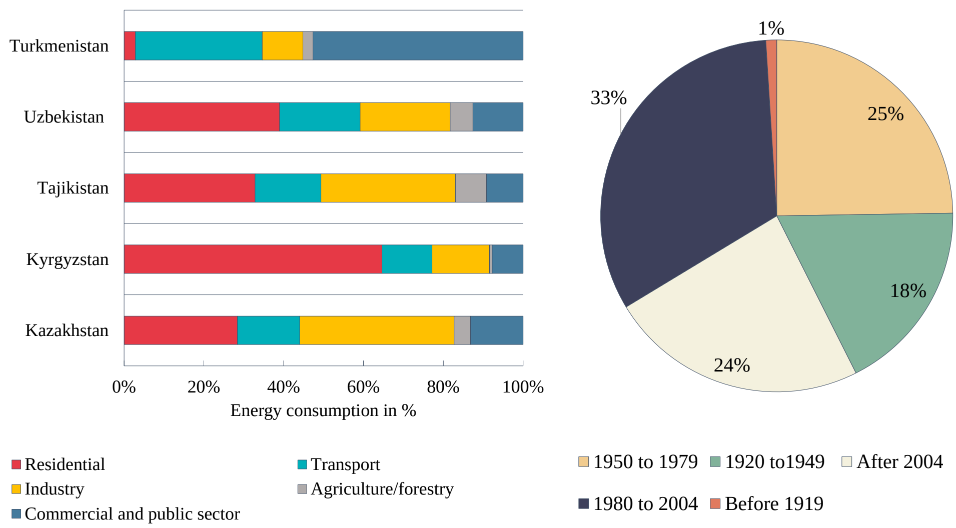

Fig. 1: Total final energy consumption by sectors in Central Asia based on International Energy Agency (left) and Residential buildings construction year in Kyrgyzstan (right) based on International Energy Charter (2018)

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From the field visit, it was identified that a typical rural house has natural walls with a thickness of 0.35 m to 0.50 m without any insulation. The uninsulated earthen floor is constructed with wooden beams and floorboard with a total thickness of 0.20 m to 0.40 m. Similar to the floor, the ceiling consists of a wooden beam structure and open space under the roof. Further to this, the installed windows in the houses were mostly cracked and exposed to air leakages. This typical building profile is partially applicable to most rural communities as families assist each other with house construction and transfer knowledge of building styles. Therefore, the housing profile in most rural communities is relatively homogeneous in Kyrgyzstan (Mehta et al., 2020).

The literature review identified that the energy use per square meter of Kyrgyz households is almost 3-5 times higher as compared to European homes. The annual heating energy consumption of Kyrgyz buildings varies between 320 and 690 kWh/m^2/year. Because of the mountainous and high-altitude characteristics, Kyrgyzstan's climate is characterised as sharp continental with a long and harsh winter (-20 to -30 °C in the mountainous areas). The cold and extended winter in the country defines house heating as a primary need for Kyrgyz people. Due to the remote location and low population density, high-altitude rural Kyrgyz houses are generally not connected with modern energy services to meet the primary energy need, which is space heating in this case (Mehta et al., 2020). The absence of modern energy services forced local people to extract their energy needs from the local surroundings. Fig. 2 represents typical high-altitude rural Kyrgyz houses.

Fig. 2: Typical rural residential / family houses in high-altitude Kyrgyzstan (Source: Author)

To maintain thermal comfort, local rural people use traditional heating stoves operated with solid fuels during the winter months. Currently, the thermal comfort in Kyrgyz households is not that high compared to other global regions. Most rural houses in Kyrgyzstan are simple buildings typically constructed with soil, clay-straw, or adobe without any insulation parameters and resulting in low thermal comfort inside the building. The most relevant reason for this high demand is the lack of insulation in most rural Kyrgyz houses (Beringer et al., 2021b). The current buildings in rural Kyrgyzstan are often poorly insulated, which results in a high heat flow rate out of the building (c.f. Fig. 3).

Fig. 3: Thermography of a typical rural house

1.2 Sustainable and environmental challenges

Mehta et al. (2021) identified that the average rural Kyrgyz family needs to employ 2–6 tons of coal (cost ~50–250 €), 1.5–3 m^3 of firewood (cost ~5–30 €), and 1–2 truckloads of cow dung (most of the time self-prepared, but in case they outsource, it costs ~5–10 €) for house heating. The overconsumption of non-sustainable solid fuels significantly contributes to the production of indoor and outdoor air pollution. According to Brakema et al. (2019), the high-altitude rural settlements in Kyrgyzstan are particularly vulnerable to Chronic Obstructive Pulmonary Disease

(COPD) and significantly experience respiratory issues because of the housed air pollution. Also, the available widespread forest cover (i.e., riparian forests) is often exploited to fulfill the energy need of rural people. The burden on local forest cover for wood leads to a negative impact on the riparian forests in Kyrgyzstan. This is an alarming thing as the absence of energy efficiency is directly or indirectly connected with the ecology and climate change in the country (Lauermann et al., 2020).

2. The need of research and research methodology

2.1 The need for sustainable housing insulation

Such high heat demand is expected to remain the same unless the implementation of energy efficiency is fully realized. Hence, the application of insulation is one of the most promising solutions to overcome this problem. The implementation of building energy efficiency can help to reduce the existing residential heat demand by 50-70% (Mehta et al., 2020). However, due to the geographical isolation (i.e. distance from the major economic centres), modern building materials are costly and rarely available for the rural population. This is the same for the insulation materials. Besides availability, affordability is the key concern for the high-altitude rural population. Many rural households, especially in mountainous areas, do not have a permanent source of income because job opportunities are often scarce. Due to unstable income sources and low-income scenario in rural Kyrgyzstan, the application of thermal insulation to their homes is not considered practical for most rural households. Therefore, there is an urgent need to identify insulation solutions that should be sustainable, affordable and locally obtainable by considering the local assessment (especially the different rural house design). To our knowledge, there is no study made available to the scientific community that articulates the thematic and technical knowledge about sustainable insulation for high-altitude Kyrgyz houses.

2.2 Research methodology

To provide a complete guide on sustainable insulation for high-altitude Kyrgyzstan, methodically, the presented research article investigated three key dimensions; why (use insulation), which (insulation to use) and how (to use insulation) theoretically and technically. By these three key pillars, the study provides a comprehensive and comparative analysis of the conventional materials (extruded polystyrene, polyurethane foam), sustainable materials (sheep wool, reed, straw) and concept insulation materials (composites of more than one material, which are currently in development). All types of available materials in Kyrgyzstan were evaluated on their thermal, chemical and physical properties. However, the main aim of the paper is to develop theoretical knowledge and provide scientific knowledge only about available sustainable insulation materials. Fig. 4 shows a graphical representation of the research methodology.

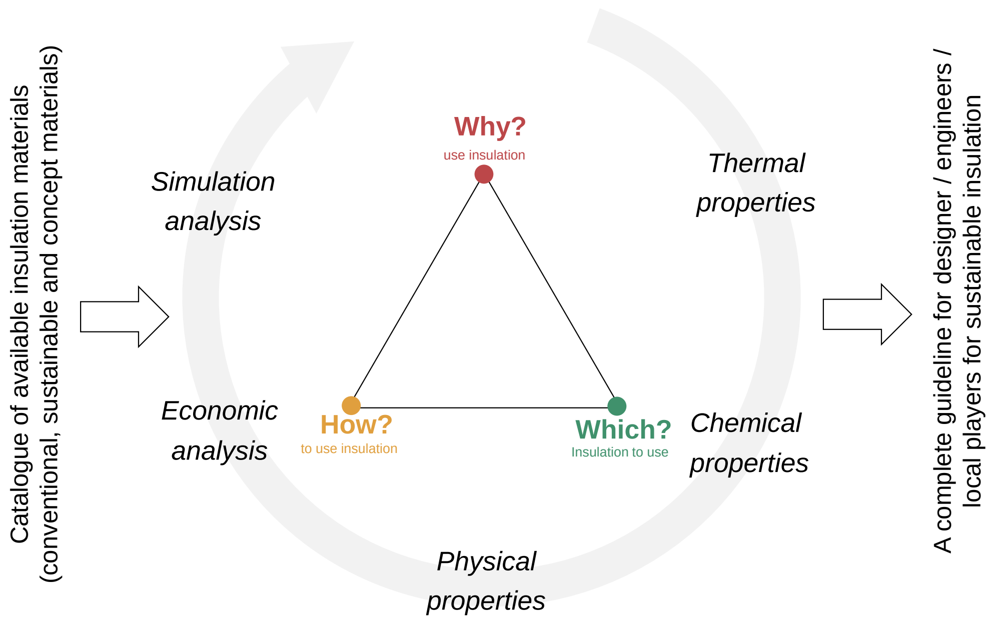


Fig. 4: Research methodology for proposed research article

Therefore, in order to investigate the technical performance and affordability of such sustainable materials, a detailed technical parametric study was performed for the two predominately types of rural Kyrgyz houses. The data / information required for the presented research was collected from the author's visit to the site and the literature review.

3. Catalogue of available insulation materials in Kyrgyzstan

Thermal insulation materials (from now on insulation materials as this study deals only with materials whose main purpose is to reduce heat flux) investigated in this study are divided into three groups. These groups are non-sustainable materials, sustainable materials, and concept materials. Fig. 5 classifies the available insulation materials (as well considered in the presented study) in Kyrgyzstan.

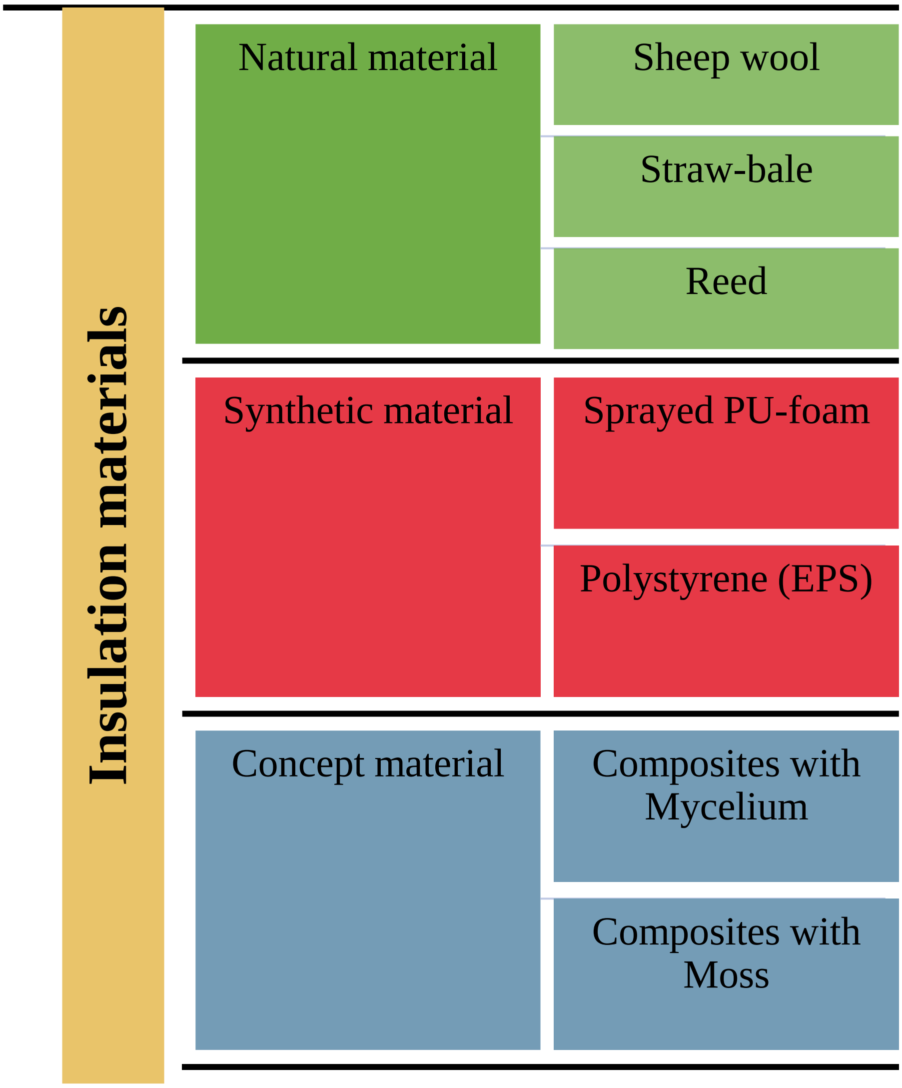


Fig. 5: Classification od insulation materials used in the presented study

To guarantee comparability between the different classes, the parameters used to analyse the materials are always identical. In that need, the presented chapter reports the parameters which are usually relevant when selecting the suitable material for insulation (thermal conductivity, density, specific heat capacity, acoustic properties, typical moisture content, compression strength, fire resistance, costs for raw material, and costs for finished material). Through an extensive literature review and market survey, Tab. 1 offers a comprehensive overview of available materials and their respective properties. It also estimates the material costs, which may vary as the construction and insulation market in Kyrgyzstan is not always stable. Raw material costs, such as those for straw from fields, can sometimes be difficult to evaluate or may not be applicable to non-sustainable materials that rely on crude oil and other chemicals that are only available in their finished form. The cost of finished materials is even more important, as it indicates the cost of the insulation material used in the house. However, the cost of installation is not included in this estimation, as it was calculated separately in the study. The costs are given in €/kg or €/m^3 (by using density for calculation). This is relevant as different thicknesses cause different quantity requirements.

Tab. 1: Catalogue of available insulation materials in Kyrgyzstan with various properties

	Polystyrene	**Sprayed PU-foam**	**Sheep wool**	**Straw bale**	**Reed**	**Composites with Mycelium**	**Composites with Moss**
Thermal conductivity in W/(m·K)	0.034 (Penoplex Ltd., 2021)	0.022-0.05 (BASF, 2019; Plag, 2022)	0.033-0.049 (Zach et al., 2012; Ruchti and Sägesser, 2021)	0.038-0.2 (Beck et al., 2004; Cascone et al., 2019);	0.045-0.065 (Keskküla et al., 2020; Plag, 2022);	0.078-0.104 (Xing et al., 2018; Dias et al., 2021)	0.044-0.046 (Bakatovich and Gaspar, 2019)
Density in kg/m^3	25-32 (WikiBath, 2020)	70 (Plag, 2022)	20-40 (Zach et al., 2012; Ruchti and Sägesser, 2021; Plag, 2022)	50-150 (Ashour et al., 2011; Cascone et al., 2019)	130-225 (Keskküla et al., 2020)	57-99 (Elsacker et al., 2019)	156-190 (Bakatovich and Gaspar, 2019)
Specific heat capacity in kJ/(kg·K)	1.3-1.7 (Vo et al., 2011)	1.5 (Plag, 2022)	1.7 (Plag, 2022)	0.6-2.1 (Asdrubali et al., 2015; Plag, 2022)	1.2 (Asdrubali et al., 2015)	0.4 (Xing et al., 2018)	N/A
Acoustics -NRC (acc. to Tiuc et al. (2016))	0.26 (Sokol, 2019)	0.28 (Tiuc et al., 2016)	0.45 (Borlea Mureşan et al., 2020)	insufficient (Cascone et al., 2019)	~ 0.4 (Oldham et al., 2011)	N/A	N/A

Moisture content	Compression strength in MPa	Costs for raw materials in €/kg	Costs for finished material in €/kg	Costs for finished material in €/m³
0.03-9 % (Jones et al., 2020; Penoplex Ltd., 2021)	0.15 (Penoplex Ltd., 2021)	N/A	12.78 (Dom Penoplex LLC, 2021)	358 (Dom Penoplex LLC, 2021)
0.01-72% (Jones et al., 2020)	0.20 (BASF, 2019)	N/A	1 (Riman company, 2021)	70 (Riman company, 2021)
20-25 % (Zach et al., 2012)	N/A	2.3-3.5 (Tuzcu, 2007; Corscadden et al., 2014)	12.46 (Corscadden et al., 2014)	436
11 % (Ashour et al., 2011; Cascone et al., 2019)	1.6-6.1 (Musa and Mohammed, 2015)	<< 0.20	< 0.20 (Kudryavtseva, 2014)	20
N/A	N/A	0.11 – 0.19 (CEEBA, 2011)	N/A	0.45-25 (CEEBA, 2011)
40-580 % (Jones et al., 2020)	0.17-1.1 (Jones et al., 2020);	0.06-0.15 (Jones et al., 2020)	N/A	N/A
N/A	0.2 (Bakatovich and Gaspar, 2019)	N/A	N/A	N/A

4. Calculation of total insulation material cost

The aim of this section is to find the most economically reasonable quantity of sustainable thermal insulation for a rural building in Kyrgyzstan. All prices given in this chapter are aimed for the Kyrgyz market and thus, are not valid for a general statement. One can read the author's previous work Beringer et al. (2021a) to get more details about sustainable insulation materials in rural Kyrgyzstan. It is important to get the overall material cost (including installation cost) to get a full picture of housing insulation. Tab. 1 shows numbers for material cost in m^3 (last column) without any installation efforts. However, depending on the thickness of the insulation layer, the required material (quantity) will be varied. The calculation is displayed in eq.1.

$$Total\ material\ costs\ (in\ €) = Total\ wall\ area\ (in\ m^2) \times Insulation\ layer\ thickness\ (in\ m)\ x\ cost\ for\ finished\ material (in\ \frac{€}{m^3}) \qquad \text{eq. 1}$$

Installation costs, the second component in economic feasibility calculations, are difficult to evaluate due to their dependence on individual cases, as well as the wide variation in transportation and personnel costs based on settlement location. However, these costs are not heavily influenced by the thickness of the insulation layer, as most processing steps are consistent regardless of thickness **e**q. 2 displays the calculation, and Tab**.** 2 provides generalized installation costs for different materials.

$$Total\ installation\ costs\ (in\ €) = Total\ wall\ area\ (in\ m^2) \times Installation\ costs\ (in\ \frac{€}{m^2}) \qquad \text{eq. 2}$$

Tab. 2: Overview of estimation of the installation costs for insulation in Kyrgyzstan

Material		Installation costs for the wall in €/m²	Installation costs for the ceiling in €/m²	How to install?
Conventional	Extruded polystyrene	8	6	Can easily be glued on a brick structure
	Polyurethane foam	6	5	Can easily be sprayed on brick structure (Riman company, 2021)
Sustainable	Sheep wool	15	6	With spcial construction applicable on wall (i.e. sheep wool, holidg structure)
	Straw bale	12	6	With spcial construction applicable on wall (i.e. straw bale, holidg structure)
	Reed	12	6	Similar to straw bale
Composite	Mushroom and plant	Not applicable as no large-scale installations were performed so far; this does not allow any calculations of break-even point		
	Moss			

5. Special focus on sustainable insulation structure

5.1. Availability of insulation materials to rural Kyrgyz population

This section will provide a detailed explanation about which insulation rural houses should use for better and more affordable energy efficiency. From the literature review, discussion with the construction agency and market survey, it was identified that conventional materials are common and accepted in urban areas (especially in Bishkek). The majority of the conventional material is imported from the neighboring countries to Kyrgyzstan (c.f. Fig 6). That has a huge influence on the cost (c.f. Tab.1). If one needs to order that material to rural areas, that could be even more costly as the price will be increased due to the material transportation to the remote / isolated community location. Hence, conventional materials are rarely used in rural areas.

Additionally, the literature review showed minimal use of composite materials in Kyrgyzstan. Given the limited availability and high cost of conventional insulation materials, rural Kyrgyz households do not usually use them. Hence, this article provides technical and scientific information on affordable insulation materials that are locally available to the rural population.

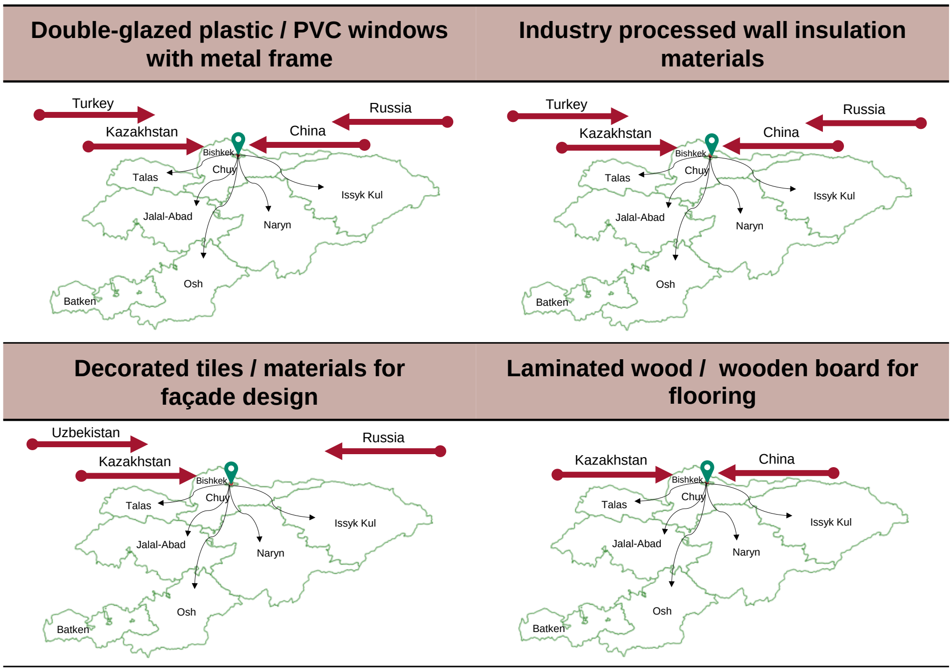


Fig. 6: Supply chain of the conventional insulation materials based on the market survey

5.2 Simulation model development

From the field visit, it was identified that there are two different types of houses available in typical rural Kyrgyz communities; 1) Open roof houses and 2) Closed roof houses.

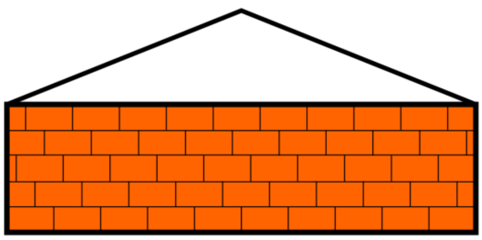
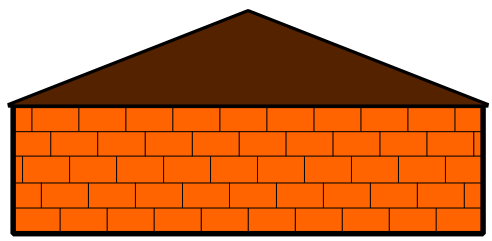
Open roof house:

Generally, in such houses, the metal roof is placed on the wooden beam ceiling. Mehta et al (2020) mentioned that the open roof house is a very common and predominant practice in rural Kyrgyzstan due to a lack of knowledge and lack of income. The open space induces a considerable amount of heat loss during windy days. Naturally, such a house has a high heat demand.

Closed roof house:

Closed roof houses are similar to open roof houses when it comes to construction work. However, as the name suggested, in these houses, the roof is ideally closed or covered with the help of metal sheets from both ends in order to prevent the wind from passing through it.

Tab. 3: Illustration of two different house models with the range of space heating demand

Open roof house	**Closed roof house**
	
Range of annual specific heat demand 250 – 330 kWh/m²	Range of annual specific heat demand 210 – 270 kWh/m²

EnergyPlus employs a heat balance algorithm that integrates DOE-2 and BLAST (Building Loads and System Thermodynamics) simulation engines to compute heat demand of the building which is widely adopted as a reliable method for simulating building energy consumption. The model estimates the heat gain / loss of individual thermal zone by considering various parameters such as heat losses through different building components (i.e., walls, floor and ceiling), local climate, occupant's behaviour, internal gains, external solar gains etc. The model then calculates temperature changes over time, based on the heat gain or loss in each thermal zone. EnergyPlus predicted heating demand for the building over the course of a year, based on the thermal characteristic of building the outside air temperature. The building simulation models were designed as single thermal zone models as there were no different thermal zones identified. The heating set-point of all the houses was considered as 20 °C to maintain pleasant thermal comfort for all simulated houses as indicated in Botpaev et al. (2012). Simulation models utilised standard settings for natural ventilation in EnergyPlus due to the unavailability of accurate data. One can read the author's previous work to get more explanation about the house construction (open house: Mehta et al. (2020) and closed roof house: Beringer et al. (2021b)), detailed building elements, and the mathematic model of the house used in this simulation study.

6. Results and discussion

6.1 Parametric study and simulation outcomes

The study aimed to assess the effects of sustainable insulation materials on two types of houses using a simulation and parametric analysis conducted with the aid of EnergyPlus and jEPlus, respectively, for wall and ceiling insulation. The parametric study involved manipulating materials and thicknesses to identify the optimal configuration for maximum insulation efficiency.

To achieve this, three insulation materials - sheep wool, straw, and reed - were selected, and their thicknesses were varied from 3 cm to 15 cm in increments of 3 cm. The results were then compared for both types of houses, and Fig. 7 dispays the comparative outcomes.

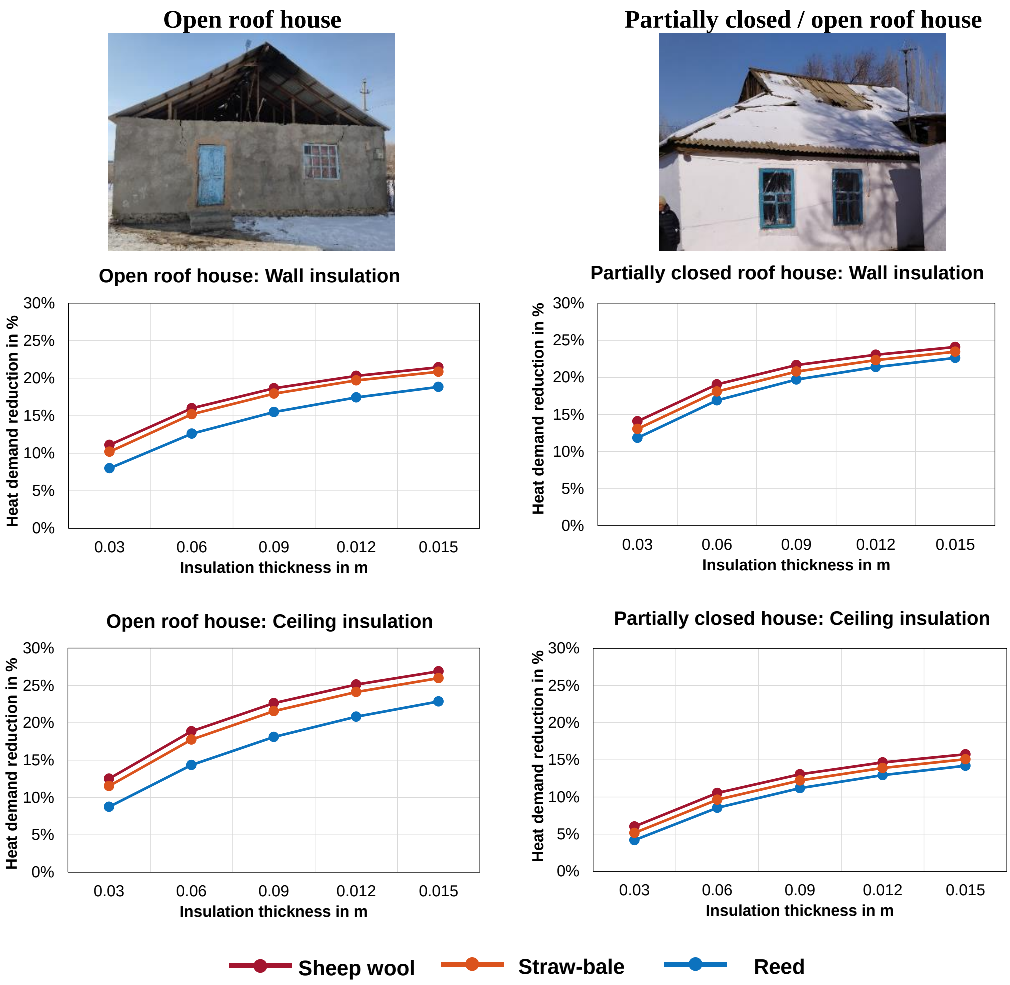


Fig. 7: Graphical representation of the parametric study based on the thickness and its effect on the heat demand reduction in %. The graphical representation provides a comparative overview and impacts of the insulation materials on the open roof house and closed roof house

6.2 Impact of sustainable insulation

Naturally, with the increment of the insulation thickness, there is more potential for heat demand reduction available. In general, wall insulation will help to reduce the heat demand up to 24% depending on the material and thickness. Similar to wall insulation, ceiling insulation also has the potential to reduce the heat demand up to 26%.

The comparative simulation results bring interesting and novel theoretical information. It can be seen from the simulation results that the insulation will be more effective in the case of a closed roof house compared to an open roof house. On the contrary, ceiling insulation is more effective in the case of open roof houses compared to closed roof houses. This finding will lead to the motivation of the sequential thermal modification in rural Kyrgyz houses.

Due to the open roof condition, the wind will pass over the ceiling which will induce a huge amount of heat losses through ceiling. Hence, investing in ceiling insulation should be the priority of the rural Kyrgyz household. This will allow reducing the heat demand more effectively. After the ceiling insulation, one can close the open roof. The author already demonstrated the positive impact of closing the roof and mentioned that "*covering the open sides of the roof raises the opportunity to decrease the specific heat demand by up to 22%.*". Once the ceiling is insulated (average heat demand saving up to 15%) and the roof is closed (heat demand reduction up to 25%), wall insulation can further help to drag down bluing heat demand. A novel information / scientific knowledge about sequential information will help rural people to make building energy efficiency more effective. The recommended thermal modifications allow for gradual investment in energy efficiency, making it financially feasible for low-income rural households in Kyrgyzstan. This contributes to the establishment of sustainable buildings in rural areas.

6.3 Limitations of the study

The study aimed to perform a comparative analysis of available house types and evaluate the impact of sustainable insulation on rural Kyrgyz houses through technical simulations. While the study conducted a parametric evaluation of insulation thickness, it did not provide any specific recommendations. Future scope includes multi-objective optimization considering heat demand reduction, cost, and insulation thickness. Sustainable insulation materials offer advantages such as higher volumetric heat capacities and lower carbon footprint compared to conventional materials. However, they also have disadvantages, including higher combustibility and higher thermal conductivity than state-of-the-art conventional materials. Considering thermal comfort, acoustic and hygroscopic properties, and cost-effectiveness are crucial to select the most suitable insulation material. The latest findings in composite materials aim to eliminate these drawbacks. Successful implementation of green building strategies has been analyzed in several publications, but large-scale experiments such as model houses are necessary for long-term observations of material changes due to weather, climate, and environment.

7. Conclusion

The presented research article carried out an in-depth assessment of available insulation materials in Kyrgyzstan from a technical, economic and sustainable point of view. Based on the three main research questions, why, how, and which, the article formulates a complete technical guide for sustainable insulation housing in high-altitude Kyrgyzstan. This guide shows a comprehensive design on *why* and *how* to build a sustainable and affordable energy-efficient building from *which* materials in high-altitude and cold climatic regions. This is how a detailed catalogue is available through the presented study in order to insulate high-altitude rural Kyrgyz houses sustainably. Therefore, by providing a complete solution for affordable and sustainable energy-efficient buildings, the research paper contributes to the knowledge. When upgrading the thermal shell of the building, material and insulation costs can be considered key parameters. Further to this, the presented study brought novel knowledge and recommended the sequence of the insulation which is not only effective but affordable as well. Unfortunately, all the listed insulation materials in the paper are still not acknowledged as insulation materials in Kyrgyzstan. Hence, it is necessary to make the local residentials aware of the enormous potential of using such materials.

8. Acknowledgement

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9. References

Asdrubali, F., D'Alessandro, F., Schiavoni, S., 2015. A review of unconventional sustainable building insulation materials. Sustainable Materials and Technologies 4, 1–17.

Ashour, T., Georg, H., Wu, W., 2011. Performance of straw bale wall: A case of study. Energy and Buildings 43 (8), 1960–1967.

Bakatovich, A., Gaspar, F., 2019. Composite material for thermal insulation based on moss raw material. Construction and Building Materials 228, 1–9.

BASF, 2019. Technical Data Sheet Walltite v.3. Spray Polyurethane Foam Insulation / Air Barrier. https://www.ecocomfort.ca/wp-content/uploads/sites/322/2020/01/WALLTITE-v.3-Technical-Data-Sheet.pdf. Accessed 6 September 2022.

Beck, A., Heinemann, U., Reidinger, M., Fricke, J., 2004. Thermal Transport in Straw Insulation. Journal of Thermal Envelope and Building Science 27 (3), 227–234.

Beringer, J., Mehta, K., Ehrenwirth, M., Trinkl, C., Zörner, W., 2021a. Performance comparison of different types of solar thermal collectors on residential space heating demand in high-altitude cold climatic environment: A simulation-based study, in: Proceedings Solar World Conrgess 2021.

Beringer, J., Mehta, K., Ehrenwirth, M., Zörner, W., 2021b. Sustainable materials for insulating high-altitude rural Kyrgyz residential houses: A parametric economic study, in: Applied Research Conference 2021. Ostbayerische Technische Hochschule Amberg-Weiden, pp. 183–188.

Borlea Mureşan, S.I., Tiuc, A.-E., Nemeş, O., Vermeşan, H., Vasile, O., 2020. Innovative Use of Sheep Wool for Obtaining Materials with Improved Sound-Absorbing Properties. Materials (Basel, Switzerland) 13 (3), 694.

Brakema, E.A., Tabyshova, A., Kasteleyn, M.J., Molendijk, E., van der Kleij, R.M.J.J., van Boven, J.F.M., Emilov, B., Akmatalieva, M., Mademilov, M., Numans, M.E., Williams, S., Sooronbaev, T., Chavannes, N.H., 2019. High COPD prevalence at high altitude: does household air pollution play a role? The European respiratory journal 53 (2).

Cascone, S., Rapisarda, R., Cascone, D., 2019. Physical Properties of Straw Bales as a Construction Material: A Review. Sustainability 11 (12), 1–19.

Corscadden, K.W., Biggs, J.N., Stiles, D.K., 2014. Sheep's wool insulation: A sustainable alternative use for a renewable resource? Resources, Conservation and Recycling 86, 9–15.

Dias, P.P., Jayasinghe, L.B., Waldmann, D., 2021. Investigation of Mycelium-Miscanthus composites as building insulation material. Results in Materials 10, 1–28.

Dom Penoplex LLC, 2021. Penoplex Comfort. https://www.kupi-penoplex.ru/uteplitel-plity-penoplekskomfort. Accessed 8 November 2021.

Elsacker, E., Vandelook, S., Brancart, J., Peeters, E., Laet, L. de, 2019. Mechanical, physical and chemical characterisation of mycelium-based composites with different types of lignocellulosic substrates. PloS one 14 (7).

2011. Info thermohouse insulation. http://www.ceeba.kg/index.php?ln=en&pg=srv. Accessed 3 May 2021, not retrievable since start of November (status of 14 December 2021).

International Energy Charter, 2018. In-Depth Review of the Energy Efficiency Policy of the Kyrgyz Republic, Brussels, Belgium. https://www.energycharter.org/fileadmin/DocumentsMedia/IDEER/IDEER-KyrgyzstanEN2018.pdf.

Jones, M., Mautner, A., Luenco, S., Bismarck, A., John, S., 2020. Engineered mycelium composite construction materials from fungal biorefineries: A critical review. Materials & Design 187, 1–17.

Keskküla, K., Aru, T., Kiviste, M., Miljan, M.-J., 2020. Hygrothermal Analysis of Masonry Wall with Reed Boards as Interior Insulation System. Energies 13 (20), 1–10.

Köbbing, J.F., Thevs, N., Zerbe, S., 2013. The utilisation of reed (Phragmites australis): a review. undefined.

Kudryavtseva, T., 2014. Hay prices in Kyrgyzstan increase by 2 times. https://24.kg/archive/en/economics/171607-news24.html/. Accessed 14 December 2021.

Lauermann, M., Betz, F., Mehta, K., Thevs, N., Ehrenwirth, M., Zörner, W., Cyffka, B., 2020. Preservation of Selected Ecosystem Services in the Floodplains of the Naryn River (Kyrgyzstan): Introducing the ÖkoFlussPlan Project, in: Geographica Augustana, pp. 47–53.

Mehta, K., Ehrenwirth, M., Missall, S., Degembaeva, N., Akmatov, K., Zörner, W., 2021. Energy Profiling of a High-Altitude Kyrgyz Community: Challenges and Motivations to Preserve Floodplain Ecosystems Based on Household Survey. Sustainability 13 (23), 13086.

Mehta, K., Ehrenwirth, M., Trinkl, C., Zörner, W., Greenough, R., 2020. Impact of Locally Available Thermal Insulation Structures on Space Heating Demand of High-altitude Rural Buildings: A Case Study of Kyrgyzstan, in: Proceedings of the ISES EuroSun 2020 Conference – 13th International Conference on Solar Energy for Buildings and Industry. International Solar Energy Society, Freiburg, Germany, pp. 1–12.

Musa, A.H., Mohammed, A., 2015. Compressive strength testing of plastered straw bale.

Oldham, D.J., Egan, C.A., Cookson, R.D., 2011. Sustainable acoustic absorbers from the biomass. Applied Acoustics 72 (6), 350–363.

Penoplex Ltd., 2021. PENOPLEX® WALL. https://penoplex.com/individual-construction/penoplex-wall/. Accessed 8 November 2021.

Plag, R., 2022. U-Wert Rechner ubakus. u-wert.net GmbH.

Riman company, 2021. Утепление пенополиуретаном в Бишкеке. https://riman.kg/. Accessed 16 August 2022.

Ruchti, M.H., Sägesser, N., 2021. Leistungserklärung. gemäß Anhang 3 der Bauprodukteverordnung (EU) Nr. 305/2011. https://www.fisolan.ch/sites/default/files/2021-11/Leistungserkl%C3%A4rung_ab%2020210111_Fisolan%20D%C3%A4mmplatte.pdf. Accessed 1 December 2021.

Sokol, E., 2019. Is Styrofoam Good for Soundproofing? Better Soundproofing.

Tiuc, A.-E., Vermeşan, H., Gabor, T., Vasile, O., 2016. Improved Sound Absorption Properties of Polyurethane Foam Mixed with Textile Waste. Energy Procedia 85, 559–565.

Tuzcu, T.M., 2007. Hygro-thermal properties of sheep wool insulation.

Vo, C.V., Bunge, F., Duffy, J., Hood, L., 2011. Advances in Thermal Insulation of Extruded Polystyrene Foams. Cellular Polymers 30 (3), 137–156.

WikiBath, 2020. Penoplex: technical characteristics, market overview. Do-it-yourself foam insulation. q2. Accessed 16 May 2022.

Xing, Y., Brewer, M., El-Gharabawy, H., Griffith, G., Jones, P., 2018. Growing and testing mycelium bricks as building insulation materials. IOP Conf. Ser.: Earth Environ. Sci. 121 (2), 1–8.

Zach, J., Korjenic, A., Petránek, V., Hroudová, J., Bednar, T., 2012. Performance evaluation and research of alternative thermal insulations based on sheep wool. Energy and Buildings 49, 246–253.