energies

Article

Residential Building Construction Techniques and the Potential for Energy Efficiency in Central Asia: Example from High-Altitude Rural Settlement in Kyrgyzstan

Kedar Mehta [1,*], Wilfried Zörner [1] and Rick Greenough [2]

[1] Institute of new Energy Systems (InES), Technische Hochschule Ingolstadt, 85051 Ingolstadt, Germany
[2] Institute of Energy and Sustainable Development, De Montfort University, Leicester LE1 9BH, UK
* Correspondence: kedar.mehta@thi.de; Tel.: +49-841-9348-6681

Abstract: Building construction in rural Kyrgyzstan is heavily dominated by earthen buildings. Old and inappropriate residential building structures contribute significantly to high domestic space heating energy consumption. Therefore, it is necessary to understand the relevant building construction techniques. However, the scant information on Kyrgyz building techniques, especially for high-altitude rural settlements, was the prime motivation to perform the presented study. The key objective of the study is to investigate residential building construction techniques in high-altitude rural Kyrgyzstan, and this was to be achieved by house visits during field trips, literature review, and pilot interviews with local people. The analysis enabled the detailed identification of individual building envelopes as well as predominant building materials to be recorded. Based on the assessment, a housing profile was created that represents the typical characteristics of traditional rural Kyrgyz houses. Furthermore, the study demonstrates the potential for energy savings in rural Kyrgyz houses of 50–70%. However, local conditions prevent people from making improvements to all domestic energy efficiency parameters simultaneously. Therefore, the study developed a 'sequential roadmap' to reduce domestic space heating demand in different phases based on simulation studies. Existing low-income rural Kyrgyz habitations can use the presented roadmap to reduce domestic space heating demand sequentially to overcome financial barriers and, therefore, contribute to establishing sustainable buildings in Kyrgyzstan. These results may be partially replicated in other Central Asian rural communities depending on their location and building characteristics.

Keywords: Central Asia; earthen high-altitude houses; building construction; vernacular buildings; energy efficiency; cold climate

check for updates

Citation: Mehta, K.; Zörner, W.; Greenough, R. Residential Building Construction Techniques and the Potential for Energy Efficiency in Central Asia: Example from High-Altitude Rural Settlement in Kyrgyzstan. *Energies* **2022**, *15*, 8869. https://doi.org/10.3390/en15238869

Academic Editors: Zhe Tian and Yan Ding

Received: 25 October 2022
Accepted: 21 November 2022
Published: 24 November 2022

1. Introduction

1.1. Setting the Scene

The dissolution of the Soviet Union in 1991 reformed the five independent countries of Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan. Central Asia is a landlocked region with a total land area of 4 million km^2 and a population of 70 million [1]. The geographically landlocked location is disadvantageous for the economic growth of Central Asia because of the limited transportation opportunities to interact with major world economic centres (i.e., Europe, Southeast Asia). This can be considered one of the key barriers to the expansion of economic activity. Because of the limited earning opportunities, almost half of the Central Asian population resides in rural areas where they rely directly on forestry, agricultural activities, and animal husbandry [2–4].

However, the energy-rich countries (Kazakhstan, Uzbekistan, Turkmenistan) enjoy an influx of capital through their energy and industrial sectors because of the enormous resources of natural gas, oil, and coal. Hence, they have a chance to invest in modern infrastructure and better housing, especially in the capital cities and urban areas. The rural areas of these countries are still under development [5]. The withdrawal of Soviet support became critical, especially for the high-altitude mountainous counties (Kyrgyzstan and Tajikistan). Their urban and populated regions focused on development through the expansion of economic activities after 1991. However high-altitude rural communities are at an economic disadvantage because of their isolated location and lack of job opportunities. Hence, Tajikistan, and Kyrgyzstan are considered low-income countries in the Central Asian context [5].

Between 60 to 80% of domestic buildings in Central Asia (mostly situated in rural areas) were constructed with earthen materials such as adobe, mud, clay, and soil during the Soviet era [6,7]. Between 1950 and 1960, energy costs were low and residential buildings were constructed with very little consideration for energy efficiency [8].

Since independence in 1991, residential construction has continued to follow the old approach from the Soviet era, with most rural homes continuing to be built with earthen materials. Since half of the rural Central Asian population lives in such buildings, they contribute significantly to the high residential energy demand [9–15]. Figure 1 shows the total final energy consumption by sector in Central Asian countries. It can be observed that residential buildings have substantially contributed to the total energy consumption framework, especially in Kyrgyzstan [16].

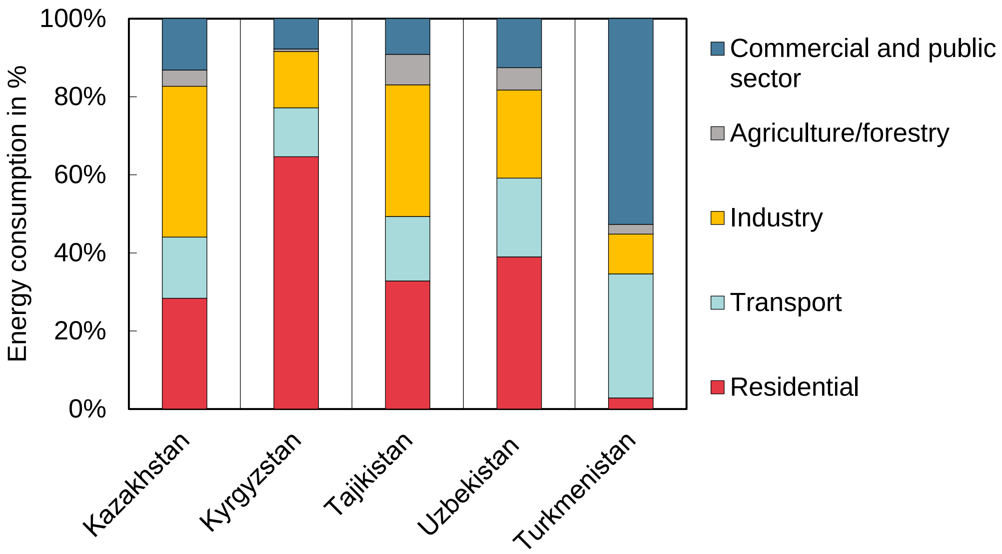


Figure 1. Total final energy consumption by sectors in Central Asia in 2018 (data according to [16]).

Because of their geographical location, most of the central Asian countries experience a cold climate with a heating period duration of between six and nine months. In this context, the age of domestic buildings and their low thermal efficiency aggravate residential energy consumption, especially for domestic space heating [17].

Of the five Central Asian countries, besides having the highest residential energy consumption, Kyrgyzstan faces a major housing concern [18]. The mountainous characteristics of Kyrgyzstan mean that only 20% of the land is available for comfortable living. As a result, most of the building stock of Kyrgyzstan is concentrated in rural settlements or semi-urban clusters [19,20]. Progressively, urban areas (such as the capital, Bishkek and its suburbs) have been developed because of the migration trend in recent years. People in rural areas have tended to migrate to urban areas in search of prosperity [18]; however, around three quarters of the Kyrgyz population still lives in rural areas. There are approximately 1.8 million dwellings in Kyrgyzstan. Due to the higher population in rural areas, the number of houses there is greater than in urban areas [21]. Figure 2 characterises building footprints in the urban and rural areas and shows that urban areas (such as Bishkek, Osh, Tokmok, Kara-kol, etc.) are both densely populated and well-structured because of the migration and development priorities. Conversely, rural settlements are remote with scattered buildings and a low population density [22].

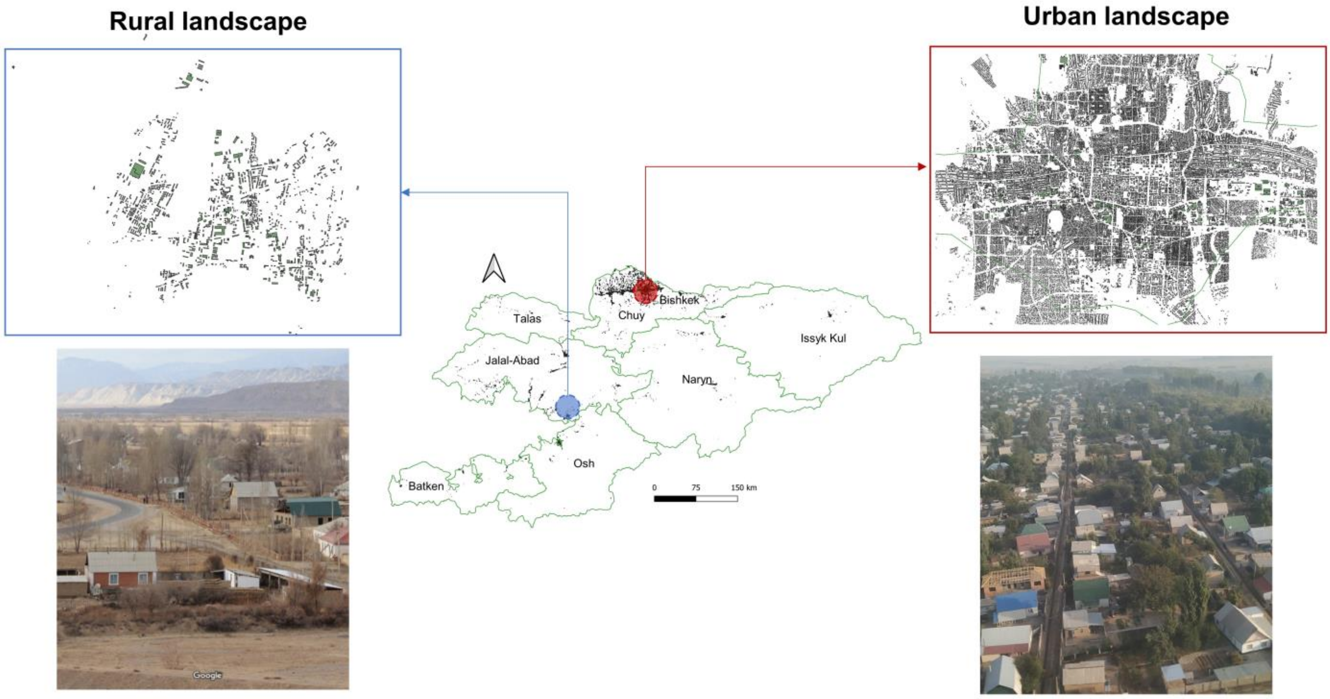


Figure 2. Exemplary building footprints of rural and urban settlement of Kyrgyzstan (Own illustration based on GIS data according to Humanitarian OpenStreetMap Team).

Because of the privatization of the housing sector in Kyrgyzstan, there is a growing trend of self-constructed houses. The rural building construction procedure is highly influenced by neighbours, because family members assist each other with building construction knowledge. This tendency combines with Kyrgyz history to give new houses an imprint of building designs and architectural knowledge mainly from Russian as well as from Turkic, Iranian, and Tibetan practices [6,23].

Rural Kyrgyz households have a high heat demand (3–5 times higher compared to European households) and lower thermal comfort due to their construction techniques and inappropriate building infrastructure. The majority of the rural building stock was built during the Soviet era (almost 50 years ago) and they follow the same construction practice to date. The current construction technique of vernacular architecture has a huge influence on energy demand. The high-energy demand is typically met with the help of traditional and non-sustainable methods, for example, the use of traditional heating stoves fired by coal and firewood. The heavy reliance on the local environment leaves a negative impact on the ecosystem, land degradation, and reduction in forest cover and ignites climate change in Kyrgyzstan.

Around 80% of Kyrgyz households use the traditional heating approach to meet high domestic space heating demand (due to inappropriate building construction) [24]. It is appropriate to consult the vernacular architectural tradition of high-altitude rural Kyrgyzstan. This holds a lot of potential to adapt historic culture and ideas to develop energy efficiency that applies to local boundary conditions. Hence, to reduce the heat demand of houses and the burden on the environment and bring sustainability to the region, it is significantly important to understand the building construction technologies of rural Kyrgyz buildings, which will allow the unlocking of the potential to reduce the high heat demand (i.e., energy efficiency).

1.2. The Gap in the Research

There are very limited studies available about vernacular architecture in combination with a different climate. Nguyen et al. [25] made a comprehensive review of the study of vernacular architecture on the global level. Figure 3a represents the estimation of the studies carried out about vernacular architecture in different regions of the world. In addition, Figure 3b represents the distribution of the studies by climate types, according to the modified Köppen climate classification system.

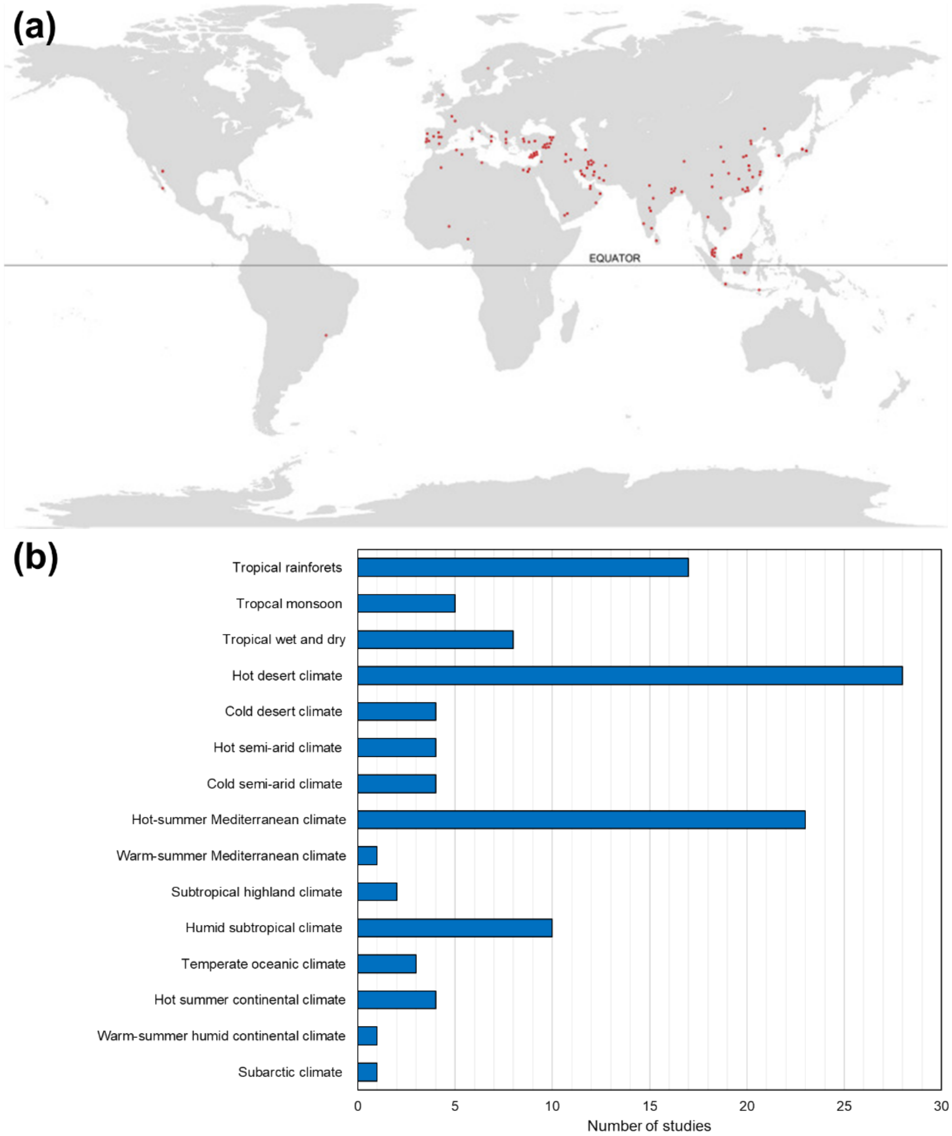


Figure 3. (**a**) Studies about vernacular architecture on a global level and (**b**) Distribution of the studies by climate types, according to the modified Köppen climate classification system (based on [25]).

It can be observed that there is very limited information about cold climates and vernacular architecture. At the same time, the old houses in the cold climatic region are the most energy-vulnerable as they need most of the energy for house heating compared to cooking and lighting. Further to this, Bergström and Johannessen [18] studied multi-apartment dwellings and the available energy efficiency measures for the same. The study contains limited information about energy use in Kyrgyz buildings, as the study focuses on sustainable housing in Kyrgyzstan with a focus on multi-apartment buildings located in Bishkek. However, their rural residential building construction techniques in combination with energy efficiency were untouched.

Also, Fodde [6] derived useful information about traditional earthen buildings in Central Asia. The paper provides an overview of the principal earthen building materials of Central Asia and the cultural aspects of traditional architecture. The main focus was to identify the manufacturing processes of various building materials in the Central Asian region. However, an in-depth investigation of building construction techniques was not explored in the presented article.

Summing up, the state of the art review revealed that the majority of the available research analysis focused either on various available materials or on urban buildings. A closer investigation of the literature on Kyrgyz building construction techniques and architectural knowledge reveals a research gap and shortcomings. There is a gap in the knowledge of the detailed construction process, current building techniques, predominant building materials, and the potential for energy savings in rural Kyrgyz houses.

1.3. Research Questions, Objectives and Methodology

By considering the existing research gap and the need for scientific contribution, the presented research article sets the goal to investigate and analyse the existing residential building construction techniques of high-altitude rural settlements in Kyrgyzstan. To achieve this research goal, the paper raises and answers the following research questions:

- What sort of building construction techniques are available in high-altitude rural Kyrgyzstan?
- What are the predominant building materials used to build high-altitude rural houses?
- What is the energy demand of the existing rural Kyrgyz houses and what is the potential for energy efficiency?

The main objective of this article is to identify the building construction methods for rural areas in Kyrgyzstan. Besides a detailed investigation of building construction techniques, the secondary objective is to present a roadmap to improve the energy efficiency of rural residential houses in Kyrgyzstan by considering the local circumstances of the country based on the locally available materials that are accessible and affordable.

To accomplish the research objective of the study, a three-stage approach was designed, which is represented in Figure 4. The research work started with data collection, as there was no authentic information available about rural Kyrgyz buildings. The data were collected through various methods, from a literature review to on-site pilot interviews.

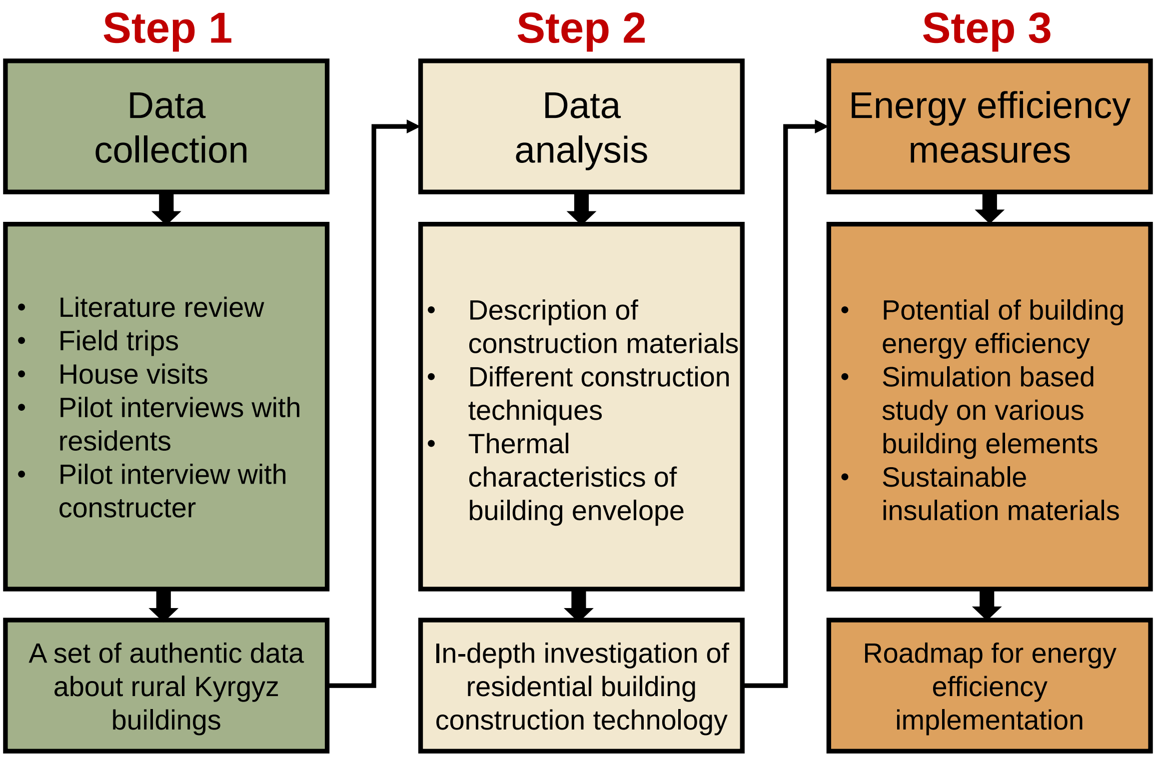


Figure 4. Research methodology of the presented article.

The necessary information was collected about the buildings from on-site household visits in the high-altitude Kyrgyz communities (Ak-Tal and Emgek-Talaa). Further to this, pilot interviews were conducted with the local inhabitants and people involved in building construction to obtain current knowledge about building construction techniques and how they are involved. In total, around 50 + houses were visited in rural Kyrgyzstan to obtain building information. The aim of the house visits was to collect data on building information such as building material, floor area, occupant behaviour, level of thermal comfort, etc. One can visit Mehta et al. [26] to obtain more information about the household survey. Stage 2 was data analysis to categorize the building construction techniques/procedure. The data were analysed by various building elements, for instance, laying the foundations, floor construction, wall construction, wall plastering, ceiling construction, roof construction, etc. They also provided a detailed description of available building construction materials. As an outcome of stage 2, an in-depth assessment was derived of the construction procedure.

Naturally, the aged, vernacular, and uninsulated building stock of rural Kyrgyzstan outlines the great potential for increased energy efficiency. After having a comprehensive understanding of Kyrgyz buildings and building construction materials, stage 3 discussed affordable and sustainable building energy efficiency. In order to provide a suitable road map, the presented study developed four different cases starting from improved windows to the insulation of the whole house by considering the existing building construction techniques.

1.4. The Novelty of the Study

The presented study is the first attempt to discuss the residential building construction techniques of the Kyrgyz houses that are situated at high-altitude and experience a cold climate. The key novel outcomes of the presented article are mentioned below:

- Scientific information acquisition about residential building construction procedure.
- A detailed assessment of the old and new/current building construction techniques in combination with the various building construction materials.
- Theory and context of the rural Kyrgyz building sector including architectural plans, routine behaviour, cultural and traditional aspects.
- A novel and sequential roadmap for building energy efficiency was designed by considering local boundary conditions.

2. Theory and Context: The Kyrgyz Building Sector

The building patterns and construction methods vary by region according to the altitude and local climate. For instance, in North Kyrgyzstan, the dwellings are earthen houses, predominantly built of rammed soil, while in southern Kyrgyzstan, adobe/mud/clay blocks are used as rudimentary building elements [8].

In urban Kyrgyzstan, almost 40% of the total residential buildings (the rest of the buildings are individual family houses) are structured as multi-apartment buildings. Most urban buildings are constructed with brick masonry, monolithic concrete, concrete panels with insulation, and also mud bricks [27]. The transition from urban areas to rural areas is marked by a change in building construction. The majority of rural houses are single-family houses of single-floor construction. Traditionally, rural buildings are built with clay and/or soil-based materials, in combination with wood for floor and ceiling structures [27]. Figure 5 represents the typical urban and rural residential buildings.

Figure 5. A multi-apartment building in the capital city (Bishkek) and a single-family house in rural Ak-Tal (Source: Author).

Mountain ranges cover a large part of Kyrgyzstan, and the climate here is characterised by extremely cold winters with temperatures ranging between about −4 °C and −6 °C in the lowlands and −25 °C and −30 °C in the mountainous areas [18]. Most of the rural population engages in agricultural and forestry activities. However, the cold climates and snowfall in the mountain regions reduce agricultural activity between October and March.

Because of the long harsh winters, the rural population struggles to generate a constant income from their agriculture occupation [28]. Modern house construction needs a significant investment, which is not often possible for rural people [23]. Therefore, a private house owner has limited opportunities for house renovation or repair because of the financial situation in rural Kyrgyzstan.

As a result of the remote location and low construction rate, modern building techniques are not yet expanded and accepted in rural regions. In the case of rural areas, self-made houses constructed from clay are a common practice. However, both urban and rural buildings are classified as low energy-efficiency buildings because of their age. Of course, the newly constructed buildings have better construction techniques with modern facilities. In any case, suitable Kyrgyz building codes are rarely considered while building a house [27].

3. Traditional Single-Family House in Rural Kyrgyzstan: An Outlook

In the Kyrgyz residential sector, single-family houses, located in rural areas, acquire most of the floor space because the proportion of the rural population is more significant than the urban population [27]. Due to their geographical isolation and poor infrastructure, rural homes are less likely to have access to public utility services such as a piped potable water supply, district heating system, or natural gas supply [29]. Because of the limited water supply, most low-income rural houses do not have an inside bathroom or shower room. Rural people generally use a community bathhouse for shower purposes. To meet drinking water demand, people fetch water from open water sources such as irrigation canals, ditches, and rivers [26].

Similarly, the district heating network for house heating only covers the capital city and urban areas. Hence, rural people use a low-efficiency traditional heating stove to maintain thermal comfort inside the house [21,27]. This solid fuel-operated traditional heating stove is located either in the middle of the heated space of the living room or placed between two walls (built between two walls) of the room with a chimney in the ceiling.

In Kyrgyz culture, living with an extended family has great importance. Therefore, several generations often live together in one household. However, this is not the same for urban areas where small families are more common. Rural houses in Kyrgyzstan consist of a floor area of 90–100 m^2 with four to five rooms (previously, it was common to have a floor area of 60–80 m^2 with one to two rooms) with an average of five to seven people in the house [23]. The typical house in rural Kyrgyzstan consists of four to six rooms, with an open room to store shoes and for miscellaneous purposes adjacent to the kitchen, living room and bedrooms. Because of the cultural tradition of eating meals together and the gathering of families for meals during the summer holidays, a living room is generally large compared to the bedrooms. Figure 6 represents the typical building plan of a rural Kyrgyz house.

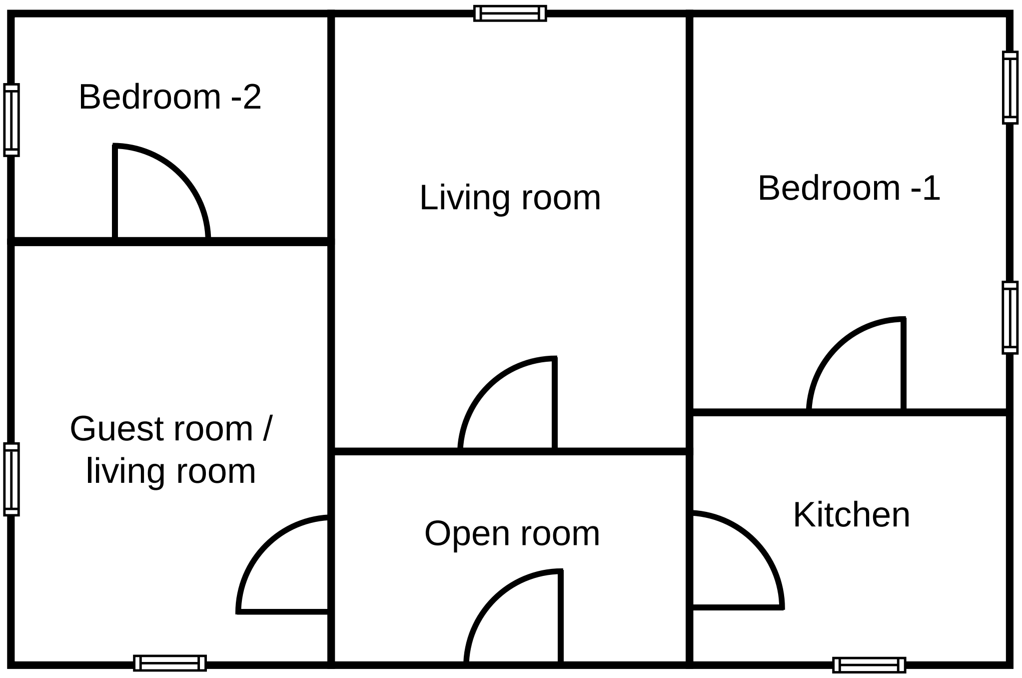


Figure 6. Typical architectural plan of rural Kyrgyz house (own illustration based on the site visit).

Especially in high-altitude mountain areas, rural settlements have low population density; therefore, most rural houses in Kyrgyzstan are detached. Outside the house, householders tend to build small storage areas and a yard to accommodate livestock. However, this storage and the open yard are not a part of the building construction and they tend to be arranged according to the available number of livestock and farming capacity. Also, most rural homes have a separate structure (room) for summer cooking.

The interactions allowed an understanding of the daily routine of local people. Based on them, the presented study derived the occupancy profile that was later used in the simulations of the Kyrgyz building to obtain accurate results. Based on the daily routine observations of various houses, a generalized occupancy profile for rural Kyrgyz houses was developed, and this is shown in Figure 7. Also, it reveals the cultural aspects of Kyrgyz citizens. It was noticed that the eldest son is in charge of looking after his aging parents. While a Kyrgyz male normally manages the home's finances, Kyrgyz women are typically in charge of domestic chores including cooking, feeding and watering animals, and refuelling solid fuel stoves.

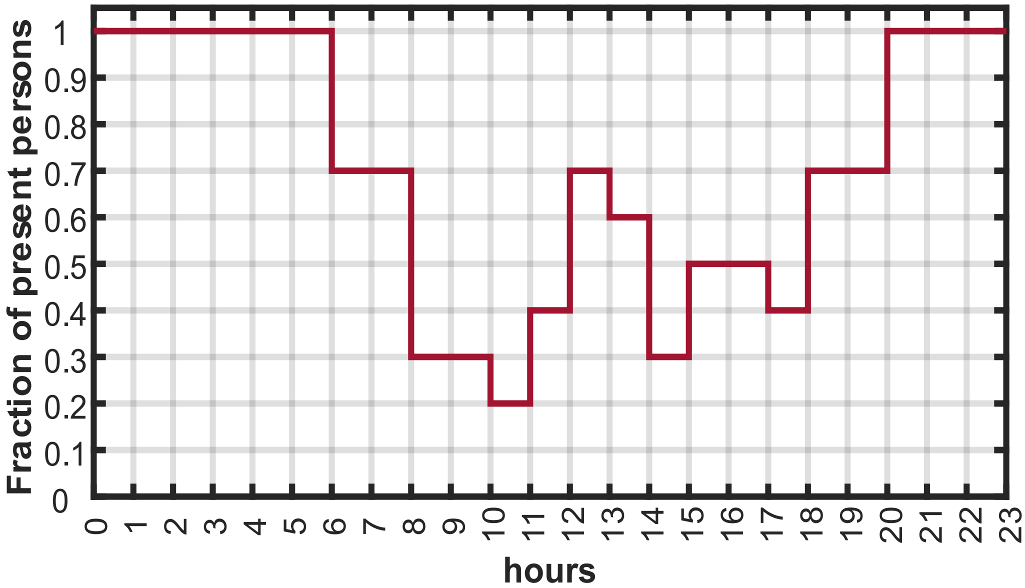


Figure 7. Daily occupancy of a typical rural Kyrgyz house.

4. The Kyrgyz Building Construction Techniques

In nomadic times, the yurt was the most common type of dwelling in Kyrgyzstan because of its portability and speed of assembly. Today, permanent residential buildings have largely replaced the yurt as a dwelling; however, yurts are still commonly used for family gatherings and special occasions, especially in the summertime. In the 18th century, Kyrgyz people began to construct permanent dwellings from mud bricks, which became a widespread transition in the Kyrgyz building sector [12]. However, because of the nomadic culture, the house structure is still usually a wooden frame. To construct a building, the adobe and/or cob techniques are adopted historically in rural Kyrgyzstan. Therefore, all buildings in rural communities tend to be quite uniform in terms of their design as well as the building plan.

The key building material for most private residential buildings in Kyrgyzstan (and other Central Asian countries) is a dust-like soil known as loess [6]. Hence, from historic times, soil-based materials have dominated Kyrgyz building practice and are considered to be low-cost building materials due to their high availability. In addition to this, low-income families naturally avoid investing in more sophisticated building materials. This section classifies the construction techniques of the various building elements such as foundation, floor, walls, ceiling, and roof based on the on-site interviews and observations of various rural Kyrgyz houses.

4.1. Building Foundation

In ancient times, natural stone or the ground were used as building foundations, and the building was directly built on the ground (without any trench foundation). However, these simple buildings were not able to withstand earthquakes. Kyrgyzstan is highly exposed to frequent earthquakes because of its active seismic zone, and Kyrgyz people learned to modify the original foundation design to resist earthquakes.

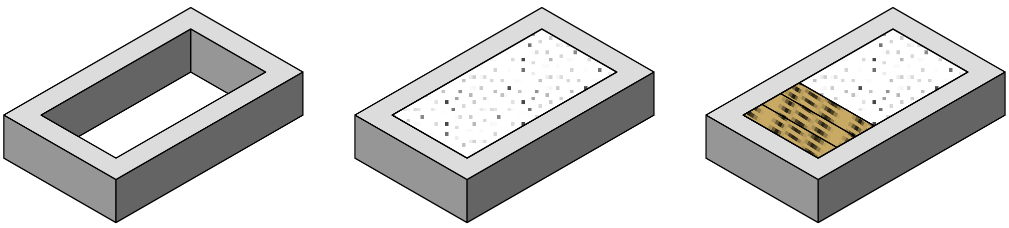
To upgrade the original foundations, a trench may be excavated 30 cm to 50 cm deep in the ground with a width of 50 to 80 cm (according to desired wall thickness). Then, boulders are used to fill the trench to give stability and prevent dampness. Today, however, concrete foundation designs are gradually replacing the old foundation techniques. Figure 8 shows examples of two Kyrgyz houses with different foundation designs.

Figure 8. Foundation with the stone (**top**) and foundation with the concrete frame (**bottom**).

Naturally, reinforced concrete-based foundations are better able to withstand earthquakes; however, this technique is expensive compared to other foundation practices as it uses cement, as well as iron bars to create the foundation. This type of foundation is therefore generally limited to the homes of high-income families. However, it can be noticed that progressively the foundation techniques in rural Kyrgyzstan have been improved to improve the stability of the house.

4.2. Floor

The earthen floor is considered to be a common practice for floor construction. This type of floor is used when building directly on the ground. Generally, to construct the floor the first step, a boundary, is created out of stone to increase stability and durability. In newly constructed houses, a foundation frame of concrete is more common than one made of stone (Figure 9). Nowadays, to prevent the cold being felt from the ground, the outer frame consists of concrete and has a total height of 70 to 200 cm depending on the house design and available finance.



(**a**) (**b**) (**c**)

Figure 9. (**a**) Foundation frame, (**b**) foundation frame filled with gravel/stones, (**c**) installed wooden beams on the floor.

To create the floor of the house, medium-sized gravel is used to fill the inside of the concrete or stone frame, and this functions as a humidity barrier. Long wooden beams are used to span the top of the frame and, finally, floorboards of pine are fixed to the wooden beams. Most rural houses have wooden floors, and while concrete floors have become more common in recent years their use is limited because of the cost of concrete. Figure 8 demonstrates the foundation and floor construction process.

Small openings are made in the outer frame for natural ventilation to generate an air gap between the gravel and the floor construction to avoid humidity. Figure 10 represents the inlet and outlet of natural air ventilation.

Figure 10. Natural ventilation inlet/outlet to the environment in the floor of rural Kyrgyz houses.

The wooden floor is easy to build, and no special knowledge or sophisticated building materials are required for its construction. However, during wintertime the provision of natural ventilation results in a cold wooden floor as cold air from the outside circulates under the floor. To prevent this, households often block ventilation holes in the wintertime. In addition, to avoid cold feet it is common to use thick wool carpet on the floor.

4.3. Walls

Walls in rural Kyrgyzstan are usually made from different soil-based materials such as mud brick, adobe brick, raw brick, clay-straw brick, clay lumps, and rammed earth. The selection of wall materials for a traditional house is based on the available cash, the actual need, and the knowledge and experience of local people. Mostly, the house owners follow the regional traditions established by their forebears.

Because of their low income as well as the limited awareness of energy efficiency in rural areas, households can rarely afford insulation materials. Hence, to reduce heat losses and gain more thermal mass, the wall itself is built with high thickness. In the past, houses typically had a wall thickness of 40 to 60 cm, according to the material quality; however, in recent years the wall thickness has been reduced to 30 cm to 40 cm by using suitable materials. However, it was observed during the on-site visit that the wall thickness varied according to the building requirements and structural design.

4.3.1. Clay/Adobe/Cob Walls

Adobe and cob are both ubiquitous building materials not only in Central Asia but over the world, and they are some of the best soil-based superior natural building materials. In Kyrgyzstan, the brick is formed by adding water to a clay and straw mixture until it becomes a sticky and firm mass with a consistency that promotes processability. It is common to add livestock manure into the mixture, which is prepared in small quantities for use immediately to prevent premature hardening.

In the past, the wet cob mixture was directly applied layer by layer to create walls. However, in that technique, a suitable shape could not be given to the wall. Hence, craftsmen introduced the brick design to give a proper architectural shape to the building. To prepare bricks, the clay-straw/cob/adobe mixture is added to a mould and pressed into the form of brick (generally 15 cm × 15 cm × 30 cm, but this varies by region). After moulding, the bricks are left to dry under the sunlight in an open area for 3–4 days before use in wall construction (Figure 11).

Figure 11. Clay-straw bricks being dried naturally.

The addition of straw brings strength to the building wall, and it also helps to absorb moisture from the clay. Because of the straightforward preparation and construction, adobe and clay-straw have become the most common building materials for wall construction in rural Kyrgyzstan.

4.3.2. Rammed Earth

Rammed earth is a widely accepted material for wall construction all over Central Asia. To make a rammed earth wall, loose soil is mainly used. This technique has the advantage over clay-straw or adobe bricks that it does not require any mixing. To construct a solid wall, a wooden support fixture is installed according to the desired wall thickness (typically 40–50 cm). To compact the soil, wooden shutters are attached to the support fixture directly on top of the building foundation. After that, loose soil is filled into the fixture and rammed with the help of a special wooden tool to compress the soil. After ramming the soil, the whole arrangement is usually left for 5 to 7 days to dry naturally in the sun, after which it forms a solid structure. The compression of the soil layer by layer will make the resulting wall more durable. Due to the compression technique, rammed earth construction is usually more durable than clay lumps or mud bricks, especially against water rising by capillary action from the ground. However, the thermal qualities of soil walls are directly dependent on the stamping techniques/compression of the soil. Today, many old rammed earth buildings are in poor condition because the masonry of the rammed earth walls does not contain any binding materials and has a high risk of deformation [30]. The principle of rammed earth construction is illustrated in Figure 12.

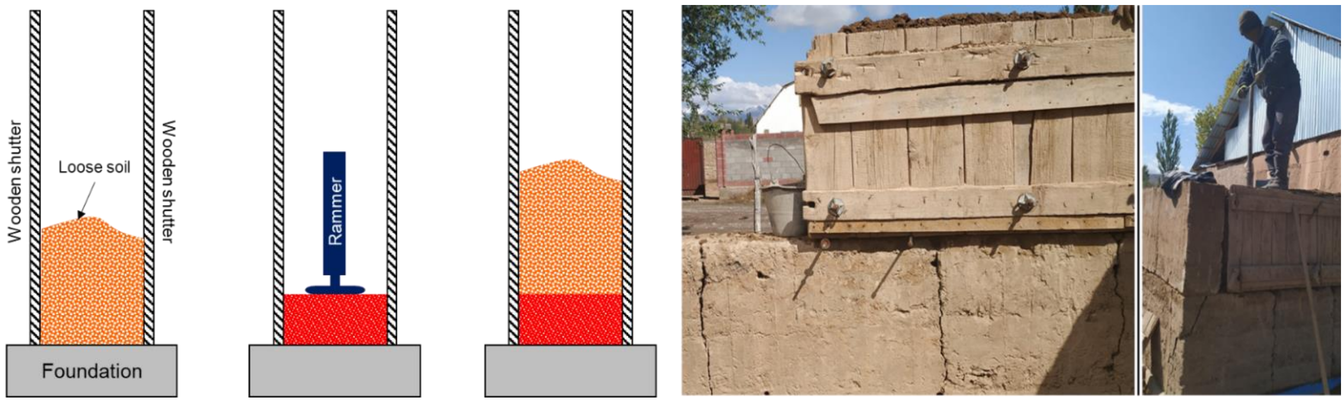


Figure 12. Rammed earth construction principles (**left**) and practice in rural Kyrgyzstan (**right**).

4.3.3. Clay Lumps

Hand-made clay lumps are known as 'Gualyak', and are prepared in round or slightly oblong shapes without the addition of extra materials. The clay lumps are arranged in a layer within a rectangular wooden frame called a 'synch'. The clay mortar/lime render layers are used to apply finished looks and hold the lumps together as illustrated in Figure 13.

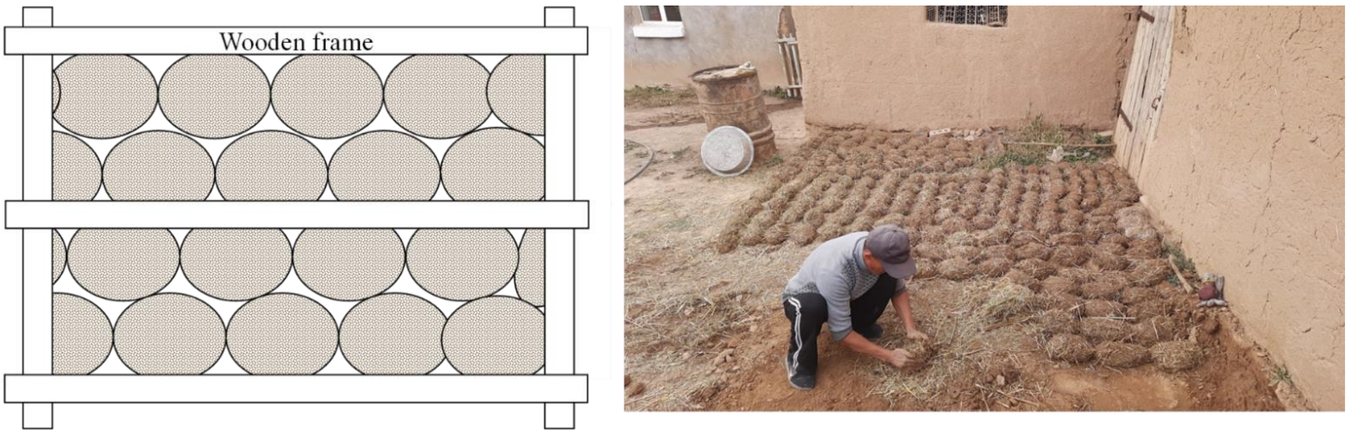


Figure 13. A wall structure with clay lumps and a wooden frame (**left**) and clay lumps in preparation (**right**).

This is a traditional technique often found in older houses, especially in seismic zones; however, it is not a common practice today.

4.3.4. Wall Plaster

The walls are usually covered by plaster to protect the wall base (clay/adobe/soil). It is very common to apply clay/silicate as plaster to protect the soil-based walls from the environment (i.e., rainfall, snowfall). High-income households can afford to decorate the façade with materials imported from neighbouring countries (Russia, Turkey, and China), which makes them costlier. Middle-income and low-income households prefer to have either clay plaster or whitewash on the exterior and interior walls (Figure 14).

Figure 14. A decorative façade or exterior wall (**left**) and a whitewashed exterior wall (**right**).

Usually, clay plaster is applied to the walls in two to three different layers (to a thickness of 2 cm to 3 cm). Smooth plaster is considered a good quality plaster. However, in rural areas, the durability of the plaster is a concern as it is applied without any proper/poor-quality materials. Hence, it tends to crack after a limited time because of environmental effects. Naturally, the cracked plaster is not good enough to protect the walls. In this case, walls are subject to erosion as well as moisture penetration.

4.3.5. Vapour Barrier

Traditional natural floors with a foundation of stones are highly vulnerable to moisture ingress. Even though rain and snowfall are low, they can be enough to cause issues of moisture ingress to the foundation of the building. This is particularly problematic in old buildings when groundwater rises through floor masonry and earthen walls through the capillary effect. This dampness results in diffusion of the soil-based walls, which can lead to mould development that appears as a collection of black dots inside the house. Sometimes, the rising dampness damages the plaster or a painted wall and this can be commonly seen in older houses.

To avoid humid walls, modern construction addresses the wall diffusion issue by including a water-resistant vapour barrier between the foundation frame and the wall. This can be visible in Figure 15. In addition to the vapour barrier, and when funds permit, the moisture diffusion process is slowed in newer buildings by increasing the floor height by up to 1 m. This will also reduce the cold coming from the ground.

Figure 15. Provision of vapour barrier to avoid water diffusion on walls.

4.4. Ceiling

A typical rural Kyrgyz house has a timber beam ceiling. To construct the ceiling, the beams (typically 0.5 m in diameter) are usually placed on the walls at a spacing of 10–15 cm. On top of the beams, wooden planks and boards are added, and over these, a layer of loose soil and straw is applied. A reed panel may be used as an alternative to straw. The idea behind using straw or reeds is to reduce heat losses through the ceiling. Lastly, a thick layer of slag or clay mortar (10–20 cm) is applied to protect the whole ceiling sandwich.

This traditional ceiling construction does not address energy efficiency or protect from the climate as well as more modern methods; therefore, the ceilings of old houses are vulnerable to moisture ingress. New buildings use an extra layer of cardboard and a vapour barrier to prevent moisture ingress into the ceiling structure and give better protection. Figure 16 shows the typical ceiling of a rural Kyrgyz house.

Figure 16. An example of a wooden-beam ceiling.

Also, to enhance the interior aesthetic of the house, high-income houses often cover the wooden beams by adding an extra layer of cardboard over the beams to hide them.

4.5. Roof

Low-income families in rural areas typically live in a house with a metal roof that is placed on a wooden-beamed ceiling. However, the gables of the roof are usually open at both ends, which creates an open space between the ceiling and the gable roof (Figure 13). Naturally, the open space induces a considerable amount of heat loss during windy days. Lack of knowledge and limited income are considered to be the primary reasons behind the open gable roof.

On the other hand, the homes of high-income households are more likely to feature a closed gable roof. The closed gable roof may use sheet metal at both ends, or four sides may be covered with sheet metal in the case of a hip roof. It was also observed from the site evaluation that a wooden closer is also widely used to improve the appearance of the gable roof. The selection of roof material is directly linked to the income of the household.

Sometimes the high-gable roof/hip roof contains a special wooden structure that is placed on the ceiling to support the sheet metal. This roof frame is held together by a ridge beam, rafters, and horizontal logs. The height of the ridge beam usually varies in the range of 2.5–3 m. Figure 17 shows the various roof designs that can be found in rural Kyrgyz houses.

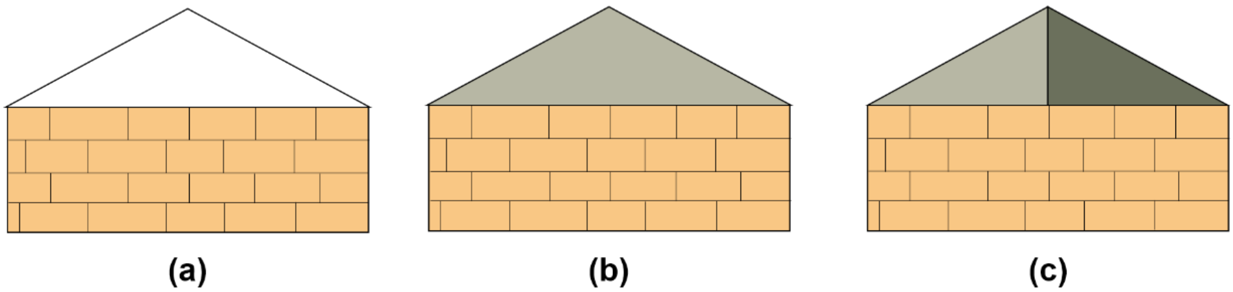


Figure 17. Various roof designs of rural Kyrgyz houses: (**a**) open gable roof, (**b**) closed gable roof, (**c**) hip roof.

4.6. Windows and Doors

Most rural Kyrgyz houses have traditional wooden-framed windows. The windows are generally double-glazed with around 3 to 5 cm of air gap. Many windows are leaky because of the cracked panes, and also the wooden frames are often poorly fitting and allow draughts. In high-altitude houses, the old and cracked windows cause high heat losses and are often responsible for condensation within the sealed unit of the double-glazed pane. Hence, improved windows can significantly contribute to reducing energy consumption. However, new buildings tend to implement PVC-framed windows. Figure 18 shows both wooden and PVC windows.

Figure 18. Traditional wooden windows (**left**) and newly installed PVC windows (**right**).

The main entrance door and other doors in a rural Kyrgyz house are made from wood with a typical thickness of 5 to 8 cm. As with the windows, uninsulated doors in rural homes are often found to be cold and draughty.

5. Outlook and Discussion

5.1. Potential of Building Energy Efficiency in Rural Kyrgyzstan

Owing to the high altitude and mountainous terrain, Kyrgyzstan experiences a cold climate with long and harsh winters. High-altitude remote communities, therefore, face an additional energy challenge because a significant amount of energy is needed for domestic space heating as well as cooking and hot water preparation [21]. Traditional buildings are built with natural materials and generally have poor thermal efficiency, and this is the main cause of the higher energy demand for domestic space heating. It has been identified that the typical domestic space heating energy consumption of uninsulated, vernacular Kyrgyz houses is 290–320 kWh/m^2, which is 3–5 times higher than European houses whose energy consumption is typically 100–120 kWh/m^2 [18,21].

The provision of district heating is limited to only 1.1 million Kyrgyz households situated mainly in the capital (Bishkek) and nearby urban areas. Most rural and semi-urban houses (more than 80%) rely on traditional but inefficient individual heating stoves fired by solid fuels such as coal and firewood [27]. However, these traditional solutions are not capable of fulfilling the high heat demand and therefore domestic heat demand often goes unmet.

Traditional heating stoves are significant contributors to local energy poverty. Solid fuel-burning stoves have a thermal efficiency of 20–40% and this inefficient combustion induces indoor air pollution, and outdoor air pollution, leading to serious health issues due to the ash particles [31,32]. Because of the lack of an appropriate energy supply, high-altitude rural communities are forced to meet all their energy needs from their surrounding environment, which promotes the intensive use of unsustainable solid fuels. Mehta et al. [26] mentioned that "during the winter period (from October to March), based on the availability of heating fuels and financial capabilities, the average rural family needs to use 2 to 4 tons of coal, 1.5 to 3 m^3 of firewood and 1 to 2 truckloads of cow-dung to meet their residential heat demand". In addition to the health impacts of burning solid fuel on traditional stoves, wood collection by rural communities leads to a negative impact on riparian forests. As a result of low incomes and the unavailability of modern building technologies, the available building codes are rarely considered when building new houses. Hence, old houses and newly constructed houses both have high energy demands for domestic space heating. Figure 19 shows a comparative assessment of the U-value (in W/m^2 K) of real buildings compared to the Kyrgyz building code.

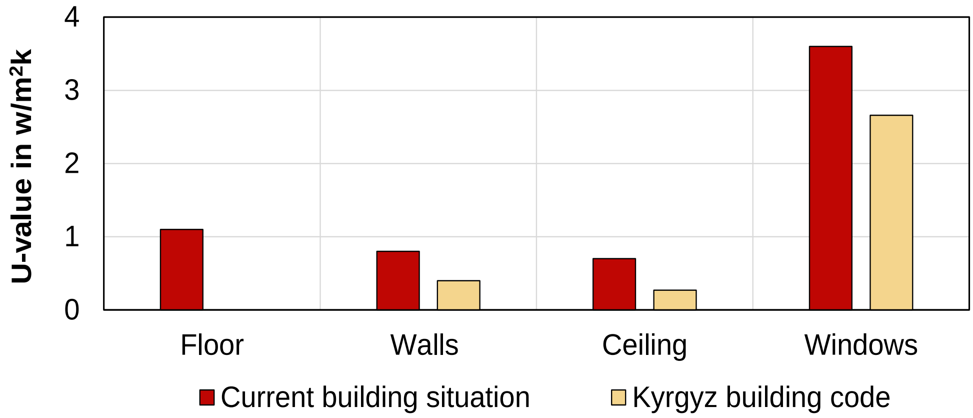


Figure 19. U-value of buildings based on the author's observations (from the developed simulation model) vs. recommended U-values in Kyrgyz building code [33].

It is estimated that rural Kyrgyz houses have the potential to reduce energy consumption by almost 50–70% through more appropriate choices of building materials, planning, thermal insulation, and more appropriate building construction techniques [34], which shows the huge potential for energy efficiency in rural Kyrgyzstan. The high heat demand for Kyrgyz houses is expected to remain the same unless the implementation of energy efficiency is fully realized.

5.2. Motivation for the Energy Efficiency Roadmap Devolvement

Rural people would like to improve their living conditions by improving building envelope qualities. However, the lack of financial resources prevents rural Kyrgyz people from improving the energy efficiency of their homes. 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 scenarios in rural Kyrgyzstan, the application of thermal insulation to their homes is not considered practical for most rural households. Also, the remote locations of high-altitude rural settlements in Kyrgyzstan restrict access to supplies of modern building materials [35]. On top of that, it was recognized through household surveys that rural people do not have enough knowledge about building energy efficiency. For example, some of the houses closed the open roof without insulating the ceiling. Of course, closing the roof can help to prevent the cold air from passing through the roof space. However, the uninsulated wooden-beam ceiling still causes high heat loss. Due to a lack of awareness and a knowledge gap, effective energy-building efficiency is not yet applied to rural Kyrgyzstan.

Summing up, there is a need to identify a suitable hierarchy of energy efficiency investments to reduce the residential space heating demand of vernacular buildings. This will allow effective and affordable building energy efficiency for rural Kyrgyzstan. In response, this article suggests a suitable order to implement energy efficiency measures by considering the local circumstances such as low income, availability of sustainable materials for insulation, and climate.

To plot a sequential pathway, a reference earthen house (base case) was developed using the building energy modelling tool EnergyPlus [36]. Modelling data were collected through interviews with local people and visual observation. Later, the model of the reference house was modified sequentially to examine the impact of various energy efficiency measures on the residential heat demand. This study explores several potential solutions starting from improved windows to the insulation of the whole house, in four different use cases. The four cases are listed in Table 1 in sequence.

Table 1. Description of the case studies designed for the simulation. The cases are arranged in sequence/steps that Kyrgyz households need to consider to realize effective energy efficiency affordably.

Base Case	**Typical Rural Kyrgyz House**
Case 1 (step 1)	Replacing the wooden windows with plastic-based windows
Case 2 (step 2)	Ceiling insulation with locally available sustainable insulation material
Case 3 (step 3)	Open roof closing
Case 4 (step 4)	Wall insulation with locally available sustainable insulation material

5.3. Base Case: Typical Rural Kyrgyz House

Based on the above discussion (eventually, based on the author's observations of the various houses and interactions with rural Kyrgyz residents), the typical uninsulated rural Kyrgyz home was modelled in EnergyPlus. The single-family home that was chosen offered 100 m^2 of living space with a single thermal zone but had no thermal insulation in its design. The house orientation was given in the north direction. To optimize solar benefits, two windows were taken into consideration, one on the eastern wall and one on the western wall, both having an area of 6 m^2. The heating setpoint for the reference home was determined to be 20 °C in order to achieve pleasant thermal comfort inside the building. The building simulation was performed for one full year to obtain the full picture of the heat demand. More scientific information about building characteristics and models can be found in Mehta et al. [20].

5.4. Case 1/Step 1: Replacing the Wooden Windows with Plastic-Based Windows

Firstly, the reference house was modified by replacing wooden windows with double-glazed polyvinyl chloride (PVC) windows. The old windows with cracked panes and wooden frames are key thermal bridges for heat leakage. The raw materials for PVC windows are usually imported from China and Turkey to Bishkek, in Kyrgyzstan, before being supplied to the local centres and regional producers. Due to the decentralized PVC window assembly process as well as low prices to implement energy efficacy measures, installing PVC-based windows is now a common practice in new houses. The average price of PVC windows ranges from 4500 to 7000 KGS (45–60 €) per square metre, depending on the location of purchase due to transport problems. In most cases, the suppliers offer free installation of PVC windows. However, the labour and transportation charges represent additional costs [37]. The simulation result shows that introducing double-glazed PVC windows to a vernacular house can reduce the total heat demand by 10%.

5.5. Case 2/Step 2: Ceiling Insulation with Locally Available Sustainable Insulation Material

The use of insulation on a vernacular building has high potential to reduce the heat demand. However, because of the remote location of high-altitude rural settlements, access to modern insulation materials is difficult. For example, industrially produced insulation materials such as extruded polystyrene foam, Styrofoam, or mineral wool are generally available only in the capital and urban areas [20,37]. Local suppliers in urban areas charge additional fees to transport the insulation materials to remote locations, which makes such insulation materials even more costly for rural dwellers. Despite the unavailability of industrially manufactured insulation products, since most rural populations engage in agricultural activities [38], they have access to several agricultural by-products that are widely available locally, and that may make effective insulation materials. Mehta et al. [20]

identified the impact of such materials on the domestic space heating demand. The common agricultural materials that can be used for insulation in Kyrgyzstan are straw-bale, reed, and sheep wool. Hence, this case simulates the ceiling insulation with natural insulation materials. Figure 20 presents the simulation results of sustainable ceiling insulation. The simulation results identified that ceiling insulation with any locally available (and affordable) insulation materials has the potential to reduce the heat demand by between 10 and 20% of the base case (typical rural Kyrgyz house).

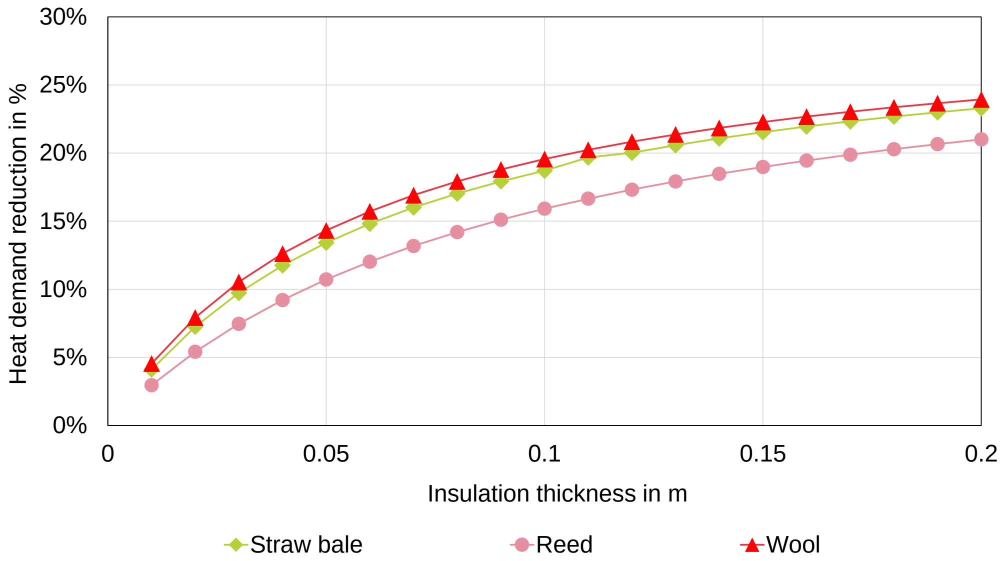


Figure 20. Ceiling insulation with locally available insulation materials with varying thicknesses of the insulation layer to present the potential of natural insulation materials in rural Kyrgyzstan.

5.6. Case 3/Step 3: Open Roof Closing

The use of an open-gable roof exposes the uninsulated wooden-beam ceiling to the cold wind and sub-zero temperatures, which induce high heat losses through the ceiling. After ceiling insulation, closing the open gable roof from both sides has a significant benefit in reducing heat demand. It was observed during the on-site visit that if and when rural Kyrgyz people can afford to close an open gable, they generally do so with metal sheets. To estimate the heat demand reduction of installing a roof closer (case 3), the base model was modified by introducing a sheet-metal closer on both open gables. The simulation results revealed that closing the open roof leads to a 20 to 25% reduction in the total heat demand of earthen houses.

5.7. Case 4/Step 4: Wall Insulation with Locally Available Sustainable Insulation Material

Similar to the ceiling, the base case was simulated with wall insulation with locally available sustainable insulation materials. Figure 21 displays the results for sustainable wall insulation.

The results showcase that sustainable wall insulation can reduce heat demand by between 15 and 20% of the base case. However, wall insulation is recommended as the last step in the energy efficiency hierarchy in the presented article. Compared to ceiling insulation, wall insulation needs a special structure to insulate the walls; also, labour might be costly compared to ceiling insulation, as it needs to cover more area for the insulation. At a certain interval, rural people apply new plaster to enhance the aesthetic of the façade. It seems reasonable to carry out the wall insulation during this renovation of the façade. Figure 22 summarizes the comprehended results of all the cases.

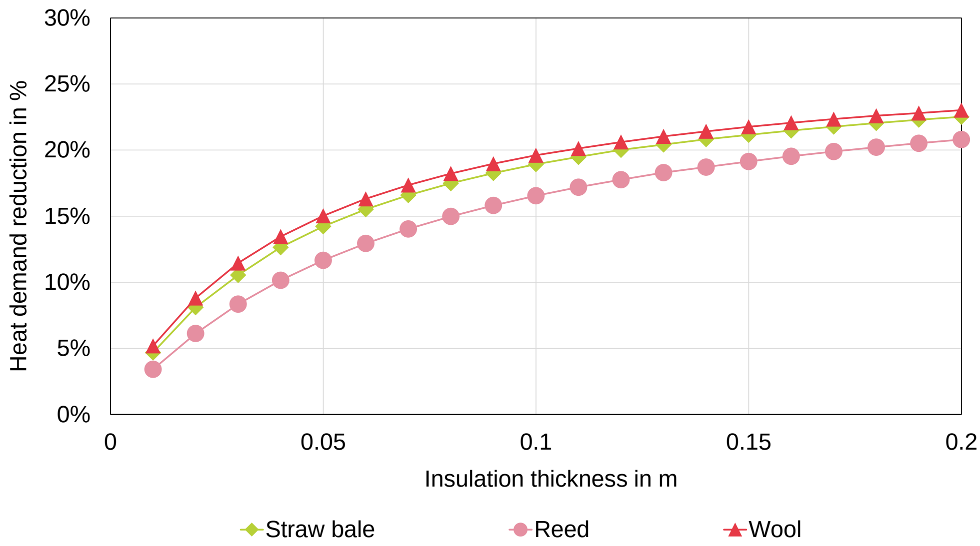


Figure 21. Wall insulation with locally available insulation materials with varying thicknesses of the insulation layer presents the potential of natural insulation materials in rural Kyrgyzstan.

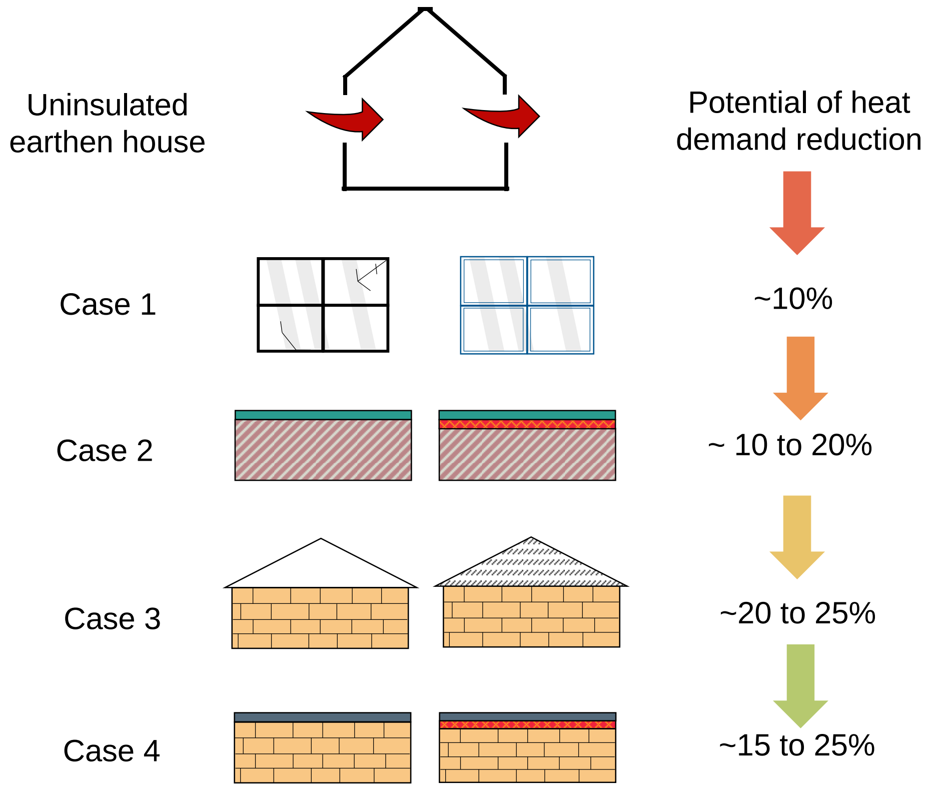


Figure 22. Recommended sequential energy efficiency parameters to reduce annual domestic space heating demand of vernacular Kyrgyz house.

Novel information presented in this article about a sequential suggestion for energy efficiency will help rural people to make building energy efficiency more effective. Also, recommended step-by-step thermal modifications will allow local people to invest stagewise into energy efficiency. The presented solution is viable in the local context and transferable to other regions/areas of Central Asia.

6. Conclusions

The key objective of the research described in this paper was to investigate the building construction techniques in rural Kyrgyzstan, especially for high-altitude remote settlements. To address the knowledge gap, the information presented in the paper was gained from a site visit and interviews with local people. Because of widespread availability and cost factors, earthen houses are standard practice in rural Kyrgyzstan. However, this vernacular architecture performs poorly from an energy perspective in the long and harsh winters there. Inappropriate building designs with inadequate insulation lead to a high domestic space heating demand. To meet this demand, the rural population burns solid fuels in traditional heating stoves. The paper proposes a suitable solution to reduce the residential heat demand sequentially by improving the building envelope.

It can be noted that the data used in the modelling were collected from a visual inspection of the buildings and interviews with local people. To enhance the initial research results, future work is necessary:

1. Experimental analysis of the building structure is highly advisable. Because most of the houses were built 40–50 years ago, it is difficult to gain accurate information about building structures (for example, the thickness and composition of the individual layers and materials of the building envelope).
2. Because of the use of traditional heating devices, there are no detailed data available on heating setpoints or heating demand profiles. The household initializes the heating process when they feel cold inside the house. In that case, it is necessary to measure the inside air temperature for a more extended period to identify the level of thermal comfort and the heating setpoint, both of which have a significant impact on the simulation results.
3. The energy efficiency only considers the existing houses right now. During the interview, it was identified that ground insulation is expensive, as it needs additional labour to carry out the ground insulation work. Therefore, the article only focuses on the building energy efficiency of the existing rural houses.

Nevertheless, the proposed roadmap was developed by considering local conditions such as low incomes, cold climate, current building structure, locally available construction resources, and geographical location. Hence, the proposed research has high potential for adoption by low-income rural Kyrgyz habitations to reduce the residential heat load sequentially to overcome financial barriers and, therefore, contribute to establishing sustainable buildings in rural Kyrgyzstan. Also, these results are partially transferable to other Central Asian rural communities based on the location and building characteristics.

Author Contributions: Conceptualization, K.M., W.Z. and R.G.; methodology, K.M.; software, K.M.; validation, K.M.; investigation, K.M.; writing—original draft preparation, K.M.; writing—review and editing, K.M., W.Z. and R.G.; supervision, W.Z. and R.G.; project administration, K.M. All authors have read and agreed to the published version of the manuscript.

Funding: The work presented in this paper was funded by the Federal Ministry of Education and Research (BMBF) of the Federal Republic of Germany within the CLIENT II funding programme International Partnerships for Sustainable Innovations under the project "ÖkoFlussPlan" (Project ID 01LZ1802A-F). The overall aim of ÖkoFlussPlan is to preserve the alluvial forests along the Naryn River and to implement sustainable energy solutions for the local population.

Acknowledgments: We acknowledge support by the Open Access Publication Fund of Technische Hochschule Ingolstadt, Germany.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. USAID. *Climate Risk Profile: Central Asia: Fact Sheet*; USAID: Washington, DC, USA, 2018.
2. Batsaikhan, U.; Dabrowski, M. Central Asia—Twenty-five years after the breakup of the USSR. *Russ. J. Econ.* **2017**, *3*, 296–320. [CrossRef]

3. Russell, M. Connectivity in Central Asia: Reconnecting the Silk Road. Available online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2019/637891/EPRS_BRI(2019)637891_EN.pdf (accessed on 5 April 2020).
4. Mehta, K.; Ehrenwirth, M.; Trinkl, C.; Zörner, W.; Greenough, R. The Energy Situation in Central Asia: A Comprehensive Energy Review Focusing on Rural Areas. *Energies* **2021**, *14*, 2805. [CrossRef]
5. Swiss Development Cooperation. *Sustainable Mountain Development. From Rio 1992 to 2012 and beyond. Central Asia Mountains: Regional Report*; University of Central Asia and Zoï Environment Network: Bishkek, Kyrgyzstan, 2012.
6. Fodde, E. Traditional Earthen Building Techniques in Central Asia. *Int. J. Archit. Herit.* **2009**, *3*, 145–168. [CrossRef]
7. Giyasov, A.; Barotov, U.; Naimov, F. Clay buildings in modern energy efficient construction. *E3S Web Conf.* **2019**, *91*, 2023. [CrossRef]
8. Satybayev, A.; Volordina, T.; Azhimatov, K.; Kalykov, A. Construction energy saving materials and their modern technology of work: In Russian. *ИЗВЕСТИЯ ОШСКОГО ТЕХНОЛОГИЧЕСКОГО УНИВЕРСИТЕТА* **2017**, *3*, 104–112.
9. Botpaev, R.; Orozaliev, J.; Vajen, K. Economically optimal level of thermal insulation for single-family houses in Kyrgyzstan. In *EuroSun2012*; International Solar Energy Society: Rijeka, Croatia, 2012.
10. Lorenzon, M.; Sadozai, C. From past to present: Building skill transfer in Tajikistan 2016. In Proceedings of the Terra Lyon 2016: Actes/Proceedings/Actos, Lyon, France, 10–14 July 2016.
11. Muslimovich, A.S.; Ulugbek Arabdjon Ogli, A.; Raufjonovna, T.D. Fergana Valley Architectural School Decoration Methods. *Am. J. Appl. Sci.* **2020**, *2*, 21–25. [CrossRef]
12. Osmonov, O.D.; Turdalieva, C. *A History of Kyrgyzstan: From Stone Age to the Present: School and University Textbook*; Sarybaev TT: Bishkek, Kyrgyzstan, 2015; ISBN 978-9967-04-680-1.
13. Guillaud, H. An approach to the evolution of earthen building cultures in Orient and Mediterranean regions What future for such an exceptional legacy? *Al-Rāfidān J. West. Asiat. Stud.* **2003**. Available online: https://hal.archives-ouvertes.fr/hal-01663127 (accessed on 20 November 2022).
14. Tukhtamisheva, A.; Adilova, D.; Banionis, K.; Levinskytė, A.; Bliūdžius, R. Optimization of the Thermal Insulation Level of Residential Buildings in the Almaty Region of Kazakhstan. *Energies* **2020**, *13*, 4692. [CrossRef]
15. Azizova, B. Architectural Longevity-in the Case of the Summer Palace Chandra-Hauly in Khiva City, Uzbekistan. *MOJCE* **2017**, 2. [CrossRef]
16. IEA. Total Final Energy Consumption by Sectors in Central Asia. Available online: https://www.iea.org/data-and-statistics?country=TAJIKISTAN&fuel=Energy%20consumption&indicator=Total%20final%20consumption%20(TFC)%20by%20sector (accessed on 5 April 2020).
17. Mehta, K.; Ehrenwirth, M.; Trinkl, C.; Zörner, W. Mapping Potential for Improving Rural Energy Services in Kyrgyzstan: Factors for Achieving Sustainable Development Goals in the Community Context. *World* **2022**, *3*, 586–606. [CrossRef]
18. Bergström, S.; Johannessen, F. *Sustainable Housing in Kyrgyzstan. Investigation of Two Multi-Apartment Buildings in Bishkek*; Lund University: Lund, Sweden, 2014; Available online: http://www.ees.energy.lth.se/fileadmin/ees/Publikationer/Ex5297-Bergstrom_Johannessen.pdf (accessed on 18 February 2020).
19. UNFCC. Hird National Communication of the Kyrgyz Republic under the UN Framework Convention on Climate Change. Available online: https://unfccc.int/sites/default/files/resource/NC3_Kyrgyzstan_English_24Jan2017.pdf. (accessed on 13 April 2021).
20. Mehta, K.; Ehrenwirth, M.; Trinkl, C.; Zörner, W.; Greenough, R. 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 EuroSun 2020, Virtual, 1–3 September 2020.
21. Mehta, K. Rural Energy Supply: A Case Study of Kyrgyzstan. Master's Thesis, Technische Hochschule Ingolstadt, Ingolstadt, Germany, 2019.
22. Schuler, M. Migration Patterns of the Population in Kyrgyzstan. *Espace Popul. Soc.* **2007**, *1*, 73–89. [CrossRef]
23. United Nations. Country Profiles on the Housing Sector. Available online: https://unece.org/fileadmin/DAM/hlm/documents/Publications/cp.kyrgyzstan.e.pdf (accessed on 11 January 2021).
24. Mehta, K.; Ehrenwirth, M.; Trinkl, C.; Zörner, W. Towards Sustainable Community Development through Renewable Energies in Kyrgyzstan: A Detailed Assessment and Outlook. *World* **2022**, *3*, 327–343. [CrossRef]
25. Nguyen, A.T.; Truong, N.S.H.; Rockwood, D.; Tran Le, A.D. Studies on sustainable features of vernacular architecture in different regions across the world: A comprehensive synthesis and evaluation. *Front. Archit. Res.* **2019**, *8*, 535–548. [CrossRef]
26. Mehta, K.; Ehrenwirth, M.; Missall, S.; Degembaeva, N.; Akmatov, K.; Zörner, W. Energy Profiling of a High-Altitude Kyrgyz Community: Challenges and Motivations to Preserve Floodplain Ecosystems Based on Household Survey. *Sustainability* **2021**, *13*, 13086. [CrossRef]
27. Balabanyan, A. *Keeping Warm: Urban Heating Options in the Kyrgyz Republic-Summary Report (English)*; The World Bank Group: Washington, DC, USA, 2015; Available online: http://documents1.worldbank.org/curated/en/555021468011161504/pdf/97409-WP-P133058-Box391503B-PUBLIC-Heating-Assessment-for-Kyrgyz-P133058-Final.pdf (accessed on 12 January 2021).
28. Sagynbekova, L. Environment, Rural Livelihoods, and Labor Migration: A Case Study in Central Kyrgyzstan. *Mt. Res. Dev.* **2017**, *37*, 456. [CrossRef]

29. FAO. *National Gender Profile of Agricultural and Rural Livelihoods-Kyrgyz Republic: Country Gender Assessment Series*; Food and Agriculture Organization of the United Nations: Ankara, Turkey, 2016; Available online: http://www.fao.org/3/a-i5763e.pdf (accessed on 20 August 2020).
30. Paul, J. Analysis of Historic Rammed Earth Construction. Ph.D. Thesis, Durham University, Durham, UK, 2008.
31. Gasparrini, A.; Guo, Y.; Hashizume, M.; Lavigne, E.; Zanobetti, A.; Schwartz, J.; Tobias, A.; Tong, S.; Rocklöv, J.; Forsberg, B.; et al. Mortality risk attributable to high and low ambient temperature: A multicountry observational study. *Lancet* **2015**, *386*, 369–375. [CrossRef] [PubMed]
32. World Bank Group. *Advancing Heating Services beyond the Last Mile: Central Asia Pilot Experience with High-Efficiency, Low-Emissions Heating Technologies: ESMAP Paper*; World Bank Group: Washington, DC, USA, 2019; Available online: https://openknowledge.worldbank.org/handle/10986/31282 (accessed on 2 March 2021).
33. Zeman, J. *Improving Energy Efficiency in Buildings, Kyrgyz Republic: Final Evaluation: UNDP/GEF Medium Size Project*; United Nations Development Programme: New York, NY, USA, 2014; Available online: https://erc.undp.org/evaluation/documents/download/7695 (accessed on 19 May 2021).
34. Boronbaev, E. Energy saving Architecture: Background, Theory and Practice in Kyrgyzstan. *E3S Web Conf.* **2020**, *172*, 19010. [CrossRef]
35. USAID. *Kyrgyzstan Construction Materials Value Chain Stakeholder Analysis: Final Report*; The International Business Council: Bishkek, Kyrgyzstan, 2015.
36. NREL. *EnergyPlus*; U.S. Department of Energy: Washington, DC, USA, 2020.
37. MEI. *Microfinancing Household Insulation and Heating Measures in Kyrgyzstan: An Assessment Study by MicroEnergy International for Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH.*; GIZ: Berlin, Germany, 2013; Available online: https://eba.klink.asia/klink/ccf9ca/download (accessed on 25 January 2019).
38. Mehta, K.; Mingaleva, E.; Zörner, W.; Degembaeva, N.; Baibagyshov, E. Comprehensive analysis of the energy legislative framework of Kyrgyzstan: Investigation to develop a roadmap of Kyrgyz renewable energy sector Clean. *Energy Syst.* **2022**, *2*, 10013. [CrossRef]