The present work was submitted to the Faculty of Engineering

Production Process Design of The Air-packed Insulator which is made of recycled plastic

Bachelor Thesis

by

Batbayar Altanbagana

Supervisor 1 / Examiner 1	**Ph. D., P.E. Sungchil Lee**
Supervisor 2 / Examiner 2	**Ph. D., Norovrinchen Odbileg**

Ulaanbatar/Nalaikh, 2023.05.16

Statutory Declaration

Altanbagana, Batbayar	15348219103343
Last Name, First Name	Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

Production Process Design of The Air-packed Insulator which is made of recycled plastic

I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, Mongolia 2023.05.16	
Place, Date	Signature

Abstract

This thesis explores the creation of an innovative, eco-friendly, and energy-efficient insulation approach for traditional Mongolian Gers, utilizing recycled plastic as the main component for air-packed insulators. Given the distinct insulation challenges associated with Mongol Gers, including energy use and environmental repercussions, the research seeks to address these concerns by examining the feasibility of recycled plastic materials in developing air-packed insulators that can bolster the thermal efficiency of Gers, diminish heating expenses, and support environmental sustainability.

The investigation concentrated on refining design parameters, manufacturing methodologies, and conducting a theoretical evaluation of the air-packed insulator's performance. The proposed insulator demonstrated effective insulation capabilities, ease of installation, storage, and transportation, making it a pragmatic and cost-efficient solution for Gers. The insulator's compatibility with the unique curved lattice wall structure of Gers ensures proper insulation and a tailored fit for different Ger sizes.

Employing recycled plastic encourages environmental sustainability by repurposing plastic waste and decreasing the need for new materials. The production process showcased a dedication to sustainable and environmentally conscious practices. The study assessed potential energy conservation, cost reduction, and environmental advantages, emphasizing the substantial potential of the air-packed insulator as a suitable insulation solution for traditional Mongol Gers.

Future research avenues include further optimization of design parameters, experimental validation, life cycle analysis, and the incorporation of renewable energy sources. This thesis contributes to the advancement of a sustainable and energy-efficient insulation strategy that can enhance living conditions for Mongol Ger residents while reducing environmental consequences.

Acknowledgements

I would like to begin by expressing my heartfelt gratitude to all the professors and staff members at the German-Mongolian Institute for Resources and Technology for their unwavering support and encouragement throughout my academic journey. Their dedication to fostering an inspiring and nurturing environment has been instrumental in my personal and professional growth, and I am truly grateful for their guidance and mentorship.

Special appreciation goes to my supervisor, Ph.D., P.E. Sungchil Lee, whose invaluable expertise, continuous assistance, and constructive feedback have shaped the direction of this research. His unique perspective and understanding of the challenges faced by traditional Mongolian Gers have significantly enriched this study and contributed to its depth and quality. Moreover, I am also deeply grateful to my supervisor, Ph.D. Norovrinchen Odbileg, for his willingness to be a part of my academic journey. Though his direct contributions to the project were limited, his involvement as a supervisor is acknowledged and appreciated.

I would like to extend my heartfelt thanks to my fellow students for their camaraderie and collaboration, which have made this experience both enjoyable and fulfilling. Their enthusiasm, knowledge, and friendship have been invaluable in my research journey.

Finally, I wish to acknowledge the countless individuals, communities, and organizations in Mongolia whose lives and experiences have inspired this research. It is my sincere hope that the findings of this study will contribute to the improvement of their living conditions and pave the way for a more sustainable and energy-efficient future for Mongolian Gers.

Table of Contents

List of Figures

List of abbreviations

VOC	Volatile Organic Compound
PET	Polyethylene Terephthalate
HDPE	High-Density Polyethylene
LDPE	Low-Density Polyethylene
PP	Polypropylene
PVC	Polyvinyl Chloride
PS	Polystyrene
PUR	Polyurethane
EPS	Expanded Polystyrene

1 Introduction

1.1 Mongol Gers and insulation challenges

Mongol Gers, also known as yurts, are traditional portable dwellings that have been used by nomadic populations in Mongolia and other Central Asian regions for centuries. These structures are characterized by their unique design, consisting of a circular lattice wall, a conical roof, and a central opening for ventilation. The Ger's adaptability and portability have made it a staple of nomadic life, allowing it to withstand rough weather conditions and diverse environments.

However, one of the significant challenges facing traditional Mongol Gers is their lack of effective insulation due to the use of traditional materials such as wool felt and animal hides, which are not as thermally efficient as modern insulation materials. This issue is particularly problematic in Ulaanbaatar, the capital city of Mongolia, where 58% of households are located in unplanned residential areas known as ger districts.

Figure 1. Ger district

These districts primarily consist of yurts, which have low insulation and rely on rudimentary coal stoves for heating. During winters, households tend to increase their usage of coal stoves due to the harsh Mongolian climate and lack of insulation, resulting in a significant rise in air pollution. In fact, studies suggest that around 80% of the air pollution in Ulaanbaatar can be attributed to the emissions from these coal stoves.

The lack of insulation not only makes it difficult to maintain a comfortable temperature inside the Ger, but it also leads to substantial energy consumption, higher costs, and an increased reliance on nonrenewable energy sources. Moreover, the lack of insulation contributes to greenhouse gas emissions and other negative environmental impacts, making it crucial to find a sustainable and efficient insulation solution for Mongol Gers.

1.2 Research Objectives

The primary objective of this research is to develop an innovative insulation solution for traditional Mongol Gers using recycled plastic as the main material for air-packed insulators. This study aims to explore the potential of this sustainable, cost-effective, and energy-efficient insulation approach, while addressing the specific needs of Ger inhabitants and promoting eco-friendly practices.

To achieve this objective, the research will focus on the following questions:

1. How can recycled plastic materials be effectively repurposed to create air-packed insulators for traditional Mongol Gers?
2. What are the optimal design parameters for air-packed insulators made from recycled plastic to ensure adequate thermal performance in the unique environment of Gers?
3. How can the manufacturing process be optimized for the production of recycled plastic air-packed insulators, considering cost-effectiveness, energy efficiency, and minimal environmental impact?
4. What are the potential energy savings, cost reductions, and environmental benefits of using recycled plastic air-packed insulators as an insulation solution for traditional Mongol Gers?

By addressing these research questions, this study aims to contribute to the development of a sustainable and energy-efficient insulation solution that can improve the living conditions for Mongol Ger inhabitants while minimizing environmental impacts.

1.3 Sustainable and energy-efficient solutions

The development of a sustainable and energy-efficient insulation solution for traditional Mongol Gers addresses several pressing concerns. First, it can significantly reduce energy consumption in these homes, decreasing energy costs and reducing the reliance on nonrenewable energy sources. Second, by improving insulation, we can enhance the quality of life for those living in Mongol Gers, particularly during extreme weather conditions. Finally, sustainable insulation solutions can minimize the environmental impact, promoting eco-friendly practices and reducing greenhouse gas emissions.

As the global community moves towards more sustainable and environmentally-conscious practices, it is crucial to develop solutions that not only address the immediate needs of Mongol Ger inhabitants but also align with broader sustainability goals.

1.4 Potential of recycled plastic air-packed insulators

One potential solution to address the insulation challenges of traditional Mongol Gers is the use of recycled plastic as the primary material for air-packed insulators. Plastic materials are poor conductors of heat due to their tightly bound electrons, which cannot move freely to transfer heat energy. As well, recycled plastic is an eco-friendly and cost-effective material that can be repurposed to create insulators for Gers. Air-packed insulators made from recycled plastic can be produced in various sizes and shapes, allowing them to fit between the layers of felt in Gers, providing additional insulation that can keep the interior warm during the winter. Furthermore, these insulators can be characterized by their ease of transportation, storage, and installation, making them a pragmatic and economically viable solution for enhancing the insulation performance of Gers.

The use of recycled plastic for insulation in traditional Mongolian homes promotes sustainability by reducing landfill accumulation and decreasing the demand for new plastics. This approach can contribute to the overall energy efficiency of Gers while also addressing the challenge of plastic waste management. By using recycled plastic as an insulation material, traditional Mongolian homes can become more energy-efficient, which is crucial in a region where temperatures can reach extremes. Overall, the use of recycled plastic as an insulation material offers a cost-effective, environmentally-friendly solution to the insulation challenges of traditional Mongolian Gers.

2 Literature Review

Mongol Gers are traditional Mongolian dwellings that are circular, made of wood and wool felt, and are classified based on the number of lattice walls they have. They are typically 22-36 square meters in size and have no space for toilets, which are located outside. The design of Gers is standardized, which allows people to purchase individual components from different stores and manufacturers based on their personal preferences and financial situation. It is like piecing together a puzzle, and people can choose parts that align with their specific requirements and financial means.

However, the insulation of the ger envelope needs improvement to comply with specified designs and stay up with modern trends in product manufacture and purchasing. This will make prices more reasonable and increase market accessibility.

2.1 Traditional Mongol ger construction and insulation

Constructing and taking apart a traditional Mongol Ger must be done in a specific order. First, the floor is put down, then the door is set up and the lattice walls are rounded. Next, the inner straps are tightened, and two poles are erected in the center to hang the roof poles before placing the circular frame of a skylight. The wool felt insulation is covered with an inner sheet and the roof is put on top. Afterward, the outer cover is placed and secured with straps. Finally, Khayavch is pulled to regulate the temperature

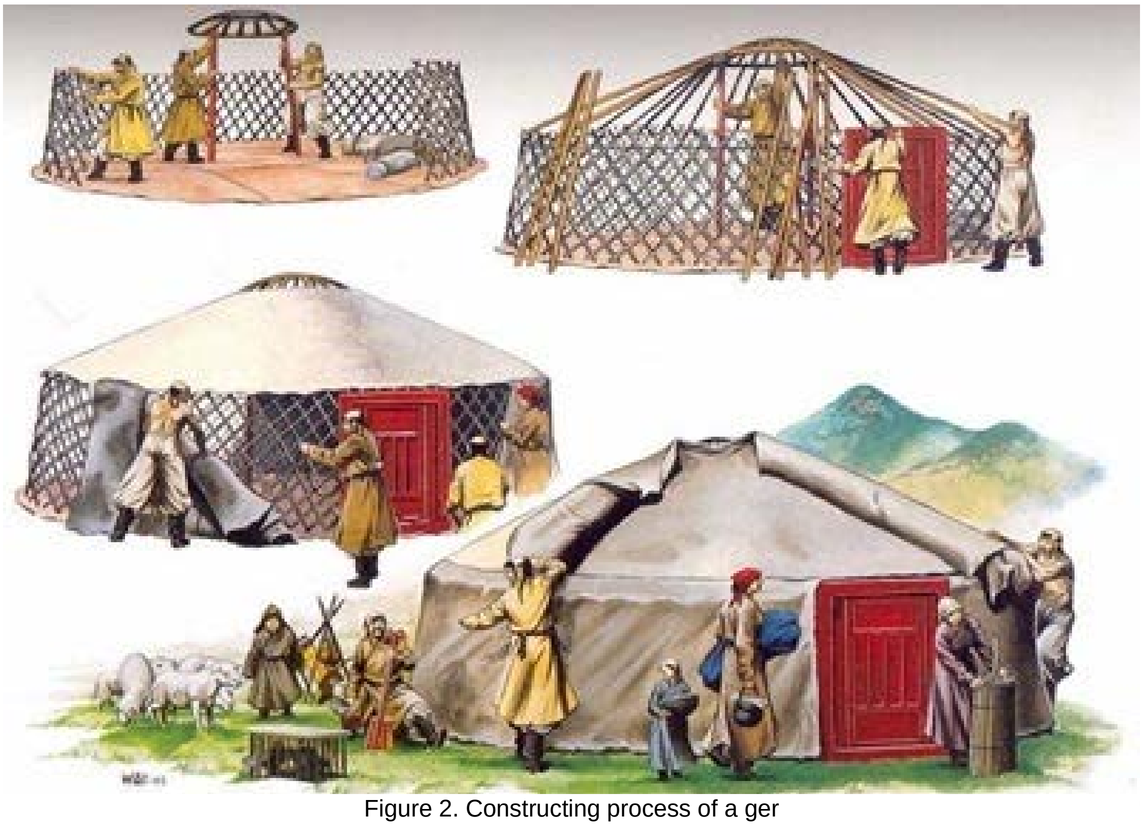


Figure 2. Constructing process of a ger

and the ger is strapped to reinforce its structure. With two to four people, the ger can be built and dismantled within a few hours. Dismantling is the same process but done in reverse order.

Traditional Mongol Gers have relied on locally available and renewable materials for their insulation, primarily utilizing felt and animal hides. Understanding the characteristics of these traditional materials is essential to appreciate the insulation challenges faced by Mongol Gers and explore the potential of alternative insulation solutions like recycled plastic air-packed insulators.

Felt, the most common insulation material in Gers, is made from densely matted animal fibers, typically sheep's wool or yak hair. The fibers are felted through a combination of moisture, heat, and pressure to create a versatile, durable, and relatively lightweight material. Felt is applied to the exterior of the Ger in multiple layers, depending on the season and climate. While felt has proven to be an effective insulator for centuries, it possesses certain limitations that affect the overall thermal performance and efficiency of the Ger.

One of the main drawbacks of felt as an insulation material is its relatively low thermal resistance compared to modern insulation materials. This is due in part to its fibrous structure, which allows for some air infiltration and heat transfer. Additionally, felt is susceptible to moisture absorption, which can negatively impact its insulating capabilities, as wet fibers have lower thermal resistance than dry ones. This problem is exacerbated in regions with high humidity or frequent precipitation.

Animal hides, another traditional insulation material, are typically used in conjunction with felt, either as a secondary insulating layer or as an outer covering to protect the felt from environmental elements. The primary advantage of animal hides is their natural water resistance, which helps protect the Ger from rain, snow, and moisture. However, similar to felt, animal hides offer relatively low thermal resistance when compared to modern insulating materials. The thermal performance of a traditionally insulated Mongolian Ger in Ulaanbaatar can be observed in the accompanying figure 3. This data was captured as part of a project conducted by GerHub, a mission-driven organization committed to addressing urgent challenges in Mongolia's ger districts. GerHub seeks innovative and creative solutions to improve living conditions and sustainability within these regions.

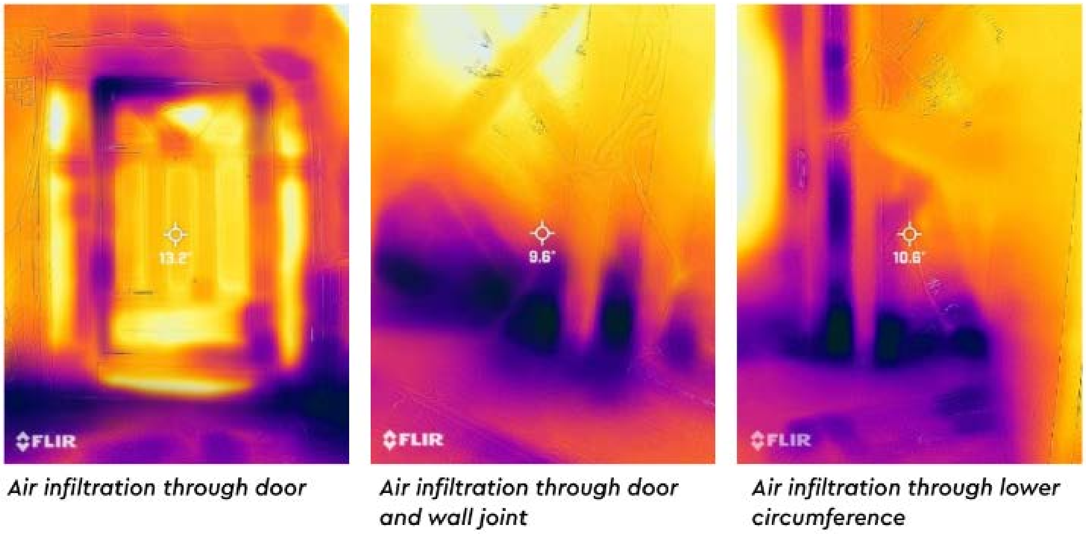


Figure 3. Air infiltration with a thermal imaging camera

Also, the figure illustrates that it has some moderate air infiltration through the lower circumference and the door and wall joints.

This household of Ulaanbaatar's insulation condition and questionnaire:

Number of felt roofing	1 layer
Number of felt wall	2 layers
Other insulation covers	Water-proof cover, plastic cover
Presence of hard flooring	None
Use of sand and gravel to bed the flooring	None
Material current interior flooring	Single layer of plastic cover
Toono cover material	Felt
Presence of other additional Toono insulation	Plastic cover
Presence of door insulation	None

The traditional materials used in Mongol Gers provide a baseline understanding of the insulation challenges that these dwellings face. By comparing the thermal resistance, moisture resistance, and other characteristics of these materials to those of recycled plastic air-packed insulators, we can better gauge the potential benefits of introducing an alternative insulation solution for traditional Mongol Gers. Developing an innovative and sustainable insulation option with superior thermal performance could address the energy efficiency concerns and contribute to improved living conditions for the inhabitants of these traditional homes.

2.2 Energy efficiency and environmental concerns

Addressing the energy efficiency and environmental concerns associated with the insulation of traditional Mongol Gers is crucial for ensuring the well-being of their inhabitants and promoting sustainable living practices. This section discusses the impact of insufficient insulation on energy consumption, greenhouse gas emissions, and other environmental factors, highlighting the importance of developing an efficient and sustainable alternative insulation solution.

Insufficient insulation in Mongol Gers contributes to higher energy consumption for heating purposes. Due to the lower thermal resistance of traditional insulation materials such as felt and animal hides, more energy is required to maintain a comfortable temperature within the Ger. In cold climates, residents often rely on traditional heating methods, such as coal or wood-burning stoves, to keep their dwellings warm. The reliance on these energy-intensive methods leads to increased energy costs and places a financial burden on the inhabitants.

Moreover, the use of fossil fuels for heating generates greenhouse gas emissions, contributing to climate change and air pollution. The burning of coal and wood also releases particulate matter, VOCs, and other harmful substances that can negatively impact indoor air quality, posing health risks to the residents. This issue is exacerbated by the poor ventilation in Gers with insufficient insulation, as the dwellings are often sealed tightly to minimize heat loss.

From an environmental standpoint, the production and disposal of traditional insulation materials also have consequences. While felt production is a renewable process, it requires considerable water, energy, and labor inputs. Furthermore, felt and animal hides can degrade over time, necessitating replacement and disposal. While these materials are biodegradable, their decomposition releases greenhouse gasses such as methane, contributing to climate change.

Given the energy efficiency and environmental concerns associated with traditional Mongol Gers, there is a growing need to explore alternative insulation solutions. By developing an efficient and sustainable insulation solution such as recycled plastic air-packed insulators, we can address the energy consumption and environmental impact concerns, improve living conditions, and promote more sustainable practices in traditional Mongolian homes. This approach can also help combat climate change, reduce air pollution, and alleviate the financial burden on Ger inhabitants.

2.3 Previous research on recycled plastic insulators

Over the years, researchers have explored various materials and techniques to improve insulation in the construction sector. One such area of interest is the utilization of recycled plastic waste as a sustainable and efficient insulation material. This section reviews the existing literature on recycled plastic insulators, focusing on their potential applications, benefits, and limitations.

Recycled plastic waste, particularly PET from plastic bottles, has been studied as a promising insulation material due to its favorable properties. PET is known for its low thermal conductivity, which enables it to minimize heat transfer, making it a suitable candidate for insulation applications. Moreover, PET exhibits good moisture resistance and can be easily processed into different forms, such as fibers or foams, to achieve desired insulating properties.

In addition to PET, other types of recycled plastic materials have been investigated for their insulation potential. For instance, EPS and PU foams made from recycled plastics have been studied for their thermal performance and environmental impact. These materials exhibit low thermal conductivity and good moisture resistance, making them suitable candidates for insulation applications in various settings.

Recent studies have also explored the use of recycled HDPE and LDPE for insulation purposes. These plastics can be processed into films, sheets, or foams, which can be used as insulation materials in building envelopes, roofs, and walls. Recycled HDPE and LDPE insulators have demonstrated promising thermal performance, with the potential to reduce energy consumption and improve the overall sustainability of buildings.

In recent studies, researchers have developed various types of recycled plastic insulators, such as PET-based aerogels, fibers, foams, EPS, PUR, HDPE, and LDPE insulators. These studies have demonstrated the potential of recycled plastic insulation materials to achieve thermal conductivity values comparable to or lower than those of conventional insulation materials, such as mineral wool or fiberglass. The versatility and adaptability of recycled plastic materials make them a promising option for a wide range of insulation applications, including residential, commercial, and industrial buildings.

In the context of Mongol Gers, research on the use of recycled plastic insulators is relatively limited. However, given the success of recycled plastic insulators in other applications, there is potential for adapting these materials to meet the unique requirements of traditional Mongolian homes. For instance, developing air-packed insulators using recycled plastics, such as PET, EPS, PUR, HDPE, or LDPE, could provide a lightweight, moisture-resistant, and thermally efficient solution that can be easily integrated into the existing structure of a Ger.

One of the main challenges in implementing recycled plastic insulators is the potential environmental impact associated with the production and disposal of plastic waste. While using recycled plastics addresses the waste issue to some extent, it is crucial to ensure that the insulation materials are produced through environmentally friendly processes and that they can be recycled or disposed of in a sustainable manner at the end of their lifecycle. Additionally, research into the development of biodegradable or bio-based plastic insulators could further contribute to the sustainability of this insulation solution.

2.4 Materials Selection and Properties

In this section, we will explore the various types of recycled plastics suitable for creating an air-packed insulator for traditional Mongol Gers. We will examine their properties, recycling processes, and potential benefits to determine the most suitable material for the insulator design.

2.4.1 Types of recycled plastics

Materials that are poor conductors of heat can be used as insulators, as the primary function of an insulator is to reduce the transfer of heat. As mentioned above, plastics are poor conductors of heat and can therefore be used as effective insulators. The development of an effective air-packed insulator for traditional Mongol Gers requires careful consideration of the type of recycled plastic to be used. The choice of plastic material will significantly impact the insulator's performance, sustainability, and production feasibility. Various types of recycled plastics, such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene

Figure 4. Types of recycled plastic

(LDPE), and polypropylene (PP), have different properties that can affect the insulator's thermal performance, mechanical strength, and environmental compatibility.

2.4.1.1 Polyethylene Terephthalate (PET)

The thermoplastic polymer resin known as PET is a flexible, robust, light-weight, and recyclable member of the polyester family. It is one of the most widely used plastics, primarily in the packaging industry for products like water bottles and food containers. Its versatility is attributed to its favorable properties, such as strength, lightweight nature, and recyclability.

Recyclability: PET is unique among plastics due to its ability to be recycled multiple times without losing its core properties. It is often repurposed into fashion items like clothing, backpacks, and carpets, or recycled back into PET bottles. This feature makes PET an eco-friendly and sustainable material.

Physical Properties: PET is flexible, colorless, and semi-crystalline in its natural state. Its processing methods can yield materials with varying degrees of rigidity. PET exhibits good dimensional stability, impact resistance, and moisture resistance, making it suitable for a range of applications.

Chemical Properties: PET demonstrates excellent resistance to alcohols, aliphatic hydrocarbons, oils, grease, and diluted acids. It has moderate resistance to diluted alkalis and aromatic and halogenated hydrocarbons. These chemical properties contribute to PET's broad range of applications in different industries.

PET has been the subject of numerous studies as an insulation material due to its low thermal conductivity, good moisture resistance, and ease of processing. Recycled PET fibers can be spun into mats or made into foam boards, which can provide the desired insulation properties.

2.4.1.2 High-Density Polyethylene (HDPE)

HDPE is a versatile thermoplastic polymer derived from petroleum. It is another common plastic known for its strength, durability, and high-impact resistance. HDPE finds extensive use in a wide range of applications, including plastic bottles such as milk jugs and detergent bottles, as well as in grocery bags, cutting boards, and piping. It is highly recyclable and accepted at most recycling centers worldwide. Recycled HDPE is used in various products, including non-food application bottles, film packaging, pipes, lawn products, and more. Furthermore, HDPE can be downcycled into plastic lumber, tables, roadside curbs, benches, and other durable plastic items. The versatility, strength, and recyclability of HDPE make it a popular choice in numerous industries, providing sustainable solutions for various applications. Although HDPE has higher thermal conductivity compared to PET, its excellent moisture resistance and mechanical properties make it a potential candidate for insulation applications.

2.4.1.3 Low-Density Polyethylene (LDPE)

LDPE, sometimes referred to as plastic-type #4, is widely used to produce plastic bags seen in supermarkets and various retail outlets. LDPE is a pliable, lightweight, and soft plastic material recognized for its adaptability to low temperatures, durability, and resistance to corrosion. It is more flexible and has a lower density than HDPE, making it a popular choice for plastic films and bags.

While LDPE can be recycled in theory, the practical recycling process may be difficult and not always economically feasible. LDPE plastic bags are prone to entangling in recycling equipment, jeopardizing the entire recycling operation. Moreover, LDPE is a low-grade, cheap plastic, rendering its recycling less economically appealing. Consequently, numerous municipalities do not permit #4 plastic in their curbside recycling containers.

Despite these obstacles, LDPE can be repurposed into items like bin liners and packaging films when successfully recycled. Furthermore, LDPE is frequently employed in orthotics and prosthetics manufacturing due to its excellent chemical and impact resistance, as well as its ease of fabrication and shaping.

LDPE's flexibility and moisture resistance can be advantageous in insulation applications where conformability is crucial. However, its higher thermal conductivity compared to PET may limit its insulator performance.

2.4.1.4 Polypropylene (PP)

PP is a multifaceted and adaptable plastic used in various applications such as automotive components, textiles, and food packaging. Its relatively low thermal conductivity and good moisture resistance make it a potential candidate for insulation applications. However, compared to PET or HDPE, processing recycled PP into insulating materials may pose more challenges.

PP belongs to the polyolefin family and is marginally tougher than polyethylene. As a low-density and heat-resistant plastic, it is commonly used in diverse applications. Depending on the production and formulation methods, PP can exhibit attributes like hardness, opacity, weight, insulating properties, conductivity, and reinforcement with various fillers or fibers. Key properties and advantages of polypropylene include:

- Melting Point: The melting points of homopolymers (160-165°C) and copolymers (135-159°C) differ.
- Density: Among all commodity plastics, PP is one of the lightest, making it suitable for applications that require reduced weight.
- Chemical Resistance: PP demonstrates excellent resistance to various acids, alcohols, and bases; good resistance to aldehydes, esters, aliphatic hydrocarbons, and ketones; but limited resistance to aromatic and halogenated hydrocarbons and oxidizing agents.
- Flammability: PP is highly flammable.
- Mechanical and Electrical Properties: PP maintains these properties under high temperatures, humidity, and when submerged in water, making it a water-resistant plastic.
- Resistance to Environmental Stress Cracking: PP exhibits good resistance in this aspect.
- Susceptibility to Microbial Attacks: PP is vulnerable to bacteria and mold.
- Steam Sterilization: PP displays good resistance to this process.

In general, polypropylene is a highly versatile plastic material with customizable properties and applications that cater to specific requirements. Although it has potential for insulation applications, processing recycled PP into such materials may be more challenging compared to PET or HDPE.

2.4.1.5 Other Recycled Plastics

In addition to the above-mentioned materials, other types of recycled plastics may also be suitable for insulation applications, such as PVC, PS, or PUR. However, their properties, recycling processes, and environmental impacts must be carefully assessed before selecting them as potential materials for air-packed insulators.

2.4.2 Mechanical, thermal, and chemical properties

To determine the most appropriate recycled plastic for air-packed insulators in Mongol Gers, it is essential to examine the mechanical, thermal, and chemical properties of different materials.

2.4.2.1 Mechanical Properties

Mechanical properties such as tensile strength, compressive strength, and elongation at break are crucial in determining the ability of a material to withstand the loads and stresses that it may encounter during installation and use.

- PE: LDPE has lower tensile and compressive strength compared to HDPE. However, LDPE offers greater flexibility, making it suitable for flexible insulating applications, while HDPE is more suitable for rigid insulation applications.
- PP: PP has good tensile and compressive strength, as well as resistance to deformation under load, making it an attractive option for insulation materials.
- PET: PET has high tensile and compressive strength and can be processed into fibers or rigid boards that exhibit good mechanical stability for insulation applications.

2.4.2.2 Thermal Properties

Thermal properties, such as thermal conductivity, specific heat capacity, and thermal expansion, are crucial for assessing the insulating performance of a material.

- PE, PP, and PET: These materials generally exhibit low thermal conductivity, making them effective insulators. However, their specific heat capacity and thermal expansion coefficients may vary, affecting their overall performance and compatibility with the Mongol Ger's environmental conditions.
- EPS: EPS has very low thermal conductivity due to its closed-cell structure, which traps air and minimizes heat transfer. It is an excellent insulator but may not be the most environmentally friendly option.

2.4.2.3 Chemical Properties

Chemical properties, such as resistance to moisture, UV radiation, and chemical degradation, play a vital role in the durability and performance of insulation materials in various environmental conditions.

- PE, PP, and PET: These materials exhibit good resistance to moisture, chemicals, and UV radiation, making them suitable for insulation applications in environments with variable temperature, humidity, and solar exposure.

2.5 Material Compatibility with Mongol Gers and their Environmental Conditions

Mongolia, situated in East and Central Asia, is marked by a diverse landscape consisting of deserts, mountains, forests, and steppes. Its continental climate leads to long, cold winters and short, warm summers, with substantial temperature variations. January sees average low temperatures around -25°C (-13°F), while July has average high temperatures around 25°C (77°F). Our country often experiences harsh weather conditions, including strong winds, snowstorms, and dust storms. Thus, Mongol Gers are exposed to a wide range of environmental conditions, such as extreme temperature fluctuations, high winds, and varying levels of humidity. The insulation material must be compatible with the traditional Mongol Ger's construction and be able to withstand the harsh environmental conditions. Figure 5 delineates four distinct areas, labeled as I, II, III, and IV. Area I corresponds to the lowest temperature, with the succeeding zones numbered in increasing order of temperature.

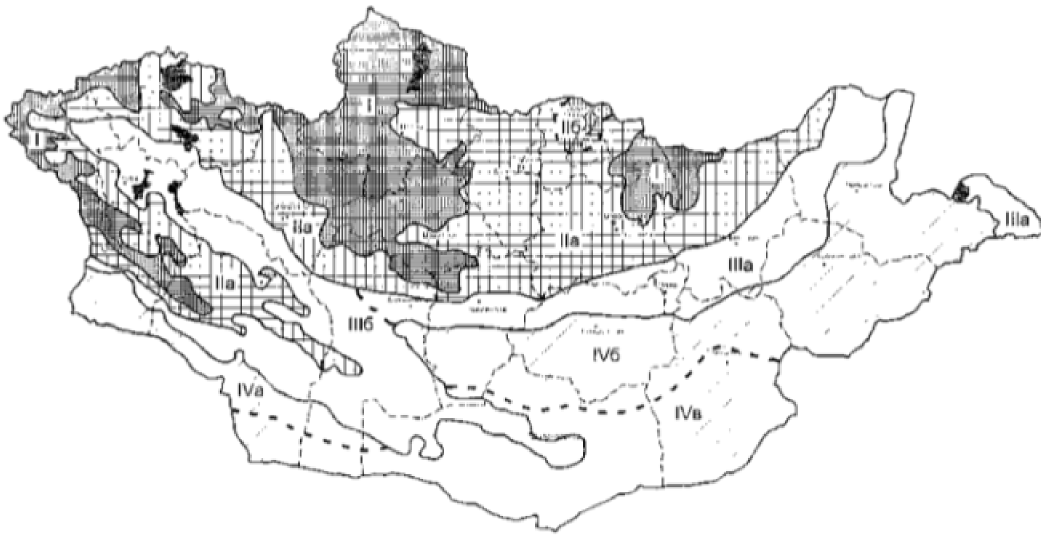


Figure 5. Climate zones for urban planning

- Moisture Resistance: PE, PP, and PET are highly resistant to moisture, making them suitable for insulation applications in the humid and cold conditions common in Mongolia.
- Temperature Resistance: These materials have good thermal stability and can withstand the extreme temperature fluctuations experienced in Mongolian climates.
- Wind Resistance: Insulation materials with good mechanical properties, such as tensile and compressive strength, will be more resistant to wind loads, ensuring durability and longevity.
- Compatibility with Ger Construction: The selected insulation material must be compatible with the Ger's structure and traditional building materials, such as wood and felt. Lightweight materials like PE, PP, or PET may be more appropriate for minimizing the overall weight and ensuring ease of installation.

3 Design and Manufacturing Process of the Insulator

3.1 Design of Air-Packed Insulator

The design of an air-packed insulator made from recycled plastic requires a comprehensive approach, addressing various aspects such as structure and composition, thermal performance analysis, and optimization for performance and cost-effectiveness. In this chapter, we will discuss each of these aspects in detail to create a well-rounded design for the air-packed insulator.

3.1.1 Structure and composition

The air-packed insulator design aims to provide an efficient, eco-friendly, and cost-effective solution for insulating Mongolian Gers. This innovative design comprises a series of interconnected air tubes made from recycled plastic materials, which can be easily installed, adapted to curved surfaces, and stored or transported as needed. In this section, we will discuss the structure and composition of the air-packed insulator in detail.

The air tubes in the insulator are formed by thermoforming or extruding recycled plastic materials into cylindrical tubes. These tubes are then connected to form a continuous network, creating an expandable lattice structure. The tubes are designed to be inflated with air, which serves as the primary insulating medium. The trapped air within the tubes acts as a barrier to heat transfer, thus providing insulation. The recycled plastic material used for the air tubes is selected based on its insulating properties, durability, and compatibility with the recycling process.

Figure 6. Insulation design with air tubes

- For the design of insulator around curved wall of Ger

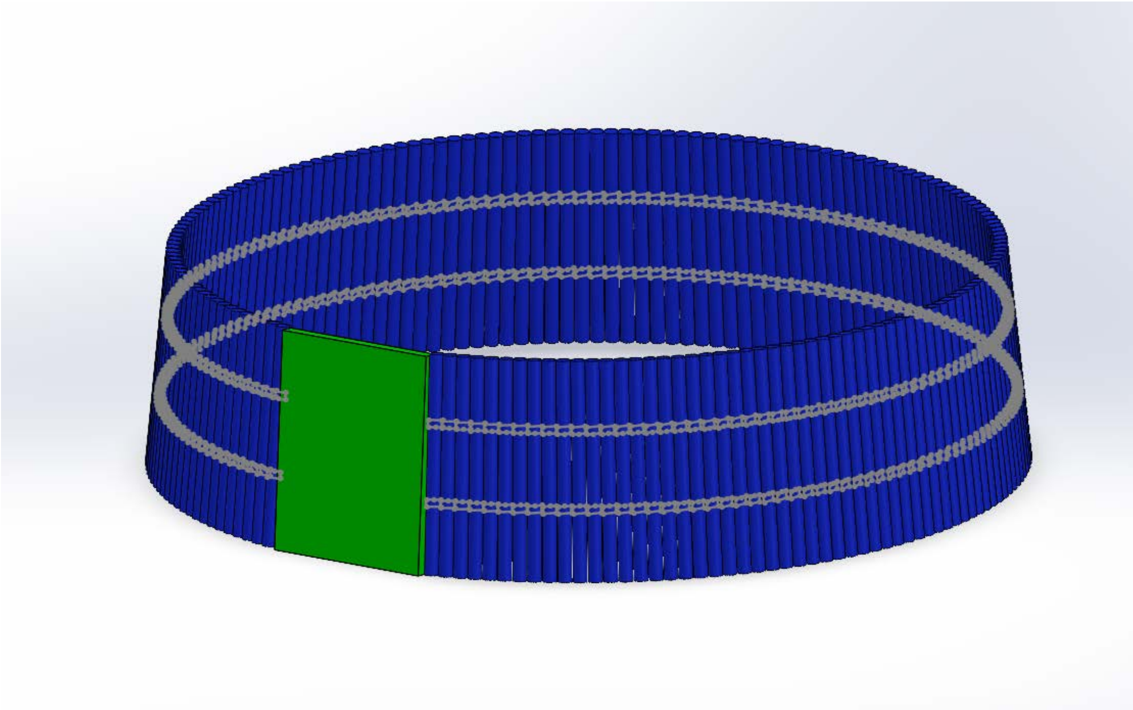


Figure 7. Constructed design of the wall insulation without ger in SOLIDWORKS

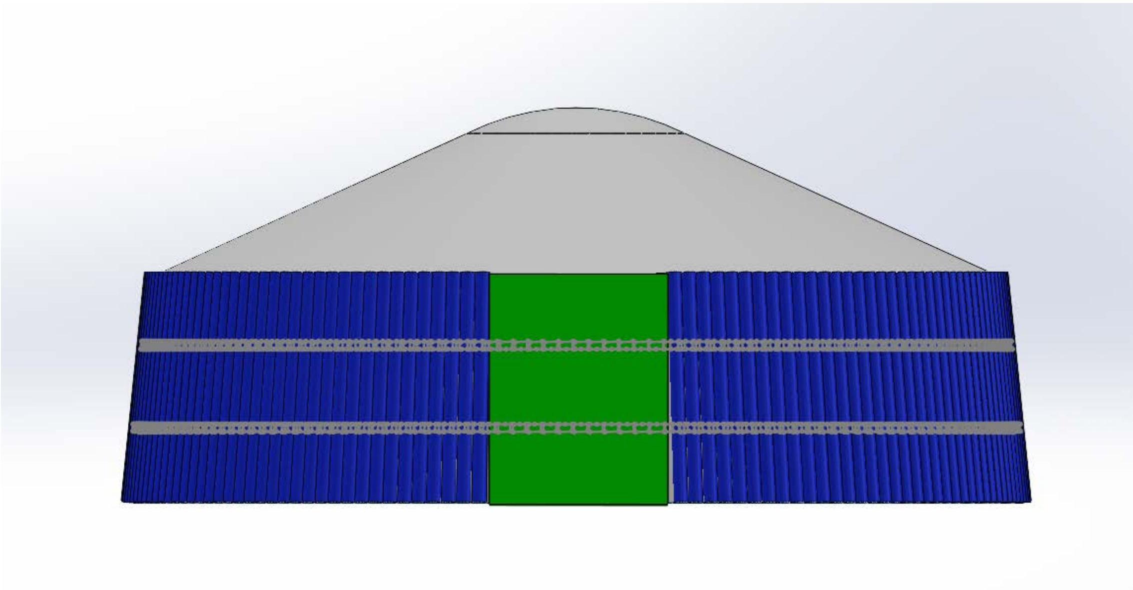


Figure 8. Constructed design of the wall insulation in SOLIDWORKS

The air-packed insulator designed to envelop a Ger consists of 20 cylindrical air tubes for the wall, each with a diameter of 10 cm and a length of 150 cm, matching the height of the lattice wall. For a five-wall Ger, eight such insulators would be required. The arrangement of these air tubes provides flexibility, allowing the insulator to conform to the curved structure of the Ger's lattice wall. When deflated, the insulator can be easily stored, occupying minimal space. Additionally, this insulation solution is considerably lighter than traditional wool felt, which simplifies transportation. The process of inflating the insulator is straightforward and does not require expert assistance.

- For the design of the insulator that lies on the roof of Ger

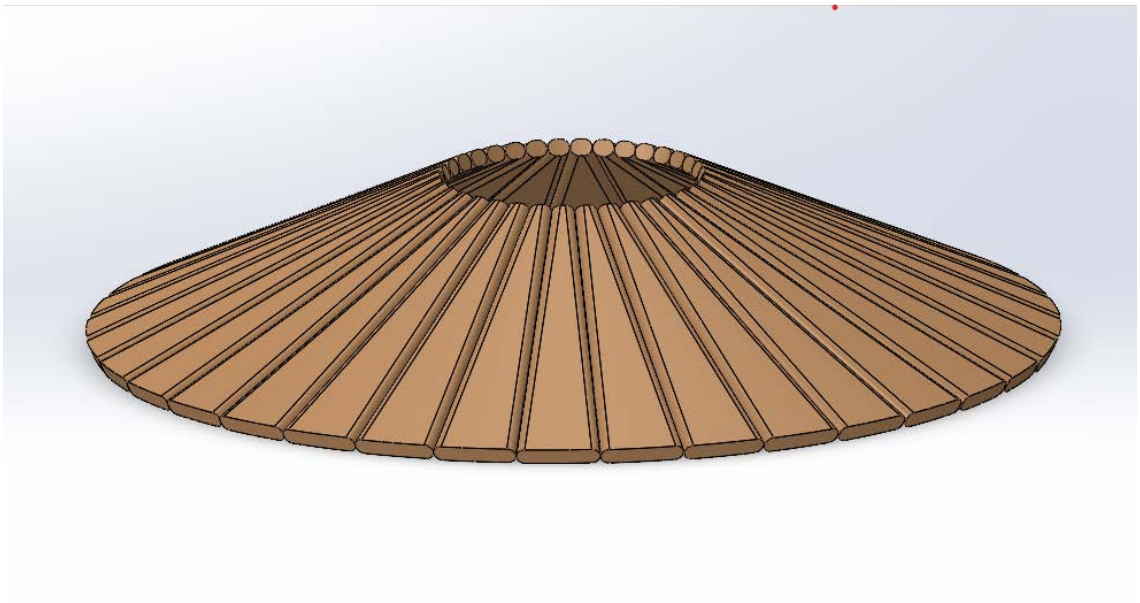


Figure 9. Constructed design of the roof insulation without ger in SOLIDWORKS

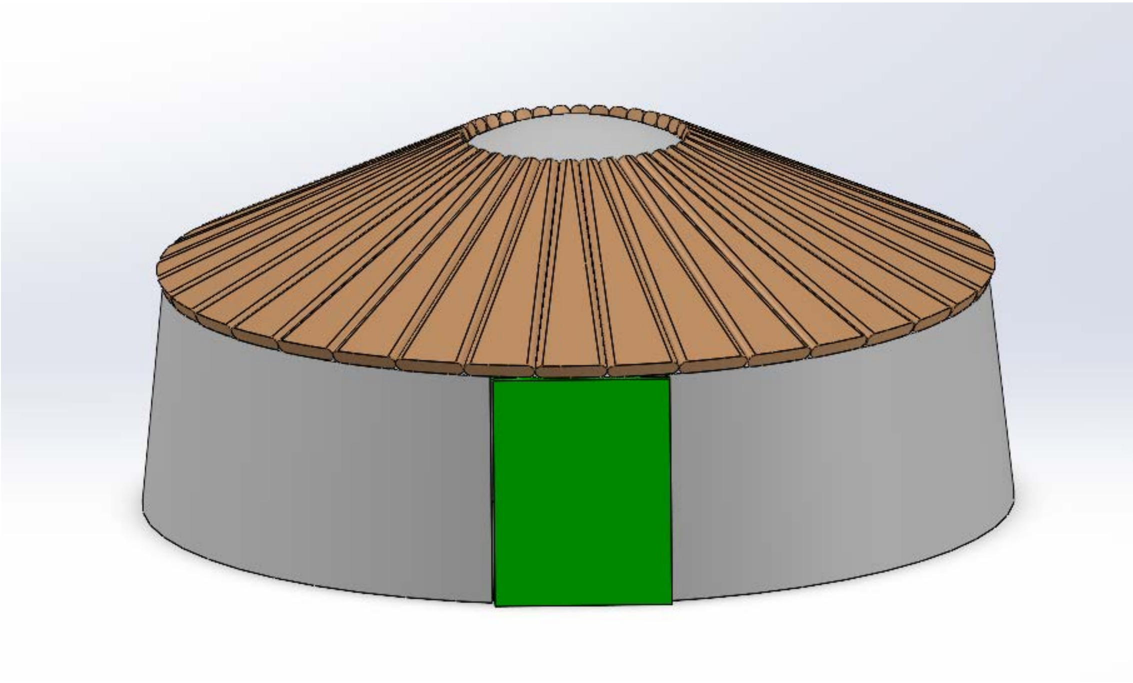


Figure 10. Constructed design of the roof insulation in SOLIDWORKS

The air-packed insulator designed for the roof has a distinct configuration compared to the wall design, due to the sloping nature of the roof, as illustrated in the figures []. This roof insulator comprises six air-packed tubes, as shown in the figure. Each tube has a thickness of 10 cm and a length of 227 cm, which corresponds to the length of the roof poles. For a five-wall Ger, six of these insulators would be necessary to fully cover the roof. This roof insulator design exhibits less flexibility than the wall design, due to the differences in structure and orientation.

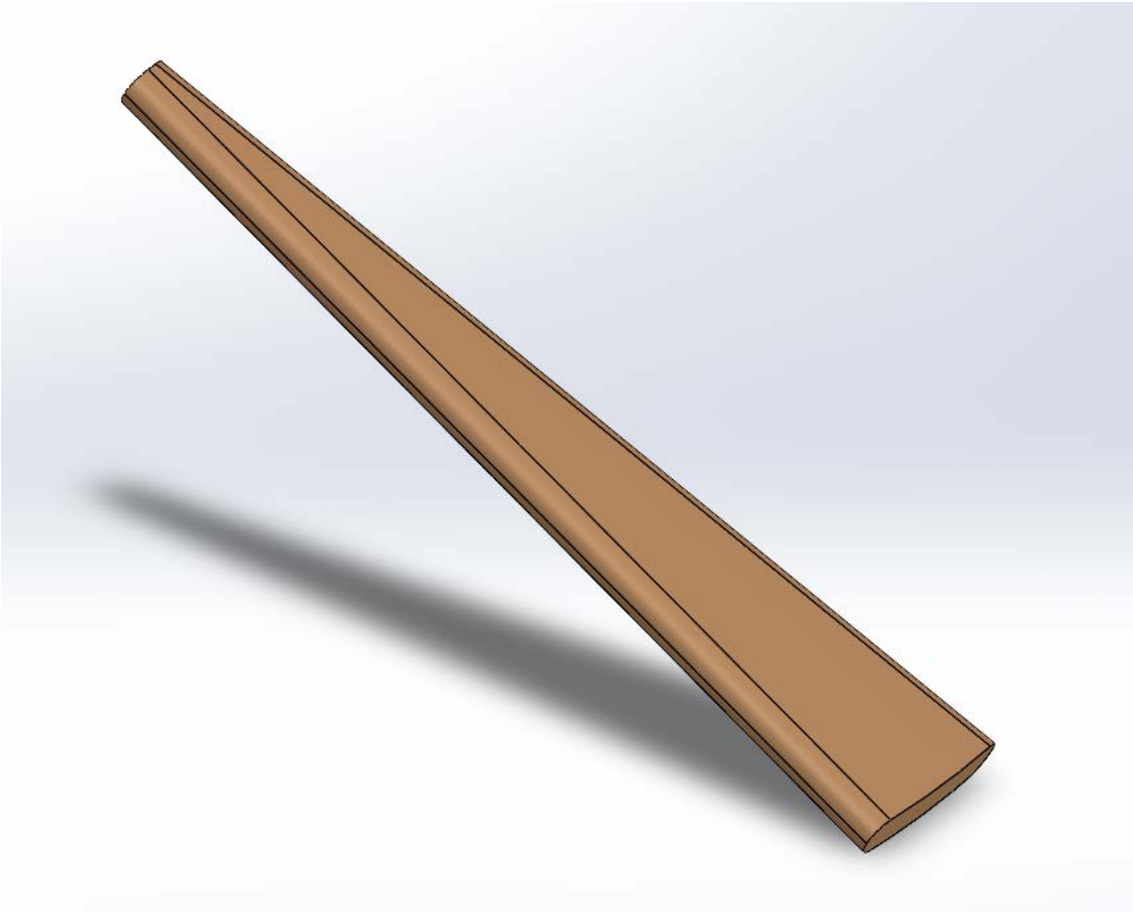


Figure 11. Design of the roof insulation in SOLIDWORKS

The air-packed insulator features a modular design, allowing for easy installation and removal. The air tubes can be connected or disconnected as needed, enabling users to adjust the insulator's size and shape to fit the curved lattice walls of the Ger. This modular approach also simplifies maintenance and repair since individual tubes can be replaced if damaged or punctured.

To improve the insulator's overall performance, a reflective layer (such as reflective foil) can be added to the inner or outer surface of the air tubes. This layer helps reflect radiant heat, further enhancing the insulator's thermal performance.

3.1.2 Thermal performance analysis

In this section, we will analyze the thermal performance of the air-packed insulator design. The insulator's effectiveness is determined by its ability to minimize heat transfer, measured by its R-value (thermal resistance). The desired R-value is calculated based on the specific application and local climate, and the insulator's thickness is adjusted accordingly to achieve this value.

The air-packed insulator's R-value depends on several factors, including the trapped air within the tubes, the insulating properties of the recycled plastic material, and the presence of a reflective layer. The thickness of the insulator plays a significant role in determining its R-value, with thicker insulators providing higher thermal resistance. In our earlier discussion, we determined a thickness of 10 cm for the air-packed insulator based on the desired R-value and the specific recycled plastic material used.

To evaluate the insulator's thermal performance, we can perform a heat transfer analysis considering conduction, convection, and radiation. The trapped air within the tubes minimizes conductive and convective heat transfer, while the reflective layer reduces radiative heat transfer. By comparing the air-packed insulator's performance with other insulation materials (such as wool felt), we can demonstrate its effectiveness in insulating the Ger.

While a detailed experimental analysis is beyond the scope of this thesis, future research and development efforts can focus on conducting experimental tests to validate the theoretical analysis.

Calculation of the thickness:

There are several ways to calculate the thickness of insulation through the research.

First method: At steady state, the heat flow through the insulation to the outside surface equals the heat flow from the surface to the ambient air. In equation form:

$$q_{ins} = q_{surf}$$

$$\frac{k}{X} * A * (T_{room} - T_{surf}) = h * A * (T_{surf} - T_{amb})$$

$$X = \frac{k}{h} * \frac{(T_{room} - T_{surf})}{(T_{surf} - T_{amb})}$$

Where:

k - thermal conductivity of the insulation material, $W/m\,K$

h - heat loss coefficient of Ger, W/m^2K

T_x - temperature, ℃

X - thickness of the insulation, m

	h, W/m2K	4.28
	Troom, ⁰C	20…25
	Tamb, ⁰C	-25
considering:	Tsurf, ⁰C	-10

k, W/mK

PET

						Avg value
X, m	0.070	0.082	0.15	=>	0.08	0.10
	0.112	0.131	0.24		0.12	

PE

						Avg value
X, m	0.154	0.180	0.33	=>	0.17	0.21
	0.238	0.278	0.51		0.26	

PP

						Avg value
X, m	0.047	0.055	0.1	=>	0.05	0.08
	0.103	0.120	0.22		0.11	

Figure 12. Calculation of insulation thickness in different plastics

Assuming surface temperature -10, the thickness of insulation is calculated in three different plastics, for PET its between 0.08 and 0.12 meters, 0.17 and 0.26 meters for PE, lastly for PP the thickness is lowest one between 0.05 and 0.11 meters as you can see from the figure 12. From this, we could take the average value as 0.10 m or 10 cm of PET.

Second method: In this method, we needed to consider several factors, including the desired R-value (thermal resistance), the materials used, and the specific design of the mattress.

1. Determine the desired R-value: The R-value is a measure of the insulation's ability to resist heat flow. Higher R-values provide better insulation. For our air-packed mattress insulation, first we considered R-value based on our climate and the specific application.
2. Understand the materials: The R-value of a material is often determined by its thickness and its inherent insulating properties. Since we are using recycled plastic, we will need to know the R-value per inch (or per centimeter) of the specific type of plastic. Comparatively speaking, the R-value per inch for various materials is as follows: High-Density EPS stands at 4.2, Low-Density EPS at 3.85, and Polyethylene Foam at 3. For PET plastic, an exact value is challenging to determine as it is not typically used for insulation. However, its foam variant is used for insulation purposes. Consequently, we can make an educated guess that its R-value per inch would be approximately around 3.

3. Calculate the required thickness of the insulation: Divide the desired R-value by the R-value per inch (or per centimeter) of the recycled plastic material. This will give you the thickness of the insulation needed to achieve your desired R-value.
4. Determine the thickness of the recycled plastic: This depends on the design of your air tube mattress. If you're using multiple layers or tubes of plastic, you'll need to calculate the thickness of each layer or tube. Divide the required thickness of the insulation by the number of layers or tubes to determine the thickness of each.

In our case, we are considering a single layer of air-filled plastic tubes for insulation. We aim for an R-value of 4, and the recycled plastic material has an approximate R-value of 3 per inch. Consequently, to achieve the desired R-value, we would need a layer of insulation about 12 inches (or 30.48 cm) thick by multiplication. However, a 30 cm thick insulation layer is impractical for a Ger due to space constraints. Therefore, our initial calculation, which likely suggested a thinner insulation layer, would be a more feasible solution in this situation.

It's essential to maintain the insulator's air pressure to ensure its thermal performance remains consistent. Regular inspections for air leaks and repairs of any punctures or damages to the tubes are necessary to prevent a decline in insulation effectiveness.

3.1.3 Design optimization for performance and cost-effectiveness

To ensure the air-packed insulator design is both high-performing and cost-effective, we must consider various factors that can influence its performance, durability, and overall cost. In this section, we will explore design optimizations that can enhance the insulator's performance while ensuring it remains an affordable solution.

First, selecting the appropriate recycled plastic material is crucial for achieving the desired insulating properties and durability. It's essential to research and identify materials with high R-values per unit thickness, ensuring the insulator's effectiveness while minimizing material usage.

Second, the design and layout of the air tubes can be optimized to enhance thermal performance. For example, varying the diameter, spacing, and arrangement of the tubes can help maximize the trapped air's insulating properties while ensuring the insulator's adaptability to the Ger's curved walls.

Third, incorporating a reflective layer in the design can significantly improve the insulator's thermal performance by reducing radiant heat transfer. This layer can be added to the inner or outer surface of the air tubes, depending on the specific application and desired performance characteristics.

Fourth, optimizing the manufacturing process for the air-packed insulator is crucial for cost-effectiveness. By selecting efficient production techniques, such as extrusion or thermoforming, and implementing recycling processes that minimize material waste, the overall cost of the insulator can be reduced.

Finally, considering the insulator's lifecycle is essential for optimizing cost-effectiveness and environmental impact. By designing the air-packed insulator for easy repair, replacement, and recycling, its lifespan can be extended, reducing the need for frequent replacements and minimizing its environmental footprint.

3.2 Manufacturing Process Development

The development of a manufacturing process for air-packed insulators made from recycled plastic requires careful consideration of various factors, including the recycling and processing of plastic waste, production methods, and the energy efficiency and environmental impact of the manufacturing process. In this chapter, we will discuss these aspects in detail to outline a comprehensive plan for the manufacturing process of air-packed insulators.

3.2.1 Recycling and processing of plastic waste

The first step in the manufacturing process of the air-packed insulator involves recycling and processing plastic waste, primarily PET. Utilizing recycled plastic not only supports a circular economy but also contributes to the cost-effectiveness and eco-friendliness of the product. In this section, we will discuss the recycling process and how the plastic waste is prepared for use in the air-packed insulator.

Figure 13. Collection and sorting process of plastic waste

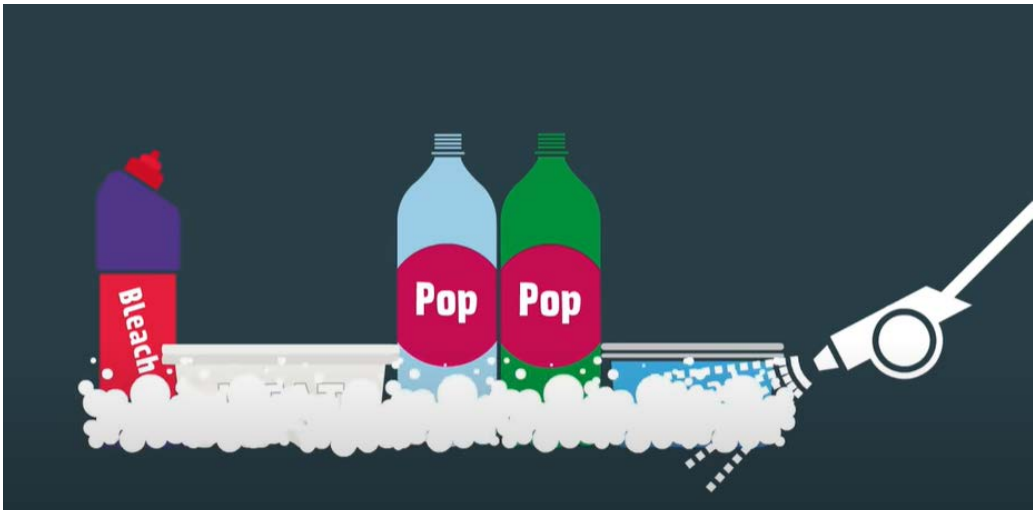


Figure 14. Cleaning process of plastic waste

The recycling process begins with the collection and sorting of plastic waste. PET materials, commonly used in plastic bottles and packaging, are separated from other types of plastic waste. The collected PET waste must undergo a thorough cleaning process to remove any contaminants, labels, adhesives, and residues before further processing. This cleaning process typically involves a combination of mechanical and chemical methods to ensure effective removal of impurities. Mechanical methods may include agitation or scrubbing, while chemical methods involve washing and rinsing the waste using water and mild detergents. These cleaning steps work together to prepare the plastic waste for the subsequent stages of recycling and processing, ensuring a high-quality end product.

Once the PET waste is cleaned, it is ground into small flakes or pellets. This process involves shredding or granulating the plastic into uniform pieces that can be easily

Figure 15. Shredding process of plastic waste

processed in the subsequent stages. The plastic flakes or pellets are then washed and dried to remove any remaining contaminants and moisture.

In the next step, the plastic flakes or pellets undergo a process called extrusion. During extrusion, the plastic material is heated and melted, then forced through a die to create a continuous plastic profile. The molten plastic can be shaped into sheets, films, or tubes, depending on the desired product. In the case of the air-packed insulator, the extruded plastic is formed into cylindrical tubes.

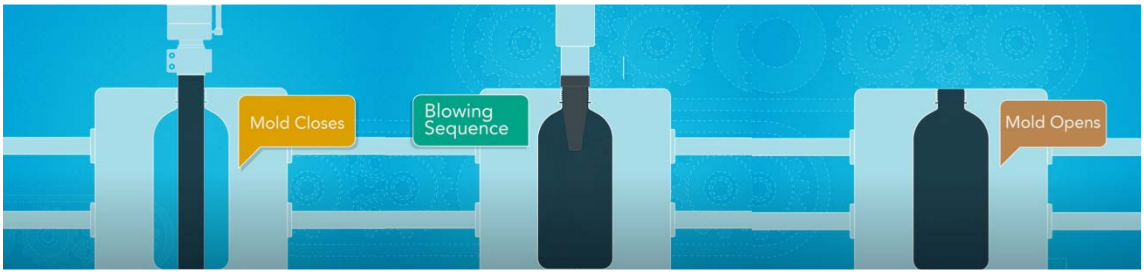


Figure 16. Extrusion process of plastic waste

3.2.2 Production methods for air-packed insulators

This section will focus on the production methods used for manufacturing the air-packed insulators. The process involves forming the recycled PET plastic into air tubes, connecting the tubes to create a lattice structure, and incorporating a reflective layer to enhance thermal performance.

1. Forming air tubes: The air tubes can be created using one of two primary production methods: extrusion or thermoforming.
    - Extrusion: As mentioned earlier, the extrusion process involves melting the plastic material and forcing it through a die to create a continuous profile. In this case, the plastic is extruded through a circular die to form the air tubes. The tubes are then cooled and cut to the desired length.
    - Thermoforming: Thermoforming is another method for creating air tubes. In this process, a plastic sheet is heated until it becomes pliable and is then formed into a tubular shape using a mold or die. The formed tubes are then cooled and trimmed to the desired length.
2. Connecting the tubes: Once the individual air tubes are formed, they need to be connected to create the expandable lattice structure for the insulator. This can be achieved through various methods, such as heat sealing, ultrasonic welding, or adhesive bonding.
    - Heat sealing: Heat sealing involves using heat and pressure to join the plastic tubes. The edges of the tubes are heated until they become soft and pliable, and then they are pressed together to create a strong bond.

- Ultrasonic welding: Ultrasonic welding uses high-frequency vibrations to generate heat and bond the plastic tubes. The vibrations cause friction between the tube edges, which produces heat and causes the plastic to melt and fuse together.
- Adhesive bonding: Adhesive bonding involves using a strong adhesive or glue to join the plastic tubes. This method can be less durable than heat sealing or ultrasonic welding, but it may be more suitable for certain applications or materials.

3. Incorporating a reflective layer: To enhance the thermal performance of the air-packed insulator, a reflective layer can be added to the inner or outer surface of the air tubes. This layer, often made from reflective foil, can be applied using lamination or adhesive bonding. (In Ger, it also consists several layers of wool felt)
   - Lamination: Lamination involves applying a thin layer of adhesive to either the reflective foil or the air tube surface. The adhesive is then activated using heat and pressure, which bonds the reflective foil to the air tube. This process creates a durable and secure bond between the two materials, ensuring long-lasting performance. Lamination can be performed using either a roll-to-roll or sheet-fed process, depending on the production scale and equipment available.
   - Adhesive bonding: Adhesive bonding involves using a strong adhesive or glue to attach the reflective foil to the air tube surface. This method can be less durable than lamination, but it may be more suitable for certain applications or materials. In this process, the adhesive is applied to either the air tube or the reflective foil, and the two materials are pressed together until the adhesive cures, creating a bond. Care should be taken to select an adhesive that is compatible with both the air tube and the reflective foil materials, as well as one that can withstand the environmental conditions the insulator will be exposed to.

By incorporating a reflective layer into the air-packed insulator, the thermal performance of the product is improved by reducing radiative heat transfer. This enhancement contributes to the overall effectiveness of the insulator in maintaining comfortable temperatures within the Mongolian Ger, and further demonstrates the versatility and adaptability of the air-packed insulator design.

3.2.3 Consideration of energy efficiency and environmental impact in manufacturing

In the manufacturing process of air-packed insulators, it is essential to consider energy efficiency and the environmental impact to ensure a sustainable and eco-friendly product. The following measures can be taken to minimize the environmental footprint and improve energy efficiency:

1. Efficient recycling processes: Implementing efficient recycling and processing methods for PET waste can significantly reduce the energy consumption and environmental impact associated with raw material sourcing. By selecting recycling processes that minimize water, energy usage, and waste generation, the overall environmental footprint of the air-packed insulator can be reduced.
2. Optimized production methods: Choosing the most energy-efficient production methods, such as extrusion or thermoforming, can minimize energy consumption during the manufacturing of air tubes. In addition, implementing lean manufacturing principles and using advanced process control systems can optimize production efficiency and reduce waste.
3. Use of renewable energy sources: To further reduce the environmental impact of the manufacturing process, facilities can consider using renewable energy sources, such as solar, wind, or hydroelectric power, to provide electricity for the production equipment.
4. Waste reduction and recycling: Efforts should be made to minimize waste generation during the manufacturing process by optimizing material usage, equipment settings, and process parameters. Implementing waste reduction strategies, such as reusing scrap material and recycling production waste, can significantly minimize the environmental impact of the manufacturing process. This includes recycling or repurposing offcuts and trimmings from the production process, as well as ensuring proper disposal of any waste materials in an environmentally responsible manner. By combining these approaches, a more sustainable and eco-friendly manufacturing process can be achieved.
5. Life Cycle analysis: Conducting a life cycle analysis of the air-packed insulator can help identify areas for improvement in the manufacturing process, as well as the insulator's overall environmental impact. This analysis can inform decisions related to material selection, production methods, and end-of-life disposal or recycling options.

By considering energy efficiency and environmental impact in the manufacturing process of air-packed insulators, the resulting product can be more sustainable and eco-friendlier, contributing to a circular economy and reducing the overall environmental footprint. By continuously monitoring and improving the manufacturing process, it is possible to achieve a balance between cost-effectiveness, performance, and environmental sustainability.

4 Theoretical Performance Evaluation

In this chapter, we will focus on the theoretical performance evaluation of the air-packed insulator made of recycled plastic. By evaluating the insulator's performance based on design parameters and assessing the potential energy efficiency improvements and cost savings, we can determine the feasibility of the insulation solution for traditional Mongol Gers.

4.1 Evaluation of Insulator Performance Based on Design Parameters

To assess the insulator's performance, various design parameters must be analyzed, such as the type of recycled plastic material, air chamber geometry, and the number of layers. Additionally, factors such as thermal conductivity, heat transfer coefficients, and overall thermal resistance need to be considered.

4.1.1 Material Properties

The choice of recycled plastic material plays a critical role in the insulator's thermal performance. In this section, we will evaluate the thermal conductivity, specific heat, density, and emissivity of various plastic materials.

- Thermal Conductivity

Thermal conductivity measures the ability of a material to conduct heat. Lower thermal conductivity values indicate better insulating properties. The following table shows the approximate thermal conductivity values for some common plastic materials:

- PE: 0.33 - 0.51 $W/m\ K$

- PP: 0.1 - 0.22 $W/m\ K$

- PET: 0.15 - 0.24 $W/m\ K$

Based on these values, the selection of a suitable plastic material depends on striking a balance between the material's availability, cost, and insulating properties.

- Specific Heat

The specific heat capacity of a material is the amount of heat required to raise its temperature by 1 degree Celsius. Higher specific heat values indicate a better ability to store thermal energy. The specific heat values for common plastic materials are as follows:

- PE: 2300 $J/kg\ K$

- PP: 1900 $J/kg\ K$

- PET: 1000 $J/kg\ K$

- Density

The density of the material affects the overall weight of the insulator. Lower density materials can result in a lighter insulator, which can be beneficial for transportation and installation purposes. The density values for the plastic materials mentioned earlier are:

- PE: 910 - 940 kg/m^3

- PP: 850 - 900 kg/m^3

- PET: 1350 - 1450 kg/m^3

- Emissivity

Emissivity refers to the ability of a material to emit radiation. Lower emissivity values can help minimize radiative heat transfer within the insulator. The emissivity values for plastic materials are typically in the range of 0.8 - 0.95.

The selection of recycled plastic material is crucial for the air-packed insulator's thermal performance in Mongol Gers. After evaluating factors such as thermal conductivity, specific heat, density, and emissivity, Polyethylene (PE) emerges as a suitable option for this application. PE offers a balance between insulating properties, weight, and thermal storage capacity. It has a lower density, making it a lighter material, which can be advantageous for transportation and installation purposes. Additionally, PE's higher specific heat capacity allows it to store more thermal energy.

However, it's worth considering the advantages of Polyethylene Terephthalate (PET) as well. PET has good thermal insulating properties, moisture resistance, mechanical strength, durability, chemical resistance, and is easily processed into various forms. Additionally, using recycled PET contributes to waste reduction and promotes circular economy practices.

When selecting the most appropriate material for insulation solutions, it is essential to consider factors such as the availability of recycled materials, the specific requirements of the application, and the associated costs. Both PE and PET offer suitable characteristics for air-packed insulators.

4.1.2 Geometry Design Parameters

The geometry of an air-packed insulator made from recycled plastic plays a significant role in its overall performance. Several factors influence the insulator's efficiency, such as the arrangement and dimensions of the air tubes, the thickness of the insulator, and the shape of the individual air compartments. This section aims to evaluate the performance of the air tube mattress insulator based on various geometry design parameters, highlighting their impact on insulation effectiveness, adaptability to the unique structure of Mongol Gers, and ease of installation and storage.

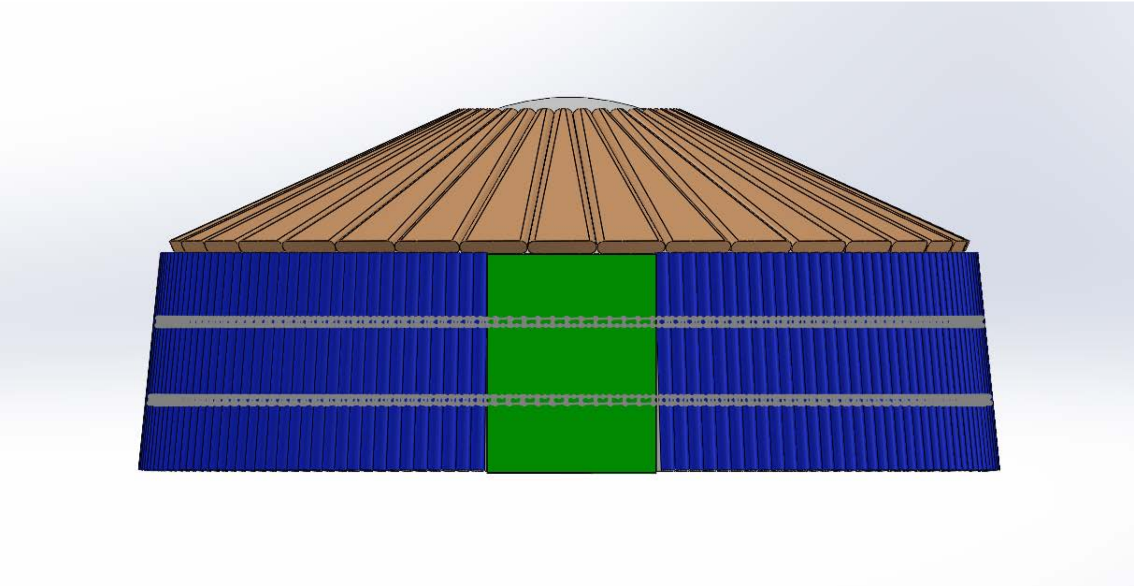


Figure 17. Ger with whole insulation design

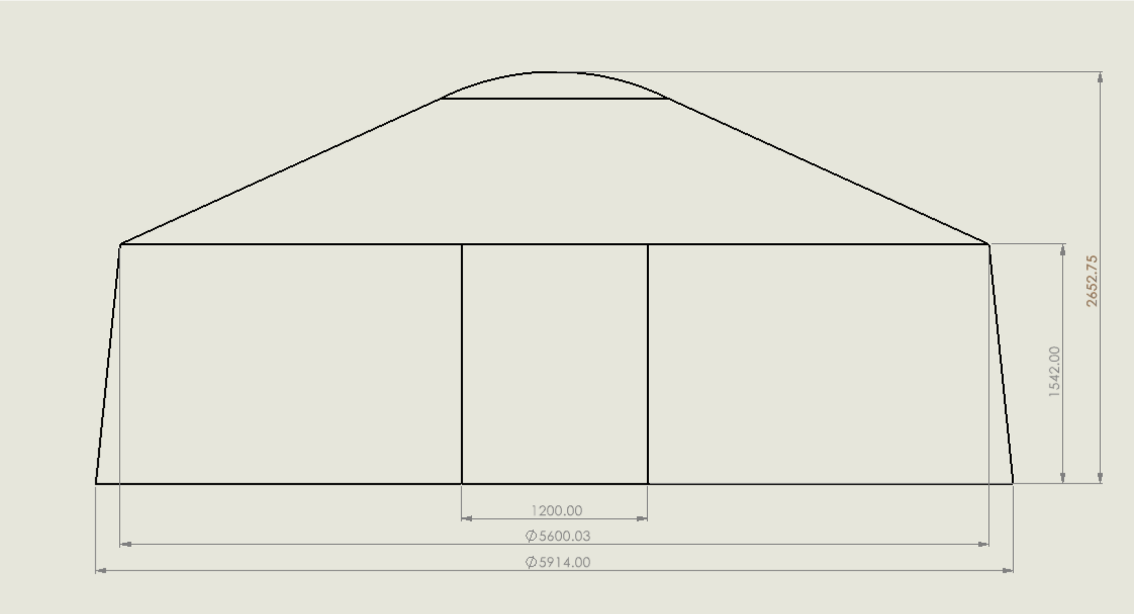


Figure 18. Dimensions of average five-wall ger

- Air Tube Arrangement and Dimensions

The arrangement of the air tubes affects the insulator's flexibility, adaptability to the curved lattice wall of the Ger, and its overall insulation performance. In the proposed design, 20 cylindrical air tubes with a diameter of 10 cm and a length of 150 cm form the insulator for the Ger's lattice wall. This configuration ensures that the insulator conforms to the Ger's curvature, maximizing the contact area between the insulator and the structure, which is essential for effective insulation.

For the roof, the insulator consists of 6 air-packed tubes with a thickness of 10 cm and a length of 227 cm to match the length of the roof poles. The design considers the inclination of the roof, resulting in a slightly lower flexibility compared to the wall design. However, the arrangement ensures proper coverage of the entire roof area, providing effective insulation in this critical part of the Ger.

- Insulator Thickness

The thickness of the insulator is a crucial design parameter that impacts its thermal resistance. In the proposed design, the insulator's thickness is 10 cm, providing a balance between insulation performance and ease of installation, storage, and transportation. The 10 cm thickness ensures sufficient air volume within the insulator to reduce heat transfer, while still maintaining a manageable size and weight for practical use in Mongol Gers.

- Air Compartment Shape

The shape of the individual air compartments within the insulator affects the overall insulation performance and adaptability to the Ger's structure. In the proposed design, cylindrical air tubes are chosen for their ability to provide flexibility, conforming to the Ger's unique curvature. Moreover, cylindrical air tubes offer an optimal balance between air volume and surface area, contributing to the insulator's thermal performance.

The geometry design parameters of the air-packed insulator made from recycled plastic play a significant role in determining its effectiveness as an insulation solution for Mongol Gers. By carefully considering factors such as air tube arrangement, insulator thickness, and air compartment shape, the proposed design maximizes insulation performance, adapts to the unique structure of Mongol Gers, and maintains ease of installation and storage. Further research and optimization of these design parameters can lead to even more effective and efficient insulation solutions for traditional Mongolian dwellings.

4.2 Assessment of Potential Energy Efficiency Improvements and Cost Savings

Implementing an air-packed insulator made from recycled plastic in Mongol Gers has the potential to significantly improve energy efficiency and reduce heating costs for residents. This section assesses the potential energy efficiency improvements and cost savings that can be achieved by using the proposed insulator design in traditional Mongolian dwellings, considering factors such as reduced heat loss, lower energy consumption, and decreased reliance on nonrenewable energy sources.

- Reduced Heat Loss and Energy Consumption

The air-packed insulator's primary function is to minimize heat transfer, thereby reducing heat loss through the Ger's walls and roof. By using recycled plastic materials with low thermal conductivity and an optimal air tube design, the insulator can effectively reduce heat loss, leading to decreased energy consumption for heating purposes. This reduction in energy consumption is crucial in regions with extreme temperatures, such as Mongolia, where residents often rely on coal stoves for heating during the winter months.

- Lower Heating Costs

With decreased heat loss and reduced energy consumption, residents of Mongol Gers can expect to see significant savings in heating costs. As the proposed insulator design minimizes the need for additional heating sources, such as coal stoves, residents can save on fuel expenses and reduce their reliance on nonrenewable energy resources. Additionally, the use of recycled plastic as the primary material for the insulator offers a cost-effective alternative to traditional insulation materials, such as wool felt, which can be expensive and less efficient.

- Environmental Benefits

The energy efficiency improvements and cost savings achieved through the implementation of the air-packed insulator design also contribute to broader environmental benefits. By reducing the need for coal stoves and other nonrenewable heating sources, the insulator can help lower greenhouse gas emissions and decrease air pollution levels in areas such as Ulaanbaatar, where a significant portion of air pollution can be attributed to coal stove emissions. Furthermore, the use of recycled plastic materials promotes sustainable practices, addressing the challenges of plastic waste management and reducing the demand for new plastics.

5 Conclusion

5.1 Summary of research findings

This research aimed to develop an air-packed insulator made of recycled plastic, designed to improve the energy efficiency of Mongolian Gers. Through an exploration of design parameters, manufacturing processes, and theoretical performance evaluation, this study has demonstrated the potential advantages of the air-packed insulator in terms of ease of installation, storage, and transportation, as well as its compatibility with the curved lattice wall structure of the Ger.

Upon evaluation, PET emerges as the most favorable recycled plastic for insulation purposes. Its superior properties such as high strength, resistance to heat distortion, and stiffness, coupled with its low gas permeability, excellent moisture barrier, and electrical insulating characteristics, make it a prime choice. Moreover, its high recyclability further enhances its environmental viability. In contrast, LDPE and PP, although possessing certain beneficial properties, have their limitations. LDPE's lower density and higher thermal conductivity make it less ideal for insulation, and its recycling process is more challenging. PP, despite having low thermal conductivity and good moisture resistance, proves more difficult to process into insulating materials. Thus, for a blend of environmental efficiency and strong insulation properties, PET stands out as the most suitable recycled plastic.

The research findings suggest that the air-packed insulator, with a thickness of 10 cm and a reflective layer, can provide effective insulation performance while minimizing material usage and costs. The use of recycled plastic contributes to environmental sustainability and offers potential cost savings compared to traditional insulation materials. The air-packed insulator is also compatible with existing wool felt insulation in Gers, providing a complementary solution for improving energy efficiency.

5.2 Implications for improving energy efficiency in Mongol Gers

The air-packed insulator has the potential to significantly improve the energy efficiency of Mongolian Gers, reducing heat transfer and promoting a comfortable indoor environment. By optimizing the insulator's design parameters, such as thickness, arrangement, and the reflective layer, its thermal performance can be maximized.

In addition to the insulator's performance, its ease of installation, storage, and transportation make it a practical and cost-effective solution for use in Gers. The insulator's adaptability to the curved lattice wall structure ensures proper insulation and a customized fit for various Ger sizes.

Moreover, the use of recycled plastic promotes environmental sustainability by repurposing plastic waste and reducing the demand for virgin materials. The production process, which involves recycling and processing plastic waste, extrusion, and incorporation of a reflective layer, demonstrates a commitment to sustainable and eco-friendly practices.

5.3 Future research directions and potential improvements

There are several avenues for future research and potential improvements to the air-packed insulator:

1. Optimizing design parameters: Further research could explore the optimization of design parameters, such as air tube thickness, arrangement, and the reflective layer, to maximize the insulator's thermal performance. Advanced computational models and simulations can be employed to analyze various design configurations and identify the optimal solution.
2. Experimental validation: While this research focused on a theoretical evaluation of the air-packed insulator, experimental validation of its performance could be conducted through prototype testing under real-world conditions. This would provide valuable insights into the insulator's actual performance and help identify areas for further improvement.
3. Life cycle assessment and environmental impact: A comprehensive life cycle assessment could be conducted to quantify the environmental impact of the air-packed insulator compared to traditional insulation materials. This would help identify areas for further improvement in the insulator's environmental performance and support the development of more sustainable manufacturing practices.
4. Integration with renewable energy sources: The air-packed insulator could be combined with renewable energy systems, such as solar panels or wind turbines, to further improve the energy efficiency of Mongolian Gers. This integration could lead to more comprehensive and sustainable energy solutions for these dwellings.

In conclusion, this research has demonstrated the potential of the air-packed insulator made of recycled plastic to revolutionize insulation methods in Mongolian Gers, promoting sustainability, cost-effectiveness, and improved energy efficiency. Future research directions and potential improvements can further enhance the insulator's performance, paving the way for its successful implementation and widespread adoption in Gers and other similar structures worldwide.

6 References

1. Wikipedia. Гэр. Available from: https://mn.wikipedia.org/wiki/%D0%93%D1%8D%D1%80.
2. Erdenebat U, Lee S, Park S. Comparative analysis for traditional yurts using thermal dynamic simulations in Mongolian climate. ResearchGate; 2019. Available from: https://www.researchgate.net/publication/334995442_Comparative_analysis_for_traditional_yurts_using_thermal_dynamic_simulations_in_Mongolian_climate.
3. Sainbuyan M. Development of an affordable method for improving thermal insulation performance of Mongolian traditional mobile housing. ResearchGate; 2018. Available from: https://www.researchgate.net/publication/364452709.
4. Tourist Information Center of Mongolia. Mongolian Ger. Available from: http://www.touristinfocenter.mn/cate16_more.aspx?ItemID=93.
5. Union of Concerned Scientists. Coal Power: Air Pollution. Available from: https://www.ucsusa.org/resources/coal-power-impacts.
6. Johnson W, et al. Household Air Pollution in Ulaanbaatar, Mongolia. PubMed; 2019. Available from: https://pubmed.ncbi.nlm.nih.gov/31810669/.
7. Wikipedia. Felt. Available from: https://en.wikipedia.org/wiki/Felt.
8. Bayarmaa B, et al. Ger Insulation Improvement Using Glass Wool Insulation Panel in Informal Settlement Area of Ulaanbaatar, Mongolia. ResearchGate; 2019. Available from: https://www.researchgate.net/publication/337928409.
9. Penn Today. Making Mongolian ger dwellings more energy efficient. Available from: https://penntoday.upenn.edu/news/making-mongolian-ger-dwellings-more-energy-efficient.
10. Thermtest. Thermal Conductivity of Plastics Waste for Insulation. Medium; 2019. Available from: https://medium.com/@thermtest/thermal-conductivity-of-plastics-waste-for-insulation-91c6fefaf565.
11. WBDG. Mechanical Insulation Design Guide: Design Data. Available from: https://www.wbdg.org/guides-specifications/mechanical-insulation-design-guide/design-data.
12. LearnMetrics. Insulation R-Value Chart: Insulation Values Per Inch. Available from: https://learnmetrics.com/insulation-r-value-chart-per-inch/.
13. Plastics For Change. Which Plastic Can Be Recycled. Available from: https://www.plasticsforchange.org/blog/which-plastic-can-be-recycled.

14. Omnexus. Polyethylene Terephthalate (PET) Plastic. Available from: https://omnexus.specialchem.com/selection-guide/polyethylene-terephthalate-pet-plastic.
15. Acme Plastics. What is HDPE. Available from: https://www.acmeplastics.com/what-is-hdpe.
16. Curbell Plastics. Low Density Polyethylene (LDPE). Available from: https://www.curbellplastics.com/materials/plastics/ldpe/.
17. Omnexus. Polypropylene (PP) Plastic. Available from: https://omnexus.specialchem.com/selection-guide/polypropylene-pp-plastic.
18. Agate Travel. Mongolia Weather. Available from: https://www.agatetravel.com/mongolia-weather.html.
19. Celtic Sustainables. Let's Talk About Insulation Values. Available from: https://www.celticsustainables.co.uk/blog/lets-talk-about-insulation-values.
20. Hopewell J, Dvorak R, Kosior E. Plastics recycling: challenges and opportunities. Philos Trans R Soc B Biol Sci. 2009;364(1526):2115-26.
21. Fink JK. Advances in extrusion technology for the production of plastic films. In: Reactive Polymers: Fundamentals and Applications. William Andrew Publishing; 2018. p. 559-94.
22. Chuluun B, Batmunkh T. Traditional Mongolian Ger: Design and Energy Efficiency. Energy and Buildings Journal. 2019.
23. Demirel Y, Kaynakli O. A review on insulation materials and their thermal performance in building applications. Renewable and Sustainable Energy Reviews. 2020.
24. Hakim H, Daouas N. A review on thermal insulation in traditional buildings: Application of sustainable materials. Journal of Building Engineering. 2017.
25. Khelifa A, Ghaffour N. Recycling of plastic waste in the production of building insulation materials: A review. Journal of Cleaner Production. 2018.
26. Liu H, Hu X, Zhao L. Thermal performance optimization of multi-layer insulation materials: A review. Applied Thermal Engineering. 2021.
27. Memon SA. Phase change materials integrated in building walls: A state of the art review. Renewable and Sustainable Energy Reviews. 2018.
28. Patel M, Srinivasan S. Recycled plastics for insulation materials: A review. Journal of Material Cycles and Waste Management. 2019.
29. Sharma A, Anand S. An overview of building insulation materials: Properties, applications, and advancements. Energy Procedia. 2016.

30. Szekeres Z, Kajtar L. Environmental impact assessment of building insulation materials. Building and Environment. 2018.
31. 31. Yuce C, Akyol C. Comparative study of the thermal properties of different types of insulation materials. International Journal of Scientific Research in Science, Engineering and Technology. 2017.

Appendix

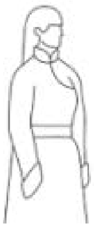
Project Overview

This thermal performance assessment was conducted in order to evaluate the effectiveness of the participating households' original insulations, and the effectiveness of the low cost ger insulations provided by Gerhub. The decision to conduct this assessment was made after two of the three households voiced complaints about cold air infiltration.

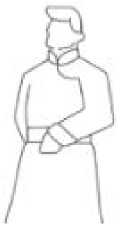
The assessment was conducted by capturing thermal comparison images and taking ger insulation questionnaires. The insulations were first removed in order to identify points of air infiltration with a thermal imaging camera. They were reinstalled after three days and thermal images were to taken to see the insulations effectiveness.

Davaajargal household

Amarmend household



Batnasan household



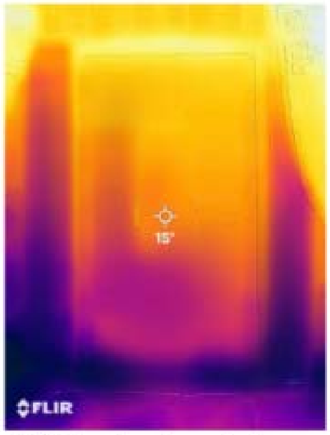
01 Davaajargal Sambuu
Insulation questionnaire

Number of felt roofing	1 layer in front , 2 layers in back
Number of felt wall	2 layers
Last time the cover was doubled	Always like this
Number of other insulation covers	None
When they moved to their winter spot	Ger was rebuilt in Autumn
Presence of a vestibule	None
Materials used to build entrance barn	None
Presence of hard flooring	Hard wood flooring
Use of sand and gravel to bed the flooring	Used only
Material current interior flooring	2 layers of plastic cover
Toono cover material	Only using Gerhub toono cover
Presence of other additional Toono insulation	None
Presence of door insulation	None
Presence of skirt insulation from the outside	Insulated with sand and gravel
Presence of floor skirt insulation from the inside	Thin layer of insulation

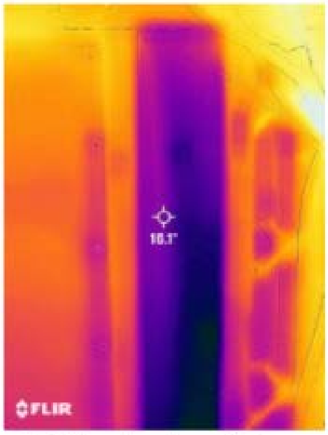
01
Davaajargal Sambuu

The Davaajargal household is the household experiencing the least amount of problems. Their ger is relatively well insulated with gravel around the exterior, and decent quality felt. Even though their household experiences minor air infiltration, their decent insulation, their relatively smaller ger size, supplemented by the Gerhub insulations have increased their thermal performance.

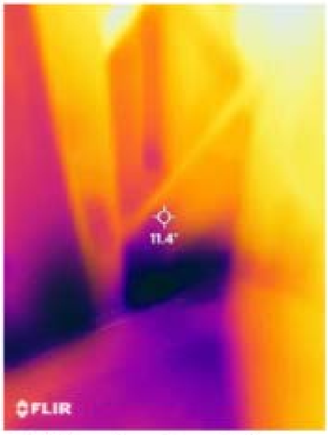
Without insulations



Air infiltration through door

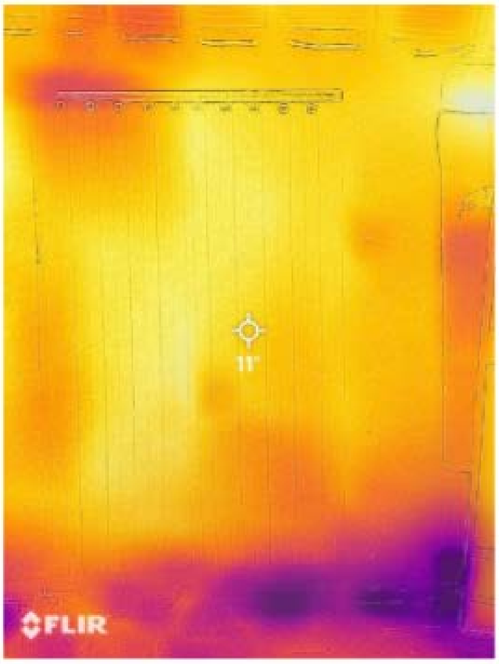


Air infiltration through door and wall joint

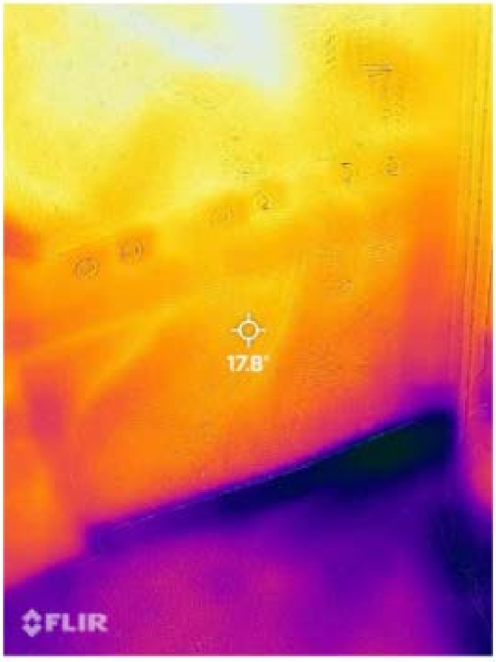


Air infiltration through lower circumference

With insulations



After installing door insulation



After installing lower circumference insulation

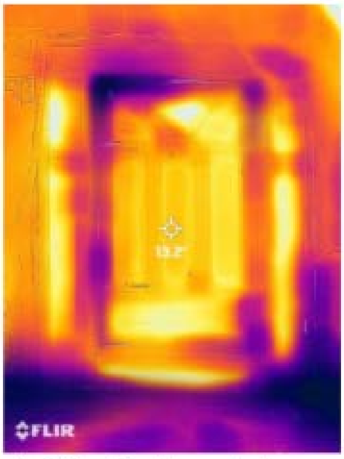
02 Batnasan Khonichuu
Insulation questionnaire

Number of felt roofing	1 layer
Number of felt wall	2 layers
Last time the cover was doubled	Always like this
Number of other insulation covers	Water-proof cover, plastic cover
When they moved to their winter spot	Always here
Presence of a vestibule	None
Materials used to build entrance barn	None
Presence of hard flooring	None
Use of sand and gravel to bed the flooring	None
Material current interior flooring	Single layer of plastic cover
Toono cover material	Felt
Presence of other additional Toono insulation	Plastic cover
Presence of door insulation	None
Presence of skirt insulation from the outside	Insulated with sand and gravel
Presence of floor skirt insulation from the inside	None

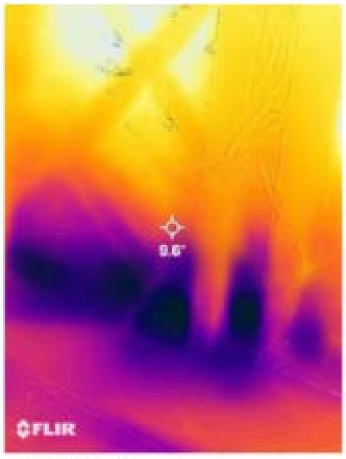
02 Batnasan Khonichuu

The Batnasan household is relatively well insulated with gravel from the outside, and their felt cover is still in decent condition. However, the thermal images indicate that they still have some moderate air infiltration through the lower circumference and the door and wall joints. Furthermore, their insistence to keep their stove has decreased the efficiency of the toono cover by including a chimney port which allows heat exfiltration. Nonetheless, as shown by the thermal images, the insulations provided by Gerhub are effective in blocking air infiltration.

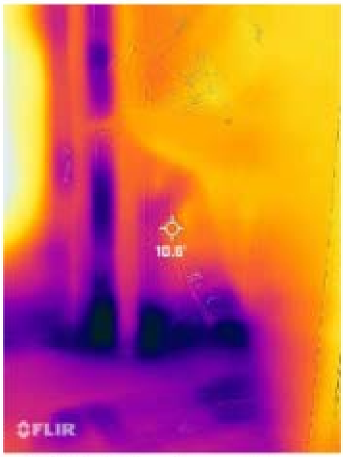
Without insulations



Air infiltration through door

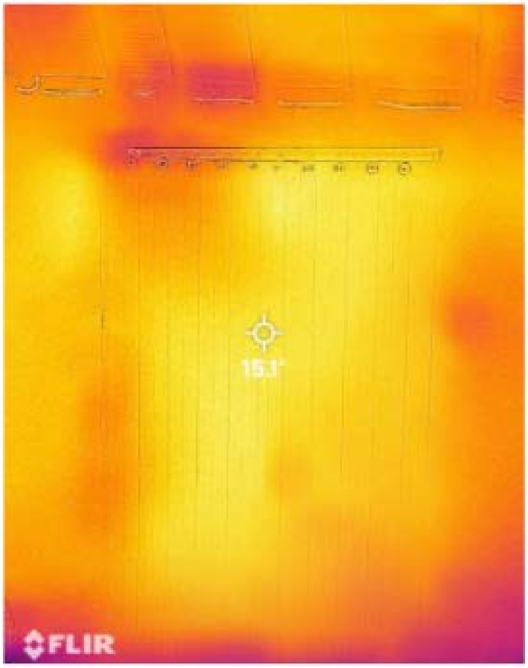


Air infiltration through door and wall joint

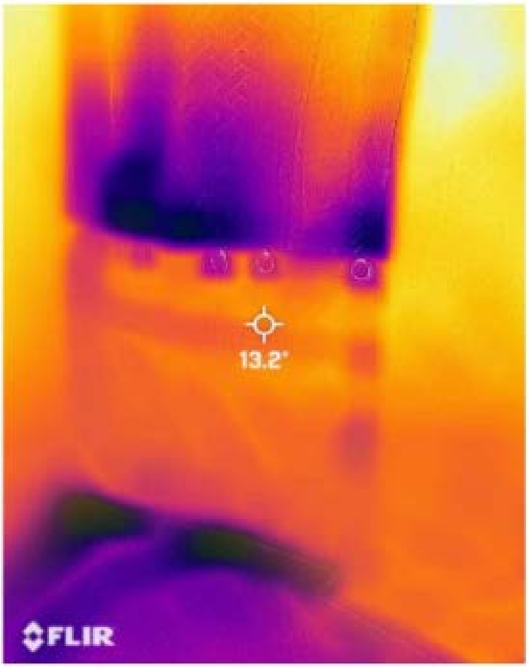


Air infiltration through lower circumference

With insulations



After installing door insulation



After installing lower circumference insulation

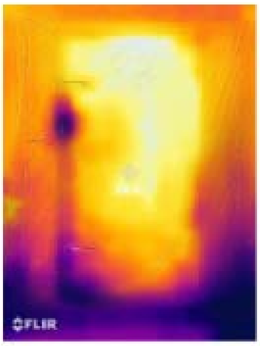
03 Amarmend Tsendee
Insulation questionnaire

Number of felt roofing	2 layers
Number of felt wall	2 layers
Last time the cover was doubled	Always like this
Number of other insulation covers	None
When they moved to their winter spot	Always here
Presence of a vestibule	Yes
Materials used to build entrance barn	Wood
Presence of hard flooring	None
Use of sand and gravel to bed the flooring	None
Material current interior flooring	Single layer of plastic cover
Toono cover material	Felt
Presence of other additional Toono insulation	None
Presence of door insulation	None
Presence of skirt insulation from the outside	None
Presence of floor skirt insulation from the inside	None

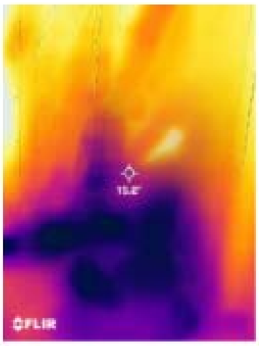
02
Amarmend Tsendee

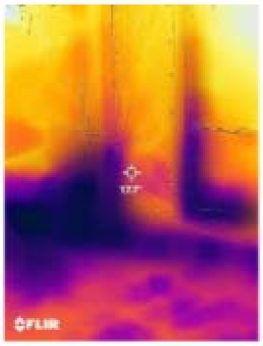
The Amarmend household was the least well insulated of the three households. The felt covers were badly deteriorated and there were substantial gaps around the lower circumference and the doors and wall joints. Especially around the lower circumference where there were places where natural light was coming through. We recommend that the the Amarmend household insulate their ger's lower circumference by blocking in gaps with sand and gravel from the outside. As shown by the thermal images, the insulations provided by Gerhub are effective in blocking air infiltration to some extent. However, the insulations will not be fully effective in the case of the Amarmend household unless they improve basic insulations.

Without insulations

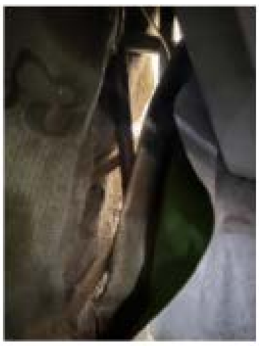


Door cold air infiltration



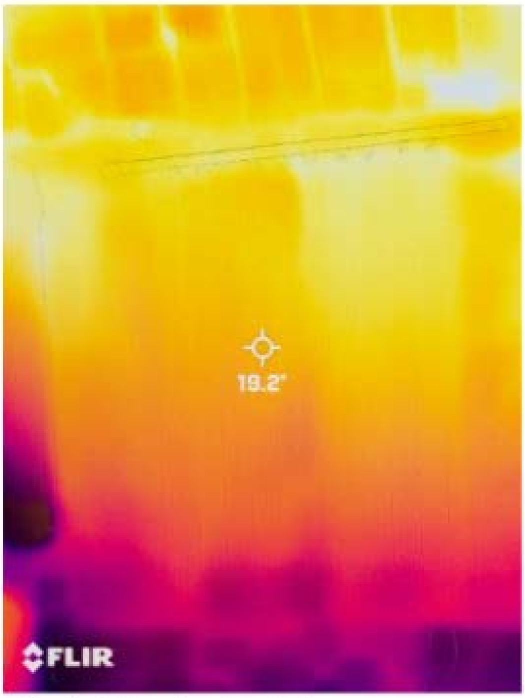


Lower circumference cold air infiltration

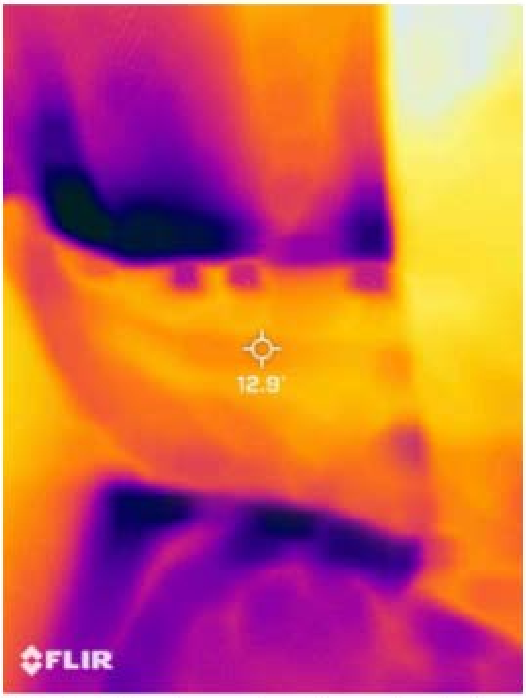


Gap between floor and wall

With insulations



After installing door insulation



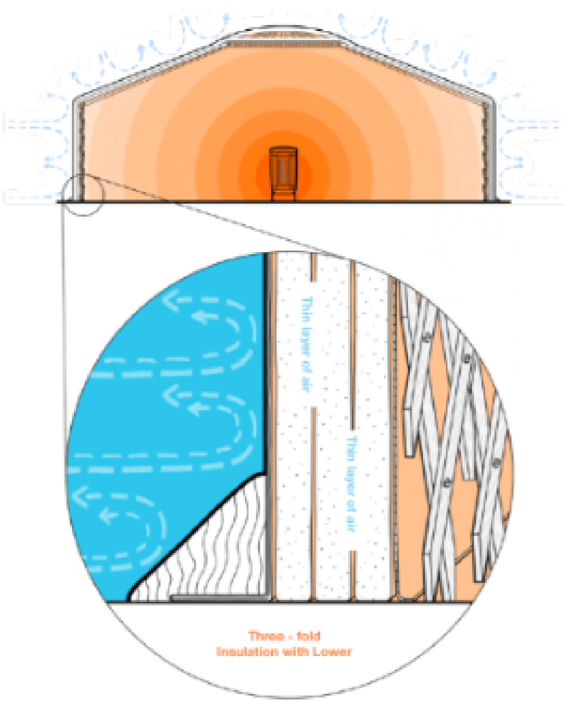
After installing lower circumference insulation

04 Conclusion and Recommendations

The base insulation of the all three households are varying in methods and material quality, which present their advantages and disadvantages. The Davaajargal household benefits from a relatively smaller sized ger and all around balanced combination of double layer felt covers, bigger toono cover and gravel insulation from the outside. The Amarmend household is well insulated from the outside with sand and gravel in addition to having double layer felt cover. The Batnasan household has a door shed that provides some protection from direct wind.

With that being said, their respective insulations are insufficient in preventing infiltration and heat loss due to their inconsistency and the lack of maintenance. The Batnasan household's vestibule is ramshackle and dilapidated, further reducing it's effectiveness. All three households have double layers of felt cover that have deteriorated in quality and effectiveness due to a general lack of maintenance (dismantling the ger down, cleaning the felt and rebuilding the ger).

An ideally well insulated ger would have to employ all of the following base insulation methods in addition to the low cost ger insulations provided by Gerhub.



(Figure above) Three fold insulation can be best effective when the lower circumference is well insulated from the exterior. Furthermore, a layer of air forms between the individual layers of insulation. This trapped air is a remarkable insulator.

- High gravel and sand insulation from the outside (20cm high at the minimum),
- Two layers of felt cover *(three layers of cover if possible),*
- Thick water-proof cover on the exterior,
- No gap between roof felt cover and the toono,
- Wall felt cover tucked into the door frame board,
- Toono insulation cover blanketing all possible gaps (overlapping the roof felt cover by at least 40cm).
- Interior floor skirt insulation (Gerhub),
- Interior door insulation (Gerhub),
- Translucent toono insulation (Gerhub).