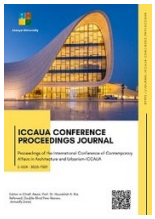

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Carbon Profiles of Mongolian Dwellings: Ger vs. Baishin

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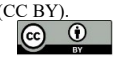

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Abstract

This study evaluates the carbon footprints of two traditional Mongolian dwellings—the portable Ger and the self-built Baishin—through a comprehensive life cycle assessment (LCA). The Ger, prevalent among nomadic communities, relies on wood and coal-fired stoves for heating, leading to high operational emissions despite its minimal embodied carbon. Conversely, the Baishin, a permanent structure constructed from timber, bricks, or concrete, incurs higher embodied emissions but can achieve reduced operational emissions with effective insulation. Utilising OpenLCA and the Ecoinvent v3.11 database, the analysis spans material extraction, construction, operational energy use, and end-of-life disposal under typical Mongolian conditions. Results highlight the Ger's lower cumulative energy demand (880,446,708 MJEq) and ecological footprint (59,409 m²a) compared to the Baishin's higher impacts (934,217,037 MJEq and 279,801,890 m²a). These findings underscore the potential for energy-efficient retrofitting and sustainable material choices to mitigate emissions. The study provides actionable insights for developing low-carbon housing strategies tailored to Mongolia's cold climate, contributing to climate change mitigation while preserving cultural heritage.

Keywords: Ger; Baishin; Life Cycle Assessment; Vernacular Architecture; Sustainable Housing.

1. Introduction

Mongolia's carbon emissions have shown a marked increase in recent decades, with 2023 levels reaching 28 million metric tons of CO_2 equivalent (Mt CO_2 eq) – a 7.7% rise from 2022 and nearly double the country's 1970-2023 average (Boyle, 2024; World Bank, 2023). While animal husbandry and energy sectors drive much of this growth, emerging research reveals the built environment's dual role as both an emission source and potential climate solution (Niu et al., 2024). Vernacular architecture, characterised by localised material selection and climate-responsive designs, demonstrates significantly lower embodied carbon compared to modern construction methods, particularly when using natural materials like timber and hemp lime that act as carbon sinks (Henna et al., 2021; "Historic England open data," n.d.).

Climate-resilient retrofitting strategies for traditional buildings show particular promise, with studies indicating 7-14% reductions in lifecycle carbon through non-invasive modifications that preserve heritage values("Open Research Online," n.d.; "The Embodied Carbon Emissions of Construction and Retrofit Materials for Traditional Buildings | Historic England," 2024). These approaches gain urgency as Mongolia faces compounding challenges: rising emissions from economic development, increased climate volatility, and the embodied carbon costs of conventional construction. Recent analyses of vernacular dwellings in diverse climates reveal their inherent thermal resilience – stone-walled structures in India maintained 40% better U-values than modern equivalents during temperature extremes (Henna et al., 2021), while UK heritage retrofits achieved carbon neutrality through synergistic material choices and occupant behaviour adaptations ("The Embodied Carbon Emissions of Construction and Retrofit Materials for Traditional Buildings | Historic England," 2024). Vernacular building in Egypt has similar carbon emissions to Modern buildings' carbon emissions in warmer climate regions, while the Colombian Bamboo building is already proving carbon reduction (Ali and Hagishima, 2012; Rincón et al., 2023).

The convergence of traditional wisdom and contemporary innovation presents a viable pathway for Mongolia, where nomadic *Ger* structures embody low-carbon design principles. Strategic integration of airtightness improvements, sustainable material sourcing, and passive climate control could potentially decouple urban growth from emission trajectories while enhancing community resilience (Platform, 2025).

As global concern over climate change intensifies, understanding the historical and regional dynamics of carbon emissions becomes essential for developing context-sensitive strategies for the future. Mongolia is experiencing some of the most rapid and severe impacts of climate change globally. Over the past 70 years, the country has seen an average

temperature increase of about 2–2.24°C, which is roughly twice the global average (Erdenesukh, 2003). This warming has been accompanied by shifts in precipitation patterns, increased frequency and severity of extreme weather events, and widespread environmental degradation. With its unique climatic challenges and rapid urbanisation, Mongolia offers a critical case study. Historically, the country's carbon footprint has been shaped by the evolution from traditional vernacular dwellings, such as the *Ger*, to modern construction practices (King, 2012).

Vernacular architecture, deeply rooted in Mongolia's nomadic culture, has long demonstrated adaptive efficiency to extreme climates through low-impact materials and energy-conscious design. Preliminary studies suggest that traditional materials and techniques often result in equal or even lower carbon emissions compared to modern buildings in similarly harsh or warmer climates. However, these contributions are often underrepresented in national carbon inventories (World Bank, 2024).

This paper aims to grasp the historical trajectory of carbon emissions in Mongolia in terms of widely used vernacular housing, *Ger* and *Baishin*, assess the role of vernacular buildings in this trajectory, and explore how traditional design principles can inform climate-resilient building strategies for the future. By bridging past wisdom with modern climate imperatives, Mongolia can pioneer sustainable architectural solutions that are both culturally grounded and environmentally responsible.

2. Methodology and Case Study

2.1. Life Cycle Analysis

To conduct a cradle-to-grave carbon emission analysis for energy consumption and materials using OpenLCA ("openLCA.org," n.d.) Follow this structured approach informed by LCA methodologies and software capabilities. Scope Definitions are adopted a cradle-to-grave framework encompassing: Raw material extraction (mining, logging), Manufacturing (energy use, process emissions), Transportation (fuel combustion, logistics), Product use (operational energy demand), End-of-life (landfill, incineration, recycling) (AIA, n.d.; "Life Cycle Assessment - GSA Sustainable Facilities Tool," n.d.). Ecoinvent v3.11("ecoinvent v3.11," n.d.) The database in the OpenLCA software is used to calculate the Cumulative Energy Demand (CED) for 50 years of total energy consumption, 1975-2025 and Ecological Footprints.

Table 1. LCA Principle and Framework (ISO 14040:2006, 2006).

Building Life Cycle									
Product			Construction		Use stage			End-of-Life	
A1	A2	A3	A4	A5	B1	B4	B6	C1	C2
Raw maternal supply	Transport	Manufacturing	Transport	Construction installation process	Use	Replacement	Operational Energy	Deconstruction and demolition	Disposal
Cradle to Gate									
Cradle to practical completion									
Cradle to Grave									

2.2. Vernacular dwellings *Ger* and Baishin

The *Ger* is a traditional Mongolian dwelling designed for the harsh climate of the steppe. While *Gers* (also called yurts in other regions) typically have a circular shape with a frame made from wooden poles and a felt covering, the number of layers of material used to insulate and protect the structure. The size of the *Ger* is distinguished by the number of walls. 5 walls *Ger* is widely used for living (Purev and Hagishima, 2020). Therefore, in this study, the carbon footprint of 5 walls *Ger* is analysed. Figure 1 represent the nomadic *Ger* in Mongolia.

The base structure of a *Ger* is made of a wooden frame, which consists of lattice walls (khana) and a roof support system (uni). The frame forms a circular shape that is assembled on-site. The wooden lattice walls are flexible yet strong, allowing for disassembly and portability. The roof of the *Ger* is held up by a central support called the *uni*, which is a circular crown-like structure. The roof is also covered with felt, and an opening at the top (called the *toono*) provides ventilation, especially in summer. Insulation layers consist of several layers of textile. The innermost layer is typically a thin cloth or fabric. It serves as an initial barrier from the cold and often holds up decorative fabric. Felt is the most common and important insulation material in a traditional *Ger*. Wool felt, made from the fleece of sheep, is around 20mm thick and usually 2 layers of felt cover used. The outermost layer is often made of canvas (Tarpaulin), which helps protect the structure from external weather elements, especially rain or snow. It also prevents wind from tearing at the felt. This outer layer is typically coated with waterproofing agents to keep the *Ger* dry (King, 2012).

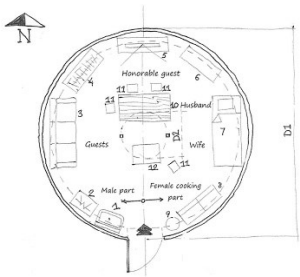
a)  b)  c) 

Figure 1. a) View of the *Ger* from outside b) Interior of the *Ger* c) Layout of the *Ger*.

The distance between the *Ger* for residence and the livestock enclosure can be covered around 200m (Kawagishi et al., 2010). Materials and Structure of the *Ger* are quoted based on Mongolian Standards (MNS 0370:2003, 2003; MNS 5801:2007, 2007; Purev and Hagishima, 2020). Table 2 represent the quantified materials of the 5 wall *Gers*. The annual energy consumption of the nomadic *Ger* is quantified as 0.4 MWh (Ganchimeg, 2014).

Table 2. The quantity of materials used for the 5 walls of the *Ger* (MNS 0370:2003, 2003; MNS 5801:2007, 2007).

	Category	**Main materials**	**Quantity**	**Unit**
A	**Earth and Ground Work***			
B	**Foundations and External Structures***			
C	**Frame and Roof Structure**			
1	Wooden external walls	Lattice wall	0.063	m^3
		Uni	0.526	m^3
		Column	0.012	m^3
		Column head	0.005	m^3
		Floor	0.186	m^3
D	**Complementary Work**			
1	Door	Felt	22.7	kg
		Cotton	12.5	kg
		Silk	0.045	kg
		Tarpaulin	5.15	kg
E	**Finishes**			
1	Roofing	Felt	289.4	kg
		Cotton	157.8	kg
		Silk	0.6	kg
		Tarpaulin	65.8	kg
2	Wall	Felt	313.5	kg
		Cotton	171	kg
		Silk	0.65	kg
		Tarpaulin	71.25	kg
3	Lower wall	Felt	625	kg
		Cotton	342	kg
		Silk	1.2	kg
		Tarpaulin	142.5	kg
	Total of Complementary Work and Finishes			
		Felt	1252.5	kg
		Cotton	683.2	kg
		Silk	2.5	kg
		Tarpaulin	284.7	kg

Baishin is a self-built detached house. According to a past study (Yatsuo, 2015) wooden *bai-shin* finishes with stucco are mainly used in informal settlement areas, detached housing. The size of the analysed baishin is a single-floor 10m x 6 m wooden baishin. Figure 2 shows a typical wooden baishin in Ulaanbaatar, Mongolia(Yatsuo, 2015). The annual energy consumption of the Baishin is 641.4 MWh in terms of heating by electricity (ikon.mn, 2025). Qualified materials of the baishin are represented on Table 3.

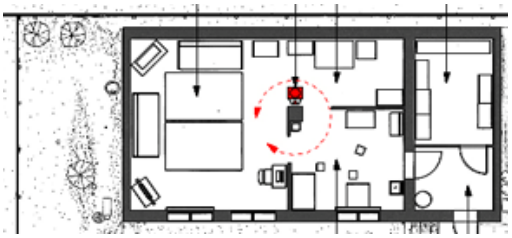
a)  b)  c) 

Figure 2. a) View of the baishin from outside b) Interior of the baishin c) Layout of the baishin (Yatsuo, 2015).

Table 3. The quantity of materials used for the bashin based on past study (Yatsuo, 2015).

	Category	Main materials	Quantity	Unit
A	**Earth and Ground Work***			
B	**Foundations and External Structures**			
1	Reinforced Concrete	Concrete	255600	kg
2		Steel, low-alloyed	12000	m3
C	**Frame and Roof Structure**			
1	Wooden external walls	Sawnwood	28.8	m3
2	Timber roof	Sawnwood	8	m3
3	Metal roofing	Metal	80	m²
D	**Complementary Work**			
1	Windows	Wood	1	m²
		Glass	3	m²
2	Lightweight partition wall	Sawnwood	9	m3
		Wood panel	36	m²
E	**Finishes**			
1	Roofing	Bitumen adhesive compound (2.5kg/m²)	200	kg
		Steel, low-alloyed	5	kg
3	Ceiling	Glasswool	128	kg
		Gypsum plasterboard	600	kg
4	Flooring	Laminate	60	m²
5	Painting	Alkit paint	10	kg

2.3. Flow of the LCA analysis

The Life Cycle Assessment (LCA) analysis focuses on the material production and embodied energy consumption of a *Ger*, a traditional Mongolian dwelling and a *Baishin*, a self-built wooden detached house in Mongolia. Figure 3 Illustrate the flow of the LCA analysis. The process begins with raw material extraction, where materials like wood, felt, and fabric are gathered. These materials are then processed into building components, such as the frame, roof structure, and finishes. The production phase involves transforming raw materials into usable components, which include the frame and roof structure as well as finishes for insulation and aesthetics. The final outputs of the LCA are the Cumulative Energy Demand (CED), which measures the total energy required throughout the product's life cycle, and the Ecological Footprint, which reflects the environmental impact, such as resource use and emissions. This analysis helps evaluate the sustainability of a *Ger* and *Baishin*'s construction process and its environmental effects over time.

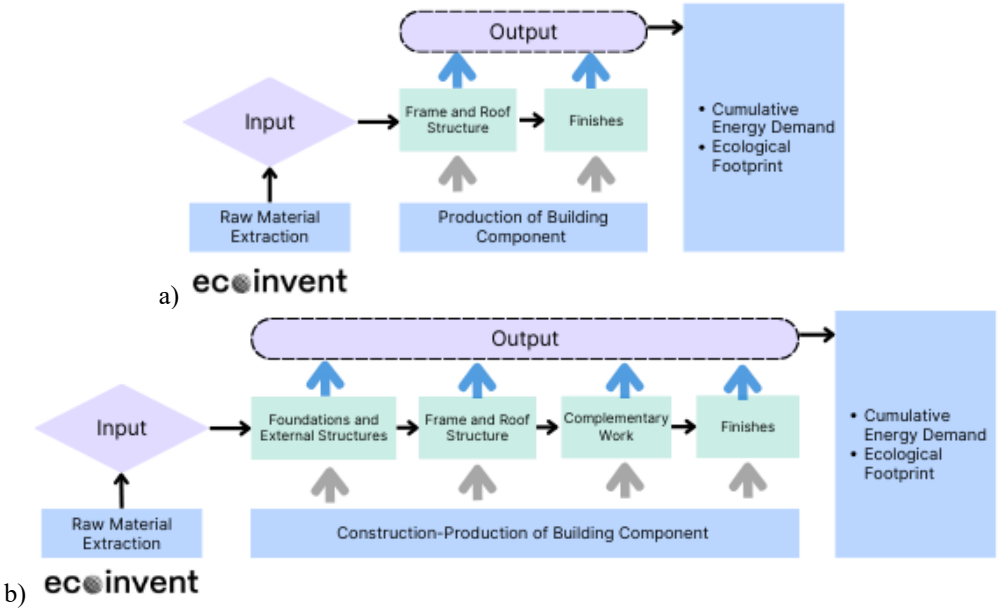


Figure 3. a) Flow of the LCA analysis for *Ger* b) Flow of the LCA analysis for *Baishin.*

3. Results

This study presents a comparative Life Cycle Assessment (LCA) of two building types, *Baishin* (MN) and *Ger-1* (MN), to evaluate their environmental impacts across key categories: Cumulative Energy Demand (CED) and Ecological Footprint. These two building types were analysed based on their total energy consumption and environmental footprint, including land occupation, CO2 emissions, and the use of nuclear energy. The results are intended to help assess the sustainability of each building type and guide decision-making for more eco-friendly construction.

Figure 4 Represent the Cumulative Energy Demand (CED) for two building types: *Baishin* (MN) and *Ger*-1 (MN). CED is a measure of the total energy consumed during the life cycle of a product or system, expressed in MJ (megajoules) or MJ Equivalents (MJEq), and represents the energy required from all sources to produce, maintain, and dispose of the building components. The graph breaks down CED into different energy categories, such as: Renewable energy resources, Non-renewable energy resources and Water-based energy resources. These categories are represented by horizontal bars, with the length of each bar corresponding to the energy demand for each resource type. The *Baishin* (MN) building consumes significantly more energy from renewable resources (especially geothermal and wind energy) compared to the *Ger*-1 (MN) building. The *Ger*-1 (MN) building, on the other hand, has a relatively lower energy demand from non-renewable resources like fossil fuels and nuclear energy. The total energy demand is represented by the final bars at the bottom, showing that the *Baishin* (MN) has a higher Cumulative Energy Demand (CED) at 934,217,037 MJEq, while the *Ger*-1 (MN) has a lower total energy demand of 880,446,708 MJEq.

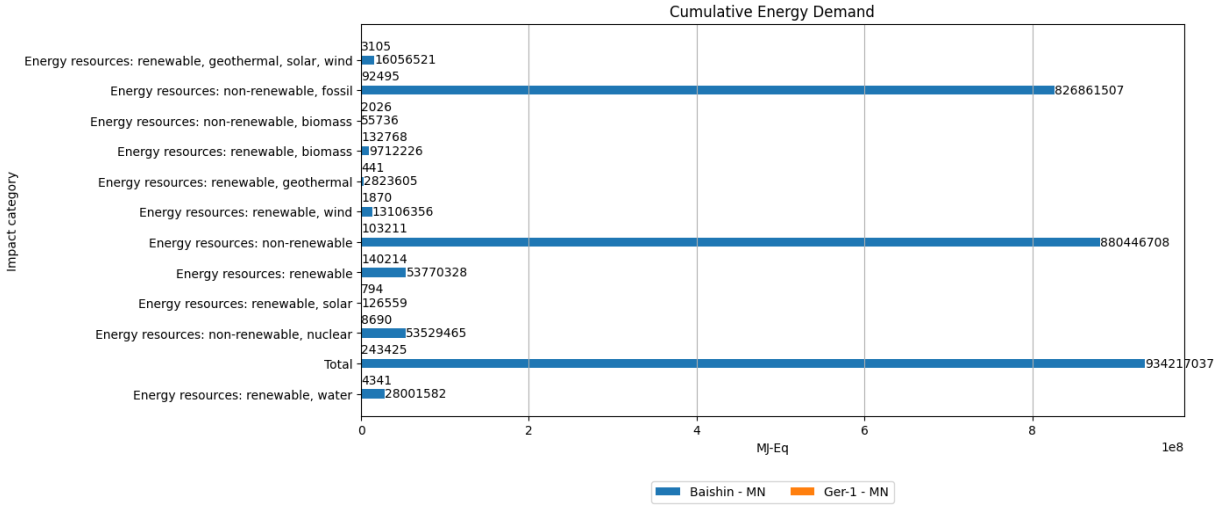


Figure 4. The Cumulative Energy Demand (CED) for two building types: *Baishin* (MN) and *Ger*-1 (MN).

Figure 5 shows the Ecological Footprint of two building types, *Baishin* (MN) and *Ger*-1 (MN), across different impact categories. The ecological footprint measures the environmental impacts of these buildings, particularly in terms of land occupation, CO2 emissions, and nuclear energy usage. The results are presented in terms of m²a (square meters per year) and m²a equivalents. Land occupation represents the land area required for the construction and use of each building. The *Baishin* (MN) building has a much higher land occupation at 7,639,779 m²a, compared to *Ger*-1 (MN), which requires only 34,668 m²a. This suggests that the *Baishin* building has a larger footprint in terms of land area, possibly due to its size or construction type. The total ecological footprint combines all the environmental impacts, and

in this case, the *Baishin* (MN) building has a significantly larger footprint (279,801,890 m²a) compared to the *Ger*-1 (MN) (59,409 m²a). CO2 emissions are generated throughout the building's life cycle. The *Baishin* (MN) building has a much higher CO2 footprint (26,167,404,048 m²a) compared to *Ger*-1 (MN), which has a CO2 footprint of 23,038 m²a Overall the graph indicates that *Baishin* (MN) has a much larger ecological footprint across all measured categories (land occupation, CO2 emissions, and nuclear energy) compared to *Ger*-1 (MN). This suggests that the *Baishin* (MN) building type is more resource-intensive, requiring more land and generating more CO2, while *Ger*-1 (MN) is more sustainable, with a smaller overall environmental impact.

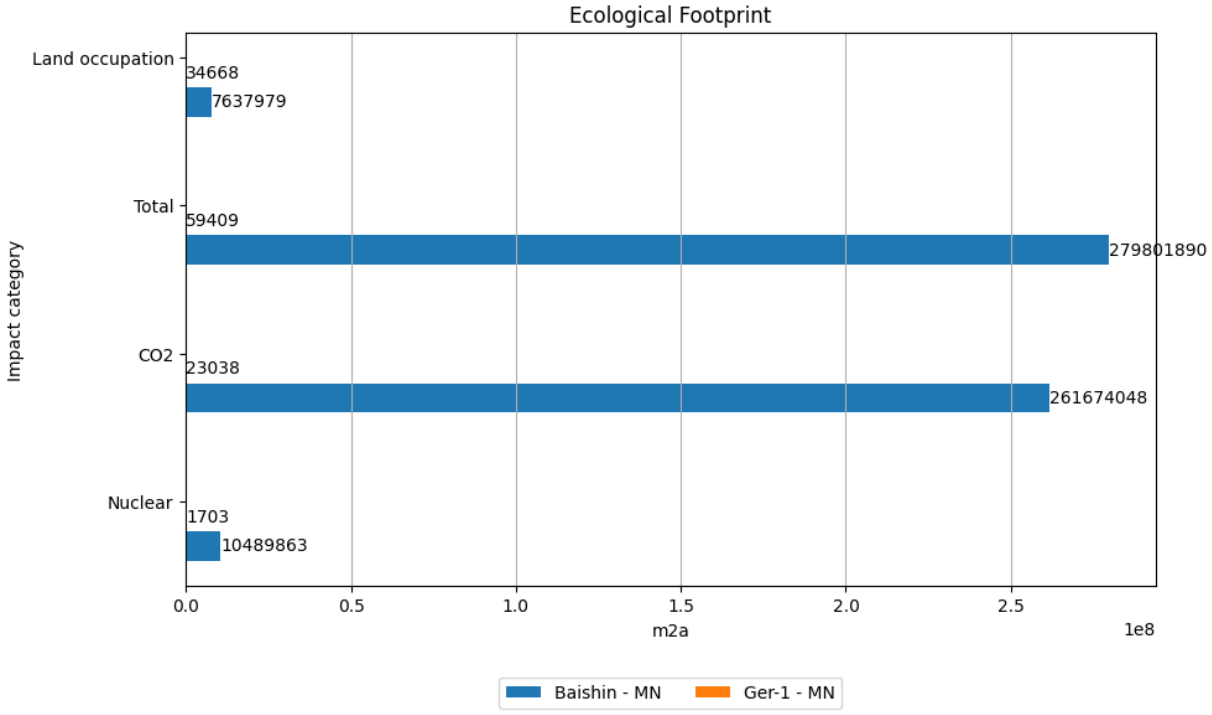


Figure 5. The Ecological Footprint of two building types, Baishin (MN) and *Ger*-1 (MN), across different impact categories.

4. Discussions and Limitations

This study provides valuable insights into the carbon profiles of the *Ger* and *Baishin* but is constrained by several limitations. Firstly, the LCA did not account for the pasture land required for the *Ger*'s nomadic lifestyle, particularly the grazing land needed for sheep that supply wool for felt insulation. This omission likely underestimates the *Ger*'s ecological footprint, as livestock grazing can contribute to land degradation and methane emissions, which are significant in Mongolia's pastoral economy. Secondly, water use was excluded from the assessment for both housing types. The production of felt for *Ger*s involves water-intensive wool processing, while *Baishin* construction relies on water-heavy materials like concrete. In Mongolia's arid and semi-arid climate, water scarcity amplifies the environmental significance of these processes, and their exclusion limits the comprehensiveness of the ecological footprint analysis. Thirdly, the study assumed typical conditions for material sourcing and energy use, which may not fully capture regional variations in Mongolia's diverse climates and resource availability. Finally, the analysis did not consider the social and cultural implications of retrofitting or replacing during the 50 years of the life cycle of the *Baishin*, which could affect community acceptance of proposed sustainability interventions. Future studies should address these gaps by incorporating land and water use data, exploring regional variations, and assessing socio-cultural factors to ensure a more complete evaluation of the dwellings' sustainability.

5. Conclusions

This study provides a detailed comparative analysis of the carbon profiles of Mongolia's traditional dwellings, the *Ger* and the *Baishin*, revealing distinct environmental impacts shaped by their design, materials, and usage. The *Ger*'s lightweight structure, characterised by its portable wooden lattice frame and felt coverings, significantly enhances its sustainability by minimising material use and embodied carbon, with a cumulative energy demand of 880,446,708 MJEq and an ecological footprint of 59,409 m²a. This design allows for easy disassembly and relocation, reducing resource consumption and waste, aligning with circular economy principles. However, its operational emissions, driven by coal and wood-based heating, highlight a critical area for improvement through cleaner energy alternatives or enhanced insulation. In contrast, the *Baishin*'s higher embodied carbon, stemming from energy-intensive materials like concrete and steel, results in a greater environmental impact, with a cumulative energy demand of 934,217,037 MJEq, substantial land occupation (7,639,779 m²a), and CO_2 emissions (26,167,404,048 m²a). Its potential for lower operational emissions through insulation is notable but insufficient to offset its construction footprint.

The *Ger*'s lightweight, low-material design offers a model for sustainable housing, demonstrating how vernacular architecture can reduce environmental impacts while maintaining cultural significance. Strategies such as retrofitting *Ger*s with airtight, sustainable insulation, adopting renewable energy sources for heating, and optimizing *Baishin* construction with low-carbon materials could significantly enhance their environmental performance. By integrating

traditional design wisdom with modern sustainable practices, Mongolia can address its rising carbon emissions, preserve cultural heritage, and adapt to the challenges of rapid urbanization and climate change. This research lays the groundwork for policy and design interventions that promote sustainable, context-sensitive housing solutions in cold climates.

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Conflict of Interests
The Author(s) declare(s) that there is no conflict of interest.

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