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Discussing the Ger Plug-In housing prototype as a sustainable and affordable housing model that addresses urgent issues arising from the growth of Ulaanbaatar's ger districts.

The Ger Plug-In: demonstrating a model for sustainable and affordable housing in Ulaanbaatar's fringe districts

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The ger, or traditional felt tent, is designed according to the demands of nomadic life. It is portable, can be easily disassembled and reassembled without any mechanical fixings, and its component parts are prefabricated and can be bought at everyday markets. A ger costs between US $600–$1,000, making it the most economical form of housing in the city. Its ease of transportation, affordability, and reproducibility in large numbers have been one of the main contributing factors to the speed and extent of the urbanisation process in the city of Ulaanbaatar *[1]*.

The population of the city has increased by 230% in the last twenty years[1] resulting in the creation of sprawling districts with no basic infrastructure that nevertheless house over 60% of the city's population. The cold winters, with temperatures reaching -40°C, mean that each ger district household uses around 3.8–5 tonnes of unrefined coal as their main heating source, contributing to toxic air pollution reaching levels reported to be 133 times higher than the World Health Organization (WHO) guideline.[2] Water is collected from water kiosks with families making at least eight trips per week to collect approximately 500 litres of water and 95% have access only to pit latrines.[3] As the population of the city has grown by an average of 38,000[4] each year between 2000–19, the urban risks associated with this form of settlement are increasing, particularly with respect to sanitation, freshwater supply, and air quality.

1 The Ger districts of Ulaanbaatar, Mongolia.

Process of transformation of ger districts

On arrival in the city most migrants continue to live in a ger within a land plot that they either claim, share with others who are often relatives, or rent. The 2002 land law allowed every Mongolian citizen to own a plot of up to 700 sq m, which has contributed to the expansion of the city's area. Over time, some residents have modified their ger adding simple wooden thresholds to prevent heat loss or building permanent concrete foundations to limit cold from the ground. Over 65%[5] of families build a simple house or *baishin*, yet based on our fieldwork, most retain a ger on the plot for additional family members, storage, or as a summer kitchen. Most still lack internal toilets and showers and are ineffectively thermally insulated. Ninety-three per cent of houses have less than 100 mm of insulation, with an average thickness of 35–60mm of expanded polystyrene (EPS) or wool, which does not meet the minimum standard set by the 'Switch Off Air Pollution Project'.[6] For self-built homes using 60 mm of EPS insulation, the approximate wall element U-value range is 0.63 W/m^{2}k for timber construction, 0.28 W/m^{2}k for blockwork, and 0.57 W/m^{2}k for brick.[7] These all fall below the Mongolian National Building Standards (BNbD23-02-09) on the 'Thermal Performance of Buildings', and the UK Building Regulations under 'Approved Document L: Conservation of Fuel and Power. Section 4: Limiting heat gains and losses' for a new buildwall element which has a U-value limit of 0.26 W/m^{2}k. The World Bank (2010)[8] has also reported that 85% of ger district residents use wood or coal-burning stoves for heating. Overtime, more established districts densify through subdivision, becoming more consolidated urban grids, while the newer districts continue to expand into virgin territory. Despite subdivision, the predominant housing typology (other than a ger) is a detached single-family house and so density is low, ranging between 2.1 structures/plot in the older districts (plot size averaging 453m^2) to 1.6 structures/ plot in the outer, newest districts (plot size averaging 734m^2). This form of urban sprawl is clearly unsustainable as each new resident contributes to worsening pollution, toxic waste, and pressures on water supply.

Because the majority of residents own their land, large-scale development requires huge investments towards compensation and infrastructure. Current redevelopment plans are undertaken through loans from the Asian Development Bank (ADB) that will ultimately have to be paid back. Mongolia currently has upwards of US $3.31 billion amount of loans, grants, and technical assistance commitments with the ADB with US $375.49 million allocated for 'Water and Other Urban Infrastructure and Services', which includes ger district redevelopment.[9] The Ger Area Development Investment Program (GADIP) invests in heating, water, and sewage infrastructure, together with kindergartens and commercial spaces to upgrade secondary subcentres. The Green Affordable Housing project promotes the creation of eco-districts comprised of six-storey townhouses with shared greenhouses supported by infrastructural connection. The project is reliant on landowners being compensated for their land in the form of 35 sq m apartments and the involvement of the private sector to deliver 10,000 affordable green housing units and redevelop 100 hectares of ger areas.[10] Even if realised, these plans will not impact the fringe districts of the city. Given that 21,000 new migrants move to the city each year,[11] an alternative solution for these sites is necessary.

Housing options

Many residents self-build their homes to a poor standard, lacking basic infrastructure with low thermal performance. An average home or *baishin* is around 50 sq m and costs around 21 million MNT (US $7,460). Some ger district residents opt to move to an apartment in the city. These have central heating and sanitation and cost approximately 80 million MNT (US $28,400) for a 40 sq m flat. It is estimated that of the 249,132 households living in a ger or single-family house, 24% would be willing to upgrade their current housing conditions on their plot.[12] They are hindered by two factors. Firstly, the lack of financial products that can enable them to borrow money at a reasonable rate and secondly, the limited number of housing products with improved energy efficiency and access to infrastructure currently available on the market.

Since 2018, new eco-banking products have been made available through financing from The Green Climate Fund, a fund set up by the United Nations Framework Convention on Climate Change (UNFCCC). The Green Climate Fund approved programmes proposed by different local financial institutions in the form of bank loans in October 2018.[13] This allows local banks to create mortgage products to access these better loan rates, 8–12% compared to 18%,[14] based on delivering housing that meets the criteria of a 20% improvement to the thermal performance stipulated by the Mongolian regulations.

The Energy Efficient Project was launched in 2020 by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), a German federally owned development agency. The project aims to set up a mechanism to link construction companies and their housing products to sustainable financial instruments if they meet criteria set out by a standardised process of thermal performance evaluation. Currently fourteen different housing products have been taken up by the scheme, each using different systems of construction, and five have been built in the grounds of Kindergarten 188 in Songino Khairkhan district as a showcase for people to view and to learn more about financing options. To kickstart the scheme, GIZ offered a 30% subsidy to the first fifty customers taking out a loan. Each product was costed between US $21,000–28,000 and ranges in area from 38.8–58.8 sq m. The aim of the project is to develop an alternate housing type that can meet or exceed the thermal performance criteria as stipulated in the Energy Efficient Project from GIZ and the criteria from leading banks such as XacBank to qualify for low interest rate green mortgages.

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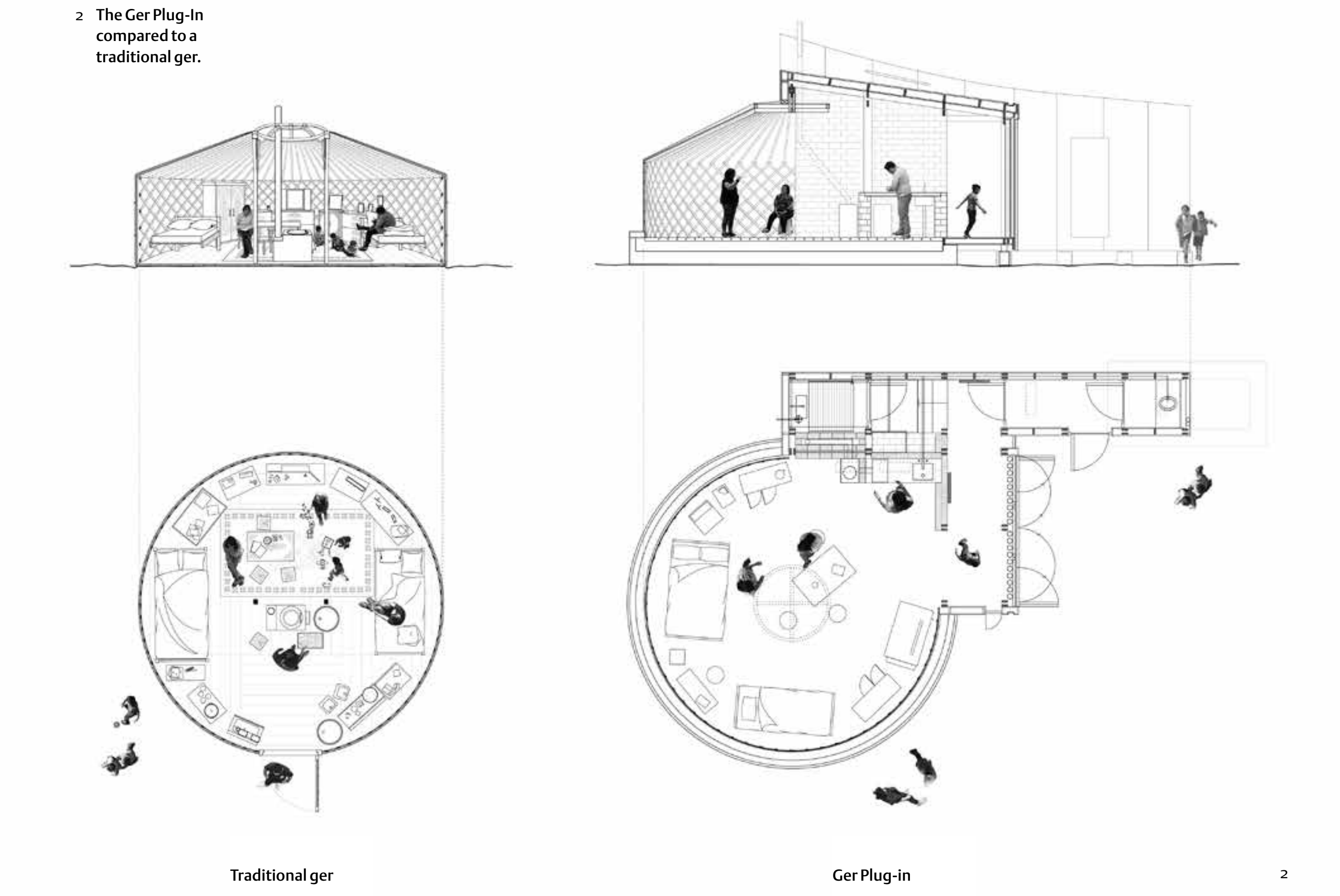
Additionally, the idea is to create a housing model that integrates the traditional ger with new construction, without compromising on performance. This is important as the ger is still a predominant dwelling type and is fundamental to Mongolian identity. Despite the shift from nomadic to sedentary living, our research indicates that even when people live in a house, the ger is still present on the plot and used to accommodate additional family members, or as a kitchen, or for storage. In one of our sample districts, 40% of plots with houses still contain one or more gers. Furthermore, the GIZ projects although built, are not inhabited, and the method of thermal performance is based on calculations from drawings based on material U-value properties. The methodology of this project is to build a prototype as a 'live experiment' whereby the house will be constructed and lived in, allowing both qualitative data and quantitative data to be constantly collected and updated.

The prototype: Ger Plug-In

The Ger Plug-In fuses the traditional structure of a ger with timber frame construction. A new truss suspends the ger from above, allowing the centrally placed columns to be removed and the stove to relocate within the thermal mass of a brick wall. This creates an open, obstruction free, and safer space, providing the family with more options for how they wish to inhabit the room *[2]*. The project improves the environmental performance of the household providing a septic treatment system and toilet; water tank and shower; underfloor heating; an electric boiler and a passive solar *trombe* wall made of black polyvinyl chloride (PVC) pipes filled with sand. The systems were selected after an appraisal of available technologies and costs. For water supply, other than truck delivery the only option would be to dig a well. The cost to reach the aquifer would be in the region of 10,000,000 MNT–12,000,000 MNT (US $3,500–$4,200),[15] making it unaffordable at a household scale. For the toilet system, the pros and cons of a flush system were weighed up against a dry, composting toilet. Given that the average temperatures between October and March fall below zero, composting toilets require additional engineering and heating, making it impractical. The selected septic tank, although water based, treats the waste on site and provides excess treated water that can be used for irrigation. The Ger-Plug in provides 7.7 sq m of glazing and average daylight factor of 4.5% compared to both the Mongolian Natural and Artificial Lighting Building Standard, and CEN (European Committee for Standardisation) Daylight Standard of ≤2%. For energy supply, Mongolia has an abundant supply of sunlight with an average photovoltaic (PV) potential of 4.3192GHI, kWh/m, which falls into the top seventy countries with the best conditions for PV.[16] However, the cost of a PV system with panels, battery storage, and an inverter is still too high for household application: a 3kW system to cover the electrical heating of a household would cost a family over US $5,000.[17] A recent attempt to trial the use of solar panels in the ger districts and to trade the resulting carbon credits may prove to be a mechanism to reduce costs and advance the transition towards

2 **The Ger Plug-In compared to a traditional ger.**



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3 The Ger Plug-in, Ulaanbaatar, Mongolia.

longer-term sustainability. However, this trial is in initial stages and the carbon market in Mongolia has to be developed as there are no measurement tools to verify the local emission reductions and to value them for the market, especially at a household scale.[18] Although they also require the burning of fuel, an mCHP (micro combined heat and power) unit would also be more efficient than electricity from the grid, but it is difficult to achieve efficiency of space and cost. A mCHP system for one to two households would require an 8 sq m engine room with additional storage space for fuel, and cost around US $15,000. Given these issues, and that the majority of energy demand is for heating, the key aim is to reduce energy consumption by increasing the thermal performance of the house. By using electricity that is produced in power stations away from populated areas instead of coal for heating, a significant reduction of air pollution can be achieved in the ger districts. Together these systems act to provide much needed basic infrastructure to the ger, reduce coal consumption, and improve energy performance.

The Ger Plug-In was completed in 2017 and a couple (Urangua aged thirty-three and Zulaa aged twenty-six) moved in [3]. They allowed us to build on their land and to access the building to conduct experiments in exchange for the structure which was funded by a private donor. Every month we asked them to provide their electric bills, and to measure their water and coal consumption. Every three months we conducted an interview to ascertain changes to their living quality. Observations of alterations in their everyday life and evidence of consumption formed a basic contextual understanding of the performance of the Ger Plug-In before commencing more detailed quantitative studies. After living in the Ger Plug-In for one year between September 2017 and September 2018, we have observed the following changes to the couple's living quality [4, 5]. Instead of having to walk thirty minutes to collect water every day, the residents have access to a one-tonne water tank – which is filled by a truck every seven to ten days. The couple take three showers a week in winter and every day during summer. They also share the shower with other families in the district. During the winter of 2018 when the lowest recorded temperature was negative -39°C, they no longer had to leave the house to access the toilet. They preferred to use electricity for their energy source rather than coal. The electrical costs were 84,400 MNT per month, or 1,590 MNT/m^2 on average for the winter (November 2018 to March 2019). This compares to an average electrical consumption of approximately 1,660 MNT/m^2 during winter for a typical ger household. In terms of coal, the residents used an estimated 93% less coal than their previous year living in a ger, an estimated 0.266 tonnes compared to an average of 3.8 tonnes. If each of the 163,000 ger households[19] was replaced by a Ger Plug-In this would result in an estimated saving of 576,042 tonnes of coal per year.

Methodological approach

The qualitative evidence provides positive feedback to support the viability of the Ger Plug-In prototype in terms of reducing coal use and having access to sanitation. However, to demonstrate more precise evidence to prove that the Ger Plug-In qualifies as a

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4 Ger Plug-In with thermal shutters open.
5 Ger Plug-In interior with Zulaa and his brother.

sustainable and affordable housing product, we have undertaken a two-fold approach. Firstly, to prove it performs better for energy efficiency than the Mongolian standard, an EUI figure based on thermal data was calculated. Secondly, household surveys were conducted to show that there is a market demand for the product and whether, based on financial data of residents, it is affordable. This mixed methodology using both quantitative and qualitative data, allows us to present the case to organisations such as GIZ and to the banks to link it to available financial tools.

Methodology: quantitative research

The objective is to establish a verified figure for the EUI, using onsite measurements and numerical modelling. Although the 'Building Norms and Regulations of Mongolia' use U-values to assess the thermal performance of buildings, both XacBank and the Mongolian Sustainable Finance Corporation have set EUI baselines based on the energy consumption of typical gers and self-built houses. EUI is a conventional indicator to evaluate energy efficiency for building design and operation. It is used to benchmark and to set targets for energy

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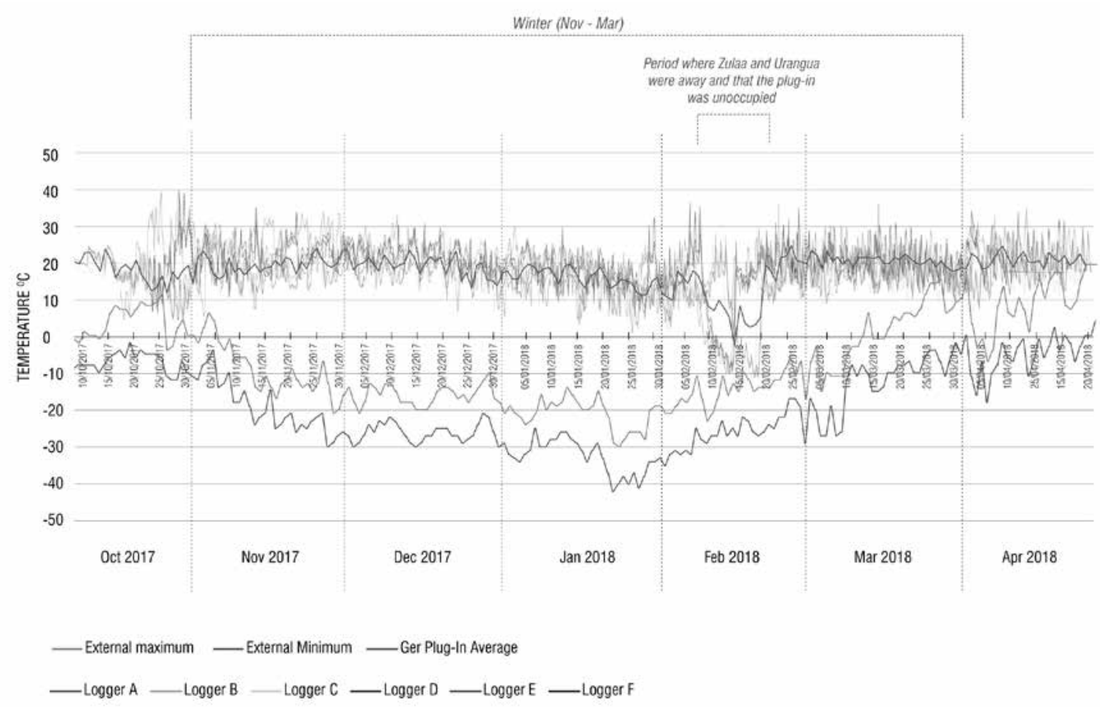
performance with respect to a specific climate condition. It is also possible to convert the energy used to the equivalent carbon emission when the source of energy generation is known. For the situation in Mongolia, the source of energy is mainly obtained by burning coal and the conversion factor for carbon emission from energy used is 14.65 MJ/kg Coal.[20]

The field data recorded the temperature inside the house against the outside temperature to show that the thermal environment is suitable for living and to monitor any temperature fluctuations. The numerical modelling was used to analyse the house design to suggest improvements to the performance and to find if any elements were underperforming and therefore could be removed. For example: to verify the optimum thickness of insulation; or whether the additional costs associated with triple glazing over double glazing were cost effective in terms of thermal performance. The measured temperature data was also used to correlate and validate the numerical model.

6a Measured Temperature for Ger Plug-in (October 2017 to April 2018).

6b Measured Temperature for Ger Plug-in vs Traditional ger (1–10 December 2017).



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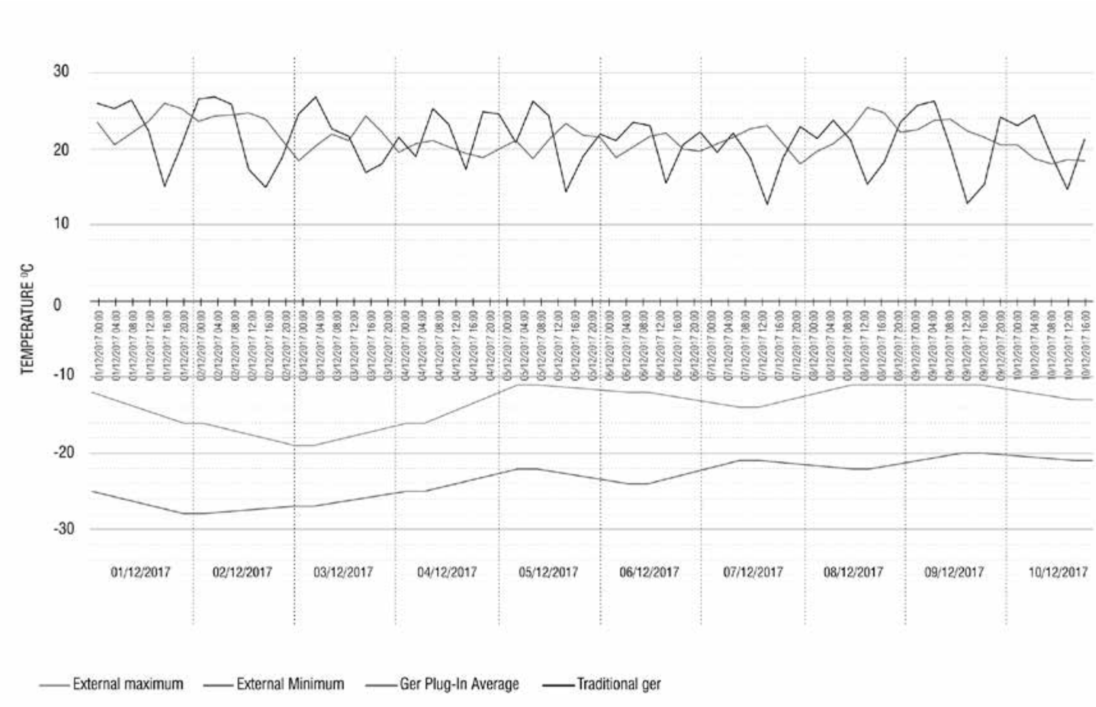

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Onsite measurements
Six HOBO UX100 data loggers were installed in the Plug-In in October 2017 at different locations, such as in the main living space, entry threshold, and oculus rooflight. Data from all loggers recorded temperatures at four-hour intervals daily from October 2017 to October 2018 *[*6a*]*. Data was also collected from four traditional gers between 6 October 2017 and 18 December 2017, with the average temperature calculated to form a baseline reading understood as a typical ger during the winter, This was used to compare the performance of a typical ger to the performance of the Ger Plug-In *[*6b*]*.

Construction material and operation profiles
The Ger Plug-In was built with material selected for a balance between performance and cost. For example: increasing the thickness of the insulation increases performance but also cost. According to the construction materials for different parts of the building, an IESVE model has been built using its library of materials with thermal properties, and assigned to the appropriate wall, roof, and floor surfaces. A summary of the materials and estimated building operation parameters used in the Ger Plug-In are detailed in Table 2.

Integrated Environmental Solutions – Virtual Environment (IESVE)
In addition to the onsite measurement, simulation was conducted for this study. Even though onsite measurement was undertaken for more than one year capturing the annual variation, simulation can be used to predict other time periods. Moreover, the simulation can test performance by varying the external conditions or changing the construction material. With a correlated model using the onsite measurement against the simulated results, the correlated simulation can be used to give further insights on the design and operation. This study used a dynamic simulation software, Integrated Environmental Solutions – Virtual Environment (IESVE), which is an approved energy simulation software for LEED® Certification Program. IESVE is a software for integrated building performance analysis providing tools for solar, external temperature, thermal analysis, heating and cooling load calculations, energy cost, lifecycle, airflow, and lighting.[21] By comparing model predictions against real measurements, a reasonable level of confidence in the IESVE has been achieved. It has been demonstrated that the IESVE model can make estimates and predictions to a reasonable level of accuracy for the purpose of examining design changes.

IESVE uses first-principles models of heat transfer, which are driven by real weather data. The model uses three-dimensional geometry of the house together with the following data: site location and local weather conditions; layer-by-layer thermo-physical properties of building elements including the wall, roof, floor, and glazing; sensible and latent gains from lights, equipment and occupants; natural ventilation and infiltration; and plant operation profiles, efficiency and fuel characteristics. With the calculations of solar impacts, indoor loads, system and building construction details, IESVE can evaluate the building performance in a variety of output aspects including: internal load distribution; thermal performance of the building, room, surface and glazing; energy and/or fuel consumption details in hourly, monthly, and annually basis; and the surface temperature and room temperature. The IESVE model simulated the impact of the building thermal insulation performance on the building energy consumption. IESVE models were conducted for the Ger Plug-In using the following input parameters:

- Building geometry based on building layout;
- Construction material details;
- Home equipment and small power of the houses; and
- Estimated occupancy density, occupancy profile and equipment operating profile.

Quantitative results
Findings from onsite measurement
The initial findings from the data recorded between October 2017 and October 2018 with the data loggers, and the comparative data from summer 2019 show:

- From October 2017 to December 2017, when the external temperature was between -9.9C and -19.8°C. The Plug-In was 2.48°C warmer than the interior of a traditional ger.
- The average daily temperature fluctuation in a traditional ger is 10.2°C, whereas it is only 4.1°C in the Plug-In.
- There was a period when the Plug-In was unoccupied during February 2018 (external temperatures average between -12.5°C and -23.4°C). During this time, heat loss occurred primarily in the threshold by the door, then at the glazed area and the brick cavity wall. Overall, it took five days for all parts of the interior to reach negative temperatures.
- Once the heating is switched off, the Plug-In remains at comfort level (above 15°C) for up to twelve hours.
- The Ger Plug-In reduces temperature extremes in the summer. Between June 2019 to August 2019, the temperature range in a traditional *ger* is from 10.2°C to 32.2°C, where it was 12.0°C to 20.8°C in the Ger Plug-In.

Findings from simulation
Using the test data from January 2018, we were able to measure temporal and spatial variations from different measurement points in multiple locations over a period of time. This was correlated with the simulation results to determine the energy usage for the Ger Plug-In. Using the average simulated results against the average test data, the EUI is 211 kWh/m^2/yr. (Based on the modelled floor area of 47m^2). Given that the actual situation is more complicated than the simulation process, it is helpful to estimate the possible lower and upper boundaries for EUI, to take this uncertainty into account. The EUI lower and

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upper boundaries are estimated to be 171 and 244 kWh/m²/yr. The lower boundary was calculated by taking the lowest set of temperatures to match with the average temperature in the simulation, and the upper boundary was calculated by taking the highest set of temperatures to match with the ones in the simulation.

Correlation and verification of results
The average temperature of the six data logger locations inside the Plug-In was compared to the simulated results using the external weather conditions, construction material, equipment used, and occupant's profile *[7]*. The resulting curves for the internal temperature of the Plug-In are compared with an average of 17% deviation, given the temperature measurements were instantaneous with many peaks and valleys, whereas the simulation was intended to capture the overall trend, thereby, this level of accuracy allows us to correlate the simulated model.

Discussion based on quantitative results

- Numerical simulation and field measurement are necessary activities to demonstrate the performance of the Ger Plug-In. The correlation process used in this study verifies the validity of the numerical simulation to predict the annual energy use and the energy use index, with the findings showing that: Comparing the average simulated results against the average test data, the average EUI is 211 kWh/m²/yr
- The lower and upper bounds of the EUI are estimated to be 171 and 244 kWh/m²/yr

The upper and lower EUI figure of the built structure of 171 and 244 kWh/m²/yr are still below the 252 kWh/m²/yr stipulated in the MSFA requirements. For the XacBank baseline of 393 kWh/m²/year, the lower EUI represents a 56% reduction while the upper represents a 38% reduction. Both fall well within the requirements of the 20% reduction criteria. Compared to a typical ger, which XacBank's baseline is 550 kWh/m²/year, the Ger Plug-In is able to reduce energy consumption by 62% based on the yearly average EUI.

These EUI figures allow us to calculate the carbon emission reduction of the Ger Plug-In when operating versus those of a typical ger and self-built house that uses coal by using emission factors of 0.88kg CO_2/kWh[22] for power plants and 3.67kg CO_2/kg Coal.[23] Based on the XacBank baselines a ger would produce 12,895kg CO_2/year and a self-built house 17,011kg CO_2/year. The Ger Plug-In, primarily operating on electricity would emit 9,885kg CO_2/year, demonstrating a 23% reduction in total carbon emissions compared to a typical ger despite having double the building area.

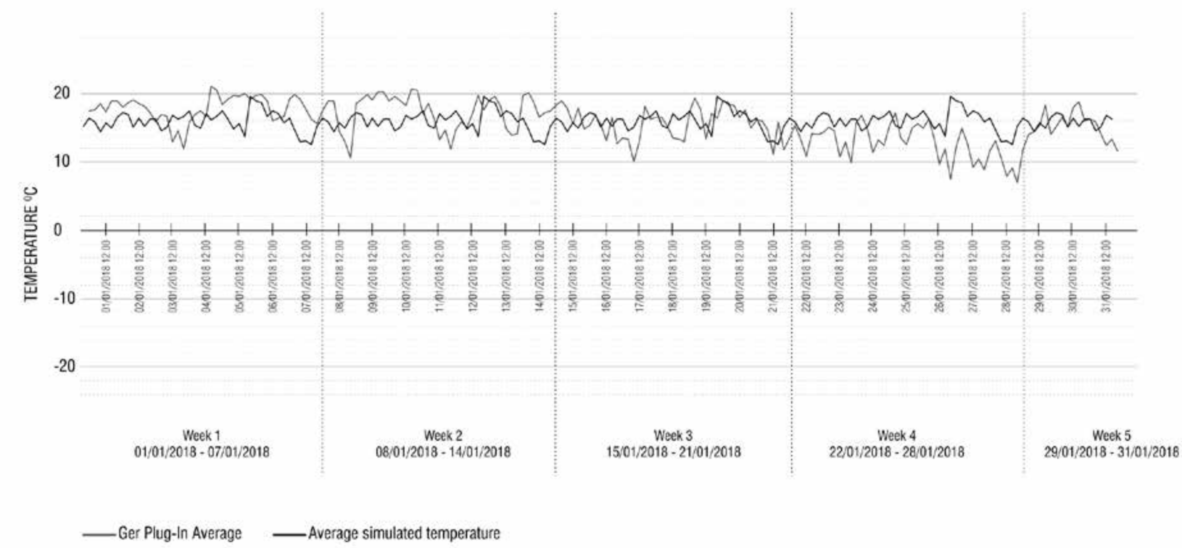
We compared the as-built EUI of the Ger Plug-In against possible improvements to the construction materials by changing the material properties associated within the environmental model. These findings include:

- By increasing the insulation from 80 mm–100 mm the average EUI is 198 kWh/m²/yr
- Changing the ger floor from a concrete floor to an insulated timber floor the average EUI is 234 kWh/m²/yr
- By using double glazing instead of triple glazing the EUI is 240 kWh/m²/yr

If the glazing is changed from triple glazing to double glazing, the EUI figure is still within the requirements of the banks. This could bring down construction costs, making it more affordable. By exchanging the concrete floor with an insulated timber floor, the EUI performance is lower but still within our target. However, casting on site takes time and cannot be conducted during the winter so a shift to a timber floor build up could be advantageous.

The quantitative analysis demonstrates that the Plug-In meets the criteria set by both financial organisations and so should be eligible for low interest rate mortgages. The next steps are to test its viability in the market to prove demand and affordability using qualitative data from household surveys.

7 Comparison of Temperatures (measured vs simulated) for Ger Plug-In, data table found in Table 3.



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Methodology: qualitative research

The Asia Foundation Mongolia, an international NGO with over thirty years of experience working in Mongolia was contracted to conduct household surveys. A questionnaire was established to collect data on residents' household income, their current housing situation, their interest in the Ger Plug-In as a future dwelling, and their biggest concerns for the ger districts. Fifty-nine surveys were conducted in November 2019. Ger districts are typologically defined according to urban (the closest to the city centre, most dense with smaller plot sizes), mid (consolidated plots with road access) and fringe (furthest from city with larger plot sizes and often the most recent migrants). Twenty-six interviews were in the fringe area, twenty-four in the mid and nine in the urban with households being selected randomly. Of these inhabitants, thirty-three (56%) lived in a ger with twenty-six (44%) living in a house.

Qualitative results

The majority of fringe district residents lived in a ger, with an even split between gers and houses in the mid area, with more urban district residents living in houses. This is consistent to findings from other studies conducted by the World Bank (2017)[24] and reflects that the longer people live in the *ger* districts the more likely it is that they will build a house. From our sample: of those living in the districts for more than twenty-one years, 80% lived in a house. However, household income did not directly correlate to housing type. From the sample of the residents earning above the median income of 1,050,000 MNT (US $373), nine lived in gers and twelve lived in houses and those in the lower income levels nine lived in a ger, and ten in a house.

For houses that were built within the last five years, when taking inflation and year built into account, it is equivalent to approximately 21 million MNT (US $7,460) and 426,912 MNT/m2 (US $152). One in three houses were built in phases. Of the twenty-five people living in a house, only two have an indoor toilet and three have an indoor shower. House dwellers consumed more coal for heating than ger dwellers primarily due to the increased area of houses and capacity for heat loss.

Only three people reported that they were content with their current housing leaving fifty-six people or 95% dissatisfied. Of the forty-eight residents living in the fringe and mid areas, thirty or 63% wished to remain in their khashaa (land plot) and make improvements to their housing situation such as building a house, extending their house, or improving their fencing. Most of these residents expect to make the improvement within three to five years and would require a loan to complete their plan.

The majority of ger district residents (82%) were in debt by over 1 million MNT (US $355). The majority of these were from pension, salary or other bank loans and were not related to mortgages or construction loans. Salary loans have an interest rate of between 18–20.4% (Khan Bank). To put this in context: if a resident took a salary loan of 30 million MNT at 20.4% annual interest rate for thirty months, the monthly repayment will be at 1,510,000 MNT. This is higher than the average monthly household income of 1,157,500 MNT.

When asked about whether a home with a toilet, shower, and electric heating would be desirable 81% of fringe and 75% (mid) residents confirmed positively. However, when asked if a ger with the same infrastructure was appealing, the results were flipped with the majority being uninterested. Once shown photographs of the actual built Ger Plug-In, the most receptive residents were those living in the fringe district with 47% of residents living in a ger as well as 22% of residents living in houses saying they would prefer to live in a Ger Plug-In. There were twelve neutral responses towards the Plug-In with many asking for more information, and ideally wanting to see it for themselves.

Discussion based on qualitative results

The results indicate that the most likely residents who would be interested in the Ger Plug-In are those living in a ger in the fringe districts. As the most recent settlers, most have not yet built a house and do not have any sanitation. Interestingly, these residents are also not the poorest and have financial capacity to invest in improved housing should mortgage terms and upfront costs become affordable. When combining both positive and neutral responses, 85% of all surveyed would be interested to purchase a Ger Plug-In for 20 million MNT or less. As a house would cost a similar amount, they would not be willing to pay more, even for the added benefits of improved access to sanitation and thermal performance. This highlights an important point regarding perception. Residents are well aware of practical issues of living in a ger: the need to change and air the felt seasonally to avoid damp; and the maintenance and cleaning of the canvas outer layer. Even though the Ger Plug-In does not require this upkeep as it uses a different form of insulation, the assumption is that it does. Additionally, a house is still seen by many as an upgrade and more permanent dwelling to a ger even though most houses do not have infrastructure and require increased amounts of fuel and electricity to heat them during winter. In terms of financing, most residents are used to borrowing money, but not in the form of mortgages. To reduce the debt burden to residents, any affordable housing product needs to be associated with a lower rate of interest, given the low incomes of residents.

Conclusion: impact of the Ger Plug-In

This paper demonstrates that the Ger Plug-In performs better than a traditional ger or a typical baishin (house) in terms of its access to sanitation, reduced heat loss, and significant reduction in coal consumption. The numerical modelling and simulation found that the average simulated EUI was 211 kWh/m^2/yr. This is 46% lower than the XacBank baseline and 16% lower than the MSFA baseline; standards set as criteria to be eligible for low interest green mortgages. The household surveys established that the residents who were most in need of and

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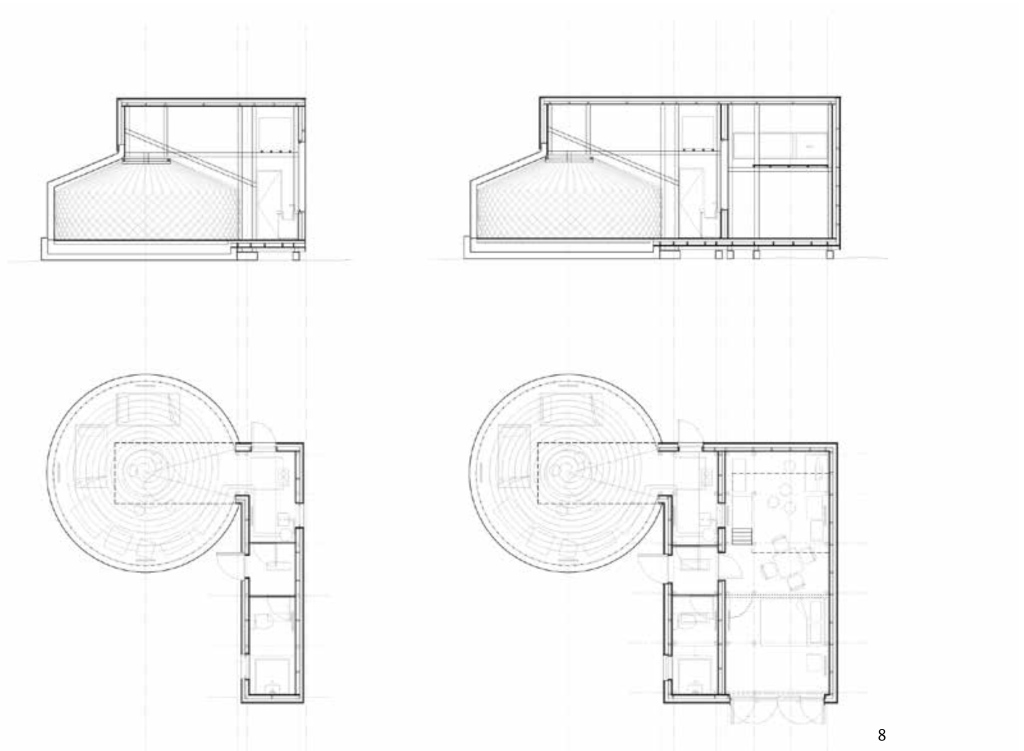


8 Core and Secondary components of Ger Plug-In 2.0.

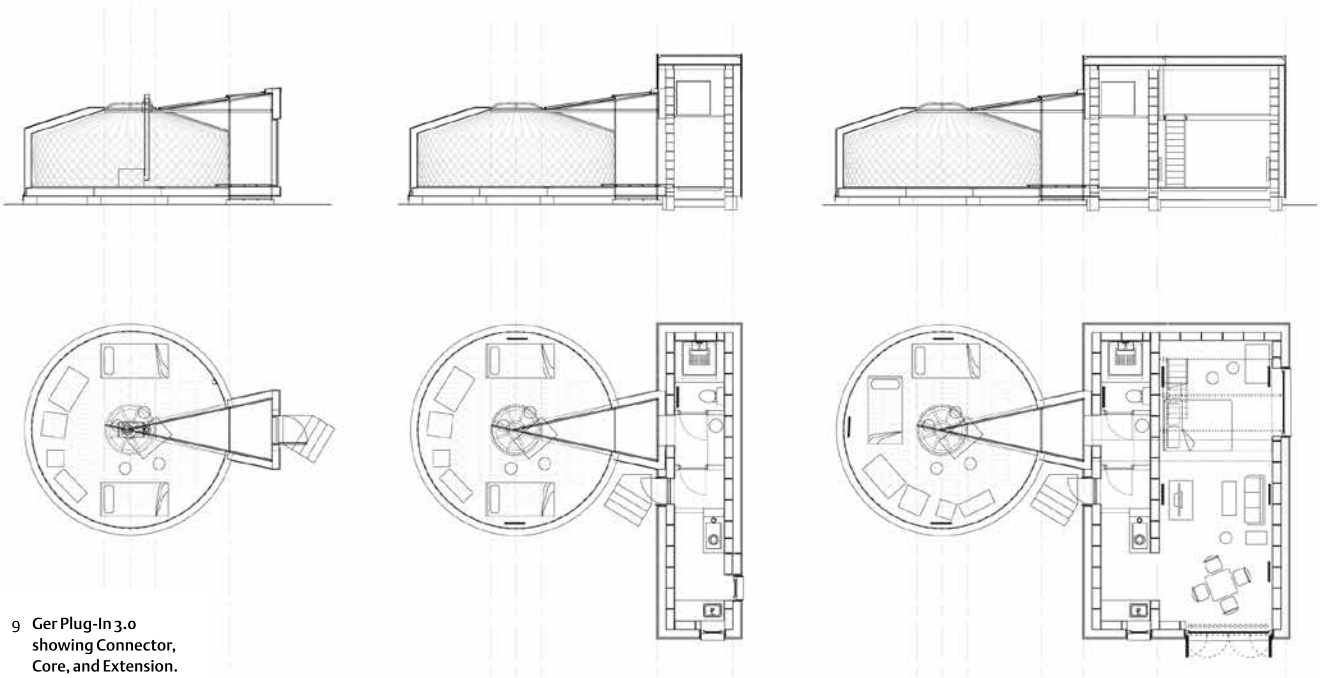
most receptive to the Ger Plug-In, are those living in the fringe districts of the city. However, the results were not conclusive enough to prove that there is an immediate market demand, with many residents wanting to visit the built prototype and to have a clear understanding of upfront costs and mortgage repayments.

The surveys did reveal that ger district residents rank affordable housing as their number one concern, followed secondly by air pollution. Clearly, there is a lack of affordable and sustainable homes to address these concerns, with many of the current offerings still beyond what the majority of ger district residents understand to be affordable, i.e., around 20 million MNT. The current models range between 38.8m²–58.8m² and cost between 59.2 million–77.9 million MNT (US $21,300–28,000). These models do not allow for expansion and have to be built in a single phase. The surveys show that ger district residents prioritise different needs; have different incomes, different household sizes and different capacities to take on loans. We also ascertained that one third of all houses were built in stages based on available income with many respondents initiating the construction of their home by first building a concrete foundation.

Next steps: iterative design, Ger Plug-In 2.0 to 3.0

The pilot project exposed two main areas in need of improvement. Firstly, because it involved removing one quarter of the ger's wall panels it led to heat losses at the interface between the ger and the new structure. This was reported to us by Tuvshinkhuu Samdan, an engineer at GIZ, who conducted thermal image analysis of the Plug-In to locate areas of heat loss. Secondly, the feedback on the financial practicalities of constructing the building in one go were that the cost was too high, and so the next iteration involved dividing the structure into two components that could be constructed in phases. The new design, Ger Plug-In 2.0, consists of a ger connected to a core component – containing a toilet, shower, kitchen unit, and heating system – and a secondary component designed as an extension that houses living and sleeping spaces. The infrastructural core is 12 sq m, and the extension is 25 sq m. Added to an existing ger of 26 sq m, the first phase house is thus a total of 38 sq m and the extended house 63 sq m *[8]*. This design takes advantage of the ger as the ready-made, cheapest way to build a dwelling in the ger districts. The idea is that residents can purchase the core unit at a relatively low price and then extend it when they need to and are financially able to do so. This aligns with the form of incremental building that we know is the prevalent model in the districts.

The design improves upon the same construction details and material build up as the Ger Plug-In. This was decided after a consultation with engineers at GIZ using their mechanism of evaluating thermal performance. GIZ advised an additional layer of 80 mm insulation and an air gap of 30 mm to prevent condensation. Because we have not changed the material properties of the materials used, we can assume that the EUI figures would still be in an effective range. This back-and-forth and subsequent finalisation of the details led to the successful certification of the Ger Plug-In 2.0 as an energy efficient dwelling in September 2021, making it eligible for the low-interest mortgages. Throughout discussions with GIZ they have responded positively to the design as they recognise that it will be the only certified housing product that integrates a ger and thus will fill a gap in the market due to its lower costs. Another set of surveys were undertaken to ascertain the market potential of version 2.0. It took



9 Ger Plug-In 3.0 showing Connector, Core, and Extension.

178 interviews to hit a target of fifty positive responses, meaning households that want to buy the Plug-In and are in a financial position to do so, representing a positive response rate of 28%. These households have no overdue or non-performing loans, possess ownership of their land, have an average monthly income of over 800,000 (US $280) per month, meet the 45% debt-to-income ratio requirement of the banks, and therefore can afford the Ger Plug-In 2.0. If this percentage is extrapolated across the 246,800 ger district households, this equates to an estimated 69,000 households who would be interested in the Plug-In, giving it a market potential of over US $749 million, based on a unit cost of $10,849. With this information the project again shifted, this time to think of the Ger Plug-In as an opportunity to create a sustainable enterprise. However, when the design was discussed with the banks, they were concerned with the implications of including what they considered a movable structure within a mortgage product. Even though the ger had become permanent due to its integral connection with the house in the design, the banks remained reticent. Some residents also pushed back against our design's inclusion of a ger. As Songino Khairkhan resident Sanchir Batbold told us: 'It is a lot of work. Rainwater cladding is really important when we think about maintenance. We are not living in a ger out of choice.'[25]

Given that the success of the prototype would be dependent on residents' ability to access finance, the product had to be mortgageable, and so Ger Plug-In 3.0 was developed. In this version the design was separated into three distinct parts: the connector, the core, and the extension. This allows the core and extension to be independently mortgaged as permanent structures separate from the ger and the connector *[9]*. It also allows the financing to be broken into smaller and more affordable tranches. In some ways it represents a conceptual inversion of our original logic. The ger does not incrementally become a house, but rather the house has the possibility of attaching a ger.

By thinking about the design in this way, the connector becomes a critical piece that could be applied to any house or existing building. The connector is a universal port, built according to the ger's geometry and dimensions yet adaptable to attach to different opening sizes. As a minimal intervention at the lowest price, the connector offers the relocation of the stove, the removal of the central columns, a threshold to prevent heat loss, and increased thermal insulation for the ger. And although this piece will not be eligible for the subsidised mortgage programme, it does open other funding streams such as Eco Consumption Loans[26] for heating or insulation retrofits.

The separation of the design in version 3.0 into distinct phases and components allows residents to choose a housing provision best suited to their needs and their income. It creates the possibility to integrate the ger or not to have one at all. The phasing of components harnesses the incremental and self-build culture that exists in the ger districts, allowing families to adapt as they see fit. However, the impact of COVID-19 and consequent closure of the Chinese border, with only intermittent reopening since February 2020 resulted in supply-chain blockages and escalating costs of materials. The cost of timber, for example, went up by approximately 70% from 2018 to 2021.[27] This meant that the estimated cost of the Plug-In increased from $10,849 in 2018 to $23,860 in 2021. To reflect this change in operations and costs, the design was adapted to minimise any materials that could not be locally sourced, exchanging the preferred timber frame with more readily available aerated concrete blocks for an update on version 3.0. This meant that the intention to set up timber prefabrication had to pause as it was no longer economically viable given that supplies of timber were much reduced. It also meant requalifying version 3.0 with GIZ and banks to make sure the new material build-up still met the criteria for energy efficiency. The inability to travel from Hong Kong to Mongolia since 2020 also impacted how quickly the project could move forward. As well as modifying the detailed design, the time was used to research the potential of using the project to create a sustainable enterprise.

Developing a sustainable enterprise

In order to develop the prototype into a product that could deliver large-scale impact in the ger districts, it became necessary to set up an architectural start-up to apply our knowledge of tested prototypes and set up local partnerships in Ulaanbaatar to build Ger Plug-Ins at scale. Any revenue generated would be fed back into the business to further develop new prototypes or improve existing products.

In 2020 this start-up, called District Development Unit was incorporated as a spin-off of the research lab at the University of Hong Kong. Based on predicted revenues and market research the demand in the first year was projected to be 1,125 units, representing a total income of over $12 million and a profit potential of $2.07 million, based on a margin of 17%, signifying the potential of the business. This was recognised by an investor in Hong Kong who was interested in helping to set up a company in Mongolia by offering financial and marketing support, albeit as a majority stakeholder. However, the economic slide and increased inflation caused by COVID-19 financially impacted ger-district residents significantly in 2021, with monthly incomes dropping by 4% while costs for construction materials rose by approximately 52%–92%.[28] This gap in affordability meant that the profit margin of the business venture was not guaranteed, and the investor backed out until the conditions changed. However, this proved fortuitous in some respects as we decided to proceed with the formation of the company as a local implementation unit, partnering with our long-term contractor and another collaborator with expertise in business management. This preserved our equity in this newly formed company, named Energy Efficient Design and Build [Энержи эфишент дизайн бюлд], and allowed us, during the winter of 2021, to prepare for the summer construction season and to launch the product. The gap between affordability and the construction costs of the required thermal performance remains the most difficult challenge, and it is still to be determined whether the product can still be attractive to residents given the economic challenges they are currently facing.

Overall, the Ger Plug-In 3.0 offers more space for less money compared to the other energy efficient housing products on the market [Table 1]. It is also the only product that is extendible, offering a possibility of incremental staging and growth according to residents' financial capacity. The long-term objective is to increase production and reduce time for onsite construction. To maintain construction quality and guarantee the thermal performance of the product the intention is to train our own construction team as part of EEDB. Initially, the team will stay small, to implement up to five orders in Year 1 (2023). This milestone will present opportunities for investment, allowing the company to acquire factory and storage space to facilitate material procurement and the prefabrication of roof trusses. This will lower costs, enable increased production and lower construction times. Based on this model, the aim is to deliver one hundred homes in the next three years.

In conclusion, the paper demonstrates how the mixed methodology of quantitative analysis (numerical modelling and simulation) together with a qualitative investigation of residents' needs and financial situation (household surveys) was used to determine whether the Ger Plug-In is both sustainable and affordable. Both methods are necessary to position the design as a viable product to the banks to access the lower rate green mortgages. If, in the next stages of development we can unlock these funds, thousands of residents in the ger districts will be able to access affordable, sustainable homes.

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Competing interests

The Authors declare none.

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