A TRANSPORTABLE AND ENERGY OPTIMIZED RESIDENTIAL BUILDING ARCHITECTURE DESIGN FOR THE MONGOLIAN CLIMATE

A dissertation presented

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Abstract

The intensity of human activities adversely affects nature, and the environmental surroundings and climate change. As part of the initiatives reducing the adverse impacts, sustainable architecture importance is increasing. Depending on the climate, culture and lifestyle, the residential buildings in the world have varying architecture. One of the unique architecture is nomadic architecture. For the nations with nomadic culture, transportable housing type is

dominantly used. However, in the field of transportable building, there is a lack of research on building physics. This type of residential building challenges more the architectural and engineering design in respect of material and structure selection attached to mandatory characteristics of portability, indoor comfort, the feasibility of energy generation and operation in various sites, and energy efficiency.

The research aims to improve existing yurt in terms of indoor comfort and energy efficiency without sacrificing the key concepts of the yurt and that is compatible with Mongolian climate. Mongolian context has selected as the base environment as it has one of the most extreme and severe climates in the world. To fulfill the set of objective, as an inception the literary review on various transportable residential building has performed which has found there are 9 different shapes of yurts used around the globe. On the basis of the 9 types of yurts found, the best shape yurt is identified through the comparative analysis using dynamic thermal simulation method.

The development has conducted within the frame of yurt opening, orientation, structural material, building system. For each of the component, various versions are tested and optimized using simulation tool IDA-ICE 4.8 and the best outcomes are determined in terms of energy efficiency and indoor comfort. Finally, the best versions are combined to form the optimized transportable residential building.

Background of research

The intensity of human activities adversely affects nature, and the environmental surroundings followed by climate changes apart from the many signs of progress and developments invented by humans. The footprints of human living related to lack of sound management include reduction in pure water resource, air pollution, solid waste and which are countless to mention which have especially intensified during the past 50 years. The adverse environmental and social footprints are necessitated to be reduced through people's daily actions which involve architecture and development in architectural science.

In the architectural sector, the initiatives are set to contribute to environment protection. One of them is Architecture 2030, that they set a big target to make entire new buildings to be Net Zero Energy by 2030 [1]. In the settled building architecture and construction, there is growing number of progressing works held by famous architects and engineers in the green building sector. However, there is a lack of researches in the transportable building sector. Transportable building is the essential means of housing in nomadic culture countries. In addition, it is important for the people who are involved in seasonal and occasional delegations in lack of infrastructure, and for a certain extent useful for tourism purposes.

One of the oldest, classic and widely dispersed types of transportable building is 'yurt' which is common and fundamental for nomads. The main features of yurt are portable, ergonomic and

environment-friendly which fits for the purpose of dealing environmental problems as well as human shelter needs. The yurt structure, materials, and operations have not been significantly changed since the ancient times. However in this modern society where the people's requirements on living standard, comfort and social needs are incomparably changed and increased from those back to thousands of years. And there is a lack of prior study on indoor comfort and energy consumption on yurts.

Research objective:

The main objective of this research is to study indoor comfort and energy consumption of current yurt which is vernacular traditional transportable residential building and to develop modern yurt which improves the indoor comfort and energy consumption of yurt.

To fulfill the objective, the following goals have set:

1. Review current literature on the transportable vernacular architecture and verify compatibility to Mongolian climate.
2. To find the optimal shape form of the yurt with the purpose of improving energy and indoor comfort, thermal dynamic simulation will be performed for different shapes of a yurt in Mongolian climate setting.
3. To identify the most efficient and comfortable yurt, comparative analysis will be conducted for varying types of yurts. The yurt characteristics of opening, orientations, structural materials, systems and operation of the yurt will be used in thermal dynamic simulation tool.

4. Find the yurts with optimal characters from the simulation.
5. Collect the characters which optimal characters to the yurt and make a new yurt collected the best-resulted characters from the simulation.
6. Developing transportable, adapted, energy efficient and low tech solution which meets modern architectural concepts.
7. To find the optimal transportable residential building in the extreme changes in climate zones, develop the traditional vernacular architecture, used by the validated professional thermal dynamic simulation tool with the high resolution of climate data.

Research questions:

- Does current yurt provide indoor comfort which meets the modern living standard of occupants?
- How can we develop yurt to make it more energy efficient and comfort?
- How to achieve today's energy consumption and indoor comfort requirement in an existing yurt?
- What has to be changed, replaced, redesigned, and modified on a traditional yurt to develop a modern building development?

Research limitation:

- The research specifically focuses on energy efficiency for the transportable building; therefore it might not be the best solution

for the purpose of settling down in the same location for a long term.

- In the study, energy efficiency and those related materials are considered with priority; hence the economic and financial matters are not taken account.
- The research is conducted in only Mongolian climate zone and expected to be useful for other cool climate countries as Mongolian climate is one of the severe and extreme condition.

Initial points of research

1. In Mongolian context, yurt is widely used accommodation in respect to both of the nomadic and residential living style which relate to the country's culture and tradition. The main structure of yurt satisfies the main functional need of being movable as well as livable. However, from the modern living standard point of view, the livability is diminished as the comfort does not qualify for a high standard.
2. It is essential to maintain the main function of the portability of yurt. However, comforts as the complementary attribute to portability has been untouched and underdeveloped. The comfortableness concept involves massive characteristics, but the most impactful factors for Mongolian settings are deemed to be energy efficiency and indoor climate comfort.
3. Beyond the Mongolian and other nomadic country settings, the yurt has started to be used in other countries for travel,

entertainment, and tourism purposes. For this hand, the enhancement in comfortableness of yurt is demanded.

Initial problems

1. Mongolian climate has a very high-temperature difference between summer and winter which has 80 ºC.
2. The nomadic and transportable building is not studied in a building physic science.
3. The traditional vernacular yurt is undeveloped during the history. The development was decoration and changes some details.
4. Today 45% of households live in a yurt and 29% of whole yurts are not connected to electricity supply in Mongolia.
5. The yurt has no heating system and household burn the wood, coal and other materials for the heating in cold seasons which contributes to the biggest problem of pollution in the capital city and other areas of Mongolia. The thermal comfort of the yurt is not an approvable category in the winter due to yurt has not heated.
6. The materials used for yurt structure have not necessarily changed during the history and for the people who live in a yurt in contemporary, yurt does not provide the necessary comfort
7. The yurt must maintain its transportability to fit for a nomadic lifestyle. Hence, it can't apply big building service systems and the potential changes to yurt must consider lightweight, fast and easy assembly.

Research method

The main body of research will apply simulation method. The thesis will cover 4 separate but interlinked groups of researches.

1. Literature review. As the initial research, the related literature on transportable building, vernacular nomadic residential building will be reviewed and discussion will be included Chapter 2. In Chapter 3, literature on climate design of transportable residential building in the cool climate zone will be reviewed and discussed.
2. Comparative analysis. Comparative analysis will be held for the different shapes of traditional vernacular yurts and which will be examined for Mongolian climate zones. For this analysis, simulation tool will be applied for the energy and indoor comfort of the different shapes of the yurt with the same boundary conditions. And the study will be discussed in Chapter 4.
3. Optimal characteristic yurt development. On the basis of results received from Chapter 4, the traditional yurt will be developed through examining the different characteristics of other yurts and the best results for each characteristic will be combined to build the optimal yurt. And Chapter 5 will demonstrate this process and discussion.
4. On the basis of previous studies discussed in prior chapters, new prototype concepts on the transportable residential building

will be designed. And concepts will be simulated for ensuring the prototype as an optimal solution.

Research structure

In below *Figure 6*, the research structure is demonstrated in a diagrammatic form.

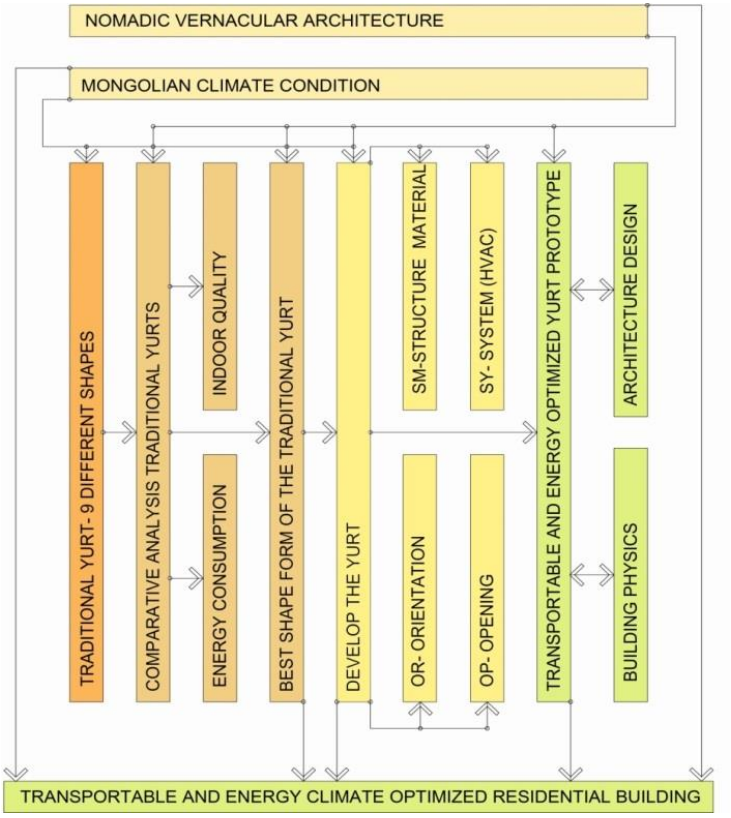

Figure 1: Research structure diagram for the topic

Conclusion

I investigated types of the yurt. The yurt as a nomadic vernacular architecture has been used in the different natural and climate zones during the thousands of years. The yurt is adaptable and energy efficient low tech dwelling solutions in nomadic cultures. In modern times, even in those nomadic countries, only small numbers of people live in yurt due to urban sprawl. An exception is Mongolia, where 45.4 percent of households live in the yurt. Although there are also examples, when yurts are imported for residential and business purposes into countries, which do not have nomadic culture, the use of yurts has eminent interest in Mongolia. This was the motivation of my research.

As a starting point I studied the different type of yurts, and I have identified 9 different shapes of yurts that are used around the world.

For the identification of adaptability and performance of different types of yurt to the needs of inhabitant and climatic conditions, I performed their analysis using the thermal dynamic simulation by IDA-ICE 4.8 code. The IDA-ICE 4.8is a validated simulation tool focused on energy consumption and indoor comfort and climatically parameter input the data.

1. **From the point of view of energy need and comfort, I found that the 13th century Mongolian yurt has the best shape and performance, since that type of yurts needs 28 to 59% lesser**

energy for ensuring a thermal comfort better than other yurts.

- The comparative analysis of the yurt shapes was done for in the Mongolian climate conditions. The performance indicators used are the area ratio, energy consumption, energy balance, and indoor comfort.
- The energy needs for cooling is approximately 10 times less than those for heating under Mongolian climate condition.

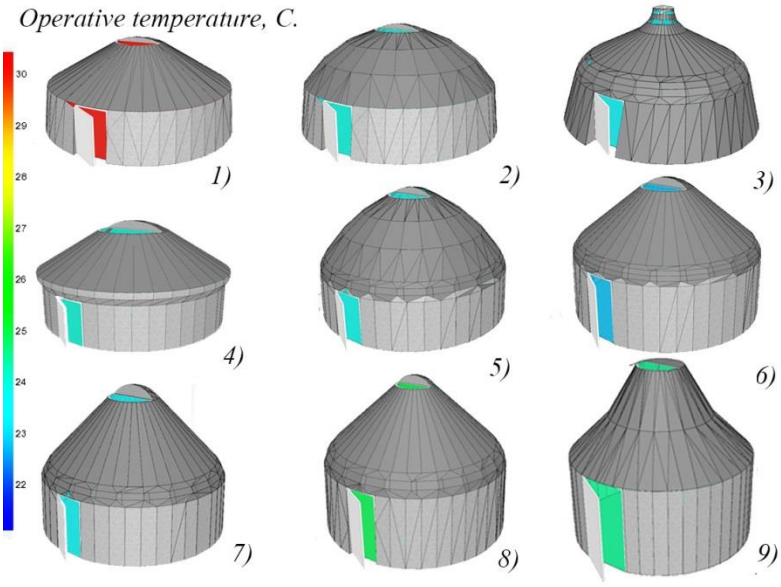

Figure 2: Dynamic thermal simulation models of different types of traditional yurts with indicated operative temperatures. 1) Mongolian yurt, 2) 13th-century Mongolian yurt, 3) Hunnu

Related paper:

- *Gantumur Tsovoodavaa, Rowell Ray Lim Shih, Mohammad Reza Ganjali Bonjar, István Kistelegdi, "A review and systemization of the traditional Mongolian yurt (Ger)", Pollack Periodica, Hungary, 2018.*
- *Gantumur Tsovoodavaa, István Kistelegdi,"Comparative analysis for traditional yurts using thermal dynamic simulations in Mongolian climate", Pollack Periodica, Hungary, 2019.*

2. The traditional yurt has two main heat loss elements: the envelope area and the top opening. As a result of simulation, top opening is found to be the main functional element for the indoor air quality and cooling. The envelope area's insulation material (sheep wool felt) has found to be insufficient for proper insulating of the yurt. It is important since on the basis of these findings several recommendations could be developed for improvement of these elements.

The following conditions should be taken into account while identifying the recommendations:

- To further development of the insulation material, it is essential to consider material features to be thin, lite weight, strong and high thermal conductivity as which must meet the transportable, adaptable, and low tech requirement**.**
- Possibility of replacing the top opening with a window would be preferable.

Related paper:

- *Gantumur Tsovoodavaa, Rowell Ray Lim Shih, Mohammad Reza Ganjali Bonjar, István Kistelegdi, "A review and systemization of the traditional Mongolian yurt (Ger)", Pollack Periodica, Hungary, 2018.*
- *Gantumur Tsovoodavaa "The energy consumption and indoor comfort of the Mongolian traditional yurts in Mongolian climate", Proceeding of the Mongolian Academy of science, Mongolia, 2018.*

3. For the development of the yurt to highly energy efficient, high comfort, and modern transportable residential building the following recommendations have been formulated:

- Considering the top opening, the three-pane glasses show the best result.
- The top opening generally provides daylight through the skylight, and as a result of development, the more lighting is enabled to be entered.
- In the summer season, light eternal shading element is recommended.
- For energy efficiency purpose, no windows on the wall are recommended, however, in case of window setting, it is better to be as small as possible.
- The orientation of the yurts did not show a high effect in relation to its circle layout.
- However, the south, south-east and south-west orientations have shown slightly better results.
- The study predicts if the circle layout and shape form is changed, the orientation would have been effective.

- The insulation materials development is the Silica aerogel blanket is best-resulted material for the yurt compared with other insulation material.
- The optimized the structure of envelope is 40mm PCM, 100mm Silica aerogel blanket and waterproof material.
- The PCM material has highly affected the cooling but 40mm PCM is suitable for the yurt. Because the yurt should be lightweight structure.
- The waterproof material can use any materials but the tarpaulin and Gore-Tex material are the best materials for the yurt due to air change with the insulation material.
- It has found that heating electric radiator and simple fan coil are more energy efficient than other types of heating systems.
- For ventilation, the Enthalpy wheel AHU is more energy efficient ventilation system for the yurt.

The above options have been selected on the basis of comparative analysis.

4. **Natural ventilation in the yurt acts as an air exchanger and also cooling the yurt via dome chilling effect from the top opening and lower edge of the wall (khayaa). During summer, natural ventilation can be used for the yurt. However, the operation is important to this time because the openings are mechanically performed for open and close actions. The mechanical operation is preferred than**

automation in relation to Mongolian severe and unpredictable weather.

5. **It is justified by analysis, that the yurt resulting after implementation of all recommendations will have better performance in all categories compared to any other types of yurts. The energy consumption is decreased by 50% including the air handling unit.**

6. **To developed and redesigned into modern building requirement in terms of energy positive and high comfortable building while keeping the main functions of adaptable, lightweight and transportable. The developed yurt's size and layout are changeable follow the function, natural and climate condition. It is three times lesser energy consumption than the traditional yurt and has high indoor comfort.**

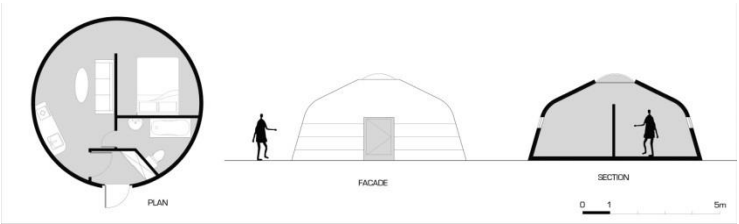

Figure3: Drawing of the developed and optimized yurt with plan, façade, and section (Family yurt-1).

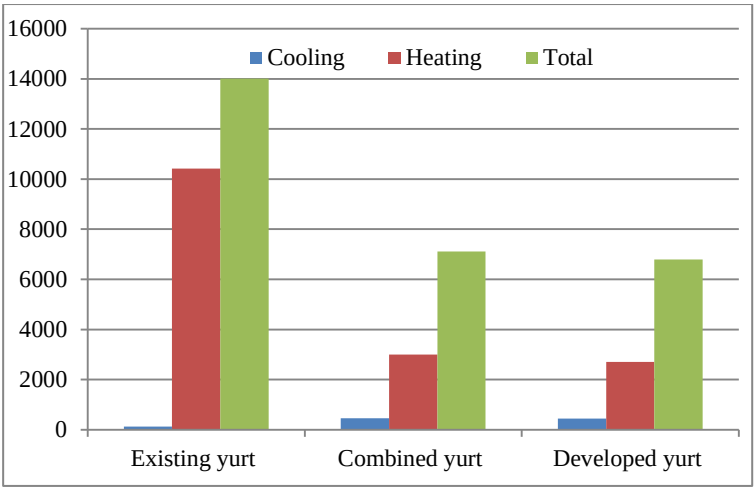

Figure 4: Comparison of the existing yurt combined yurt and developed yurt with system energy.

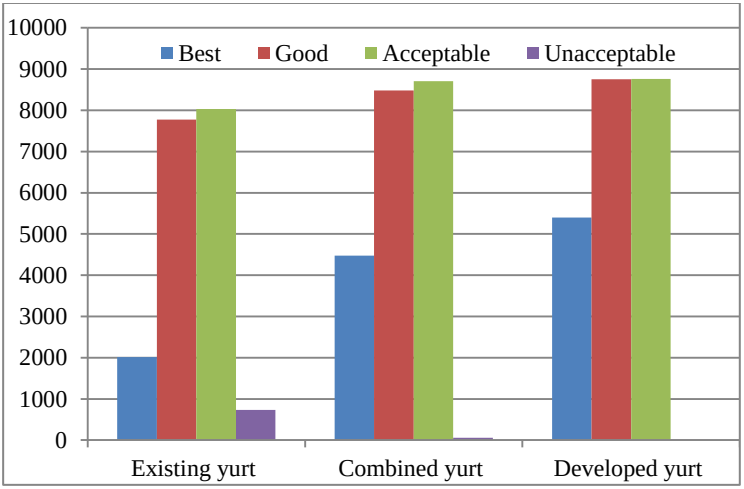

Figure 5: Thermal comfort comparison of the existing yurt, combined yurt, and developed yurt

List of Publications
Published:

1. A review and systemization of the traditional Mongolian yurt (Ger)

Author: Gantumur Tsovoodavaa, Rowell Ray Lim Shih, Mohammad Reza Ganjali Bonjar, István Kistelegdi
Journal: Pollack Periodica, Hungary.

2. Comfort and energy performance analysis of a heritage residential building in Shanghai

Author: Chu Xiaohui, Ganjali Bonjar Mohammad Reza, Gantumur Tsovoodavaa, Rowell Ray Lim Shih, Balint Baranyai
Journal: Pollack Periodica, Hungary

3. Importance of developing Ulaanbaatar regional for site in sustainable development and optimal setting of the capital city

Author: Gombo. J, Ulziisuren. D, Tsovoodavaa .G
Journal: Scientific transactions # 08/155, School of Civil Engineering and Architecture, Mongolian University of Science and Technology, Ulaanbaatar, Mongolia, 2014, ISBN 1560-8794
Language: Mongolian

4. Energie-Design-Fachplanung in einem Tech-Lab-Projekt: Planungsunterstützung in Form von thermischen und strömungstechnischen Simulationen anhand eines Fallbeispiels „NOÉ“ Tech-Lab an der Universität Pécs, Ungarn

Author: István Kistelegdi, Bálint Bachmann, Gabriella Medvegy, Tsovoodavaa Gantumur, Mohammad Reza Bonjar Ganjali, Bálint Baranyai, István Ervin Háber
Book: Bautenschutz, Nachweismathoden und Anwendungen, Germany, 2018, ISBN 978-3-00-060009-8
Language: German

Published in conference proceeding:

5. The widening of the walkway and the cycleway

Author: Byambajargal.B, Tsovoodavaa.G

Conference: Scientific conference in land administration and urban design
Journal: Scientific conference proceeding in land administration and urban design, Ulaanbaatar, 2014 *(Full paper)*

6. Hungarian active house, refurbishment, dynamic thermal simulation, energy analysis

Author: Tsovoodavaa Gantumur, Istvan Kistelegdi
Conference: 12th Miklos Ivanyi International PhD and DLA symposium, 3-4 November 2016
Journal: 12th Miklos Ivanyi International PhD and DLA symposium, University of Pecs, Hungary, ISBN 978-963-429-094-0 *(Abstract)*

7. Review and systemization of the traditional yurt

Author: Tsovoodavaa Gantumur, Istvan Kistelegdi
Conference: 13th Miklos Ivanyi International PhD and DLA symposium, 3-4 November 2017
Journal: 13th Miklos Ivanyi International PhD and DLA symposium, University of Pecs, Hungary, ISBN 978-963-642-780-1 *(Abstract)*

8. The aesthetic and effects of contemporary, digital arts in architecture

Author: Urnukh Darizav, Tsovoodavaa Gantumur
Conference: TDK Rezume PTE MIK 2017
Journal: TDK Rezume PTE MIK 2017, University of Pecs, Hungary *(Abstract)*

9. Comparative analysis for traditional yurts using dynamic simulation in Mongolian climate

Author: Tsovoodavaa Gantumur, Istvan Kistelegdi
Conference: 14th Miklos Ivanyi International PhD and DLA symposium, 29-30 October 2018
Journal: 14th Miklos Ivanyi International PhD and DLA symposium, University of Pecs, Hungary, ISBN 978-963-429-284-5 *(Abstract)*