POLLACK PERIODICA
An International Journal for Engineering and Information Sciences
DOI: 10.1556/606.2019.14.2.9
Vol. 14, No. 2, pp. 97–108 (2019)
www.akademiai.com

COMPARATIVE ANALYSIS FOR TRADITIONAL YURTS USING THERMAL DYNAMIC SIMULATIONS IN MONGOLIAN CLIMATE

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Received 11 July 2018; accepted 27 December 2018

Abstract: The yurt is one of the ancient living units for the nomadic cultural country. The yurt is a nomadic vernacular architecture, which has been developed for 3000 years. There are 31 counties using the yurt, out of which 13 of them use their traditional yurt around the world. Basically, the yurt was used as residential housings and today, also to some extent, for commercial and touristic purposes under different climates. Analyzing existing literature, as well as scientific publications it is apparent that besides architectural and structural topics, there is no existing investigation or published paper about building physics analysis of these buildings. Current research aims to create a database about energy and climate comfort qualities of traditional yurts using dynamic calculation tools. As a result, to intend to learn from the traditional yurt technology and to develop a completely new and modern building prototype based on the yurt-experiments in next step of research. Firstly, finding optimal solutions for a contemporary yurt-building' should be applied under Mongolian climate conditions, since this form of housing is still used in this country, and, in addition, the comfort and energy performance of the yurts were surprisingly satisfactory under extreme weather conditions, by temperature differences between summer and winter of approx. 80 K.

Keywords: Vernacular architecture, Nomadic country, Mongolian climate, Climate zone, Dynamic simulation, IDA ICE code, Energy, Thermal comfort, Indoor air quality

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1. Introduction

There are nine different types of traditional yurts around the world, which are used in 31 countries, out of which 13 countries use its own traditional yurt [1], [2]. In this study, IDA ICE 4.8 thermal dynamic simulation tool was applied and the mathematical model was built through simulating different versions of a yurt in conjunction with various climate zones of Mongolia. The purpose of this paper is to find the optimal yurt shape in consideration of energy consumption and indoor comfort. Mongolia is one of the countries, which have the hardest climate due to its huge temperature variance between winter and summer [3]. Therefore believing that the optimal yurt version fits for Mongolian climate can be also applied to varying climate zones of the world with slight or appropriate modification.

2. Climate conditions

Mongolian climate has a very high-temperature difference between summer and winter in relation to the continental location [3]. Its territory consists of four main zones differing by natural conditions, including forest mountain, steppe mountain, steppe, and desert zone.

In below, *Fig. 1* illustrates four zones as numbered by I, II, III and IV. Zone I refers to the coldest temperature and others are numbered according to its temperature in ascending direction.

In *Table I* climate and the geographic information is systemized on cases of chosen climate stations from all climate zones and subzones.

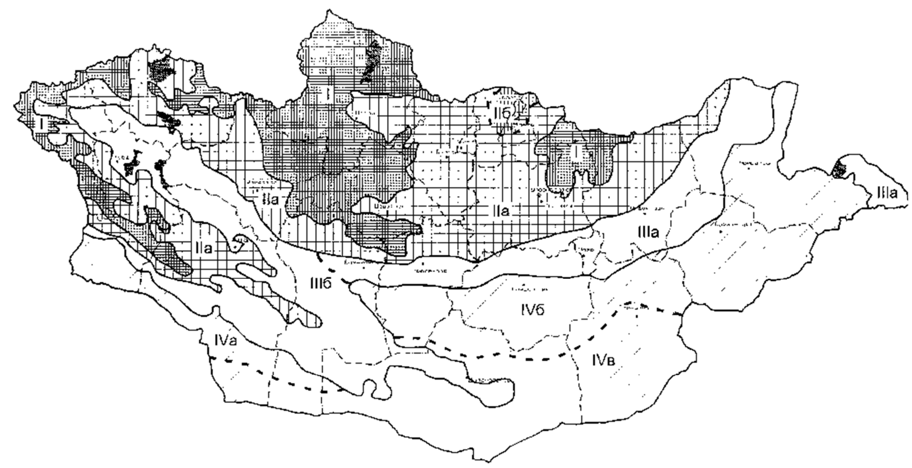

Fig. 1. Climate zones for urban planning [4].

For the simulation, Tosontsengel station from the 1st climate zone was chosen, because it has the most extreme temperature difference and located in the north-west of

Mongolia and highly elevated. In this area, the lowest peak temperature record was -53.0 ºC in 2006 and the maximum temperature was 33.8 ºC [4], [5].

Table I

Climate zones based on 'Meteonorm' climate database [5]

Climate Zone	Name	Coordinate	Elevation	Minimum air temperature, Deg-C	Maximum air temperature, Deg-C	Relative humidity of air, %	Direct normal radiation, W/m^2	Wind speed, x-component, m/s	Wind speed, y-component, m/s
I.	Tosontsengel	48.7N 98.3W	2108	-36	33	62.3	203.1	-0.3	0.1
II.a.	Ulyastya	47.7N 96.8W	1753	-36	33	60.0	211.6	0.0	-0.1
II.b	Sukhbaatar	50.2N 106.2W	1124	-35	34	70.1	194.2	-0.2	0.0
III.a	Choir	46.4N 108.4W	1269	-31	36	57.6	183.4	-0.5	0.1
III.b	Altai	46.4N 96.3W	2213	-35	28	67.4	213.8	-0.5	0.1
IV.a	Bulgan, Khovd	46.1N 91.5W	1189	-34	33	44.5	264.0	-0.2	0.3
IV.b	Choibalsan	48.1N 114.5W	747	-32	35	56.1	185.9	-0.5	0.2
IV.c	Sainshand	44.9N 110.1W	961	-28	39	51.8	269.7	-0.6	0.2
City	Ulaanbaatar	47.9N 106.7W	1350	-35	33	60.4	180.1	-0.0	-0.0

3. Modeling and simulation

After defining the appropriate geological location, a weather profile for hourly resolved 5 years average weather data was generated from the 'Meteonorm 7' climate databank [6] for this simulation. The nine differently shaped yurts gathered from existing and historical practice [1], [2] are built on the mathematical model, whereas there were similarities in between the shapes as all yurts' floor plan is round, has a central door and an opening on the top (*Fig. 2*).

To contrast, the shapes of those nine types of yurts, the orientation of the yurts were set identical, and identical climate station weather data in a whole year period was applied [7]. The floor areas are set same, albeit volume, 'top' opening, and door dimensions are different, following the shape form of the yurt. Under the material specifications, traditional materials of a wooden frame and felt (sheep wool) are considered in the simulations.

The more detailed comparative analysis on volume, envelope area, door, and opening area and A/V-ratio (envelope surface Area divided by Volume), S/F-ratio (Surface area divided by Floor area) of traditional yurts are shown in *Table II*. The 13th-century Mongolian yurt shows the best results in the comparison, but Mongolian yurt has shown the closest result to 13th-century Mongolian yurt (*Fig. 2*). The best outcomes from each of the parameter are highlighted in grey as shown in *Table II*. Regarding the set points, according to the yurt nature, 'very poor' criteria were applied for thermal bridges, 'normal residential building' criteria was applied to the opening and the door schedules, furthermore, the indoor mean temperature was set between 21 and 25 °C.

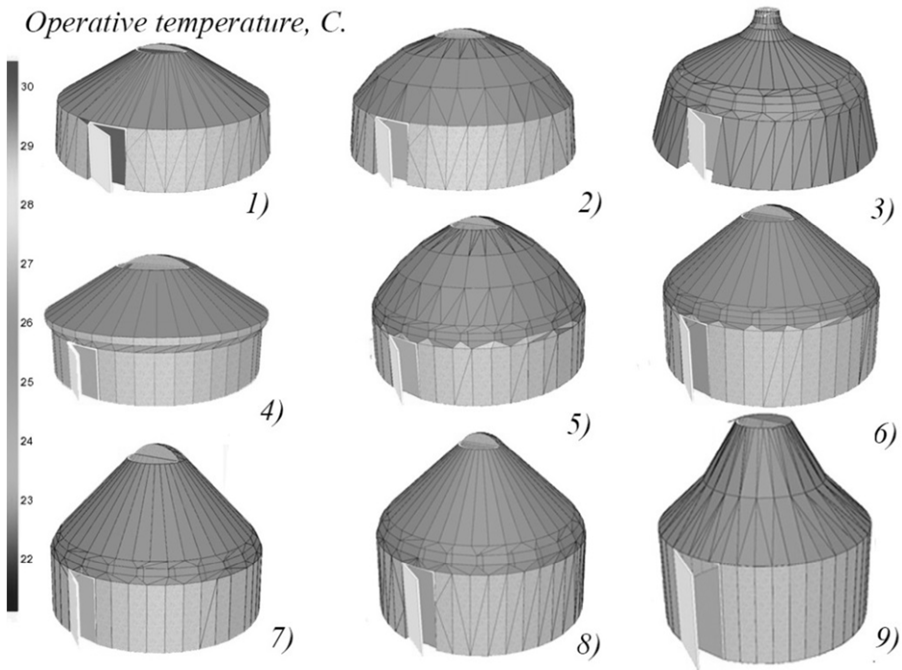

Fig. 2. Dynamic thermal simulation models of different types of traditional yurts with indicated operative temperatures. 1) Mongolian yurt, 2) 13th-century Mongolian yurt, 3) Hunnu yurt, 4) Inner Mongolian yurt, 5) Hungarian yurt, 6) Kazakh yurt, 7) Kyrgyz yurt, 8) Double wall yurt, 9) Afghanistan yurt [1], [2]

4. Results and comparative analysis

4.1. The energy performance of the yurt

In this section, used energy demand, delivered energy and energy balance of the nine yurts will be comparatively analysed on the basis of thermal dynamic simulations.

The 13th-century Mongolian yurt and Mongolian yurt are slightly different in the general shape information in *Table II*. However, the two yurts are significantly different for the delivered energy result due to heating and cooling which depend on the size of the top opening.

Table II

General information on traditional yurts

Yurt type	Floor area [m²]	Volume [m³]	Envelope area [m²]	Average U-value [W/m²K]	Door area [m²]	Opening area [m²]	S/F [m²/m²]
Mongolian yurt	28	50.3	82.8	1.374	1.38	0.83	1.96
Hunnu yurt	28	58.1	86.7	1.336	1.39	0.83	2.10
13th century Mongolian yurt	28	49.7	81.2	1.333	1.42	0.27	1.90
Inner Mongolian yurt	28	65.9	96.3	1.418	1.26	2.05	2.44
Yurt type	Floor area [m²]	Volume [m³]	Envelope area [m²]	Average U-value [W/m²K]	Door area [m²]	Opening area [m²]	S/F [m²/m²]
Hungarian yurt	28	78.9	100.6	1.339	1.53	0.87	2.59
Kazahk yurt	28	83.3	104.6	1.314	1.8	1.02	2.74
Kyrgyz yurt	28	82.1	103.6	1.366	1.93	1.02	2.70
Double wall yurt	28	95.1	112.5	1.315	2.36	0.54	3.02
Afghanistan yurt	28	108.6	128.3	1.363	4.53	0.95	3.58

The lighting (0.14 kWh) and equipment (0.36 kWh) show the same results in the simulation for all types of the yurt. As illustrated in *Fig. 3* and *Fig. 4,* 13^{th}-century Mongolian yurt shows the best result in system energy.

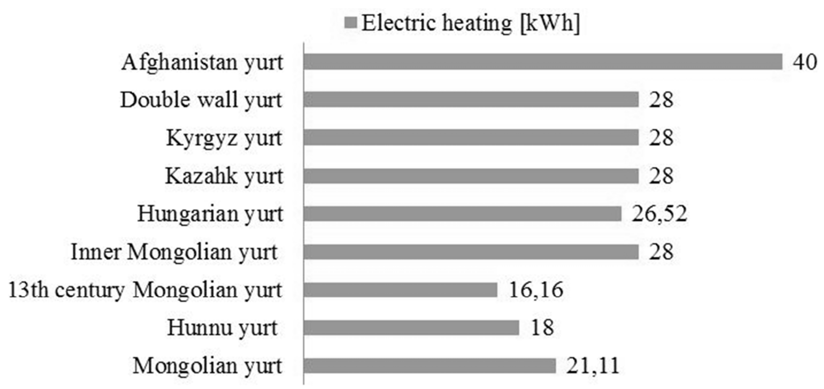

Fig. 3. Used heating energy demand in traditional yurts

The delivered (purchased) energy of traditional yurts is shown; also the best energy consumption which is the best results for heating (*Fig. 5*) and cooling (*Fig. 6*) energy were performed in 13^{th}-century Mongolian yurt and in Mongolian yurt respectively.

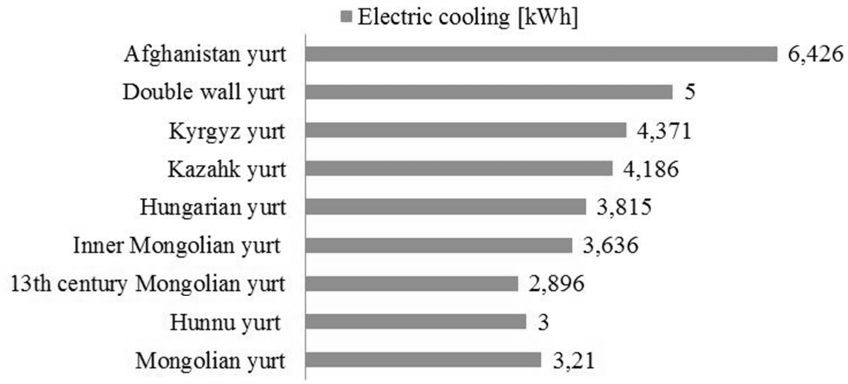

Fig. 4. Used cooling energy demand in traditional yurts

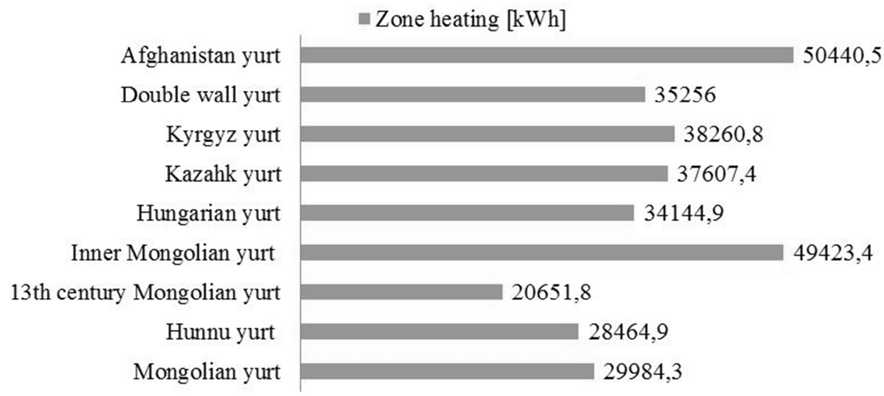

Fig. 5. Zone heating in the delivered energy of traditional yurt

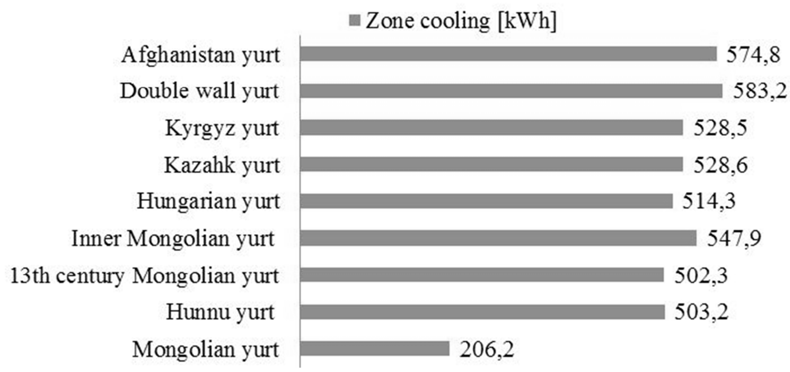

Fig. 6. Zone cooling in the delivered energy of traditional yurt

As it is illustrated in *Table III* under the total heat loss indicator, Afghanistan yurt shows the largest and 13th Mongolian yurt shows the smallest result.

Table III

The energy balance of traditional yurt

	Envelope & Thermal bridges, kWh	Internal Walls and Masses, kWh	Window & Solar, kWh	Infiltra-tion & Opening s, kWh	Total heat loss %
Mongolian yurt					
During heating	-19533.3	-356.1	-833.9	-11180.6	59.0
During cooling	-38	15.5	49.3	-21.3	
Rest of time	-101.3	6.8	9.5	-41.1	
13th-century Mongolian yurt					
During heating	-18658.3	-298.3	-406.7	-5797.2	46.6
During cooling	-30	9.9	22	-8.3	
Rest of time	-102.3	1.5	5.3	-18.3	
Hunnu yurt					
During heating	-19658.3	-356.7	-826.9	-11663.9	60.9
During cooling	-267.6	21	56.6	-41.6	
Rest of time	-267.6	21	56.6	-41.6	
Inner Mongolian yurt					
During heating	-23505.6	-489.7	-1886.9	-27483.3	99.1
During cooling	-248	42.7	117.3	-58.8	
Rest of time	-219.7	4.9	18	-70	
Hungarian yurt					
During heating	-22283.3	-383.6	-866.1	-13930.6	69.8
During cooling	-198.9	23.2	58.7	-44.9	
Rest of time	-225.8	0.5	7.8	-53.7	
Kyrgyz yurt					
During heating	-24105.6	-480	-1063.9	-16605.6	78.6
During cooling	-182.8	27.7	67.9	-44.6	
Rest of time	-182.8	27.7	67.9	-44.6	
Kazakh yurt					
During heating	-23327.8	-453.3	-1040.6	-16780.6	77.4
During cooling	-180.6	26.9	65.9	-46.9	
Rest of time	-180.6	26.9	65.9	-46.9	
Double wall yurt					
During heating	-24891.7	-485	-755.8	-13111.1	73.0
During cooling	-139.4	21.1	44.8	-40.1	
Rest of time	-139.4	21.1	44.8	-40.1	
Afghanistan yurt					
During heating	-27627.8	-928.3	-1492.5	-23958.3	100
During cooling	-116.8	41.6	83.7	-49.2	
Rest of time	-116.8	41.6	83.7	-49.2	

The heat loss from the envelope and thermal bridges appear in between 34.1 and 51.5% heat loss from the opening are from 10.7 to 50.9%. In respect to envelope and thermal bridges, Afghanistan yurt shows the highest heat loss and referring to infiltration and openings the Inner Mongolian yurt shows the highest heat loss. In the summertime, envelope and thermal bridges and top opening and infiltration provide cooling effect and Afghanistan yurt has biggest envelope area.

4.2. The comfort of the yurt

In this section, indoor air quality and thermal comfort will be analyzed through the facilitation of the simulation.

Indoor air quality: The result shows the bigger the volume, the lesser the CO_2 concentration in yurts, which proves that there is a negative relation between volume and CO2. In *Fig. 7* and *Fig. 8* the 13th century Mongolian yurt and Afghanistan yurts' CO_2 level are shown as a representation as they have the highest and lowest results, respectively.

The maximum CO_2 levels for each of the nine yurts are previously shown in the paper. In the simulation, scheduling for top opening coverage is set as open for daytime and closed for night time which effects to the yurt CO2 level. Accordingly, CO2 increases in the night much higher than the approvable level in the standard [8].

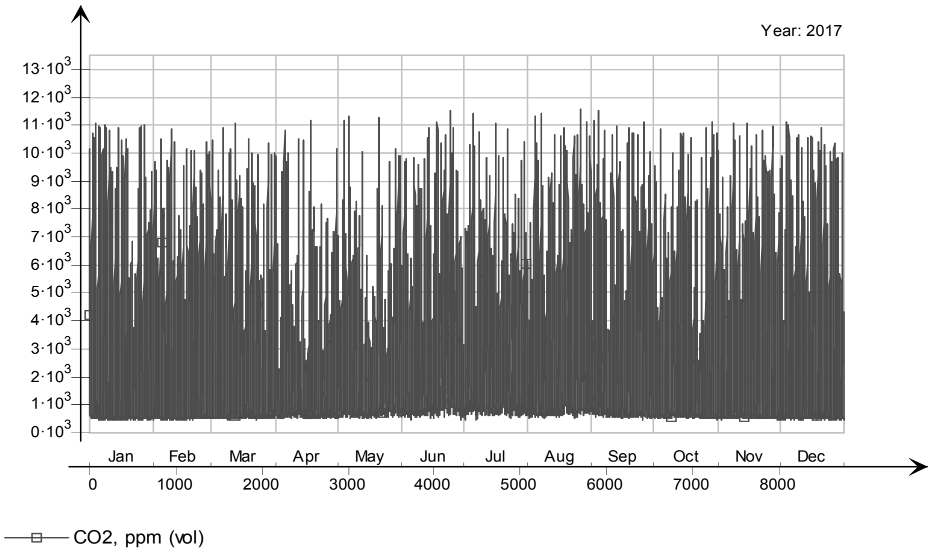

Fig. 7. CO_2, ppm of the 13th-century Mongolian yurt, (8760 h)

Thermal comfort according to EN 15251: Fig. 9 shows thermal comfort from the best to the unacceptable category depends on the operative temperature and illustrated the numbers of the occupancy hours. The most thermal comfortable yurt is the 13th-century Mongolian yurt.

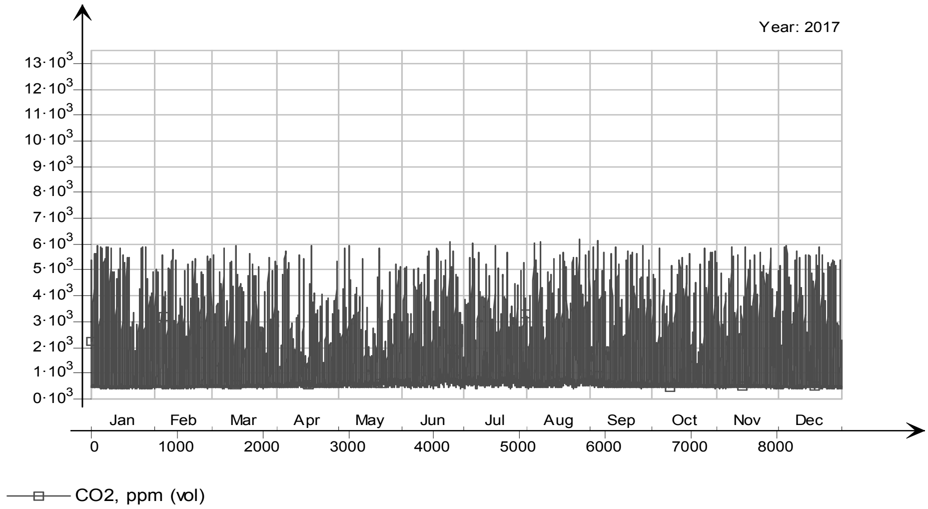

Fig. 8. CO_2, ppm of Afghanistan yurt, (8760 h)

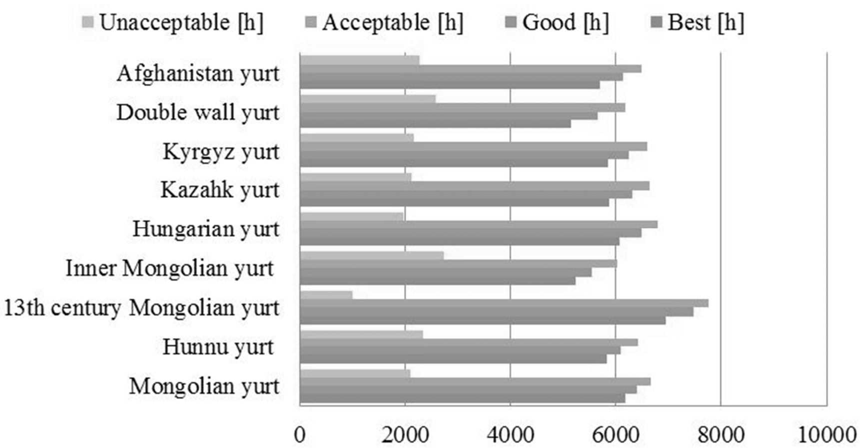

Fig. 9. Thermal comfort category and numbers of occupancy hours

The comparative result on the Predicted Mean Vote (PMV) is shown in *Fig. 10*, *Fig. 11*, the best-resulted yurt is the the13th-century Mongolian yurt (*Fig. 10*) Hunnu yurt, and Mongolian yurt is also good resulted in the simulation results but settled higher than the approvable level in the standard [9]. Afghanistan yurt (*Fig. 11*) shows the highest variance on PMV, because the PMV and the enveloped area have a direct relationship.

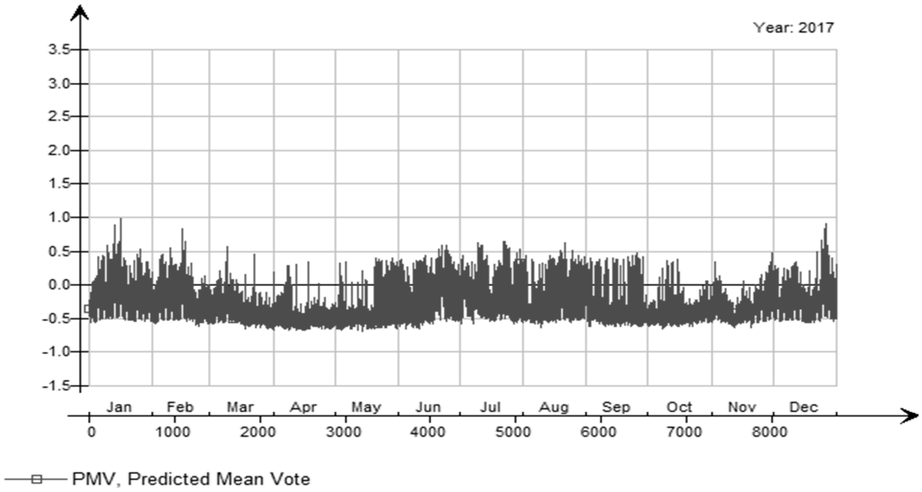

Fig. 10. PMV of a traditional 13th-century Mongolian yurt

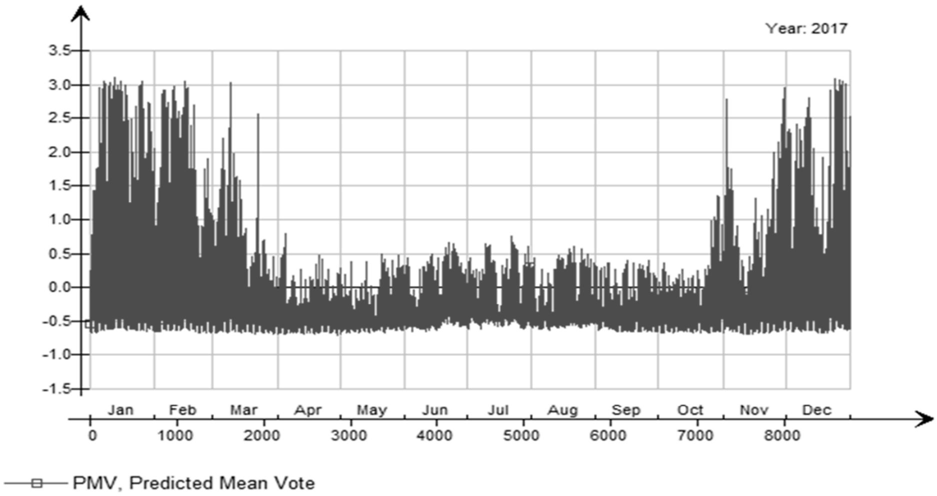

Fig. 11. PMV of traditional Afghanistan yurt. (8760 h)

5. Conclusion

In this study, the nine differently shaped yurts are simulated in the climate settings of Mongolian extreme conditions. However, to support the comparative analysis, the yurts' round plan is set identical and depending on the shapes the volumes differ. The study examines the energy and comfort as part of the research on finding optimal yurt for Mongolian condition. The simulation shows varying results depending on the criteria. Regarding surface/floor area, the 13th-century Mongolian yurt is best, followed by Mongolian yurt with a trivial difference. Also, 13th-century Mongolian yurt shows best results on system energy and delivered energy for heating. For cooling, Mongolian yurt shows the best result as it has a bigger top opening than 13th-century Mongolian yurt. The top opening helps the cooling by the ventilation. The greatest heat loss is obtained in the envelope and thermal bridge losses in all the models, while the second amount of the heat loss is generated by the top opening. In the summertime, these help the cooling.

The CO_2 level of the yurt corresponds to the top opening schedule, during the night the top opening is covered and the CO_2 level exceeds an acceptable level. The top opening has a crucial role in ventilation.

In consideration of thermal comfort, all yurts show lower than the acceptable level under PMV results, however, 13th-century Mongolian yurt better results in comparison to others. In general, 13th-century Mongolian yurt has better energy consumption and is more comfortable than other yurts in the settings of Mongolian climate. On the basis of this study, it has found that there is a room for improvement in modern Mongolian yurt from the angles of energy consumption and comfort. In the future researches 13th-century Mongolian yurt will be considered as the basis for further developments in accordance with its best results revealed from the current study.

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