An Investigation on Thermal Performance of Rocky Architecture Approaching Thermal Comfort with Less Energy Load

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ABSTRACT: The rocky architecture is a kind of sustainable architecture that points to human hard effort for adaption with natural environment by combining human settlements with nature. Despite of the value and precious of this type of architecture, it cannot be used everywhere, due to its specific geographic and topographic features. Therefore the analysis of these Architectural features in term of structure, thermal performance, compliance with environmental conditions and how to adjust the internal temperature, could be a way towards functional features that could be used in modern architecture and in conformity with the objectives of sustainable development.

Given the importance of the issue, this paper focuses on the thermal performance of the rocky architecture of a Sample in Iran’s kandovan village. Thermal performance is specified by comparing the results of recording indoor environment condition with the requirements for thermal comfort and energy used to adjust the internal thermal status.

Keywords: energy, Thermal comfort, Rocky architecture

INTRODUCTION

In last decades, due to the energy and environmental crisis, optimization of energy usage and conservation of biological and environmental resources have been taken into account as important parts of the architects’ goals. So studying the thermal performance of buildings can be a good clue to optimization. Buildings with organic texture possess a better thermal performance compared with hand-built buildings because of the land use as thermal protection. It seems that these buildings have more favourable internal thermal conditions and most of the times are put in comfort range or reach this range with lower energy usage.

As the village of the Sample (KANDOVAN) has a special topography and the number of these samples is limited, houses with normal and hand-built bricks have been built by growing the population and the need for more space for living (Fig. 1).

In this paper the validity of this theory has been studied by investigating the thermal performance of one of these buildings in organic texture of KANDOVAN and comparing it with buildings built with normal bricks then solutions have been suggested for sustainable development in this texture. In this regard we first investigate the rocky architecture, specially the kind of KANDOVAN.

ROCKY ARCHITECTURE

The ROCKY ARCHITECTURE is kind of the battle of human with rock in order to make the appropriate space. In other words, rocky architecture will not be created by the use of usual materials; but it is made from the natural rock and works unlike the ordinary architecture. The usual architecture creates the shell of a skeleton and by using that, reaches the fraction of a space from the whole of it. It means that in the usual architecture, space is a result of the built skeleton or structure; while it is vice versa in the rocky architecture. In this spaces architecture begins with space; it means that it begins with creating small spaces and end with creating big ones [1].

We divide the rocky architecture into two forms from the point of space and skeleton:
1- Structures which are totally free. It means that we first cut a part of a mountain and put it away, and then we create multiple spaces there. In these buildings we can use windows and openings. The facade could be sculptured and manipulated; such as many Indian temples and the graves near BEYTOL-MOGHADDAS.

2- Structures which have been cut inside the mountain. Here just the inner space of the rock is taken into account. The rocky architecture of KANDOVAN in Iran (Fig.2), CAPPADOCIA in Turkey (Fig.3) and DAKOTA in United States (Fig.4) are of this type. However KANDOVAN is the only one that people still live in that acts as part of the major attraction of this place. It means that rocks have not been put away, but the builders have created numerous spaces inside the mountain without any facade and without changing the appearance of the mountain too much [2].

The importance of rocky architecture in sustainable development

Sustainable Development stands for meeting the needs of present generation to meet their own needs without jeopardizing the ability of future generations. The global discussion on sustainable development started officially by the global declaration of the United Nations Conference in the June of 1972. Sustainable development tries to meet some of basic needs of the human society [3]. Protection of environment has been accepted and emphasized not only as the inseparable part of the sustainable development but also as the Fundamental value that is needed for today's generation and future ones. In this regard the general goal of sustainable architecture is decreasing damage on environment, energy resources and nature. A sample of this organic texture is available in KANDOVAN village. Investigation on this type of textures with the aim of sustainable developing and using it for protect the organic texture is valuable.

THE ROCKY ARCHITECTURE OF KANDOVAN

KANDOVAN is one of the villages of the Sahand Mountain located 50 km southwest of Tabriz in Iran. KANDOVAN is placed 18 km south of osko, at the bottom of Green Mountain called Soltan Daghi. This village is placed in a cold and mountainous climate that is so cold in winter and so hot in summer. This region is placed in the altitude of 1641 meters, latitude of 37.56 and longitude of 46.07.

What has given KANDOVAN a historic identity is a large amount of cone shaped stone where people have made house, workshop, stables, and storage. The history of this village is at least 700 years old, and was formed by people fleeing from an advancing Mongol army and who used the caves as a refugee and a place of hiding. The houses are known as Karan in the local dialect. One interpretation has the word Kandovan Being a plural form of kando, a bee's hive. Another interpretation says that Kandovan means Land of Unknown Carvers. The use of 'van' to indicate the plural is found in the Avesta: cf. Ashavan [4].

In the study of geological concepts and how the emergence of a unique form of the village, research results show that In this unique village, the homes are not just built on the mountain, they are carved into it. Built out of volcanic ash and debris spewed during an eruption of Mount Sahand, these rocky structures were compressed and shaped by natural forces into cone-shaped pillars containing pockets. They have been eroded by the elements over the years into their current shapes. The formation of volcanic ash cones is local to Kandovan. Elsewhere, the ash blanketed the land. The existence of a high volume of ash and pumice far from Sahand’s crater indicates that Sahand Mountain erupted with a gigantic explosion in the distant past. Sahand’s rock is about a million years old and the last eruption of Mount Sahand is thought to have occurred within the Holocene epoch that is within the last 11,000 years [4].

In many papers [5] the results of the geology tests show that the rocks of this region are volcanic and this is tuff stone. An examination by author on the rocks also has approved this result. Based on the tests experienced by the author on a sample, the density of this rock is 1334.38 kg/m^2, the porosity is %19.4 and the coefficient of thermal conduction is 0.44 W/M^2.K.
We can explain that all of the Karans are placed in the south hillside of Sahand Mountain, dense and so the surface of each of them exposed to the space is at its minimum. The access is by stairs and inclined routes built from beside the road to the Karans.

Karan include different spaces relevant to their dimensions and heights mostly between 3 to 5 storeys that the lower storey are allocated to folds and cellars and the higher ones are used for living. Those include spaces for hall, bedroom and kitchen. The area of these Karans varies from 10 to 70 square meters and has an average of 50 square meters. There is 2–2.2 meters from the floor to the bottom of the roof and the thickness of the walls is 1–2.5 meters. The light needed for this Karans is supplied by a window with dimensions of 1.2×1.5 (m²); so the lighting inside the space is low and there is slightly dark. The inside cover of walls is a 2cm coating of plaster that both help the space becoming brighter and prevents grains and soil pouring from the rocks (Fig.2).

Thermal performance of rocky architecture

These homes may be some of the best examples of passive design in the world - where the structures were formed by nature. These are known as some of the most energy efficient homes on Earth. According to previous researches [6] the rock provides excellent thermal mass to keep the interiors comfortable throughout the long cold season and during the hot summer. On the other hand the thickness of the walls operates as a thermal mass that can play a critical role in decreasing fuel consumption.

Because the number of these Karans is limited, there will be more demand of place to live by population growth. So inhabitants of the bottom of the hillside build houses with usual brick and they live in them now. Based on the statements of residents, comparing these houses with canonical Karans, oil consumption for heating of each family living in a Karan is 25 barrels (5500 lit) and 36 barrels (7920 lit) for each family living in houses built with bricks that is about 1.5 times more than families living in Karans. Also local residents say that the homes are not only strong but also unusually ‘energy efficient’.

These homes require minimal supplemental heat during the long cold season and remain cool in the summer. This claim of residents has been investigated on thermal performance as follows.

RESEARCH METHOD

For investigating the thermal performance in this paper, studies and Field researches has been taken in 6th of January 2012 for 4 days by recording temperature and humidity of inside 2 samples of houses; the first one is haunted without any heating facilities placed on the first floor of a Karan and the second one is inhabited by people and owning heating facilities executing oil placed on the first floor of a Karan. These records are noted by 5 recorders that all of them are recorded by the time interval of 1 hour through 100 points (Table 1).

<table>
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<tr>
<th>Data Logger</th>
<th>STANDARD (ST-171)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO: 1</td>
<td>11066420</td>
</tr>
<tr>
<td>NO: 2</td>
<td>11066385</td>
</tr>
<tr>
<td>NO: 3</td>
<td>11066383</td>
</tr>
<tr>
<td>NO: 4</td>
<td>11066382</td>
</tr>
<tr>
<td>NO: 5</td>
<td>11066416</td>
</tr>
</tbody>
</table>

Continental information experienced has been processed by Microsoft Excel and compared with each other and a Psychrometric chart has been used to define the comfort range based on data recorded. A simulation program (Energy plus) is used to model a sample for investigating its thermal performance in a long period of time. The results will show us the consumed energy to reach the comfort range in these houses; at the end some solutions will be suggested to sustain the development in this region.

INTRODUCING SPACES UNDER STUDY

The information about spaces under study is shown in Table 2.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>1</th>
<th>2</th>
<th>3</th>
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</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>38</td>
<td>30</td>
<td>36</td>
</tr>
<tr>
<td>Attitude</td>
<td>1.80</td>
<td>2.20</td>
<td>2.20</td>
</tr>
<tr>
<td>Volume</td>
<td>64.80</td>
<td>66</td>
<td>79.20</td>
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<tr>
<td>Floor</td>
<td>ground</td>
<td>first</td>
<td>ground</td>
</tr>
<tr>
<td>Heater</td>
<td>none</td>
<td>Oil</td>
<td>Oil</td>
</tr>
<tr>
<td>NO. Recorder</td>
<td>1&amp;3</td>
<td>2&amp;4</td>
<td>none</td>
</tr>
<tr>
<td>Wall Thickness (m)</td>
<td>2-2.5</td>
<td>2-2.5</td>
<td>0.35</td>
</tr>
<tr>
<td>Material</td>
<td>native</td>
<td>native</td>
<td>brick</td>
</tr>
</tbody>
</table>

Table 1: Data Logger Properties
ANALYZING THE RECORDED INFORMATION

Result of analyzing thermal records of sample 1
Two recorders were put in this space. Recorder No. 1 (Fig.5) was in the front space that is linked with the entrance door. Recorder No. 3 (Fig.5) was put in the back place that is almost covered with ground. Figure 7 shows that recorder No. 3 has recorded less fluctuation in temperature compared to recorder No. 1 within the range of 11.1~11.8 °C it shows that with increasing depth the fluctuation will converge to 0.

Result of comparing thermal information of sample 1 & 2 with outside temperature

The average of the temperature of inside was 10.14 °C in sample 1(Fig.5), 22.1 °C in sample 2 and 0.6 °C for the outside. Comparing these shows us that the temperature in sample 1(Fig.5) is about 9.5 degrees warmer than the outside temperature and is 11.9 degrees colder than the sample 2 (Fig.6). The results tell us that these Karans have a good thermal performance and can provide energy saving of averagely %60 because the change of 1 degree changes the energy saving about %7[7]. It is true while in the coldest hour (5 a.m. on 7th January 2012) that the temperature is - 4 °C and the temperature in the back space inside sample 1(Fig.5) is

Result of analyzing thermal records of sample 2

Again two recorders were put in this space. Recorder No. 2 (Fig.6) was in the front space that is linked with the entrance door and is nearer to the heating facilities. Recorder No. 4(Fig.6) was put in the same space but with more distance from windows, doors and heating facilities. Figure 8 shows the comfort range of temperature for inhabitants of this house that is between 21.1 and 25.3 °C , by considering all the other factors that infect comfort to be constant, the comfort range of temperature has been fluctuating for about 4 degrees because of existing people inside the house all over the recording period. Due to the fact that the heating facility was rudimentary and it was not possible to adjust the temperature it seems that “it is possible to decrease comfort temperature by1°C and optimize the demand by %7” [7] by using a device that is under control.

Data logger number 5 has recorded information in free space and has been exposed to the air within the period of recording.

Figure 7: Thermal Information of Sample 1

Figure 8: Thermal Information of Sample 2
11.2 °C; with the difference in temperature for about 15 °C, energy demand is decreased dramatically (Fig.9).

Results of thermal and humidity information analysis on psychrometric chart

Points 1 - 20 are belong to the sample 1(Fig.5, Table2) and points 21 - 40 are belong to the sample 2 (Fig.6, Table 2) and points 41-60 show outside temperature. These points have been resulted from the average of every 5 points. (We have totally 100 points recorded).

The yellow range is for comfort range, the blue one is for comfort range while using a heat mass and the red one is for comfort range while using inactive solar energy. These ranges was defined by the software “weather tools” while activity is sedentary, relative humidity is %50 and dry temperature is 25 °C in January (Fig.10).

Comparing the location of congestion of recorded points with ranges of comfort shows that %30 of the points in sample 1 (there was not any heating facility) falls within the comfort range when we use heat mass for energy resource. It prepares tolerable situation without the need for any active heating. This declares that Karans falls within the comfort range by using much less energy or by using sunlight properly.

Points recorded in sample 2 do not fall within the comfort range while heating facility has been used in. This is because of high humidity existing that is because of permeability of the rocks of this region itself. Figure 10 shows that the situation of inside will become much better by just a little removing of moisture; it will also prevent the damage to the furniture and humidity-irresistible materials.

“ENERGY PLUS” SOFTWARE

Energy Plus is an energy analysis and thermal load simulation program. Based on a user's description of a building from the perspective of the building's physical make-up and associated mechanical and other systems, Energy Plus calculates heating and cooling loads necessary to maintain thermal control set points, conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment. Simultaneous integration of these— and many other— details verify that the Energy Plus simulation performs as would the real building [8]. In many papers [9][10] it has been used for thermal analysis of models.

Result of simulation

Due to the lack of weather data of KANDOVAN, the simulation has been done based on the weather data from Tabriz which is close to Kandovan and has a similar climate to it. For more investigation on the thermal performances of Karans 2 samples of Karans were used; one is a Karan under study and the other is a house built with bricks (Fig.1, table 2). Although the thickness of Karans’ walls is more than 2.5 meters, it is modelled as 1 meter due to limitation of software in modelling a facade thickness.

Figure 11 shows that the average heating energy required for brick houses is 2.19 times more than which is required for Karans during each year. This foundation confirms the residents' claims about annual energy usage (1.5 times more). This difference seems to be because of cultural reasons, covering type and rate of activity, efficiency of heating facilities and financial statement of residents that none of them is able to be simulated. These reasons is leaded to better adaption with environment that finally decreases the fuel consumption compared with which is simulated in the software. We can predict that by taking the thickness of the walls more than 2 meters, this difference reaches more than 2.5.

Based on Figure 11, energy needed for heating is higher in Karans than brick houses in May and June; this would be because of heating mass and delay in Karans which means by air becomes warmer, the weather inside will not get warm immediately and in order to remain within the comfort range, heating energy is needed, In
October by beginning the cold season, much less energy is needed for heating in Karans compared with brick houses because of the saved energy and this difference gets higher when the air becomes colder; because brick houses are critically exposed to environment situations.

![Figure 12: Sensible Cooling Energy [J] of Simulated samples](Image)

Figure 12 shows that energy needed for cooling is 9 times higher in brick houses than the Karans. Based on the statements of residents no cooling facility is used during hot seasons; but the result of simulation shows that energy is needed for cooling in July and August. This difference seems to be because of using information of Tabriz instead of KANDOVAN; because based on the metrological data, the average of temperature in Tabriz during these 2 months is about 2–3 degrees higher than Kandovan that according to studies in [7] this difference can lead to %14–21 decrease in energy usage.

Thermal skip in July and October on the brick houses’ samples(Fig.12) states that these houses are extremely exposed to environment situations how when it gets warmer in July it affects them immediately and the temperature inside them gets high fast; the vice versa happens in October when the weather gets cold the temperature inside decreases too much. But Karans delay the change caused by environment change because of the thickness of their walls and being located inside the earth and so they experience less fluctuation.

CONCLUSION

Investigating thermal performance of building constructions in Kandovan by analyzing thermal records, psychrometric chart and “Energy plus” software illustrated notable results that this has drawn much attention to domestic architecture and solutions have been suggested for sustainable development. We can conclude these results as follows:

1. By increasing the depth of building through the ground or using a heat mass as a source of energy and a factor of creating time delay, thermal fluctuations will reach its minimum.

2. Karans have better thermal performance compared with brick houses of the same region and provides averagely %60 decrease in energy consumption. Results of simulation have estimated heating energy needed to be 2 times higher for the brick houses than Karans.

3. While there is lack of heating facility during the coldest month of the year (January), the Karan under study falls within the comfort range caused by the heat mass for %30 of the time and falls within this range for %70 of the time if there will be appropriate use of solar energy. In other words the need for heating energy in order to fall within the comfort range is too low.

4. Cooling energy used in Karans is extremely low and negligible and it is easily reachable by using domestic parameters even if it is needed.

5. It seems that developing this village and creating needed spaces for residents is inevitable because of the dynamic and live texture of Kandovan being remained; but the constraint of the number of Karans in the region cause the need for creating other spaces. In order to achieve similar thermal performance in new buildings as Karans' thermal performance and to keep natural organic texture of this village; new buildings (or at least a part of their construction) would be made inside the land. On the other hand in order to reach suitable thermal performance like that for Karans, having walls thicker than 2 meters does not seem logical these days; so by using modern technology, finding new materials from this rock type of Karans with the same performance and low heat exchange coefficient would not be out of mind.

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Figure 1:  
http://upload.wikimedia.org/wikipedia/commons/1/1b/Village_trogloidyte_kandovan_iran.jpg  
Figure 2:  
Figure 3:  
Figure 4:  
Figure 5 & 6: by Author