546: High Altitude Design, Optimising Residential Architecture in the Alborz Mountains, Iran

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Abstract

Darbandsar is a village located in the Alborz Mountains in north of Tehran, at latitude of 36º N and at an altitude of 2500m. Its climate is characterised by snowy, cold winters and warm summers. Existing houses in this village are built to low construction standards and are not designed with respect to the high altitude climate. As a result, their energy consumption is extremely high; especially the energy demand for space heating. These houses also fail to provide adequately comfortable conditions for their occupants throughout the year. They suffer from low temperatures during winters and overheating during summers.

This paper describes how a climatically responsive design for six housing units in Darbandsar can reduce dependence on energy intensive active heating systems and significantly improve occupant comfort. This hypothesis is explored first through a detailed analysis of climate, site and occupancy patterns. Two case study buildings, located in climates similar to that of Darbandsar, are assessed in terms of their passive design strategies. Through a comparative analysis with the case study climates, passive strategies appropriate for the climate of Darbandsar are identified and the design of the six units are developed accordingly. The impact of these strategies is then assessed through parametric studies, and the final space heating energy demand of the project compared to existing benchmarks.

Keywords: High altitude climate, occupancy pattern, Passive design

Fig. 01: The design of three permanent (right) and three intermittent units (left)

1. Introduction

The objective of this project was to design six units for six actual clients in the village of Darbandsar located in the Alborz Mountain, north of Tehran, Iran (latitude 36º N, altitude 2500m). The site for this project is located in a valley and is divided in six sections for three permanent occupants on the right and three intermittent occupants on the left side of the site.

The goal of the project was to maximise the use of passive strategies appropriate to this high altitude climate in order to develop a design which is measurably superior to the existing houses in Darbandsar both in term of energy efficiency and occupant comfort.

This paper demonstrates that how this design is generated through a selection of appropriate passive strategies mainly impacted by three issues: (1) the climate, (2) the specifics of the site (3) the two different occupancy patterns. The final design as illustrated in Fig.01 shows the selection of the two very different approaches to passive design based on the two different occupancy patterns and their specific comfort adaptability and building usage.

2. Context of the project

2.1 The climate of Darbandsar

The climate of Darbandsar, with 3184 heating degree days and an average yearly temperature of 10.6ºC can be termed as temperate, although due to its high altitude it also receives high levels of incident solar radiation. Based on monthly diurnal chart illustrated in Fig.02 the average hourly incident solar radiation on an unobstructed horizontal surface ranges from minimum 100 W/m² in December and maximum 350 W/m² in June. This means the passive design strategies which might be appropriate for other temperate climates may not be necessarily suitable for Darbandsar.

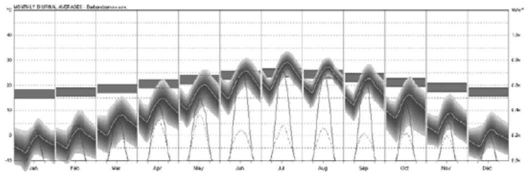

Fig. 02: Darbandsar monthly diurnal chart (Source: Weather tool 200)

2.2 The site

The site for this project is located in a valley at an altitude of 2500m above sea level. It has a very steep slope of 32º and faces southwest, 65º off south. As it is shown in the Fig.03 this site gets overshadowed in winter till 9am and from 5pm from the higher mountains.

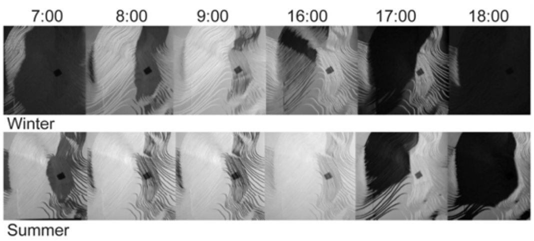

Fig. 03: Overshadowing studies using Heliodon

2.3 The two occupancy patterns

The occupancy patterns of the six units are dictated by the six clients who have already purchased the site. The occupants are divided into two groups based on their usage patterns of the building: permanent and intermittent.

Defining both types of occupancy is essential for understanding the energy demand of the units. In particular, different occupancy and usage patterns have a significant impact on the heating schedule. According to Yannas [1], occupancy patterns, and therefore energy consumption, can vary for each household according to the employment of individual occupants.

The permanent occupants: Half of the occupants are assumed to be always at home, and the other half from 6pm to 9am for the whole week. There is a continuous heating demand (24 hours) in the cold period.

The intermittent occupants: The units are fully occupied on weekends only, and are continuously heating during the cold period. There is no heating during the weekdays when the occupants are not there.

3. Choosing the Appropriate Passive Strategies for the Design

In this section, the passive strategies appropriate to the climate of Darbandsar are explored, by analysing two climatically responsive case studies in different locations which adopt different passive strategies according to their climates.

For this purpose two case studies are selected from climates which are comparable to the climate of Darbandsar in terms of temperature and solar radiation: Karen Terry House as a Passive Solar design in Santa Fe, New Mexico at the latitude of 36º N and the 'PassivHaus' in Hannover, Germany at the latitude of 52º N.

Lessons learned from this analysis provide clues as to the appropriate passive strategies for Darbandsar.

Fig. 04: Karen Terry House and Hannover Passive Houses (Source: Feist, 2003)

3.1 Climate Exploration of the Case Studies

To understand why these case studies have adopted the passive approaches they have, drawing a comparison between the ratios of the two main aspects of the climate is useful: the degree days and the incident solar radiation

The degree days are representative of the amount of heat which is required and the available solar radiation indicates the amount of solar gain which can cover the heat needed.

Fig. 05 shows that in Santa Fe, the ratio between the monthly heating demand and monthly available incident radiation is small, suggesting that there is a potential for passive solar design in this region. In the case of Hannover however, the ratio between these two climatic elements is a large number, indicating that although a large amount of heat is needed, there is not much solar radiation available. This suggests that the design in this climate cannot be much dependent on solar strategies.

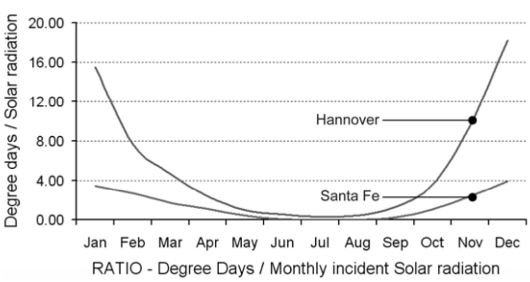

Fig. 05: Comparison of the ratio between degree days and solar radiation for the climates of Hannover and Santa Fe

3.2 Passive Strategies Chosen by the Case Studies

The result from this study is clearly reflected in the aspects of building design of the two case studies which allow their passive potential to be optimized relative to their respective climates. These aspects include orientation, building form, window ratio and type of construction.

In Santa Fe, due to high solar radiation, south orientation for the building becomes very important in terms of maximising the solar gain and also reducing the risk of overheating associated with more westerly orientations. Karen Terry house has an open, shallow plan in three levels with large are of glazing welcoming the solar radiation deep inside the space. The two parallel north-south walls are insulated adobe walls and the floor is a high thermal mass element. Also, the retraining walls, which separate the plan into three levels, are constructed of adobe and concrete blocks which contain water in order to reduce the indoor temperature fluctuations and to minimise the risk of overheating [3].

However in the case of Hannover since there is not much solar radiation available, the design is less dependent on a south orientation. Due to the reduced contribution of solar gain, the buildings' forms are more compact and are more coupled together in order to reduce the heat losses through the building envelope. They also have a relatively small area of glazing which is distributed equally on the north-south facades. The main aim of this project is minimising heat losses through the envelope and through ventilation to the point that it can be balanced with the internal and the least available solar gains. As a result high insulation for the external elements and a high level of air-tightness are very important.

3.3 Conclusion from the Case Studies

As the possible passive strategies can differ greatly based on the different characteristics of the climate, exploring the similarities and the differences between the climate of Darbandsar and that of the case studies, gives an indication of the strategies that can be applied to the design of the six units in Darbandsar.

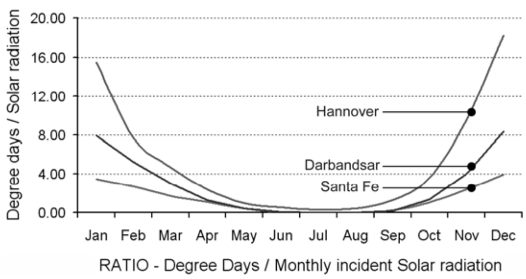

Fig.06: Comparison of the ratio between degree days and solar radiation for the three climates of Hannover, Santa Fe and Darbandsar

The comparison between the ratios of the degree days and the incident solar radiation of Darbandsar with the two cases of Santa Fe and Hannover indicates that the ratio is in the middle of the two other cases. Fig. 06 shows that in winter the solar radiation available in Darbandsar which can contribute to the heating requirements is less than Santa Fe but a lot more than Hannover.

4. Design of the Two Occupancy Units

In order to develop the design concept for the six units in Darbandsar, the passive strategies from the case studies were applied to the two different types of occupancy patterns and adapted accordingly. Through the application of these strategies, it was then demonstrated that the performance of the design for both permanent and intermittent units could be optimised.

4.1 The permanent houses strategies

As the permanent occupants are home throughout the week, there is a good opportunity to control the adaptable elements of the building. Adaptable elements may be defined as insulating night shutters or adjustable summer shades. This makes the building an 'open box' which can be exposed to solar radiation during the day and closed at night to prevent excessive heat dissipation through the glazed elements. The more the building becomes adjustable to the diurnal and seasonal changes, the more it can follow the design approaches of the passive solar design and can be dependent on solar gain as the main heat source.

As a result of this dependency, the form of the building can have a great impact on the energy balance of the units. The main elevations of the permanent units were rotated to 25º off south towards west, allowing sufficient solar radiation to fall on the surface which can then usefully contribute to meeting the space heating demand. The window ratio of the permanent units was also optimised to achieve the optimal energy balance for the unit. The relatively shallow plan of the units and the mass inside the space as thermal storage allows the solar radiation to penetrate deep inside the space and usefully contribute to space heating.

4.2 The intermittent houses strategies

By contrast as the intermittent occupants only use the buildings at the weekends, they have no control on the building's elements during the weekdays. As the result, the building loses its adaptability and becomes a 'closed box' with no solar or internal gain during weekdays. In this period the building cannot be dependent on heat gain from the sun or occupants and in the absence of any heating system, the indoor temperature will eventually tend toward the outside temperature. At the weekend when the occupants are back, they need to put a high amount of energy to warm up the space.

For this reason, these buildings can follow the approach of the Passive Houses. In this approach, one of the key strategies is minimising ventilation and fabric heat loss. Heat gains from solar energy play a small role in the thermal balance of the building. Consequently, optimised orientation for increased solar gains is not important. Instead the buildings were designed to follow the contour of the site's slope facing 65º West of South, which allows a more compact form with minimum exposed surface area, and therefore a significantly reduced heat loss coefficient. The area of windows which are the most thermal inefficient elements are minimised for the same reason. A 10% area of glazing provides adequate daylighting for the relatively shallow plan without having a significant effect on heat loss.

4.3 Coupling permanent and intermittent units

The design of the building envelope affects the energy exchange of the spaces with the outdoor environment. As heat loss is dependent on exposed surface area, the three intermittent and three permanent units are coupled together as illustrated in Fig. 07, therefore reducing excessive heat dissipation through the envelope in winter. This coupling also offers the possibility of a thermal relationship between the units which has the potential to improve occupants comfort. In an optimized way the intermittent spaces can act as buffer zones for the permanent spaces and at the same time the permanent spaces can provide a preheating source for the intermittent houses.

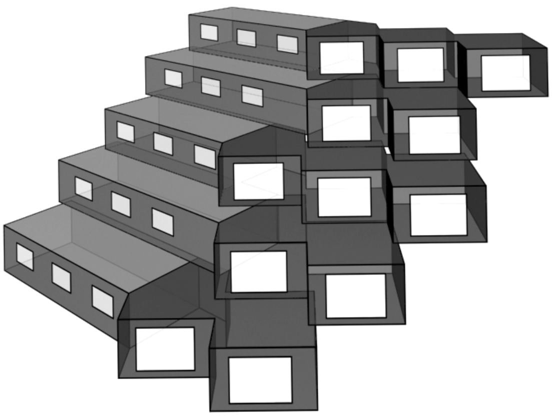

Fig. 07: Coupling Intermittent (left) and Permanent (right) units together

4.4 Introducing semi-enclosed spaces between the units

For optimizing the energy balance in both permanent and intermittent occupancy units, five semi-enclosed spaces are introduced in the design, three positioned between the intermittent spaces and two adjacent to the permanent units. They have area of 20 m² each and have opaque roofs and single glazed walls. The effect of solar gains in this space, the massive internal walls, and the heat lost from the adjacent units should make temperatures in these spaces more comfortable than unprotected outside spaces.

These semi-enclosed spaces can buffer the units as well as providing a source of preheated air for ventilation. This is especially beneficial in the highly insulated intermittent units where, the proportion of heat loss through ventilation becomes more critical.

In winter these spaces as shown in Fig.08 can also provide closed circulation route inside the site to prevent people to be exposed to the harsh outdoor environment while in summer interconnecting these multiple spaces creates a stack effect along the circulation route to further improve ventilation and dissipate excess heat.

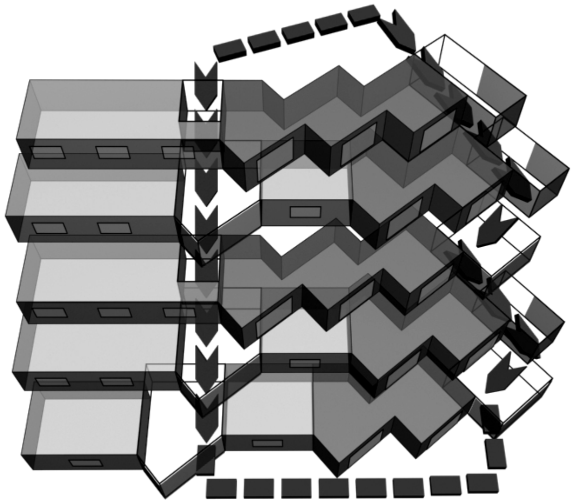

Fig. 08: Introducing the semi-enclosed spaces between the Intermittent and Permanent units

5. Parametric Studies

In this design stage after defining the passive strategies appropriate for the two different occupancy units, two key issues are necessary to be analysed:

1. What space heating demand should be targeted for a dwelling unit in Darbandsar?

2. To what extent it is necessary to optimise the physical properties of the units in order to achieve this target space heating demand? In other words, exactly how much can the existing standard of building construction be improved through reduced fabric and ventilation heat-losses?

In order to answer these questions, a series of theoretical models were assessed using the dynamic thermal modelling tool, TAS (EDSL. v 9.0.9). The performance of these models was investigated in four steps of improvement of the building characteristics in reference to fabric and ventilation heat-loss. The first step is based on the characteristics of a typical house in Darbandsar and the fourth step is close to the PassivHaus standards in terms of fabric insulation.

In order to see the effect of varying insulation, air change rates, window ratios, site layouts (in terms of coupling and de-coupling buildings), it was necessary to maintain same occupancy gains and gain pattern for each step of the parametric assessment. A comparison was also drawn between the effect of these changes in

climates of Darbandsar, Santa Fe and Hannover, from the case studies.
Table 01 summarises the detailed design parameters for the four steps.

Table 01: The defined four steps for the parametric studies

Step 1: Reference Case (Derived from the field work)	DG: U = 2.8 W/m²K walls, no insulation: U = 1.2 W/ m²K roof, insulation: U = 0.6 W/ m²K ground floor: U = 0.3 W/ m²K infiltration 0.5, ventilation 0.3 ach
Step 2 (base case derived from case studies)	DG: U = 2.8 W/m²K roof, insulation: U = 0.6 W/m²K walls: U = 0.5 W/m²K ground floor: U = 0.3 W/m²K infiltration 0.5, ventilation 0.3 ach
Step 3 (the best case achievable in Darbandsar)	DG with night shutters walls: U = 0.28 W/m²K roof: U = 0.22 W/m²K ground floor: U = 0.2 W/m²K infiltration 0.3, ventilation 0.2 ach
Step 4 (Close to the PassivHaus standards in terms of fabric insulation)	DG Coated walls: U = 0.12 W/m²K roof: U = 0.12 W/m²K ground floor: UV 0.2 W/m²K infiltration 0.3, ventilation 0.2 ach

The following parameters were kept constant in all four steps:

Orientation: South
Volume of the building: 324 m3
Area: 120 m2
Internal gain: 7.5 W/m2
Mean house temperature: 21ºC

The results from this parametric analysis are presented in Fig. 09. The curved lines from the top to the bottom show the stepped results for a detached house with 10% window ratio in Hannover and Darbandsar and a terraced house with 20% window ratio in Darbandsar and Santa Fe. It is clear that by reducing fabric and ventilation heat losses, it is possible to bring down the annual energy usage under 20 kWh/ m² in most cases. But how should the optimum level of insulation for a building in Darbandsar be determined, so that it is not over-insulated?

"Step 3" represents the best performance achievable considering the material available, cost and construction standards in Darbandsar. Fig. 09 demonstrates how a larger area of glazing and coupling can contribute to achieving the same annual space heating demand as a detached house with smaller windows. In comparison, a detached unit with 10% window ratio sited in Hannover would require a more insulated envelope (step 4) in order to achieve the same space heating demand as a terraced house with 20% window ratio in Santa Fe which is insulated close to "Step 2". This shows the critical affect of the climate in defining the level of insulation necessary for a building in that climate.
From above assessment, it is seen that the target space heating demand should be around 20 kWh/ m2 through the selection of passive strategies appropriate to the climate and occupancy pattern with acknowledging the limitations in terms of construction and performance of buildings in Darbandsar.

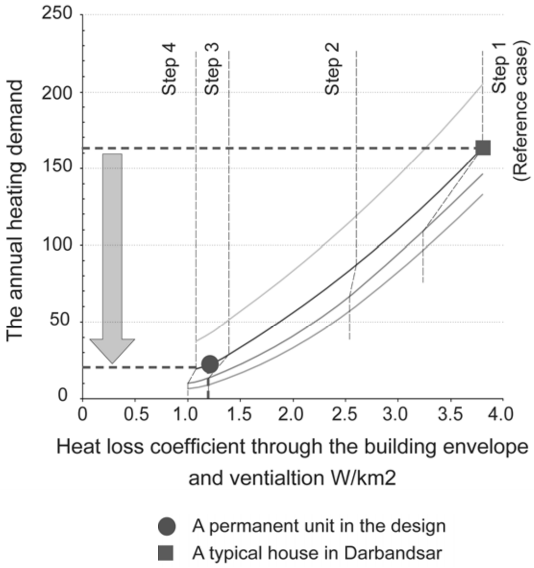

Fig. 09: Parametric studies (Source: TAS V 9.0.9)

As it is shown in the Fig. 09, this target is derived from the case of terraced house with 20% window ratio which is insulated at the "Step 3" level. Other factors including orientation and thermal buffers can also have an impact on the space heating demand without increasing the requirement for insulation.

6. Design Performance

For investigating the design performance in terms of the annual heating demand, one permanent unit was assessed in TAS. The circle dot in Fig. 09 represents the current design performance of one permanent house. The annual heating demand of this unit is close to 20 kWh/ m² which compared to a typical unit in Darbandsar represents a reduction from 160 kWh/ m² to 20 kWh/ m². Although this permanent unit is insulated to the level of "Step 3" (the best case achievable in Darbandsar), it is performing close to "Step 4". This improvement is the result of the chosen design strategies as were described in the design process, importantly coupling and thermal buffering.

6.1 Monthly heating demand

The monthly heating demand of the permanent unit is also compared to a current existing typical building in Darbandsar as it is shown in Fig. 10. This shows that the free running period can be significantly extended as a result of the passive strategies, and therefore the heating period reduced. This means that by getting closer to higher standards in the building envelope, it is possible to introduce a new balance between summer and winter in the indoor environment of the house.

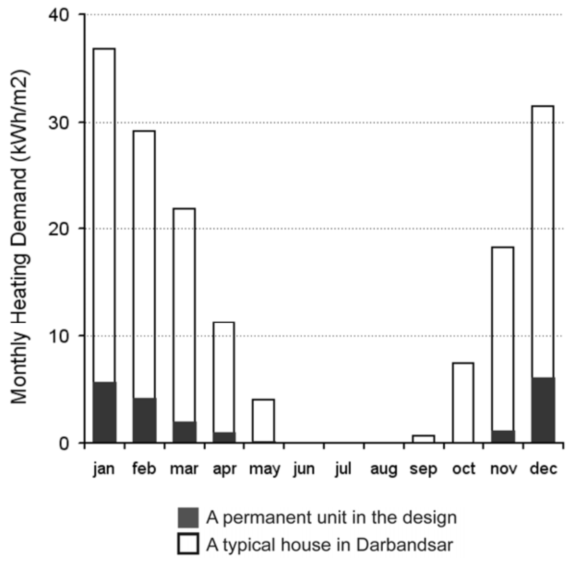

Fig. 10: Comparison of the monthly heating demand between a typical unit in Darbandsar and a permanent unit in the design proposal (Source: TAS V 9.0.9)

7. Conclusion

In this paper two main goals were identified:

- Minimise the space heating demand for these houses by exploiting passive strategies appropriate to the climate of Darbandsar.

- Demonstrate that the design proposal was measurably superior to the existing houses in Darbandsar both in terms of energy efficiency and providing comfort for the occupants.

The designed units achieve a space heating demand to degree day ratio of 0.006 (20 kWh/m² ÷ 3184 DD, base 18º C). This is more than the value of 0.0045 (15 kWh/m² ÷ 3379 DD) for the Hannover PassivHaus.

This lesser performance was anticipated by the parametric studies and is caused mainly due to low standard of construction and materials in Darbandsar that cannot match PassivHaus standards.

However the true comparison and success of this Design proposal lies in its comparison to the existing building stock of Darbandsar. In typical buildings, most energy is expended on space heating, so any passive design strategies which can reduce this demand can make a significant reduction in overall energy consumption. The space heating of the proposed units is estimated at around 20 kWh/ m². This represents an 87.5% decrease as compared to existing building stock which has a heating demand of around 160 kWh/ m². The design proposal succeeds in responding to the specifics of the site, climate and occupancy patterns and produces a new efficient building type for Darbandsar which can inform similar constructions in many areas of the mountain region of Iran.

6. Acknowledgements

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7. References

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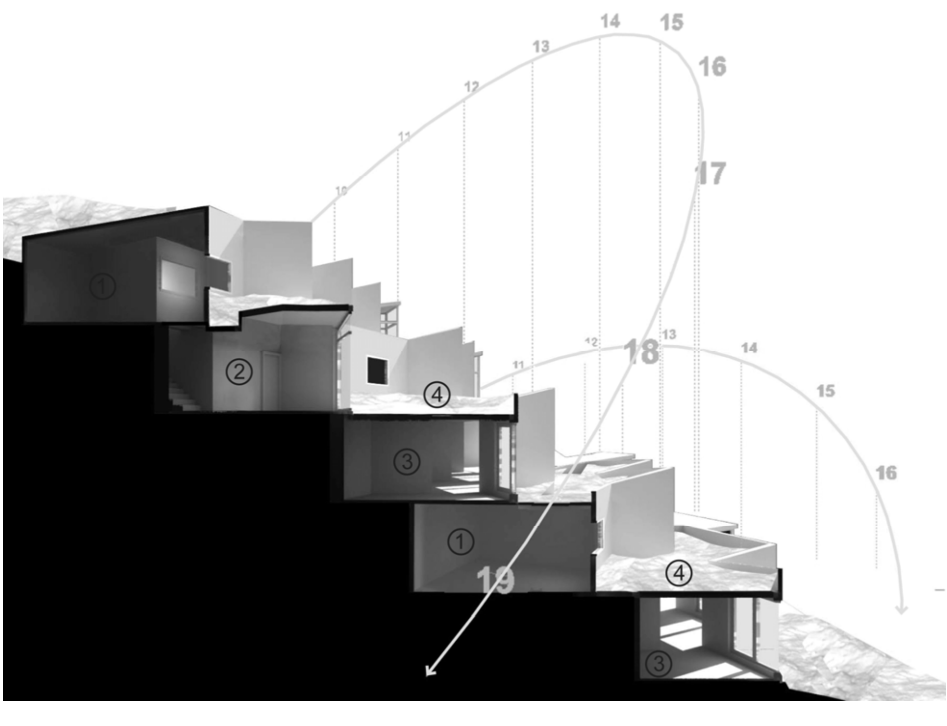

Fig. 11: Seasonal building's operation

1. *Intermittent units*
2. *Permanent units*
3. *Semi - enclosed Spaces: These spaces can be utilised as public nodes for social activities in the cold period of winter. During summer they provide a pleasant indoor environment by enough ventilation through the glazing area.*
4. *Terraces: In the summer, the terraces can be used for social activities.*