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A STUDY OF LOCAL ENVIRONMENT OF HARRAN HISTORICAL DOMED HOUSES IN TERMS OF ENVIRONMENTAL SUSTAINABILITY

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ABSTRACT

The aim of this study was to emphasize the close relationship between the local environment of the city of Harran and sustainability. In this study, the domed houses of Harran, a district in the province of Sanlıurfa located in the Southeast of Turkey, were studied to investigate the natural ventilation performance, climatic data and insulation properties of the materials used in the houses. In this paper, firstly, the physical environment parameters of the region were described. Then detailed experimental studies were carried out to determine the natural ventilation characteristics of the houses. The experiments conducted in this study were carried out on one of the most preserved houses in the city. The application of natural ventilation designed in contemporary buildings maintaining harmony with nature was discussed and some recommendations on the relationship between buildings and local environment parameters were presented. We strive to find the balance between the environment, and sustainability. Vernacular Harran houses present messages good harmony of nature with human being life in concept of a healthy environment, cleaner production, climatic building design and re-usable building material. The domed houses of Harran in the hot arid climate region are noteworthy examples regarding good design for a sustainable future. Houses' extraordinary architectural features provide environmental comfort inside the houses without the need for energy consumed by air conditioning and other remedies. Harran houses are interesting samples that have reached daily life with the use of recycled materials and the construction-making period that reduces energy consumption. Houses offer solutions that respond to survival needs of inhabits as well as environmental comfort.

Contribution/ Originality: This study contributes to find the balance between the environment, and sustainability. This study has illustrated how the vernacular domed houses of Harran simply and admirably correspond to hot and cold environments as well as a comfortable living environment which is both cost-effective and humanitarian. In addition, in terms of ecology, all these traditional materials have low environmental impact in their production, reusability and even natural dissolution.

1. INTRODUCTION

Every building around the world requires large amounts of energy for heating and cooling [1-6]. The biggest challenge the continuously developing economy faces today is balancing its rapid residential building programs in

order to protect the environment and conserve energy through the introduction of long-term energy-efficient strategies that have a sustainable ethos [7]. Vernacular houses in hot and arid regions are very effective in terms of energy saving and the necessity to keep the environment clean [8, 9]. Domed and vaulted roofs have been used in the middle East and in central parts of Iran for centuries (Figure 1 and 2) [8, 9].

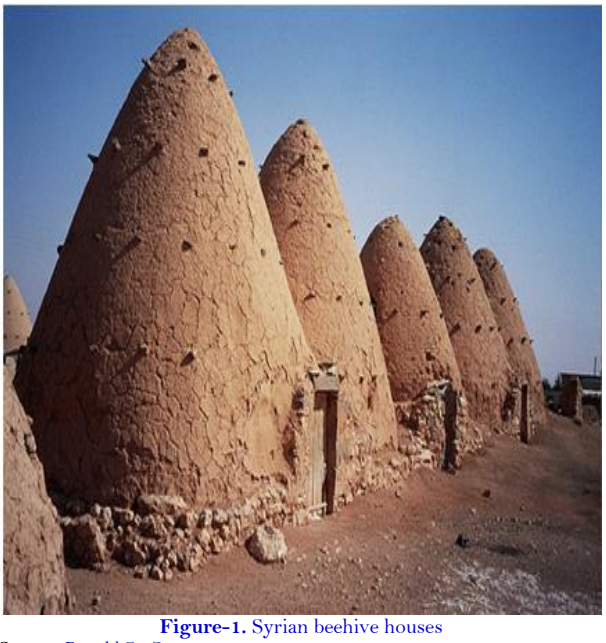

Figure-1. Syrian beehive houses
Source: Ronald [10]

Figure-2. Vernacular domed houses in Iran
Source: Bakhshi, et al. [11]

Natural ventilation and passive cooling are two of the most important features of domed roofs. During summer days the domed roofs would have up 40% of its area shaded from the sun due to its architectural style as opposed to a flat roof. Thus, some parts of the roof are cooler than others. A ventilation opening is placed at the apex of the roof to accelerate ventilation. The opening acts like a suction cowl in that it creates a negative pressure over the opening and extracts indoor air [12]. Therefore, the vernacular domed houses maintain lower indoor temperatures during the hot summer months and reflect more sun light than flat creating a more comfortable environment to live in Koita [13]; Ettoumi, et al. [14]; Olgyay [15]; Fathy [16]; Mainstone [17]; Bowen [18]; Tang, et al. [19].

The Harran vernacular domed houses, which are a perfect example of climate-oriented architecture, have become a popular research topic for many researchers such as Demirbilek [20-25]. In this paper, firstly, the physical environment parameters of the region were described. Then detailed experimental studies were carried out to determine the natural ventilation characteristics of the houses. The application of natural ventilation designed in contemporary buildings maintaining harmony with nature was discussed. Finally, some recommendations on the relationship between buildings and local environment parameters were presented.

2. MATERIALS AND METHODS

When conducting this study, the historical design and natural ventilation system of the Harran vernacular domed houses was especially considered. The historical design of the houses consists of a single story, an opening on the dome, a long row of rooms aligned one after the other (interconnected rooms), and a courtyard encircled by a high wall in front. The rooms are almost in equal square shapes, connected internally by arched doorways and rarely) have small windows opening to the courtyard. There is a dome on each room all of which are different in diameter and height. Ventilation is essentially the application of fluid dynamic principles to the flow of air in house openings. It is the function of the barometric pressure and dry-wet bulb temperatures of the indoor and outdoor..

The difference in temperature and pressure is known as natural ventilation. The natural ventilation distribution in the houses is completely defined by:

i. Physical parameters of the airways namely, shape, area, length, direction, and friction factors.
ii. Layout of the openings.
iii. Pressure sources in the system.
iv. Interconnections between the airways, openings, and pressure systems

A comprehensive field study was carried out to determine the natural ventilation distribution in vernacular Harran houses. As shown in Figure 3 the plan of the building selected for this study was redrawn with respect to the location of the structure. The doors and windows of the house, which provide natural ventilation, were measured. The airflow rates at each opening and climatic parameters such as dry and wet bulb temperatures, humidity, wind speed and direction were measured throughout the year.

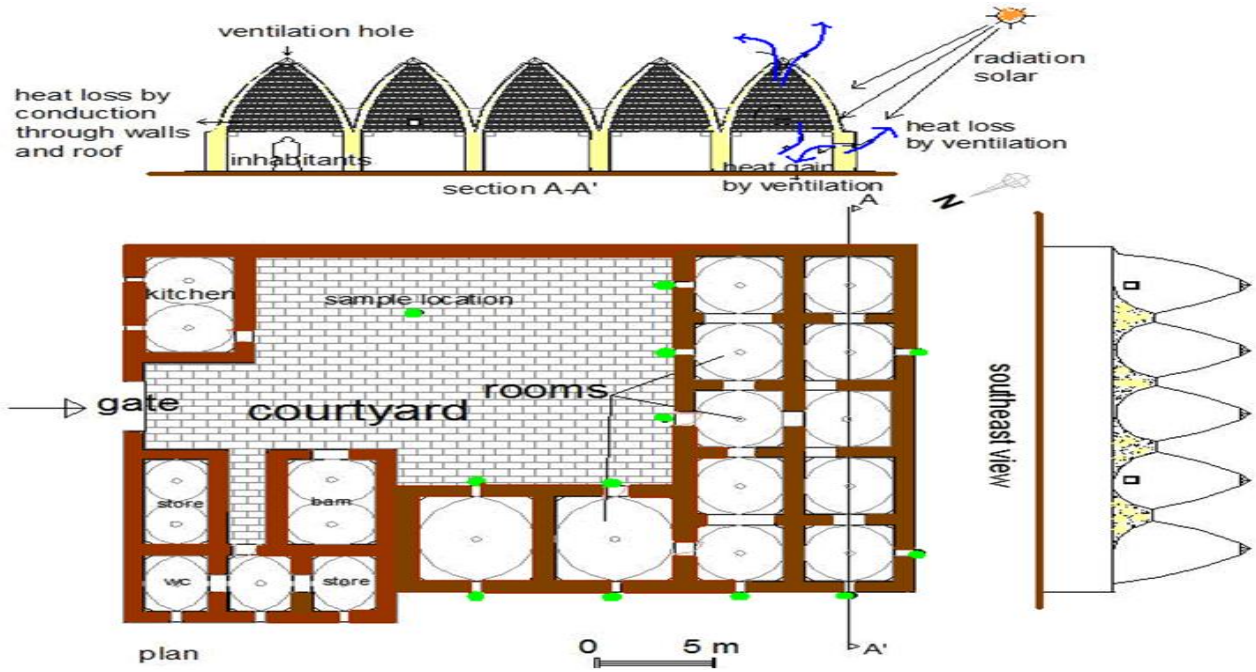

Figure-3. Plan of the Vernacular Harran House Selected for this Study

Source: Field work (2015)

In the study, Casella made series number B.S.2642 portable handle shaking thermometer was used to measure the dry-wet bulb temperatures of the indoor and outdoor environment of the house. The dry bulb temperature was considered for natural ventilation pressure and wet bulb temperature was considered for psychometric studies. Wind related data were obtained from the meteorological station of the province. The airflow rate was calculated by multiplying the cross-sectional areas of all the openings and the speed of airflow. The airflow speed of the house was continuously measured by a digital anemometer. Anemometers are the most used instruments in measuring airflow speed.

To measure the natural ventilation pressure of the house more accurately, a continuous monitoring system that measures the temperature of the house air as a function of time and globe temperature was installed. The following approximate formula was used to determine the natural ventilation pressure:

$$P_n = \frac{P_B L}{0.287}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

Where P_n is the natural ventilation pressure in Pascal (Pa), P_B is the average barometric pressure in Pa, L is the vertical height of the building in m, T_1 is the average temperatures of the outdoor in °C and T_2 is the average temperatures of the indoor in °C [26].

2.1. Site Description

Harran (36°52'N, 39°02'E), also known as Carrhae, which means "intersection of routes and travel" is a town built on a plain located in the Southeast of Turkey (Figure 4). It is a very ancient city which used to be a major Mesopotamian commercial, cultural and religious center. The known written documents of ancient Assyrian and Hittite regarding Harran indicate that its history goes as far back as 2500 BC [24].

Figure-4. Location of Harran

Source: Kürkçüoğlu [24]

2.2. Physical Measurements

Harran is located within historical walls (Figure 5). Figure 6 shows various Harran vernacular domed houses and the house selected for this study.

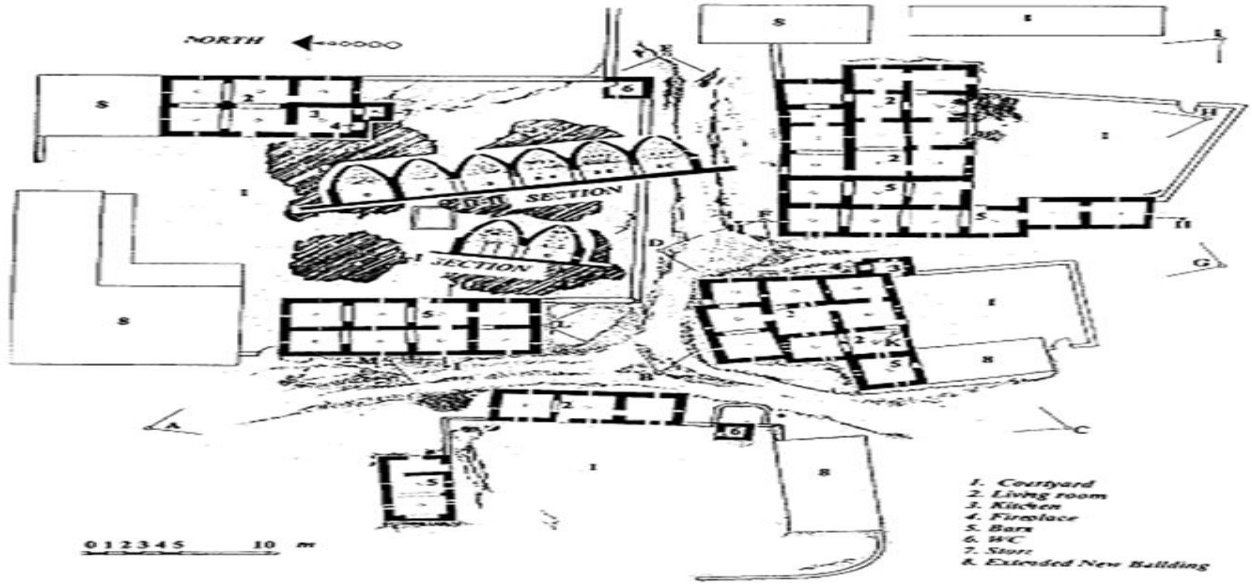

Figure-5. Plans and sections of a typical Harran neighborhood

Source: Ozdeniz, et al. [21]

(a) External view (b) The house selected for this study

(c) Courtyard of the house (d) Indoor of the house

(e) Ventilation hole (f) Indoor roof

Figure-6. Parts of the Harran vernacular domed houses

Source: Field work (2015)

The experiments conducted in this study were carried out on one of the most preserved houses in the city. The house is close to 100 years old and consists of 11 living rooms, one kitchen and five service rooms' storerooms, a barn, and a toilet all situated around a courtyard. The house has two doors, both of which open out to the courtyard for climatic considerations and a well, which is in the middle of the courtyard, used for water supplying purposes

2.3. Climatic Conditions of the Region

Harran has continental climatic features where the seasonal and diurnal average temperature ranges are quite high. Harran is one of the driest regions in Turkey, with an annual average rainfall of 482.4 mm (Average of the last 15 years) [1][26] (Figure 7).

[1] [https:// https://www.turkiye.gov.tr/harran]

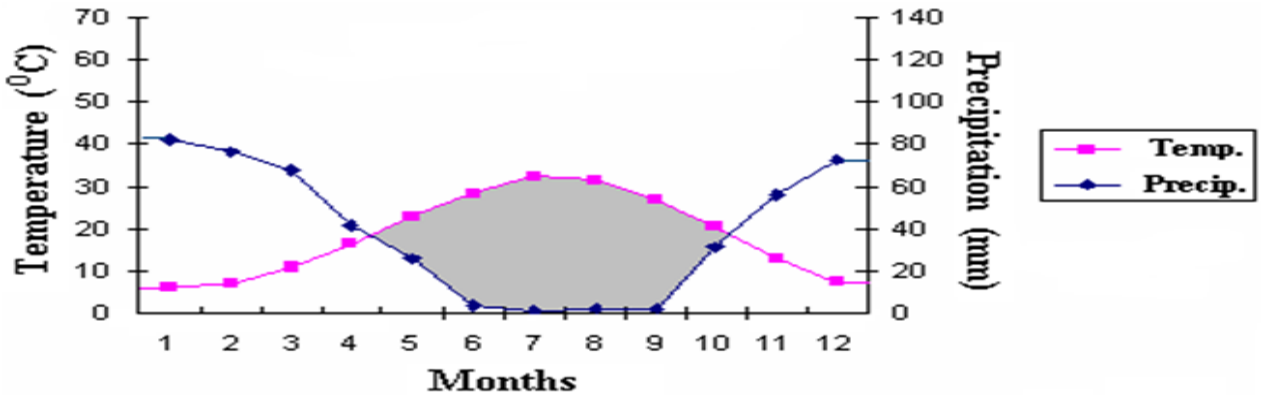

Figure-7. Temperature and precipitation features of the region

Source: Loomis and Wallace [26]

2.4. Materials

Vernacular domed Harran houses are examples of one-store mixed system adobe houses that are shaped like beehives and built from clay bricks which are either sun dried or burned bricks collected from ruins [21]. In the past, people used to build their houses with materials they could find easily, such as adobe, brick and stone. A limited amount of stone used between the top corners of the base walls and the dome.

3. RESULTS

The object of the air and pressure quantity surveys was essential to determine the amount of air passing through the house and pressure loss occurring in the indoor spaces of the house. In the field study, all of the above surveys were conducted in a vernacular Harran house for a year. The results of the surveys were evaluated in detail.

3.1. Analysis of Airflow Quantity

The unit of measure for air quantity that is most commonly used for ventilation purpose is volume in cubic meters per second. Air quantity is the product of the average airflow velocity and cross-sectional area of the airway at the point of measurement and can be measured using the following equation:

$$Q = VxA$$

Where Q is the quantity of airflow (m^3/s), V is the velocity of airflow (m/s) and A is the cross-sectional area of the opening (m^2/s) [27]. The results obtained from the field study were computed and are graphically presented in Figure 8. The positive values in the figure indicate the right airflow direction (inward) and the negative values indicate the left airflow direction (outward).

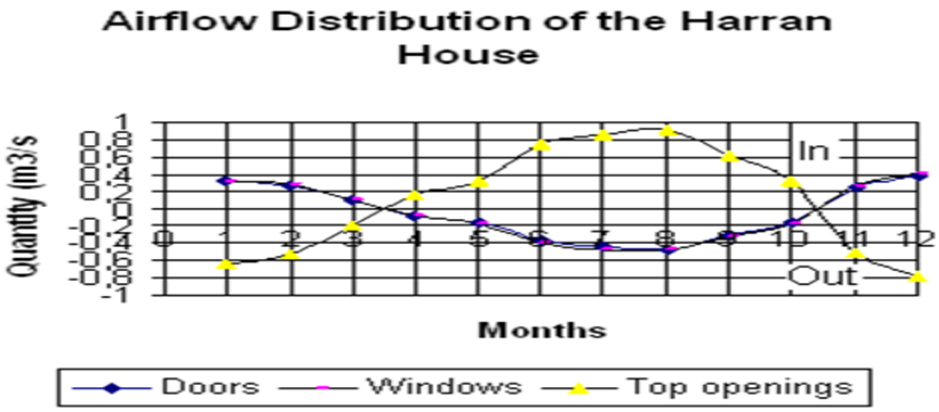

Figure-8. Airflow distribution in the Vernacular Harran House

Source: Field work (2015)

Air velocities were measured at least once every day at each sample location. The measurements of air velocity were repeated three times a day in case of direction change. Change in direction especially occurred in the spring and fall seasons, thus causing the direction of ventilation to become very dynamic during these seasons. The direction of the airflow during these seasons was sometime intake, sometime return or there was not any circulation at all. The air velocity measurements at one station were completed after nine spot readings and one continuous reading.

In this study the mean of the cumulative readings were taken into consideration. Another consideration was to determine the leakage of airflow through the house. Unintentional air loss directly to the return from the intake is known as leakage. Leakage can occur through the doors, windows and top openings of houses. The leakage amount for the house selected for this study has a range of 2.0-6.0% of total airflow quantity.

3.2. Analysis of Pressure Surveys

The analysis of the vernacular Harran house ventilation system, including the evaluation of modifications, requires accurate data that can be obtained only by a detailed pressure quantity survey. Pressure quantity surveys obtain a pressure gradient along the circuit under investigation and determine the amount of natural ventilation pressure.

The most important parameters that are measured in a pressure survey are pressure drop measurements and dry-wet bulb temperatures of the airflow in the house. Pressure loss measurements were carried out at all openings of the house and the results were calculated using Equation 1. The obtained results were computed monthly and are illustrated in Figure 9.

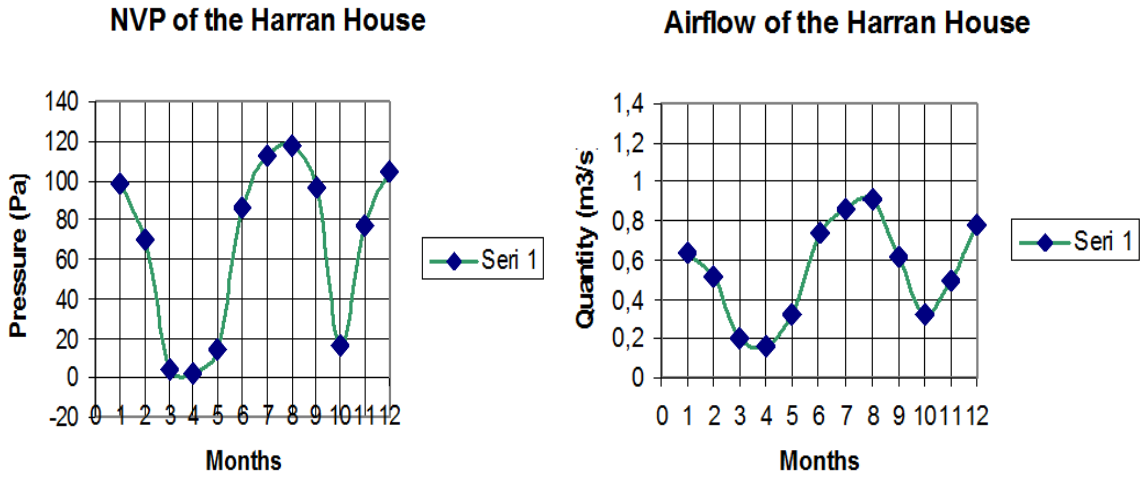

Figure-9. Natural ventilation pressure of the House Selected for This Study

Source: Field work (2015)

Temperature differences between indoor and outdoor cause changes in air density. Air density has a great effect on the natural ventilation pressure. Therefore, natural ventilation pressure increases in winter and summer but decreases in spring and autumn.

3.3. Material Consideration

In hot, arid environments, houses need to be sealed off, especially during mid-day, to keep the indoor temperature as low as possible. A heavy weight material on the walls and the roof is more likely to in terms of what as it will store cold air during the night and reradiate it during the day when temperatures rise to uncomfortable levels.

In this study, the materials used in vernacular Harran houses were investigated to examine their insulation properties. Harran houses are made up of adobe walls and a conical dome built from bricks. For the base walls, sun

dried adobe bricks which are 60-70 cm in thickness and a small amount of stone are used. The conical dome is built by sliding the flat bricks inward in each row. The dome wall is 30-35 cm in thickness and is in a sense a fake dome, because unlike ordinary domes, the loads are conveyed in a vertical direction. Mud mortar is used as a joining material and sliced straw is added into the mud for rendering purposes. The houses are rendered externally every year. The technical characteristics of the thermal insulation materials currently used in the houses were investigated and by using the following equation the thermal resistance and time constant of the houses was determined. The results are illustrated in the Table 1.

$$\tau = \frac{1}{k}\sum_{n=1}^{N} \rho_n e_n C_n$$

Where $\frac{1}{k}$ is thermal resistance and defined by e/λ (e is thickness and λ is conductivity of the wall), ρ_n is density of material, C_n is heat capacity [27].

Table-1. Insulation properties of the material used in the Harran House.

Material	Density ρ (kg/m³)	Thermal Conductivity λ (W/m °C)	Specific Heat C (J/kg °C)	Thermal Resistance $\frac{1}{k}$ (m² °C/W)	Time Constant τ (hours)
Adobe	2000	2.1	936	0.33	86
Bricks	1400	0.6	936	0.67	54
Dried straw and clay	1800	1.2	936	0.52	97
Stone with mortar	2200	1.4	1008	1.11	68

Source: Dalgic and Karakus [27]

The process of thermal transfer described in Table 1 is very slow since it lasts several tens of hours before reaching its final state. This means that vernacular Harran houses are intensive to the quick variations of the external temperature and show very good thermal insulation.

4. CONCLUSIONS

The major results of Harran vernacular houses obtained from structural and environmental studies and analyses are summarized as:

- Comfortable living environment
- Cost-effective and humanitarian
- Seasonal average airflow rates were obtained as 0.87m³/s, 0.48m³/s, 0.65m³/s and 0.23m³/s for the summer, fall, winter and spring seasons, respectively. The maximum average airflow rates were obtained in the winter and summer seasons due to the high temperature differences between the indoor and outdoor environment of the house. Therefore, the residents usually close the openings to manage the extreme differences in the climate during these seasons to maintain a comfortable indoor environment. A person with moderate activity inhales 52.5 lt/min of air, if 20 people live in the house their air requirement is 0.017m³/s and by choosing 2.5 as safety factor it can increase up to 0.043m³/s. The lowest airflow rate, 0.23m³/s, is in the spring season, during which the sufficient air quantity is still supplied.
- The natural ventilation pressure was zero in the last week of March, the first few days of April, the last few days of October and the first ten days of November and ranged from 2.32 to 117.72 Pa in April and August, respectively.

In ventilation planning, leakage is evaluated by a system of rough allowances since it often cannot be measured accurately. The leaking air does not help in the ventilation of indoors so it is doubly disadvantageous. Leakage quantity does not exceed 3% in the measurement and by painting or smooth plastering this ratio can be more minimized.

(i) Airflow direction changes with respect to unequal air density between indoor and outdoor of the house. The direction was upward from November to March and downward in the rest of year. In case of no air movement, the dwellings directly breathe the clear atmospheric air which is indicator of a healthy environment.

(ii) The Harran house is a good example of climatic building design in a hot dry climate, with thermal insulation and heat capacity of the building envelope. The materials used in the vernacular houses have comparatively high insulation capacity; the lowest time constant is found for bricks as 54 hours. This means that very cool spaces are obtained under extremely hot exterior temperatures of summer.

(iii) The materials used in the region are mostly composed of clay. As a natural material, clay, absorbs the surrounding moisture in high-humidity conditions and discharges the moisture in low humidity conditions. The other materials like stone, raw earth, straw possess clear advantages of local availability as well as psychologically speaking, are closer to the human ears.

This study has illustrated how the vernacular domed houses of Harran simply and admirably correspond to hot and cold environments as well as a comfortable living environment which is both cost-effective and humanitarian.

In addition, in terms of ecology, all these traditional materials have low environmental impact in their production, reusability and even natural dissolution.

The domed houses of Harran in the hot arid climate region are noteworthy examples regarding good design for a sustainable future. Houses' extraordinary architectural features provide environmental comfort inside the houses without the need for energy consumed by air conditioning and other remedies. Harran houses are interesting samples that have reached daily life with the use of recycled materials and the construction-making period that reduces energy consumption. Houses offer solutions that respond to survival needs of inhabits as well as environmental comfort. Consequently, we strive to find the balance between the environment, and sustainability. Vernacular Harran houses present messages good harmony of nature with human being life in concept of a healthy environment, cleaner production, climatic building design and re-usable building material.

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