The Passive Solar of Yazd: Reflections and Performance Evaluation after 10 Years Use

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ABSTRACT
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Yazd, a desert city located in the center of Iran has very long and fantastic history of coordination with nature to cope with very harsh climate of the region. Two, three or four sided traditional courtyard houses considered as the best prototype of sustainable architecture, which few follow logically. This paper presents traditional concepts using a passive solar house designed and built by present author in 2001. The research evaluated the family reactions, positive and negative aspects and performance features of the house under the concept of "post occupancy evaluation". The results indicated that family likes and dislikes are about the negative feeling of the cool draft in the sitting area, good lighting and views, some acoustical problems and positive feeling of cool air from the cold sunken courtyard. In general, the positive reflections of the family were much more than negative aspects.

1. Introduction
The past few decades have forgotten that the traditional architecture and city planning of Iran has experienced some magnificent ways of harmonizing with nature. Iranian building industry

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following the footprints of modernism are consuming more than 40 percent of energy in the country, much more than many developed countries. It causes problems such as increased CO₂ and global warming, increased heating and cooling bills of building owners, air and water pollution, increased psychological problems due to separation from nature, running short of energy resources and many more.

By reviewing academic research publications and taking part in Iranian national and international conferences on energy saving outlooks and experiences, the author found very limited research proposals or real projects on passive solar architectural designs and no evaluated building. Therefore, the research constructed the current passive solar house to evaluate energy saving in modern life and explain the living patterns of family in this house.

![Figure 1: Site plan.](image1)

![Figure 2: Exterior view looking north.](image2)

2. **Mathematical Model**

The passive solar house which was constructed and moved in 2001, was designed following some of the traditional concepts of passive solar designs and built on an urban plot measuring 13.00 m on the frontage and 25.00 m depth where most of the buildings are single or two stories
construction (Figures 1 and 2). For better understanding of traditional passive solar designs, the paper explained Yazd climate and traditional houses.

2.1 Yazd

The city of Yazd is located at latitude 32 degree south, near central desert of Iran.

2.1.1 Climate

It has hot and dry weather during summer and cold winter with an annual temperature difference of about 61 degree Celsius, maximum of 45°C and 12% relative humidity in summer and maximum of -14°C and 73% relative humidity in winter. The maximum mean dry bulb temperature (DBT) is 39.3°C in July (26.4°C annually) and the minimum mean is -6 in January (11.5°C annually). The mean relative humidity is 32%. Maximum mean is 73% in January and minimum mean is 12% in June, July, August, and September. Yearly hours of sunny sky are 3188 hours (minimum with 185 hours in January and maximum with 345 hours in July). Predominant wind direction in summer is from northwest with some humidity. In the summer time, the mean wind speed is 5.6 m/s and in the wintertime, the mean wind speed is about 4.8 m/s from southeast and west. Dusty wind is from northeast, which usually causes many problems and occurs mostly in springtime.

![Figure 3: Yazd city fabric.](image)

2.1.2 Traditional Houses

Aerial view of a portion of Yazd old city fabric shows houses with inner courtyards, woven together like a fabric creating harmonized and complicated city fabric. These courtyards manage

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and avoid unwanted natural forces and capture what God has given to use and to create magnificent spaces with the proper use of material to give warmth in winter, coldness in summer and meaning to the life of inhabitants (Figure 3).

![Figure 4: Plan of four-sided house.](image)

![Figure 5: Aerial view of the house.](image)

Houses, with different size and design, built in three or four sides and in different levels to follow the strategy of reaching water in depth through “Qanat”. Moving from one side to another took place according to the change of season. Vertical movements also took place in summer from cellar - which used in the afternoon - to “Talar” at the evening and to the roof at night.

Rooms facing southwest (Queble) and southeast, use direct gain concept through large windows in wintertime, store energy by thick mud brick walls and floors and control the heat loss by the use of heavy drapes.

“Talar” with high walls shades a portion of the house for evening use of the family, after moving up from cellar. Large water pool and trees, sprinkled brick floors and breeze blowing from
wind catcher cool the “Talar” down by the passive concept of evaporative cooling. This concept also used differently in current passive house. Figures 4, 5 and 6 show a four-side traditional house.

![Figure 6: Cross section of the house.](image)

![Figure 7: Ground floor plan.](image)

![Figure 8: First floor plan.](image)

2.2 The building design principle and passive solar components

The design strategy was to have a modern type of living, using some traditional concepts with new technology. The house, designed to have private and public zones with indirect entry. Located on the second floor is the sleeping zone and a multipurpose room (study, guest room, summer afternoon sleeping). The storage is located in the cellar (Figures 7, 8, 9). In addition to a sizable
front yard, we can find a 50 m² backyard with high walls for shading, designed to act as a summer natural ventilator with a portion, located on the basement level (Figure 10). A sunken court yard has a water pool for evaporative cooling (Figure 11). No mechanical room for heating was planned, it helped to save some construction and equipment cost. Two gas heaters and a fireplace provided heating supplement, but the family only uses one of the heaters most of the winter time.

Figure 9: Basement plan.

Figure 10: Canals for cool air movement to sitting room.

Figure 11: Water pool for evaporative cooling.
Total 10 m² of double pane glass panels were used in both Trombe walls and 20 m² of double pane glass panels were used on south-east facing walls to heat and store solar energy during cold season. The opened upper controllable dampers to outside forced hot air naturally to the outside and cooled air (by the use of evaporative cooling) drew out consequently from the underground canals. Figures 12 and 13 show summer and winter passive performance. A fan forced cool air from the basement to the first floor through a vertical shaft. This shaft naturally transferred heat of a gas fired heater in basement to sleeping area during winter time (Figure 14).
Opening the windows in south and north provides natural ventilation during summer evening and nights. The house stored the coolness for the next day, while all the windows from outside and inside cover the house from the sun’s radiation (Figures 15, 16, 17, 18).

A simple black storage tank placed in double pane glass box on the roof to supply enough hot water from March to October. This tank, connected to gas fired heater in the basement is to pre
warm water when needed in the other months of the year (Figure 19).

![Figure 18: Interior view looking north.](image)

Figure 19: Black water storage tank in a double pane glass box.

3. Study Details

The monitoring system consisted of 12 thermometers and sensors located in different parts of the interior and exterior spaces to measure ambient air temperature and relative humidity. Some of the measurement analyses are as follows:

a. Maximum outside dry bulb temperature of the house was normally 3 to 4°C higher than national weather meteorology readings due to urban warm up.

b. Back yard maximum dry bulb temperature was lower than front yard by about 4°C and sunken court yard dry bulb temperature was lower than back yard about 5 to 12°C, and it was due to the shading of this space most of the day.

c. Basement dry bulb temperature fluctuated from 25°C in winter to 28°C in summer time.

d. Maximum dry bulb temperature in sitting room fluctuated from 26°C to 30°C and normally was 27°C in summer time.
e. The dry bulb temperature of the air discharging from underground canal fluctuated from 21°C to 25°C.

f. First floor maximum dry bulb temperature was 29.2°C in 18th of July, whereas, outside temperature was 43.4°C according to meteorology reading. It was 44.5°C in front yard and 42°C in back yard according to our records.

g. Sitting room minimum dry bulb temperature was 19.5°C while outside temperature was -3.4°C at 6 am in a winter morning.

h. Temperature fluctuation of air outlet from Trombe wall on a typical winter day on January 17th (Figure 20).

i. Temperature fluctuation of water from passive solar water heater (Figure 21). Maximum water temperature was 60°C and 43°C at 14 pm of August 13, and October 26, respectively.

![Figure 20: Temperature fluctuation of air outlet from Trombe wall in a typical winter day (Jan 17, 2011).](image)

![Figure 21: Water temperature (°C) fluctuation of passive solar water heater, 2011.](image)

3.1 Energy Consumption and Saving

Using Solar Load Calculation (SLR), which relates the monthly net solar energy absorbed by the building to the monthly net building heating Load (Harris et al, 1985), calculated annual solar saving (SS) of 11.7510^6 BTU by direct gain parameters and 7.2510^6 BTU solar saving by Trombe wall performance. Total solar saving 19.2510^6 BTU divided by total annual heating load 52.6510^6 BTU gives the solar saving factor of 36%.
Actual Consumption of gas for heating, calculated to reexamine the SLR method of calculation. Considering the heating energy saving for water heater, the final passive solar heating performance of the house resulted in 44% energy saving.

Cooling load calculation concluded to be 86338 BTU/hr., which passive cooling means and two water coolers provided as needed (Ayatollahi, 2003).

The research surveyed and questioned 23 similar houses about their energy consumption. It analyzed the results and compared it with the passive solar house. The solar house used 20% less water and 48% less cubic feet of air per minute (CFM) from the use of water coolers.

3.1.1 Estimation of Energy Consumption and Saving

Total heating load = Q building + Q water heater  
(1)

Q total = 92196 BTU/hr + 43232 BTU/hr
Q total = 135429 BTU/hr

Calculation for actual energy consumption applied for heating (gas, fire heater, and fireplace) was 75442 BTU/hr:

Q total load – Q total consumption = Q saving  
(2)

135429 BTU/hr – 75442 BTU/hr = 59987 BTU/hr

Q saving/Q total load = SSF

59987/135429 = 44% Total Solar saving factor

4. Discussion

The study explained the design intent, passive concepts and components of a solar house and compared it with the traditional concepts of harmonizing with nature. The research proved the hypothesis and in some cases reached higher results than what proposed. The designed passive solar system supplied water heating, space heating and cooling as expected for the house. To enjoy the benefits of the solar savings, the family members should also learn to adopt and communicate with nature and its unpredicted sudden changes.

Designing to harmonize with nature rules and forces requires strong relationship between
living patterns and the building function, in a way that both act as one. Traditional man and
traditional architecture have lived by each other for centuries and enriched each other to make life
meaningful and purposeful. To have or follow the same strategy, there is no other way for modern
man to act and function with nature, meaning moving up and down, opening and closing shutters,
windows and dampers or pulling curtains at different cycles of the day or season, wearing heavier
or lighter clothing and so on.

The author has experienced living in 3 different traditional houses. He has enjoyed watching
stars in the night sky, slept in cool cellars in hot summer afternoons, sprinkled water on brick floors
and plants, enjoyed the warmth of the sun and gathered with the family in different places of the
house. He has tried to have the family enjoy the present condition of solar house in favor of
enjoying the nature and harmonizing with it as well as energy savings.

Unfortunately, there is not any built residential solar houses in Yazd for evaluating and
comparing the family member’s behavior, needs and satisfaction. Regarding the authors' family
members, they indicated that they are generally satisfied with their solar house, but there are some
shortcomings as follows:

- Due to the height of the ceiling in the sitting area and air movement to the second floor, the
  mother feels the cool draft during winter nights, but the rest feel comfortable enough and can
  adopt easier.
- Good lighting has been the major satisfaction for the family, as the large southern window has
  been the source of day lighting and providing nice view to the front and back yard garden.
- As the air needs to move from the collection area (sitting area) to the second floor, the sound
  also moves and causes some problems.
- Sudden dust storms is the major dissatisfaction for the mother, since the open shutters and
  windows for natural ventilation and stack effects allow the dust to spread to the house.
- The rise of the humidity and dry bulb temperature in late July and August causes the water
  coolers not to function properly. The Sunken courtyard and the water pool in the backyard is
  usually the source of thermal comfort and the family enjoys the cool air from the wetted
  underground canal.

Overall reflection of the family members about the passive solar components and the design
are much more positive than the negative aspects. The calmness and the interrelationship of the
family and nature have improved the life quality, so the family has reflected the feeling of home
attachment at many different occasions.

The high cost of the gas and electricity bills have caused very high dissatisfaction for the families. Low maintenance cost of the passive solar components and low utility bills have added to the satisfaction feeling of the house and post occupancy evaluation in comparison with active solar homes costs (maintenance, utility costs etc.) (Mapako, 2005).

The research has carried out and recommended the following improvements for better results and greater family satisfaction:

- More shading implemented on the backyard by grape trellis to have cooler air through the channel and to the sitting room. During the hot and more humid days of July and August, the water cooler does not work properly. Therefore, very cold water in the back yard small pool helps to cool down the house.
- The children (12 and 10 years old boys) have been adapted to coordination and controlling techniques of opening and closing the windows and shutters and have become very sensitive to the changes of the days and seasons, but it will take more time for my wife, since she is very sensitive to dust. In spring, dusty wind from northeast, usually blows inside through the open windows and causes many problems.
- To improve some of the window operation techniques for easier and more comfortable functioning.
- Operation of outside drapes must become more comfortable and make them operable from inside.
- To design and apply movable insulated door over the passive solar water heater for night insulation and better performance.
- To apply more passive solar heating on the south façade by designing a greenhouse to reach above 50% solar saving.
- To increase chimney effect (Ayatollahi, 2002; Ayatollahi, 2005) on the master bedroom clear story window to force hot air out.
- Constructing East and West plots of the house will improve insulation properties of both walls.

5. Conclusion

The study showed the importance of post occupancy evaluation to understand the reflections and performance evaluation of the users. Some of the shortcomings of the passive solar
components did not effect the satisfaction of the family members and persist to improve the detailing and controlling devices of the house.

The low utility, maintenance and building costs of the passive solar homes in comparison to active solar homes should encourage the home builders and designer to choose passive solar strategies during the design concept generation and apply active solar components if the conditions apply.

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7. References


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