Armanshahr Architecture & Urban Development, 11(24), 41-52, Autumn 2018
ISSN: 2008-5079
EISSN: 2538-2365

Impact of Airflow on Moderating Thermal Conditions in Vernacular Houses; Case Study: Bandar-e Lengeh Houses in Hot and Humid Climate of Iran

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Received 11 March 2018; Revised 30 October 2018; Accepted 21 November 2018

ABSTRACT: As an example of extreme hot humid climate, the southern marginal rim of Iran is a perfect candidate for studying climatic patterns. Attention to climatic components in housing design process within this area is therefore essential. Benefitting from the airflow and avoiding heat and radiation are among the most effective approaches towards moderating heat conditions in hot and humid areas. Vernacular houses are principally built to adapt to the climatic needs. Bandar-e Lengeh in southern rim of Iran has vernacular houses with unique patterns to make use of the airflow. With the aid of the Design Builder software application, this article examines heat conditions in such houses in accordance with local wind patterns and airflow in the climatic structure of the houses. It also tries to investigate the extent to wich such airflow effective can be effective in moderating indoor heat conditions of the climatic conditions in Bandar-e Lengeh houses. The article has a practical purpose, which is being followed through application of graphical and simulation packages using Design Builder software version 4.2.0.045 and the ASHRAE55 thermal comfort model. The climate statistics data are prepared by Meteorem 7 software, using weather data from Meteorological Organization of Iran. Conformance of the obtained simulation results show that local wind-flow currents in Bandar-e Lengeh combined with unique climatic patterns of the local houses can help moderation of indoor thermal conditions and provide the best ambient status, regarding air currents temperature and relative humidity in certain hours of the day.

Keywords: Airflow, Vernacular Houses, Bandar-e Lengeh, Hot-humid, Thermal Moderation.

INTRODUCTION

No special attention is usually paid to climatic and environmental context features of the contemporary houses. These similar buildings are not in harmony with their environments and do not contribute in moderating the environmental conditions. In modern houses feature of climate and environmental context is not considered; so, the similar structures in different climates are not in harmony with their environment. Statistics show that in 2013, Iran's natural gas consumption is 52% of total gas consumption in Middle East (Energy Balance Sheet, 2016, 394), and in 2014 in Iran, about 47% of natural gas consumption and 48% of electricity consumption has been the allocation of household (Energy Balance Sheet, 2016, 117). One of the world's most critical climates is the hot and humid region in Iran. Hence, incorporating climatic components in design of houses within the area is essential.

Study of the details of local climate components fully reveals their impact on local houses. In this paper, Bandar-e Lengeh, located in the tropical macroclimate on the southern margin of the country, possessing a synoptic weather station, was chosen as a case study. The paper intends to study local wind patterns, to assess their impact on the native housing structure and to investigate the extent to which such airflows have been effective in moderating indoor heat conditions of the climate in Bandar-e Lengeh houses, and to see what their optimal influence conditions are.

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“To effectively improve heat rejection from buildings by natural means, the physical characteristics of the building should be sufficiently understood by the designer” (Al-Obaidi et al., 2014, pp. 283-297). A summary of the guidelines provided by the researchers on the use of airflow in buildings in hot and humid climates are extracted and summarized into four levels: A- general form and schematic plan of the building B- organization of the building components C- specifications of the building components D- construction details.

A- General form and schematic plan of the building: The best deployment of the building is at the highest tip of the slope just beyond the body of water in the summer wind direction. It is necessary to consider wind direction so that building and rooms are orientated accordingly (Givoni, 1998, p. 383) and that windows orient towards the summer dominant wind (Hyde, 2000, pp. 29-32). Taking advantage of the useful wind gust at its blowing height (Salmon, 1999, p. 124) and use of windward room in areas close to the sea has a considerable impact on the efficiency of local wind patterns (Kasmaee, 2003, pp. 94-96). Use of static systems to employ radiation toward providing natural ventilation may be useful (Givoni, 1998, p. 383).

The schematic plan shall be used for maximum design ventilation (Hyde, 2000, pp. 29-32) and extensive project plan (Givoni, 1998, p. 383), narrow elongated structure for maximum predicted ventilation (Rappaport, 2009, pp. 151-155). Low compression buildings, single layer buildings to create current, and transition of main living spaces to the higher floors to enjoy the airflow would enhance efficiency of the building towards greater ventilation in the building (Tahbaz, 2013, pp. 148-150) and (Tahbaz & Jalilian, 2008, p. 160).

B- Organization of the building: In pursuit to create airflow through spaces, distributed organizations (Rappaport, 2010, pp. 151-155), and consideration of spaces divisions to materialize this possibility is recommended (Givoni, 1998, p. 383). Open formations through functional areas, minimal contact and maximum air circulation inside the building would provide ventilation throughout spaces. Use of central courtyard along with light and ventilation to the depth of all living spaces (Hyde, 2000, pp. 29-32) and raising the building above the ground level to create ventilation under the building are among useful strategies in this area (Rappaport, 2009, pp. 151-155).

C- Building components: Making use of high ceilings to reduce the ground level temperature; introduction of airflow (Rappaport, 2009, pp. 151-155); employment of roofed semi-open functional spaces in areas with suitable wind blow as important elements of house pattern (Salmon, 1999, p. 124); wide and big verandas with high roofs for day activities (Tahbaz, 2013, pp. 148-150) (Tahbaz & Jalilian, 2008, p. 160) would make building spaces suitable for creation of natural ventilation.

D- Construction details: In order to allow airflow possibility and to guide it indoors, use of porous materials (Rappaport, 2009, pp. 151-155), straw and grass is useful in construction of houses (Fathy, 1986). Use of openings on both sides in higher floors to create current, narrow windows and openings, and wooden or brick meshes in front of wide windows to simultaneously create airflow and shadow are among approaches related to windows and construction details (Tahbaz, 2013, pp. 148-150; Tahbaz & Jalilian, 2008, p. 160 and Fathy, 1986).

Other aspects of vernacular houses are examined by Afshari Basir et al., (2017), Zandieh et al., (2012), Sanaei & Jafari (2016) and Izudinshah Abd. Wahab et al. (2014).

METHODS

This study consists of three major steps; first of which investigates the conditions and specifications of the buildings, to be considered for natural ventilation in hot and humid climates that are extracted and summarized into four levels. These levels are: a- Overall plan and configuration of the building b- Organization of the building components c- Specifications of building components d- Building details, based on the research thesis literature. Then the four levels are evaluated in Bandar-e Lengeh vernacular houses features. Having adapted the theoretical basics of the study to the patterns of Bandar-e Lengeh houses, climatic patterns are justified and the preliminary basics to enforce and implement simulation for houses with intended patterns is provided.

The second step consists of the local climate study of this location, which was conducted with aid of the Bandar-e Lengeh epw climate file for the average of 2000 to 2009 AD, the Climate Consultant software application version 5.5 and the ASHRAE55[1] Model for thermal comfort. Next, the Bandar-e Lengeh climatic position was evaluated using the ten-year statistics, while proper months for the study and review were selected by conforming temperature conditions against relative humidity.

The third step relates to simulation in version 4.2.0.054 of the Design Builder software application. In that, two examples of the Bandar-e Lengeh native houses were simulated in accordance with climatic samples of the houses and related available climatic data in that area, while open or closed state of their windows at different times of the selected months were examined and planned for, based on the local wind pattern in those months.

SPESIFICATIONS OF THE BANDAR-E LNGEH HOUSES

In terms of form, two different types of houses may be observed in Bandar-e Lengeh. The first type is introvert, where the building forms around a central courtyard, in which, special consideration is paid to the use of the facing or adjacent sides with respect to solar movement in different seasons or times of the day. In the sense of general plan and shape of the building, the introvert type has large windward rooms in different corners of the central courtyard, allowing the incoming air, blowing from the sea direction or other desirable fronts to flow inside the building. The windward rooms have connecting windows to other adjacent spaces to lead airflow through other rooms and to moderate thermal conditions. In terms of building components organization, the components, being higher than the ground level by almost one storey are formed around a central courtyard. The rooms having numerous apertures and windows open unto each other, transforming the plan structure into a lightweight and porous one to let airflow throughout the structure spaces.

Semi-open verandas and hallways are among essential components of the building that introduce shaded areas in between closed and open spaces of the courtyard and make it possible that the air current entered into the building through vents or ventilation, flow into the entire spaces of the structure. Spaces are either single layered or consist of two or more layers. Fig. 1 is a schematic plan showing airflow mechanism in the Fekri house, Bandar-e Lengeh.

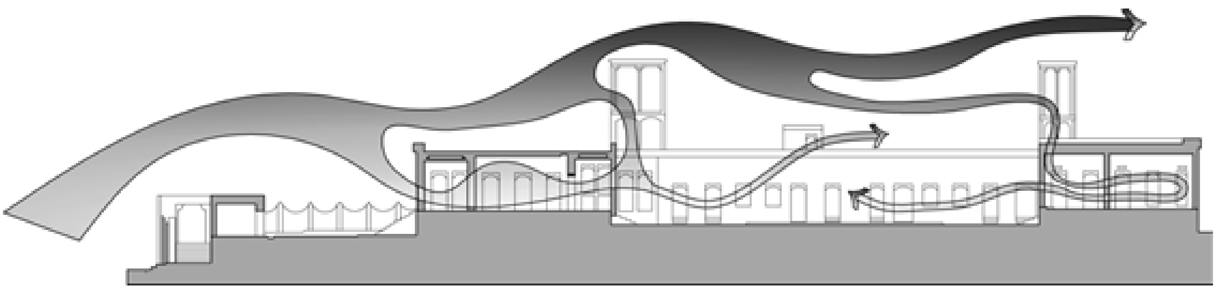


Fig. 1. Airflow System in the Fekri House, Bandar-e Lengeh*

The second type of houses in Bandar-e Lengeh is extrovert as the building is located in the middle of the courtyard. As far as general plan and form is concerned, despite being large and compact in size, the houses are quite porous with respect to their interior nature. In the sense that using numerous voids in between spaces allows the airflow throughout the building. Formation of the building components in this type is such that semi-open corridors or hallways around closed living spaces, intake the airflow from outside and move it around the closed living spaces with plenty of voids. The houses are located above the ground level surface to safeguard against ground moisture in the areas close to the sea while taking full advantage of the desirable sea breeze.

Regarding building components, large south-facing verandas also protect the backspaces, in this direction, against intense solar radiation while at the same time making use of south breeze. Construction details include septum walls with plenty of pores all over, facing useful regional winds (Nikghadam, 2013, p. 78). In terms of building components, large balcony facing south and backspaces in the face of intense solar radiation and at the same time protect their southern breeze. Details of the building including walls, with many openings in all directions and the winds are useful area. Fig. 2 shows an image air stream at Bastaki house, Bandar-e Lengeh. Fig. 3 shows the position and orientation of two studied houses in Bandar-e Lengeh and Table 1 shows some of the specifications of Fekri and Bastaki houses.

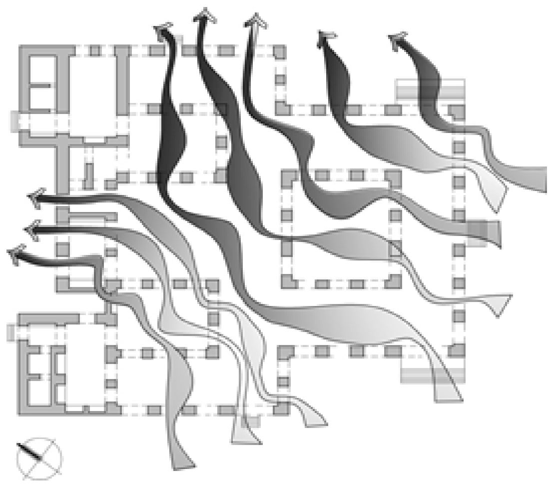


Fig. 2. Airflow System at Bastaki House, Bandar-e Lengeh*

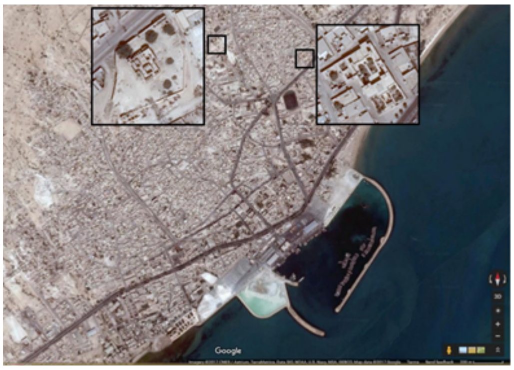
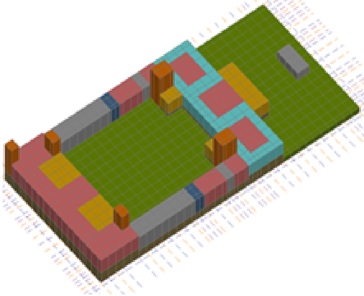
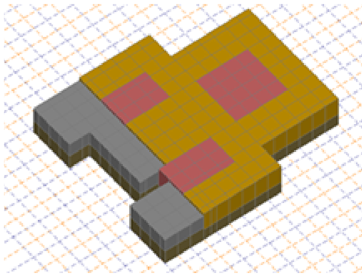
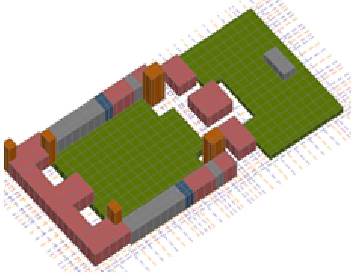
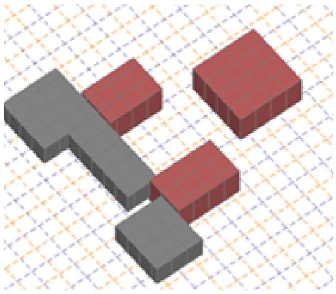
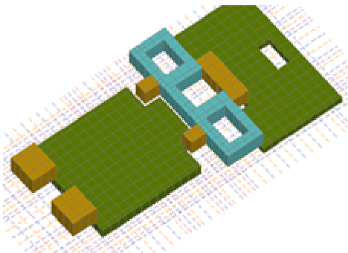
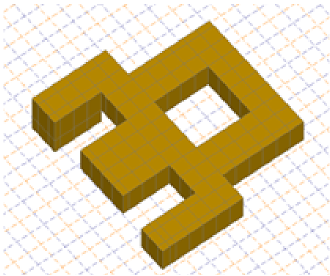


Fig. 3. The Position of Two Studied Houses in Bandar-e Lengeh Map

Table 1. Specifications of Two Houses

Fekri House (Introvert Type)	**Bastaki House (Extrovert Type)**	
		Schematic 3D
100% of the Total Space 40% is the Central Courtyard	100% of the Total Space	Percentage
		Closed Spaces
39% of the Total Space	42% of the Total Space	Percentage
		Open and Semi Open Spaces
21% of the Total Space	58% of the Total Space	Percentage

Introverted Sample, Fekri House

Fekri house is an introvert type with two courtyards. Functional spaces in Fekri house are all positioned at ground level and living spaces on both southeast and northwest sides. On the northwest side, the central courtyard-facing semi-open spaces stand in front of the closed spaces; on the southeast side, allocated strictly to the summer living areas, semi-open spaces pass through closed spaces. House entrance is made possible through the building from the Southeast side. In reaching from the courtyard to the closed living spaces, one has to pass through semi-open living spaces or semi-open communication spaces. The rooms are positioned with nested relation between them. That is, one may pass through a closed living space to the next or to the backspace. Building windows are toward the central or the outer courtyard. The overall composition of the house is semi-compact with five windward rooms. Fig. 4 shows the ground level plan of the house. In the southeast side facing north, semi-open corridors between closed spaces are shaded.

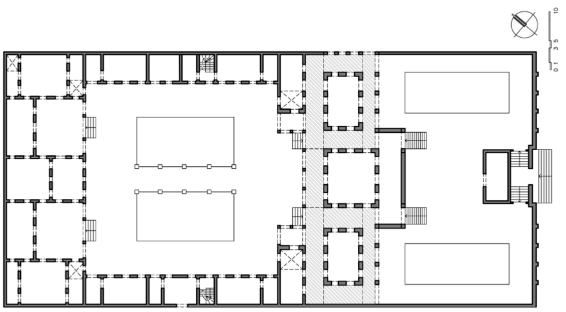


Fig. 4. Fekri House Plan, Ground Level*

Extroverted Sample: Bastaki House

Bastaki house is an extrovert style as the building is located in the middle of the courtyard. Yard of the house is formed at a level of about four meters above the level of the adjacent street. Functional spaces in Bastaki house are positioned on the ground floor level, which is one story above the courtyard level. Semi-open spaces move around closed spaces in the form of wide corridors. House entrance is through the courtyard on southeast side of the building. To reach from courtyard to the closed living spaces, one must pass through semi-open living spaces or semi-open connection spaces. Placement of the rooms and connection between them is separate and through semi-open corridors. That is, it would be possible to walk from semi-open corridor to the semi-open living space and from there, again back to the next semi-open communication space. Closed living spaces are located within the building.

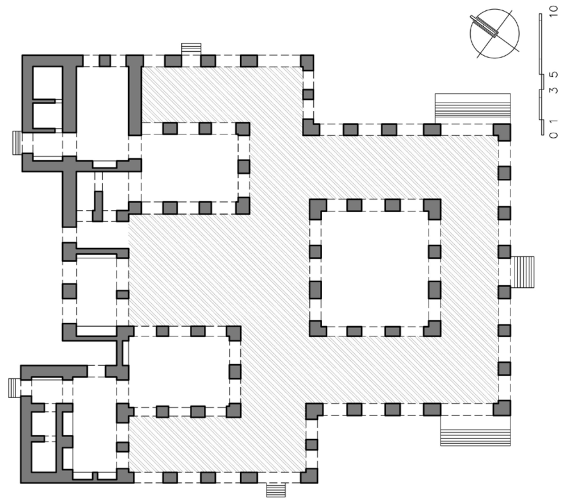


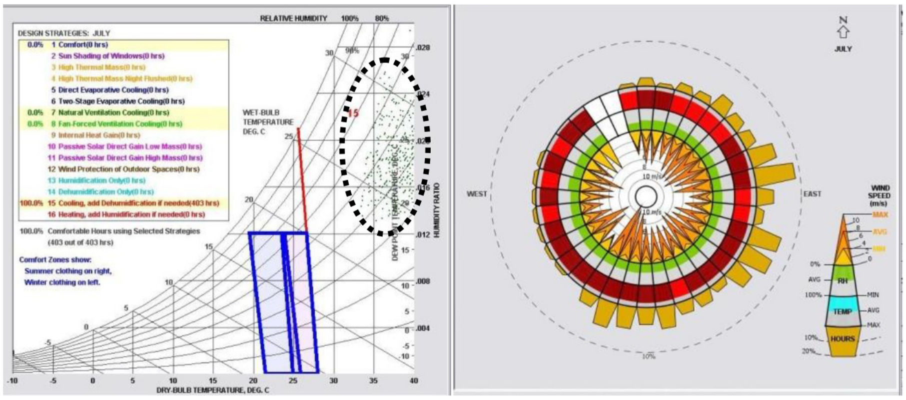
Fig. 5. Bastaki House Plan, Ground Level*

The overall composition of the house is compact, but as semi-open spaces pass through closed spaces; it is considered transparent to airflow since air current is free to reach throughout the structure. Building windows open to the surrounding yard from all directions. Side spaces are located on the northwest side with their back to the desired area wind during very hot months. Fig. 5 shows the ground floor level plan of the house. Wide semi-open connection of spaces around closed spaces are shaded in the plan. The spaces called as semi-open communication spaces in this study have actually had residential occupancy in the past, due to their airflow circulation simplicity that provided desirable living space for residents.

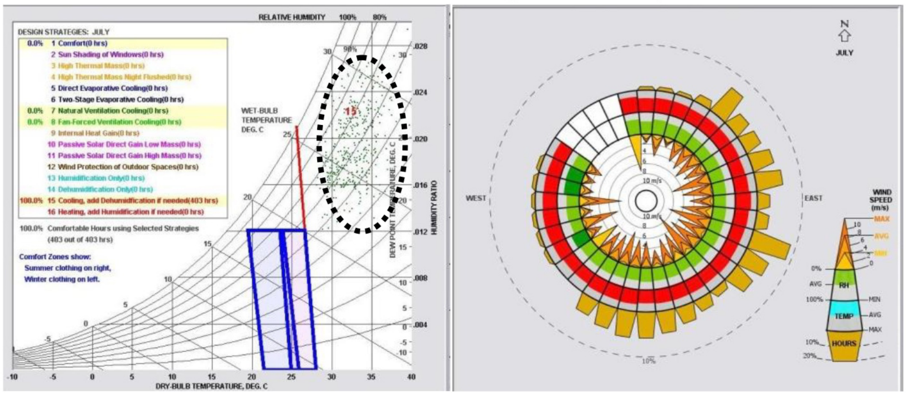
AIRFLOW PATTERNS AND COMFORT CONDITIONS[2]

The investigation on thermal adaptation methods reveals that first preference of the respondents is window opening (77.4%) (Abiodun, 2014, pp. 1-18). Bandar-e Lengeh wind diagram shows that between 9 A.M. and 9 P.M. in July, the prevailing airflow temperature is over 38°C, which is higher than that of the body temperature. Not only does this process help the moderation of environmental conditions, but also has a negative impact. However, the same currents have a temperature between 24 to 38°C and a relative humidity of 30% to 70% between 9 P.M. and 9 A.M. when wind is useful for moderating thermal conditions. Winds blowing from the northeast to the southeast have a frequency of approximately 10% of the time; they are suitable for natural ventilation. According to the ASHRAE55, thermal model for July, thermal conditions in day and night is such that thermal comfort may only be achieved by using mechanical cooling system and dehumidifiers. Fig. 6 shows local winds and comfort conditions in days and nights in July in Bandar-e Lengeh.

The City wind diagram in April shows that the air currents (with day temperature in the range of 24 to 38°C and night temperature in the range of 20 to 24°C) may bring thermal comfort. Direction of the winds with higher time frequency is mainly from northwest to the southwest in April. Thermal comfort conditions in April show that in 52% of cases, thermal conditions is well established and in 3% of the times, natural ventilation is required to maintain comfort conditions. Thermal conditions are well maintained in 12% of times in the days and 19% is achieved with the help of natural ventilation. In other times also, assisted natural ventilation can reduce the burden on mechanical devices. Fig. 7 shows local winds and comfort conditions in days and nights in April in Bandar-e Lengeh.



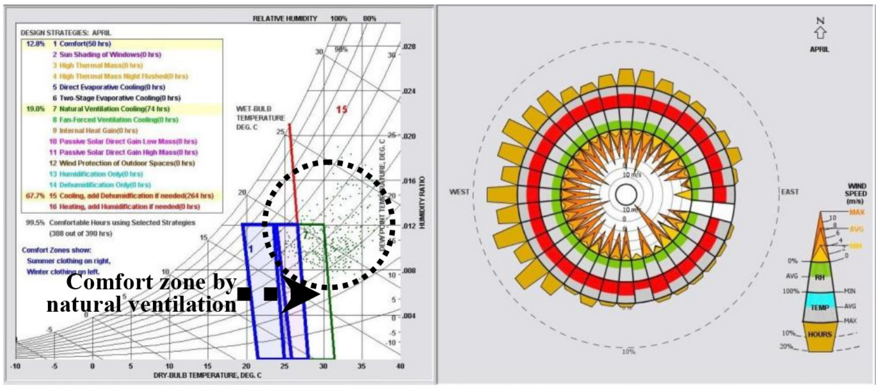
Comfort model & wind pattern in day



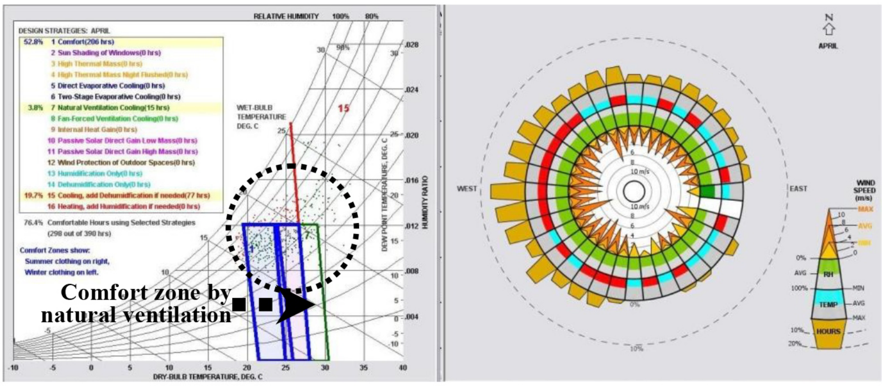
Comfort model & wind pattern at night

Fig. 6. Local Winds Patterns and Comfort Conditions in Day and at Night in July

Derived from Climate Consultant Software Version 5.5 and the ASHRAE55 Model for Thermal Comfort



Comfort model & wind pattern in day



Comfort model & wind pattern at night

Fig. 7. Local Wind Patterns and Comfort Conditions in Day and at Night in April
Derived from Climate Consultant Software Version 5.5 and the ASHRAE55 Model for Thermal Comfort

FINDINGS AND DISCUSSION

For simulating in the Design Builder software program, structural specifications of a sample of both Bandar-e Lengeh introvert and extrovert houses were input to the software. Both houses are similar in terms of structural conditions, the most significant of which were considered as the following and simulation was performed. Number of residents for both houses was considered 0.02 persons per square meter, which is roughly equal to 14 and 20 people per house, regarding 700-m^2 area in the case of Bastaki house and 1000 m^2 in the case of Fekri house. Since conclusion in this paper is drawn from comparison of natural condition in different situations, efforts are done to use substitute materials with maximum similarity to the indigenous samples, for the sake of simulation, in view of the fact that old materials are used in construction of this region's vernacular houses (lightweight sea stone and black ash mortar in the walls and wooden timbers and straw in roofs) do not have specific physical characteristics in the software. Accordingly, the inner and outer walls material on both sides is lightweight rock with a compound mortar composed of a dense combination of glass, stone, and lime (instead of black ash mortar that is composed of lime, ash and clay) and without insulation; and roofing materials of wood covered with mortar from bottom and lightweight wood on top with no insulation. Simulation was performed accordingly. The roof timbers, wood and straw, and the physical characteristics were specified in the application. It has been trying to replace materials with maximum similarity to the native sample used in the simulation. Materials related infiltration air change rate was assumed to be 3 times an hour and the maximum airflow equal to 0.05 cubic meters per meter per second while windows and vents are open. Fig. 8 shows a model of the house at 15 P.M. on July 15 at in the software. Bastaki house is an extrovert and Fekri house an introvert sample in this research.

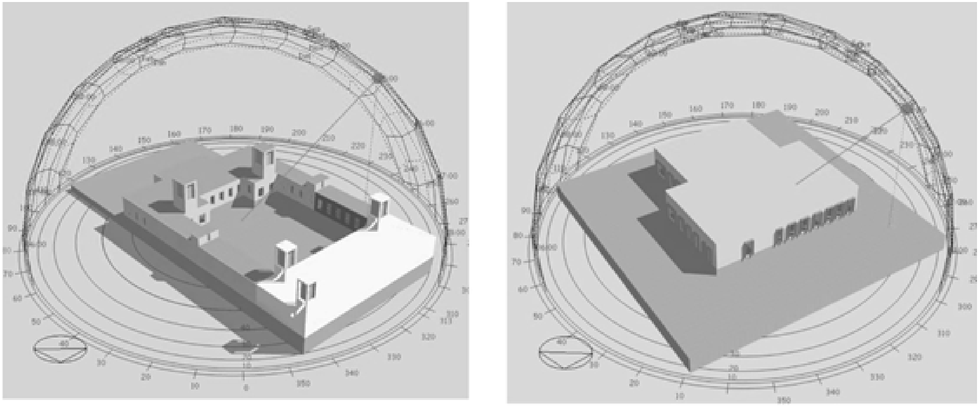


Fig. 8. Bastaki (Right) and Fekri (Left) House Model

When the air temperature is higher than that of the human body temperature, it has no effect on thermal conditions; study of which, as related to the houses was conducted in terms local winds and their temperature difference between day and night. Three general types of ventilation conditions were considered in both houses. First, the effective interior thermal conditions were compared with those of the outside air temperature, regardless of natural ventilation. Secondly, thermal conditions inside and outside the building were compared while all windward vents and windows were open throughout day and night. The comparison was done for both the houses in July, when the worst summer thermal conditions exist and in April, during which, days are hot and nights are moderate.

Simulation of the Houses in July

Studies showed that in the Bastaki house, if the windows were closed during the day in July, while the outside temperature varies in the range of 33°C to 43°C during the day, the temperature would be fixed between 41 to 42°C. If the windows are open all day, natural ventilation will have little impact on moderating environmental conditions. Thus, the component increases indoor heat of the house and the temperature reaches 36°C at night and up to 42°C in day.

Thermal moderation status diagrams -for the times when the windows in both case study houses are open all day long- show that the effect of natural ventilation component during the day is positive in terms of thermal conditions, or in other words, it causes house environment heat increase, but it is negative from 16 P.M. to 7 A.M. the next morning, or cause space cooling. Fig. 9 shows the effect of natural ventilation on thermal moderation status of both houses studied in all day hours. The impact of the inner and outer walls and the ceiling on warming the area during night, and the effect of foundation materials in lowering day temperature are specified in the diagram.

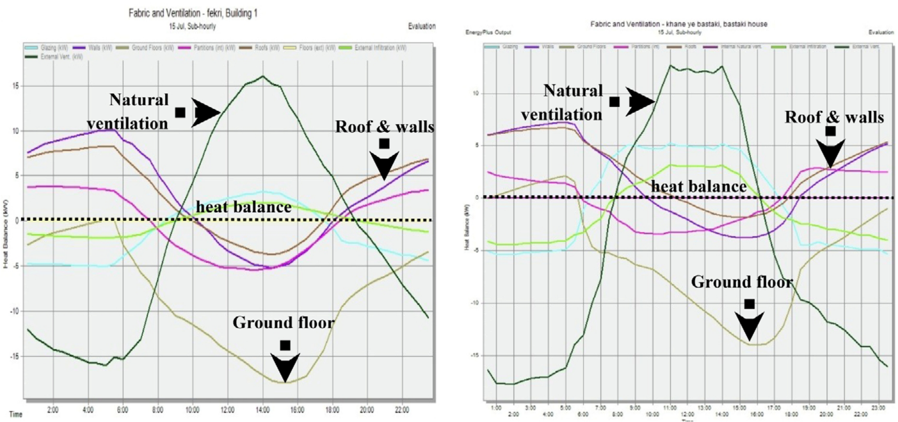
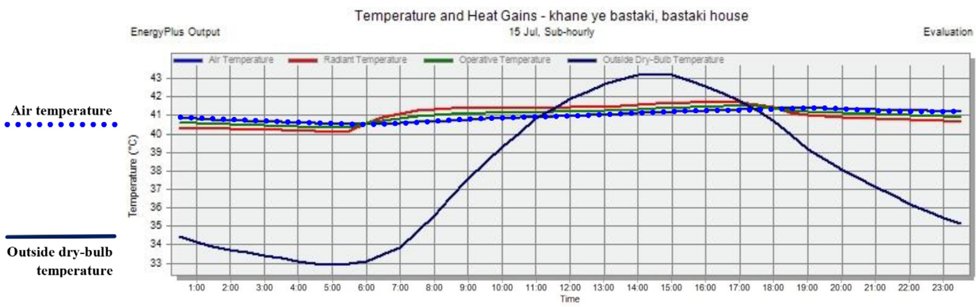


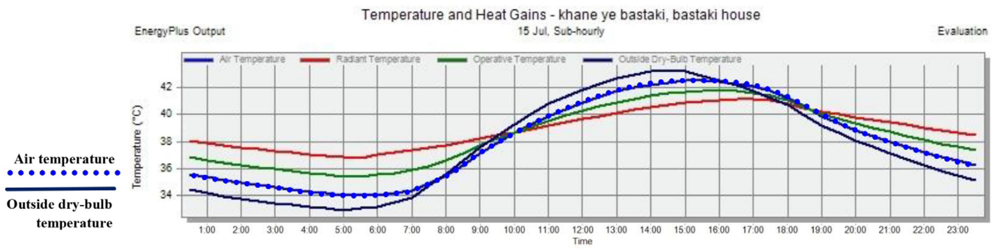
Fig. 9. Thermal Moderation Status when the Windows are Open All Day Long in the Bastaki (Right) and Fekri (Left) Houses

Natural ventilation in Fekri house, between 9 A.M. to 7 P.M. and in the Bastaki house, between 8 and 16, provide for positive thermal balance. Software aided simulation showed that if the windows are opened 90 minutes after the time when airflow no longer causes indoor air temperature increase and stay open until airflow no longer increases indoor air temperature, indoor temperature state will then have better conditions. Thus, the windows in the Fekri house were closed from 9 A.M. to 20:30 P.M. and in the Bastaki house from 8 A.M. to 18 P.M., but were kept open at night time. This study showed that if the windows are kept closed during the day and are opened from 6 P.M. to 8 A.M. the next morning, natural ventilation causes the indoor temperature to drop by about 5 degrees Celsius and hit 38°C in day and 35°C at night. Fig 10 shows a comparison of thermal conditions state at the Bastaki house when the windows are closed, open or open only at night.

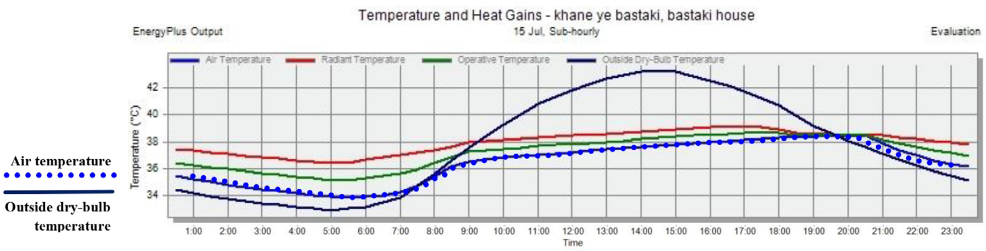
Simulation of the Fekri house, which is the introvert example in this research work, also showed similar results. The study revealed that the open mode of windward room's windows and vents all day long leads to thermal moderation temperature of higher than zero between 9 A.M. to 7 P.M. that helps daytime environment temperature to rise accordingly. If the windows are closed during the day, thermal conditions would improve and that the outside temperature drops from higher than 43°C to 38°C in summer living area and to 39°C in the case of winter living area. Diagrams show that in such conditions, relative humidity would drop considerably. In all circumstances examined above, inner building temperature has been higher than the outside, which is according to the thermal moderation diagram due to the heat kept in the stonewalls of the building.



When windows are closed all day and night long



When windows are opened all day and night long

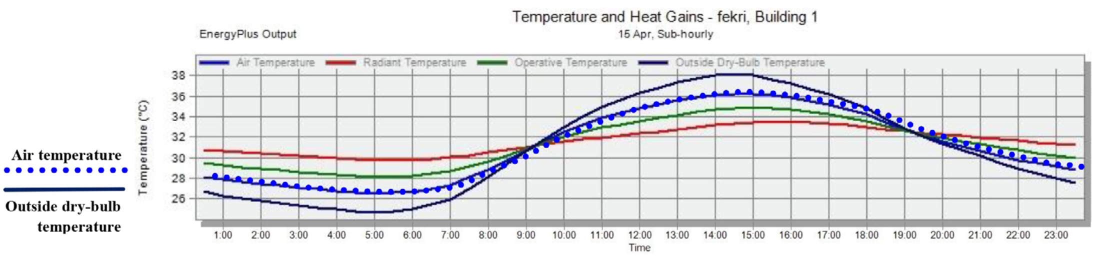


When windows are opened at night and closed in day

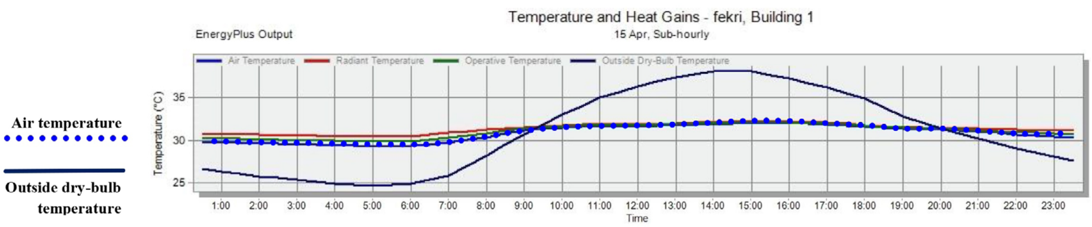
Fig. 10. A Comparison of Thermal Conditions in July for Different Types of Natural Ventilations Stated in the Study in Bastaki House

Simulation of the Houses in April

April simulation of Fekri house showed that although airflow temperature is below 38°C and are acceptable for heat moderation, still closing the windows during the day would improve thermal conditions in the building during the day. But still, as for July, indoor temperature at night is higher than that of the outside. In case the windows and vents are open all day long, room temperature drops from 38°C to 35°C, but if windows are closed during the day, the temperature reaches 32°C and drops by 6 degrees. Fig. 11 shows a comparison of thermal conditions state at Fekri house when the windows are open throughout day and night or open only at night, for April. Simulation of Bastaki house in April also showed a similar situation with Fekri house. In the case that the windows remain closed during the day and open at night, the maximum effective internal temperature drops from 38°C to 33°C during the day. Diagrams also showed that the relative humidity in both intended months lowers considerably inside the building, by optimizing the voids open times.



When windows are opened all day and night long



When windows are opened at night and closed in day

Fig. 11. Comparison of Thermal Conditions in Different States of Natural Ventilation in the Fekri House in April

Fig. 12, shows the relative humidity state in Fekri house when the windows are open according to the planned program for the July. This is while the average relative humidity values outside this month vary in the range of 57% to 75% in this month.

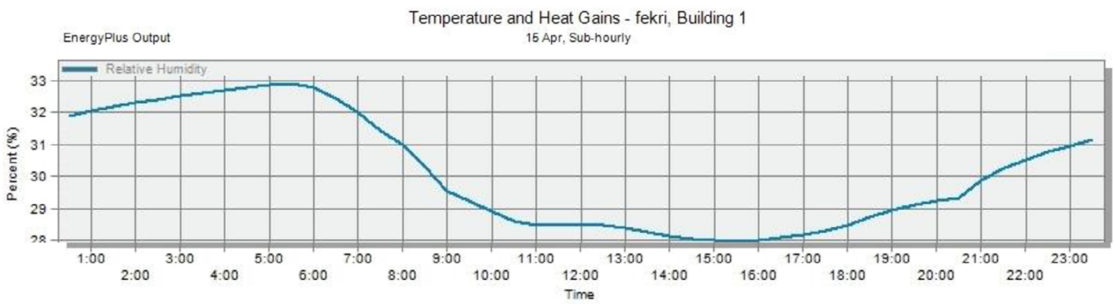


Fig. 12. Relative Humidity in the Fekri House in April when the Voids are Closed During the Day

CONCLUSION

Bandar-e Lengeh extrovert and introvert type houses, meet the conditions of the regional wind patterns in terms of general structure, formation, components and windows details. Simulation of an example of each of the two introvert and extrovert houses in the Design Builder Software Application revealed that using natural ventilation by opening windows and vents, have been worked out to take advantage of the region's desirable winds in this climatic patterns. This has caused changes in the thermal conditions of the building.

The study also showed that the extrovert and introvert climate patterns response to natural ventilation and thermal conditions moderation is almost identical. Albeit with the difference that the duration in which hot winds can pass in the daytime through building windows and warm up the house environment air is shorter in the extrovert house than that of the introvert one, the extrovert house may therefore have longer time to enjoy airflow.

The results showed that the impact of windows open position or natural airflow on thermal conditions directly depends on the temperature of the local winds. Thus, the wind flows with temperature higher than 38°C, small changes in thermal conditions are induced for a short period. Closing the windows when hot wind flow during the day, and opening them at night hours and in times when cooler breezes flow, thermal conditions of the indoor rooms change to a desirable level in the next day and the air temperature moderates by about 6°C.

Open position of the windows and vents at night also have positive impact on thermal conditions at night, but the outside air temperature is always lower than that of inside the house. So, residents are recommended to take advantage of open and semi-open outside space which are in the direction of desirable night airflow.

In July, the hottest month of the year, comfort condition is the worst and in April with hot days and moderate nights, the pattern to keep windows open or closed is the same i.e. they are better be closed during the day and open at night. In addition, the relative humidity is significantly reduced and helps to the improved thermal comfort conditions by introduction of natural ventilation with the previously mentioned conditions for both two months.

For a closer examination, regarding all physical specifications of the materials used in the houses, the impact of the materials on thermal conditions of the building should also be examined.

ENDNOTES

1. ASHRAE is the abbreviation standing for: American Society of Heating Refrigerating and Air-conditioning Engineers.
2. The climatic diagrams are based on epw climate file for the average 2000 to 2009 AD, processed by the Climate Consultant software application version 5.5 and the ASHRAE55 Model for thermal comfort.

* The original source of the drawings is from "Office of Cultural Heritage of Hormozgan, Bandar Abbass". The drawings are redrawn basically and represented diagrammatically by the author.

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