Potentials of Vernacular Climatic Solutions (VCS) in Energy Efficiency of Domestic Buildings in Hot and Humid Climate: The Case Study of Bushehr, Iran

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Abstract

This study aims to use vernacular climatic solutions (VCS) of traditional dwellings of Bushehr in common residential buildings of this city in southern Iran and answer to the question that "What is the effect of VCS in terms of energy consumption in these buildings?" This research was conducted on two levels. At the first level, after selecting an existing model of common residential buildings and short-time field measurements from local climate throughout the year, the collected data was used in simulation and some changes in terms of improvement in shading, natural ventilation and insulation of external walls and roof as vernacular climatic strategiesweremadein this building. At second level, the proposed models of common residential buildings were offered and the data collected at the first level was used in their simulation in two states of with and without using VCS. All models were simulated with the Design Builder software under natural ventilation conditions in moderate periods of the year while split air-conditioning systems were used during hot and humid periods. The findings showed that in the existing model, discomfort hours, cooling energy consumption and CO_2production reduced by 54 percent, 44 percent and 22 percent, respectively. In the proposed models, these values showed a decrease by 10 to 20 percent, 42 percent and 32 to 34 percent, respectively. It is also predicted that using the VCS in common residential buildings of Bushehr, could reduce the energy consumption of each household by 3500 kWh per year.

Keywords: Vernacular climatic solutions, Hot and humid climate, Energy consumption; Common residential buildings

1. Introduction

It is generally acknowledged that the building sector accounts for about one-third of the total energy consumption worldwide (Rubio-Bellido, Pulido-Arcas, & Cabeza-Lainez, 2015),which leads to a significant amount of greenhouse gas emissions (A-T. Nguyen, 2010). Due to population growth, increased urbanization and improvements in living standards, most of the energy consuming buildings will be located in the urban centers of the developing world. The depletion of energy resources and the risk of climate change are demanding for a sustainable development path based on renewable sources of energy and energy efficiency (P. Hennicke, 2010). Vernacular buildings, either individually or as a whole settlement, are the best examples of the harmony among human behavior, building and natural environment (M.R.Sumerkan, 2007). It contains inherent, unwritten information about how to optimize the energy performance of buildings at low cost by using local materials. Over the course of time, vernacular dwellings have evolved to respond to challenges of climate, building materials and cultural expectations in a given place (M.Previtali, 2010). Besides, it seems to be the result of the hundred years of optimization to provide a comfortable shelter in a local climate using available materials and known construction technologies (Bodach Susanne, 2014). Several studies have proven that better thermal performance can be achieved by passive measures in vernacular architecture (Borong et al., 2004; Dili, Naseer, & Varghese, 2010; Dili, Naseer, & Zacharia Varghese, 2011; Shanthi Priya, Sundarraja, Radhakrishnan, & Vijayalakshmi, 2012). Revisiting the traditional buildings with satisfactory climate adaptation seems inspiring for climate-responsive building designs (Xu Hong, 2016). The city of Bushehr in hot and humid region of Iran has one of the most severe climatic conditions in this country; thus, energy saving in common residential buildings appears to be very difficult due to its severe climatic conditions and thermal preferences of residents in using air-conditioning systems in all seasons; besides, in 2012, it has had the highest domestic electricity consumption in building sector (Brahmand Zadeh & Rezaei

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Ghahroodi, 2014). Vernacular dwellings of Iran have the significant relationship with local climate (Tahbaz & jalilian, 2008); therefore, applying vernacular strategies in hot and humid regions of Iran as a model for designing contemporary houses for such climates can lead to optimal energy consumption and improved level of comfort (Nikghadam, 2015). Many researchers emphasized that vernacular dwelling's patterns in hot and humid areas use maximum shading and natural ventilation for high temperature and relative humidity adjustment (Nikghadam, 2016). This study aims to use vernacular climatic solutions (VCS) of traditional dwellings of Bushehr in common residential buildings of this city. These solutions, including shading, natural ventilation and insulation of external surfaces such as walls and roof (Mohammadi, 2017), were used in the existing and proposed models of common residential buildings. The discomfort hours, cooling energy consumption and CO_2production were also investigated.

2. Background

Many studies were carried out on climate-responsive buildings and the passive strategies used in them in hot and humid regions where the role of shading and natural ventilation in improving thermal comfort and reduction of energy consumption in contemporary buildings has been specifically mentioned, either separately or simultaneously (Aldossary, Rezgui, & Kwan, 2014; Cheung, Fuller, & Luther, 2005; Haggag & Elmasry, 2011; Hammad & Abu-Hijleh, 2010; Hirano, Kato, Murakami, Ikaga, & Shiraishi, 2006; Malhotra, 2005; Oropeza-Perez & Østergaard, 2014; Perez & Capeluto, 2009; Prajongsan & Sharples, 2012; Radhi, 2009; Taleb, 2014; Toe & Kubota, 2015). However, none of these studies, carried out in different countries such as United Arab Emirates, Thailand, Mexico, Malaysia and the United States, have examined the impact of vernacular climatic strategies of traditional dwellings in common residential buildings. Other studies conducted by Ranjbar et al. (ranjbar, pourjafar, & khaliji, 2010), Mohammadi et al. (Mohammadi & Ayatollahi, 2011), Nikghadam (Nikghadam, 2015, 2016), Shahmortezaei et al. (Shahmortezaei & Sabernejad, 2016) and Hazbei et al. (Hazbei, Nematollahi, Behnia, & Adib, 2015) in the cities located in hot and humid regions of Iran, including Bushehr and Dezful have examined and identified the most important passive and vernacular strategies such as shading and natural ventilation in the traditional building existing in the historical texture of these cities by field study and simulation, which have recommended using such solutions in the contemporary buildings. However, they have not mentioned the effect of using these strategies on internal thermal comfort conditions and energy consumption of common residential buildings.

3. Geographical Location and Climate Properties of Bushehr

Bushehr City is located on the southwest border in the geographical region of the Coast of Oman Sea and the Persian Gulf with very hot and humid summers and temperate winters. The intensity of solar radiation is excessive and in over 6 months of the year, the weather is sultry and the rainfalls are scarce but torrential. According to the statistics from the meteorological calendar of Iran (from 1951 to 2000), the average minimum temperature of the coldest month in Bushehr is 10.1° C, while and the average maximum temperature of the hottest month is 38.1° C. The highest temperature occurs in July and August and the lowest temperature is seen in January and February.

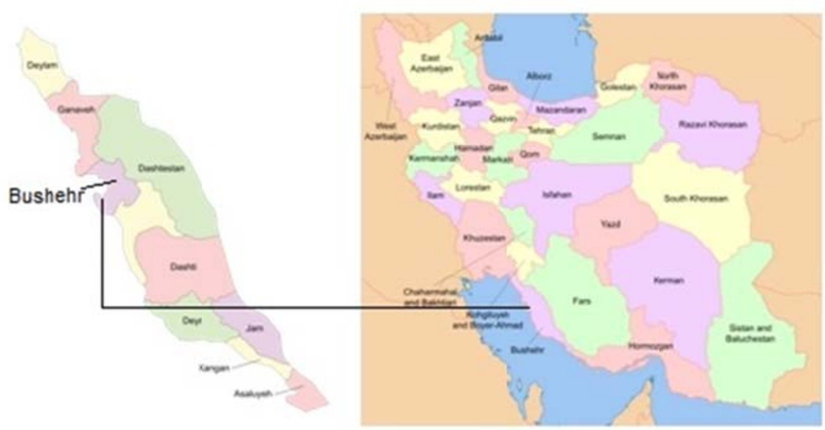


Fig. 1. Location of bushehr province in the country (Source: google image)

Based on the Climatic Calendar of Bushehr City[1], shown in Figure2, in 34% of the year times, the outside dry bulb temperature varies from 0° to 22° C. During day and night, from December to February, it is required to use thermal mass. However, in March, it is comfortable during the day and the use of thermal mass is only required during the night. In 22% of the year, the temperature is between 22° C to 28° C during the day in March, April, and November and during the night in March and October, and to some extent, in May and November, it is dropped within the comfort zone. But, in 44% of the year, the temperature varies from 28° C to 38° C. In these circumstances, from May to October, shading, natural ventilation, dehumidification, and using air-conditioning systems become necessary.

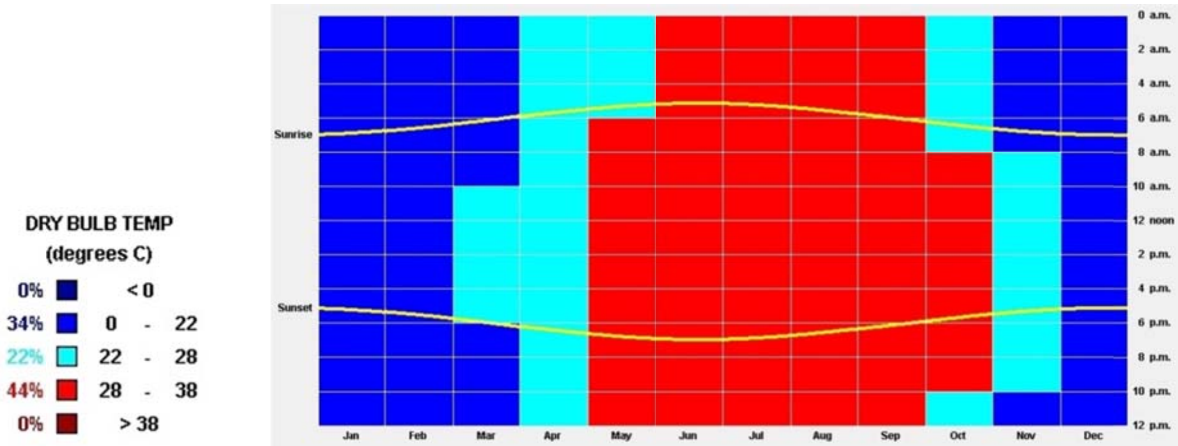


Fig. 2. Climatic calendar of bushehr (Source: climate consultant software, version 6)

In addition, the wind rose chart of this city shows that the northern, northwest and western winds, at speeds of over 8 m/s with the temperatures between 22° C to 28° C and humidity rate of 30% to 70%, are considered the favorable and dominant winds in the city.

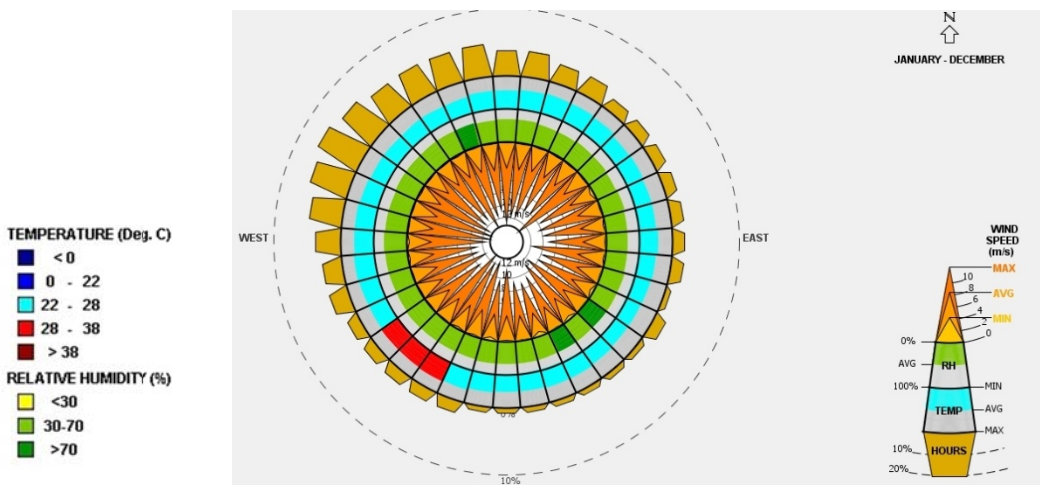


Fig. 3. Wind rose of bushehr (Source: Climate consultant software, version 6)

4. Research Methodology

This research, aiming to apply the climatic solutions of vernacular dwellings of Bushehr to the common residential buildings of this city by collecting short-term local climate data and use them in long-term prediction tool such as simulation, investigated the thermal comfort and energy consumption of common residential buildings at two different levels of improving the current status of the existing building and proposing new models for such buildings. To do so, it has used ASHRAE-55 standard and the Predicted Mean Vote (pmv) model.

4.1. Introducing the Contemporary Texture of Bushehr City

The contemporary texture of Bushehr city consists of two districts, 1 and 2. District 1 is more important in terms of size, land value, and proximity to commercial centers and most of the new and high-rise constructions are built in this district due to the limited availability and high price of land, while District 2 has maintained its original identity and its residential buildings are mostly built in the form of one-story villas. However, in recent years, the construction in this district is also increasing.

(a) (b) (c)

Fig. 4. (a) Zones of district 1; (b) Districts of Bushehr City; (c) Old city structure(*Source*: Google Maps)

District 1 consists of 15 neighborhoods, new and old commercial areas (Bazaar) of the city form the bridge connecting this district to the historical texture of Bushehr. The major neighborhoods of District 1 are (1) Baagh-e-Zahra, (2) Baagh-e-Naar, (3) Neydi, (4) Tol-e-Kouti, (5) western Sangi, (6) eastern Sangi, (7) Jofreh Mahini, (8) Benmaneh, (9) Fazilat suburb, (10) Kooye Bandar, (11) Jabri, (12) Shekari, (13) Chaharsad Dastgah, (14) Helali, (15) Sabakheh, and (16) the Bazaar. However, the Baagh-e-Zahra neighborhood is the most populated and hosts most of the new apartment constructions, which brings in much added value for the builders due to the high quality of the land. The statistics of construction permits issued by Bushehr Municipality in 2013 and 2014 showed that with 86% and 82%, respectively, District 1 enjoys the highest rate of construction permit issuance.

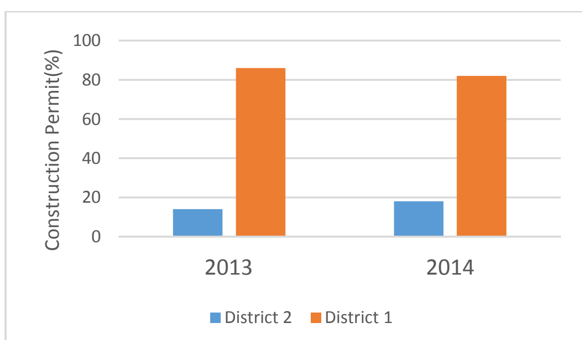


Fig. 5. Statistics of Construction Permits of Districts 1 and 2 in 2013 and 2014 (*Source*: Bushehr Municipality)

In addition, Baagh-e-Zahra neighborhoodhas respectively hosted 18% and 17.8 of the constructions, claiming the highest rate among the other neighborhoods of District 1. Four-story buildings with a total area of 600 to 700 m^2 held the largest share of the demolition and renovation permits for residential buildings among all the neighborhoods of District 1. Hence, this type of buildings is included in the samples of the common residential building construction in Bushehr.

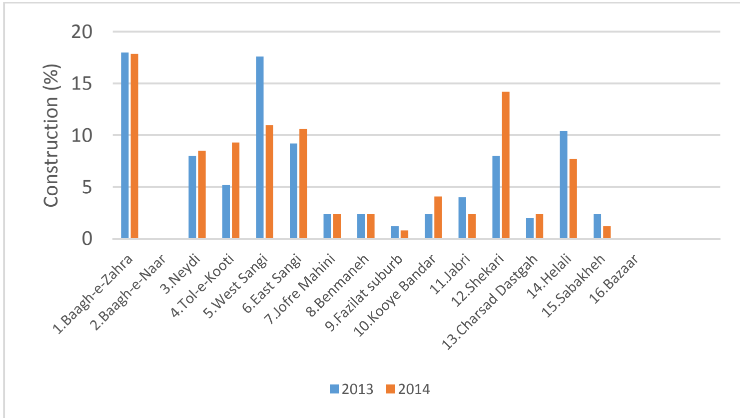


Fig. 6. Statistics of Construction Permits for the Neighborhoods of District 1 in 2013 and 2014 (*Source*: Bushehr Municipality)

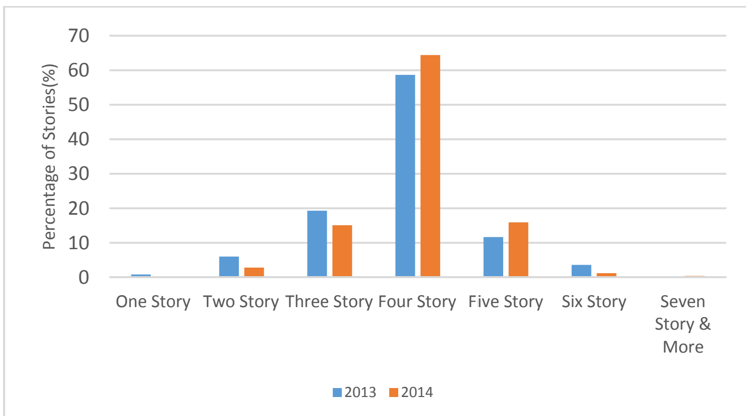


Fig. 7. Percentage of Stories of Residential Buildings in District 1 in 2013 and 2014 (*Source*: Bushehr Municipality)

4.2. Improving the Current State

To examine the current status of the common residential buildings in terms of thermal comfort and energy consumption in this study and collect the local climate data and using it in the simulation, an existing model of the common residential buildings in the form of a four-story apartment(Building 1) was selected from Baagh-e-Zahra neighborhood. These similar buildings are not compatible with their environments and do not contribute to the moderation of environmental conditions(Nikghadam, 2015). The criteria for selecting this building are listed in Table 1. This building did not enjoy passive measures such as proper shading over openings and using natural ventilation during appropriate times of the year, and its external walls lacked thermal insulation. Table 2 shows the physical properties of this building before and after the modifications.

(a) (b)

Fig. 8. (a) Selected Area from Zone 1; (b) Selected Building from Zone 1 (Source: Google Maps)

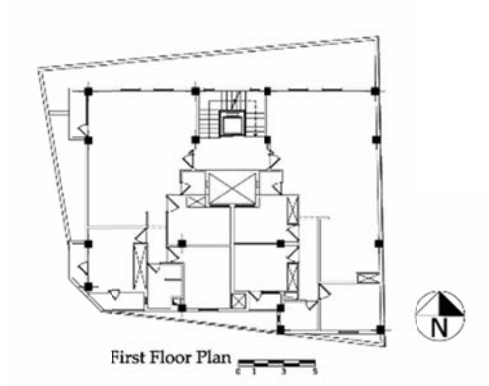
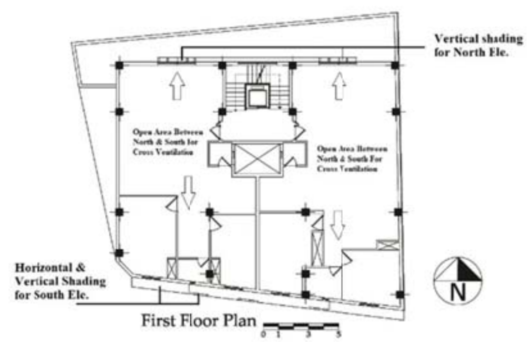
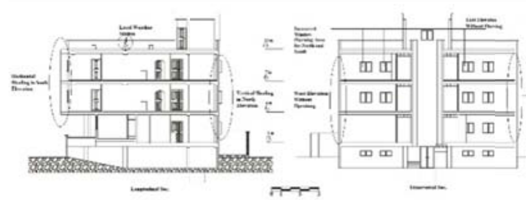
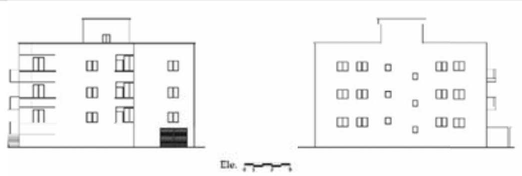
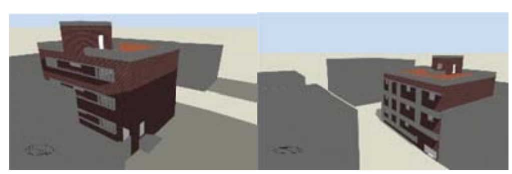
Table 1
Criteria for Selection of Building 1

Ref. No.	Criteria for Selection
1	Current occupancy and conditions for use
2	Field access
3	Roof position for collecting climatic data and absence of obstacles
4	Building security for installation of measuring equipment
5	Number of stories
6	Orientation

Table 2
Physical Properties of the Building 1 before and after Modification

Physical Properties	Before Modification (Building 1)	After Modification (Building 1a)
Total area	647m^2	667m^2
Southern shading device	None	Horizontal- 65cm
Northern shading device	None	Vertical- 30cm
Eastern shading device	Adjacency to the neighboring wall	Adjacency to the neighboring wall
Western shading device	None	No window
Arrangement of interior spaces for using natural ventilation from northern and southern openings	Improper	Proper
Times of year for using natural ventilation	March to April and October to November	March to April and October to November
Dimensions of the southern and northern windows	120*120	130*130 and 130*260
Window frame material	Aluminum- 4cm	UPVC- 4cm
Type of glass and number of panes	Ordinary- single pane	Ordinary- double pane with 1cm layer of air
Heat transfer coefficient of the windows	5.8 w/m^{2}k	3.4 w/m^{2}k
Thickness of external walls	26cm	30cm
Material of external walls	Gypsum plaster, brick, cement mortar, stone	Gypsum plaster, cement block, insulation, cement mortar, brick
Heat transfer coefficient of external walls	1.87 w/m^{2}k	0.35 w/m^{2}k
Type and thickness of thermal insulation of external walls	No thermal insulation	7cm of Polystyrene insulation
Type and thickness of roof insulation	No thermal insulation	10cm of fiberglass

Table 3
The case study building in Baagh-e-Zahra neighborhood before and after modification (Source: Bushehr Municipality)

	Before Modification (Building 1)	After Modification (Building 1a)
Plan		
Section		
Elevation		
Perspective		

4.3. Proposed Models

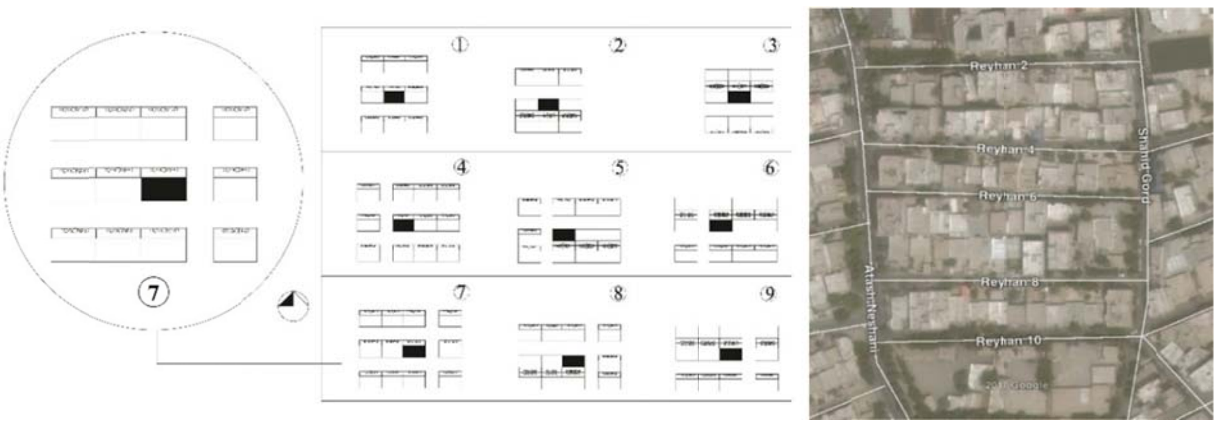
In addition to improving the current state, to propose new models of common residential buildings with a range of area of 600 to 700 m^2 in which passive strategies of vernacular dwellings of Bushehr were used in them to improve thermal comfort and energy consumption in the early stage of design phase, the possible forms were designed for a neighboring unit of these buildings and the local climate data collected before were used in their simulation. Figure 10 and Table 5 show the possible forms for these neighboring units and the details for one of the blocks (No. 7). The criteria for designing the proposed models are shown in Table 4.

Table 4
Criteria for designing the proposed models in various forms

Ref. No.	Criteria for Designing the Proposed Models
1	Proper elongation and orientation of the building with respect to the direction of sun and wind for better use of daylight and cross ventilation
2*	Suitable material in terms of thermal insulation according to Chapter 19 of National Building Code
3*	Designing suitable dimensions for the windows to create the minimum air flow required for comfort in interior spaces using CFD and taking advantage of the proportions of the openings of the vernacular dwellings of Bushehr
4	Choosing the right orientation for the windows in the building façade according to the amount of solar gain
5*	Designing the window overhangs with proper depths in different directions using shading mask method instead of deep edges for the external walls and thick walls like the vernacular dwellings
6	The minimum ratio of the external surface to the foundation to reduce heat transfer in the building
7	choosing longitudinal form for the building to accelerate natural ventilation inside and create longitudinal facades for the northern and southern fronts of the building for optimal natural lighting according to the patterns of the vernacular dwellings of Bushehr
8	Using center pivot windows for better natural ventilation instead of casement windows used in the vernacular dwellings
9	Placing the sleeping and resting spaces in the southern front and the kitchen and living room in the northern front for better use of the daylight and establishing cross ventilation between the spaces and removing any barriers to natural ventilation
10	Placing the staircase and the elevator in the northern front to use indirect daylight
11	Using central skylight in the middle of the building instead of using small central courtyards like vernacular dwellings of Bushehr and placing kitchen and bathroom and servicing spaces adjacent to it for lighting
12	Designing the model with a range of area of 600 to 700 m^2 for the entire building which is within the scope of area of the common residential apartment buildings in Bushehr
13	Placing the building on a pilot to increase the height of the building and better use of natural ventilation
14	Including 5 independent units in the whole building
15	Number of intended stories is 4 stories considering the pilot space for parking and storage
16	The level of land use in the proposed models is 70%. (in accordance with the regulations of Bushehr Municipality)
17	Using terrace on the southern side to take advantage of direct daylight and using a combination of roofed terrace and porous shells in the eastern and western fronts instead of using slides and wooden shutters as in the vernacular dwellings

(a) (b) (c) (d)

Fig. 9. Nowzari edifice: an example of traditional dwellings in Bushehr; (a) inside; (b) outside; (c) courtyard; (d) first floor plan(Source: Cultural Heritage Organization of Bushehr)



(a) (b)

Fig.10. (a) different positions for the proposed models; (b) part of the current status (Source: Google Maps)

The starred (*) items in Table 4, including using the suitable material in terms of thermal insulation, suitable dimensions for the windows for natural ventilation and appropriate shades, are important considerations in the design of the proposed models and among the climate strategies used in the vernacular dwellings of Bushehr. The reference heat transfer coefficient in these models is 794.45 w/k, which is more than the heat transfer coefficient of the building design as 534.06 w/k. Therefore, the materials used on the external surfaces(including 5cm polyurethane foam for external walls and roof) are in accordance with the functional approach of Chapter 19 of National Building Code in terms of thermal insulation. The dimensions of the windows appropriate for natural ventilation in these models are determined according to the velocity of air flow for comfort in interior spaces by using the Computational Fluid Dynamics (CFD) and simulation in Design Builder Software. Based on the simulations, the best time for using natural ventilation in Bushehr is from March to April and from November to December. Accordingly, March 30th was selected for examining the state of natural ventilation on this day in the residential building selected from the Baagh-e-Zahra zone and its modified model as well as one of the neighboring blocks in status 7.

Table 5
An example of the proposed models in position 7 (Source: author)

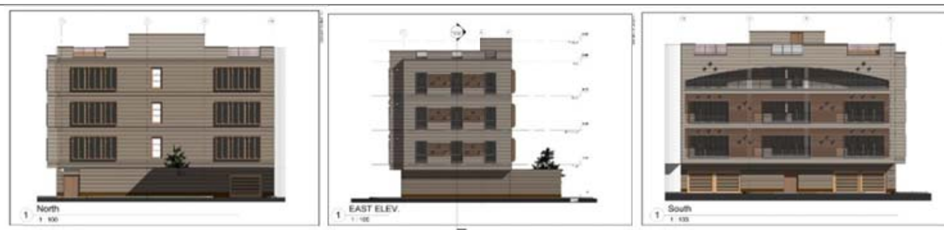
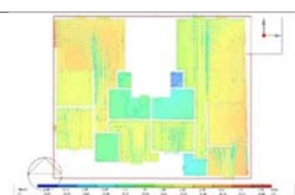
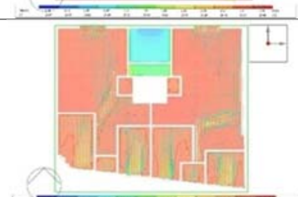
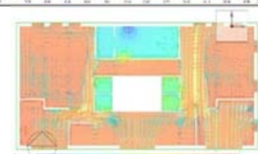
Plan	
Section	
Elevation	
Perspective	

Table 6
Internal computational fluid dynamics (CFD) on 30 March at 6 pm

	Dimension of windows(cm)	**Floor**	**CFD Model**	**Range of Operative Temp.(C)**	**Range of air velocity(m/s)**
1. First Floor of Building 1	120*120 For North and South	First		25/79~26/14	0/6~0/9
2. First Floor of Building 1a	130*130 For South and 130*260 For North	First		24/14~24/84	0/89~2/07
3. First Floor of a Proposed Model in Status 7	200*300 For South and 100*200 For North	First		23/52~24/14	1/37~3/18

According to Table 6, at a relative humidity of 50%, for a person with the clothing level of 0.5 Clo., and the metabolic rate of 1Met by considering the range of operative temperature and air velocity in the three buildings, the best state for maintaining comfort conditions along with natural ventilation was observed in Form 3, which implies suitability of the dimensions of the openings designed in this form to create thermal comfort conditions along with the natural ventilation. In addition, the module(1m×2m) used in the design of the openings in the proposed models is closer to the proportions of the openings used in the vernacular dwellings of Bushehr. If the velocity of airflow in the second and third floors is high, the air flow can be controlled by closing some of the windows.

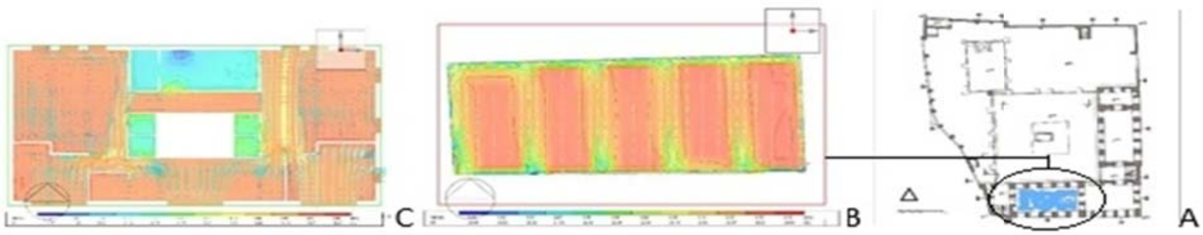


Fig. 11. Comparison of the type of ventilation using CFD;*A*: floor plan of kamandi edifice, *B*: magnification of summer zone in kamandi edifice, *C:*proposed model of the neighboring in position 7

Besides the proper design of the windows for natural ventilation, shading devices in these models were also designed based on the shading mask method and the model shading device for Bushehr city(Mohammadi & Ayatollahi, 2011). Since the dimensions of the southern windows are 2m×3m, then, based on the model shading device for Bushehr, the depth of the horizontal shade of these windows would be 1m. The dimensions of the northern windows are 1m×2m and so, their shades must be vertical with the size of 0.5m×1m. For the eastern and western elevation, given the penetration of solar radiation into the interior space and its high intensity in east and west, the horizontal shades with the depth of 1m and porous shells were used.

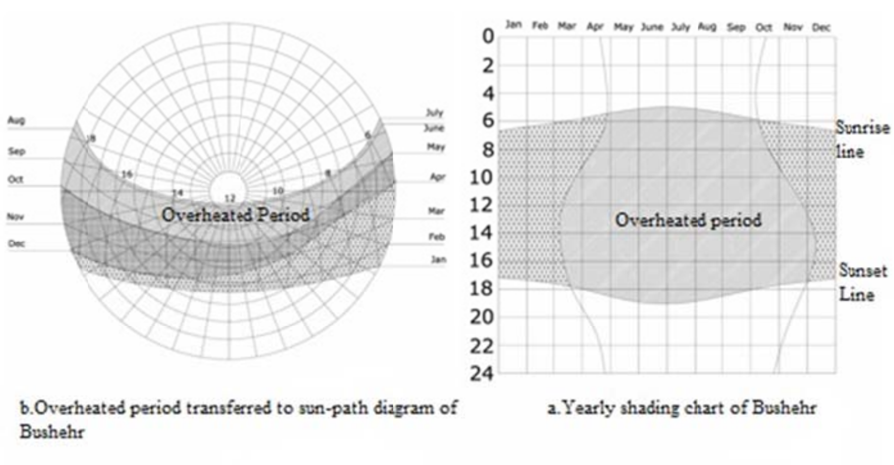


Fig. 12. (a) Yearly shading chart of bushehr; (b) overheated periods of bushehr (Source:(Mohammadi & Ayatollahi, 2011))

4.4. Measuring Equipment and Field Measurements

The status of the selected existing model of the common residential building was studied via field measurements and computer simulation. Therefore, short-term local climatic data were collected by measuring equipment over a year from the roof top of the selected building as the local climate. Then, the collected data were used in the simulation. The temperature-humidity data loggers (model: MCI-98583) and wind data loggers (model: TES-AVM-07) with the specifications listed in Table 7 were used.

Table 7
Specifications of Measuring Equipment

Environmental Parameters	Equipment	Range		Precision	
Air Temperature and Humidity	MCI-98583	Temp.	Humidity	Temp.	Humidity
		-40-85 C	0.1-99.9%	+,- 0.6 C	+,- 3 %
Wind speed	TES-AVM-07	0-45 m/s		+,-3 % +,- 0.3	

Fig. 13 . Measuring equipment

The parameters collected from the roof top of the existing building were seen as the local climate including air temperature, relative humidity and wind velocity, the values of which were measured at one hour intervals for three days per month by automatic measuring devices. The selected days were similar in terms of weather conditions and the days before the measurement were also similar to the measurement days. The values recorded were entered into the weather data file of Bushehr City used in the simulation software. Since the weather data file of Bushehr is not available on the website of the US Department of Energy, this weather data file was made by using the Meteonorm software (version 7). Regarding solar radiation, the existing information from the same weather data file, tolerating up to 8% error and 92% reliability, was used in the simulation. In this research, given the economic budget and the accuracy of the findings and results, simple short-term field measurements were used in the form of measuring parameters of air temperature, relative humidity and wind velocity over three consecutive days in each month at a local climate scale (for calibration of weather data file used in the simulation). Therefore, the simulation was first done over a year (long-term prediction) and then, short-term intervals of three days per month, which covers a total of 36 days per year or 10% of a year, were extracted from the long-term simulation.

Table 8
Measurement Dates

Selected Days											
4-6	3-5	4-6	2-4	3-5	3-5	4-6	4-6	4-6	5-7	4-6	4-6
Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.

4.5. Simulation

The Design Builder software (version 5) was used in this research which applies the Energy Plus simulation engine to calculate thermal comfort and energy consumption. The simulation software was validated by calculating its percentage error through comparing the energy consumption per year of an actual building based on the bills of electricity and gas and the energy consumption per year of the same building calculated using simulation in this software. Building 1 was used for this purpose. The actual energy consumption in the first floor of building 1 per year calculated by using electricity and gas bills and through simulation were, respectively, as 25861kwh and 23620.5kwh, which shows a difference of 9.4% between the actual consumption and the simulated consumption. This is within the allowable percentage error.

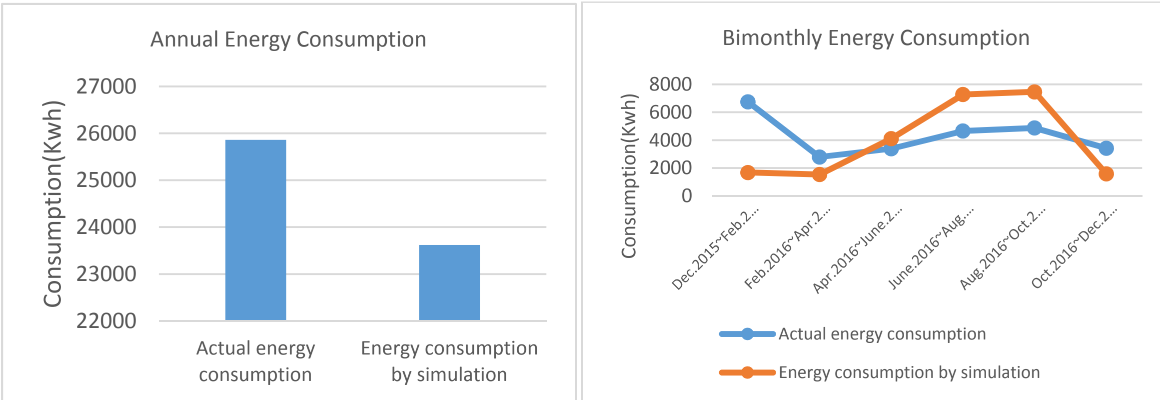


Fig. 14. Actual and Simulated Energy Consumption in the First Floor of Building 1

In the simulation of existing and proposed model of common residential buildings, the heating, cooling and natural ventilation set points were as18° C, 25° C and 24° C, respectively and the models were constantly used during the week. It is assumed that during very hot periods of the year, when air-conditioning systems reactive, the thermal comfort is provided and discomfort hours come close to zero. However, during moderate times of the year, when natural ventilation is preferable, the thermal comfort might not be fully provided by the natural ventilation and the discomfort hours increased. In this way considering other actual conditions of the models in the simulation, including the construction materials, orientation, openings, number of occupants and type of activity and clothing, thermal comfort, energy consumption and CO_2 emission of the models were calculated and compared.

5. Results and Discussion

5.1. Heat Loss and Gain

5.1.1. Internal Gain

According to Figure 15, in the comparison of the Building 1 with Building 1a, the amount of heat generated by solar gain in interior spaces was reduced from 2699.07wh/m^2 to 665.16wh/m^2 due to the improvement of the shades and elimination of unsuitable windows of the western front. Given the equal amount of heat generated by general lighting and the insignificant difference in heat generated by occupancy in the two buildings, the total amount of heat generated by the solar gain, occupancy, and general lighting over the selected days was reduced from 8113.51wh/m^2 in Building 1 to 5825.21wh/m^2 in Building 1a. In addition, in the proposed models, in the comparison of the status which didn't use passive strategies (group 1 including b,c,d,…,j) with the status which used such strategies (group2 includingb1,c1,d1,…,j1), given the equal amount of heat generated by general lighting in group 1 and 2 and the insignificant difference of heat generated by occupancy in two group, the amount of heat generated by solar gain in interior spaces varied from 5918.75wh/m^2 to 9512.38wh/m^2 in group1 and from 2364.63wh/m^2 to 3576.69wh/m^2 in group2. The total amount of heat generated by solar gain, occupancy, and general lighting over the selected days also varied from 7799.64wh/m^2 to 11395.65wh/m^2 in the group1 and from 4312.08wh/m^2 to 5518.08wh/m^2 in group2 which showed a reduction of 3487.56wh/m^2 to 5877.57wh/m^2.

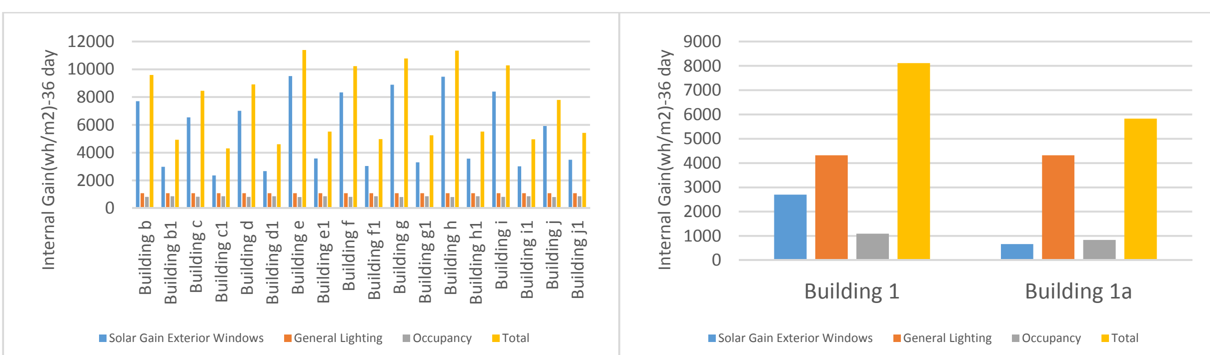


Fig. 15. The amount of heat gain in Interior spaces over the selected days

As shown in Figure 16, the total sensible cooling over the selected days in Building 1 was -10694.69wh/m^2 and -4109.18wh/m^2 in Building 1a which showed a reduction of 6585.51wh/m^2. Sensible heating was excluded due to its insignificant amount. In the proposed models, in comparison of the group 1 with group 2, the total sensible cooling varied from -10693.3wh/m^2 to -12259.8wh/m^2 in group1 and from -4374.16wh/m^2 to -4935.01wh/m^{2}in group2which showed a reduction of 6346.14wh/m^2 to 7324.79wh/m^2. Sensible heating was excluded due to its insignificant amount.

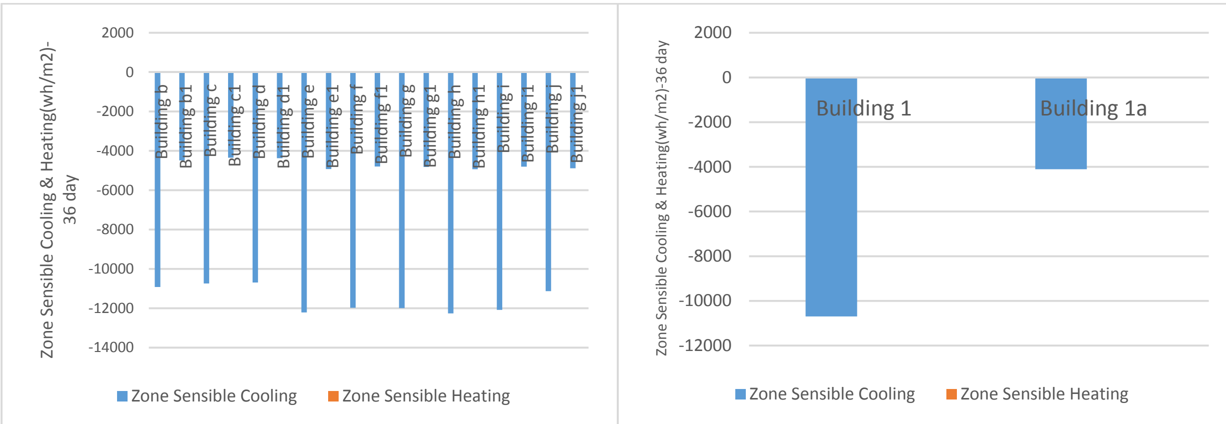


Fig. 16. Total sensible cooling over selected days

5.1.2. Fabric and Ventilation

The next important factor in the building's heat exchange after solar gain, general lighting and occupancy is fabric and ventilation. The total heat exchange from the external walls and roof of the building 1 over the selected days without thermal insulation was 3943.9wh/m^{2}and 1472.08wh/m2 which was reduced to 545.72wh/m^{2}and 287.63wh/m2 in building 1a after applying 7cm and 10 cm of thermal insulation in external walls and roof. Besides, in the proposed models, in comparison of the group 1 and 2, the total heat exchange from external walls and roof varied from2071.56wh/m2 to 2755.36wh/m2 and 1205.58wh/m2 to 1420.11wh/m2 in group 1 and from 210.52wh/m2 to 273.25wh/m2 and 387.63wh/m2 to 418.84wh/m2 in group 2 which showed a reduction of 1861.04wh/m2 to 2482.11wh/m2 and 817.95wh/m2 to 1001.27wh/m2 respectively. The total heat exchange from ceilings, floors and partitions was excluded due to their insignificant amounts. The role of natural ventilation in expelling warm air from the building was also significant. The amount of warm air expelled from building 1 over the selected days was -1420.23wh/m^2 which increased to -2119.8wh/m^2 in building 1a after the improvement applied to the interior spaces and the dimension and area of the openings. In the proposed models, in the first group, there was no expulsion of warm air by natural ventilation which increased from -878.43wh/m^2 to -1445.23wh/m^2 in the second group. In addition, as shown in Table 6, the examination done on the proposed models using computational fluid dynamics showed that the ventilation created in these models, due to the low width, is cross ventilation like vernacular dwellings in Bushehr which effectively affects the entire ventilated space inside and enjoys the required velocity at appropriate times of year to create thermal comfort conditions while in building 1, the natural ventilation flow is slow and does not have the quality required for creating thermal comfort conditions.

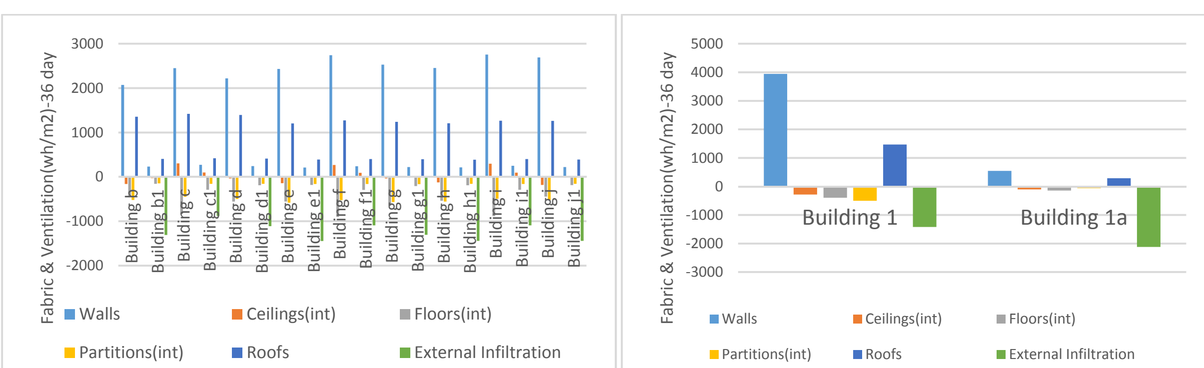


Fig. 17. Total heat exchange from fabric and ventilation over the selected days

Figure 18 shows total system loads including sensible cooling (generated by internal gain), total cooling (generated by fabric, ventilation, and internal gain) and heating over the selected days. According to this Figure, the total cooling required was -11003.4wh/m^2 in building 1 and -4336.47wh/m^2 in building 1a which showed a reduction of -6666.93wh/m^2. In addition, in the proposed models, in the comparison of group 1 and 2, the total cooling varied from -10925.5wh/m^2 to -12491wh/m^2in the group1and from -4553.24wh/m^2 to -5143.17wh/m^2 in the group2 which showed a reduction of 6372.26wh/m^2 to 7347.83wh/m^2. Heating was excluded due to its insignificant amount.

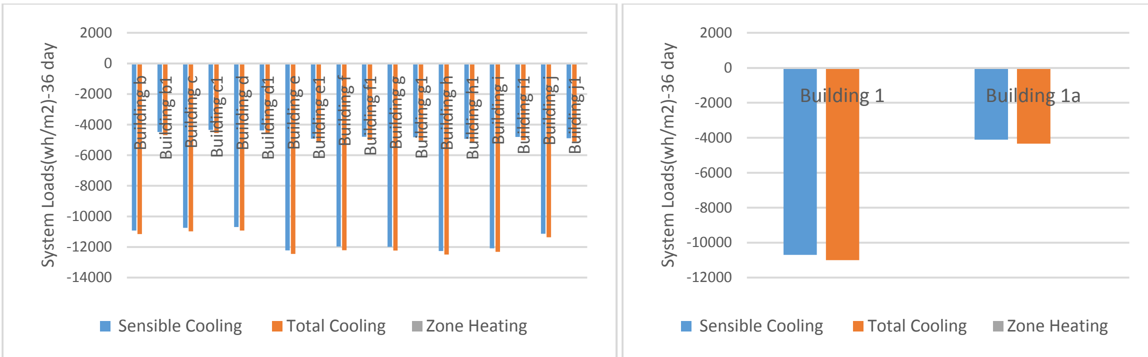


Fig. 18. Total system loads over the selected days

5.2. Thermal Comfort and Energy Consumption

Now, given the state of total system loads in each of the samples, it could be expected that the thermal comfort conditions get better in building 1a and the proposed models and the need for energy consumption for the cooling decrease. Figure 19 shows that the total discomfort hours over the selected days in building 1 was 399.01 which was reduced to 119.06 hours in building 1a. In addition, the discomfort hours in the proposed models varied from453.84 to 477.73 hours in the group1 and varied from 301.16 to 388.89 in group2 which showed a reduction of 88.84 to 152.68 hours.

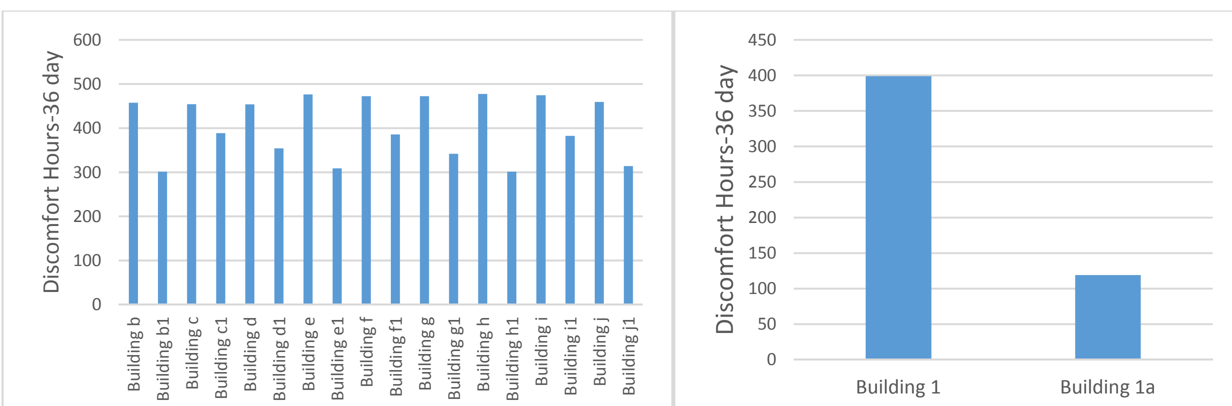


Fig. 19. Discomfort hours over the selected days

Finally, Figure 20 shows the amount of energy required for cooling and lighting over the selected days in each of the samples and the energy required for heating was excluded due to its insignificant amount. Accordingly, given the equality of power consumption required for general lighting in buildings 1 and 1a, the total power consumption required for cooling over the selected days was 6113.02wh/m^2 in building 1 and 2409.15wh/m^2 in building 1a which showed a reduction of 3703.87wh/m^2. In addition, given the equality of power consumption required for lighting in the proposed models, the power consumption required for cooling over the selected days varied from 6069.72wh/m^2 to 6939.42wh/m^2 in the group1 and from 2529.58wh/m^2 to 2857.3wh/m^2 in the group2 which showed a reduction of 3540.14wh/m^2 to 4082.12wh/m^2.

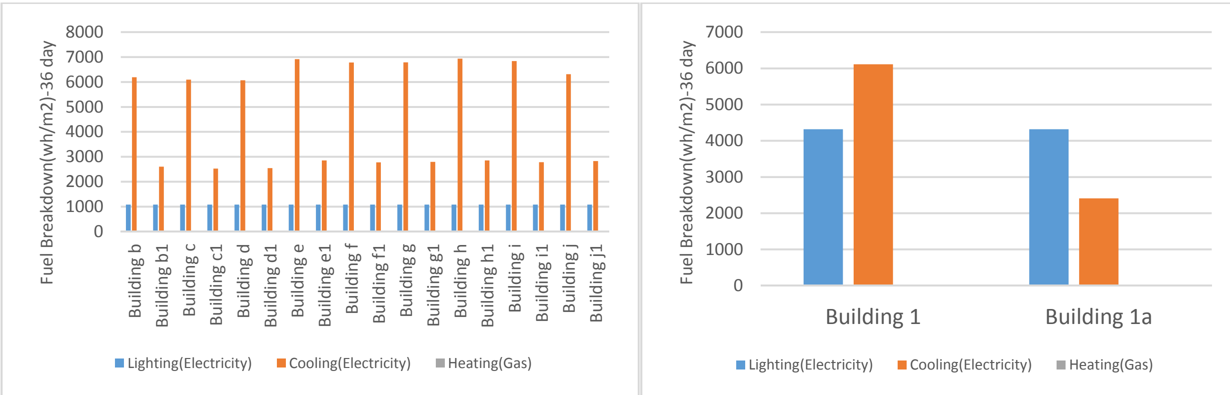


Fig. 20. Energy required for cooling and lighting over the selected days

As a result of this reduction in the cooling energy consumption, co2 production decreased in building 1a up to 2244.49kg and from 2145.3kg to 2473.38kg in the proposed models over the selected days.

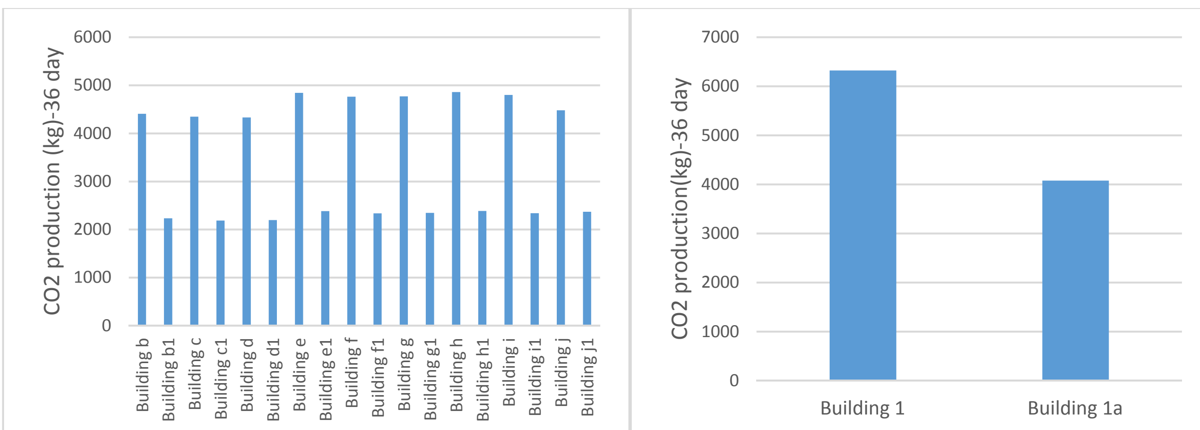


Fig. 21. Carbon dioxide emissions over the selected days

The findings of this research on the role of shading in reducing thermal load and energy consumption in hot and humid regions were consistent with the findings of Aldossary et al. (Aldossary et al., 2014) in the residential buildings of the hot and humid city of Jeddah resulted from a field study using simulation and caused 21% to 37% reduction in energy consumption. Besides, the findings of Haggag and Elmasry (Haggag & Elmasry, 2011) in the two hot and humid cities of Jumeirah and Masdar which were also resulted from a field study using simulation on the effect of using a combination of passive cooling strategies including natural ventilation, shading, thermal mass, orientation and using central courtyards in residential buildings of these two sustainable cities and caused a reduction in thermal load and optimization of thermal comfort and energy consumption were also consistent with the findings of this study. Although using the vernacular climatic solutions of these regions didn't play any role in their contemporary residential buildings.

6. Conclusion

In this study, the use of climatic strategies of the vernacular dwellings of Bushehr in the common residential buildings of this city was examined at two different levels: improving the current state of the common residential buildings and proposing models of such buildings. This study showed that using vernacular climatic solutions (VCS) of the traditional dwellings in the contemporary buildings of Bushehr, the most important of which was preventing the penetration of solar radiation into the interior spaces by creating shades over the openings, placing semi-open spaces under shades, using suitable materials in the fabric of the building and creating cross ventilation through implementing suitable openings in terms of dimension and number, was the best answer to the local climate characteristics and could improve the thermal comfort and cooling energy consumption in these buildings. The modifications made in building 1 reduced nearly 37kWh of power consumption required for cooling per square meter per year. If we assume a residential apartment flat in Bushehr to be 100m^2, that would mean more than a3500kWh reduction in power consumption of cooling systems per household. Also, this figure would be between 3500 to 4000 kWh per year per household in the proposed models.

Acknowledgements

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Endnotes

[1] This calendar was made using Climate Consultant Software (V.6) and the hourly weather data file of Bushehr which was obtained by interpolation in Meteonorm Software (V.7). The ASHRAE-55 standard and Predicted Mean Vote (p mv) model in thermal comfort were used.

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