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Comparative Analysis of Vernacular Passive Cooling Techniques in Hot Humid Regions

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Research Article

Abstract

Understanding the vernacular architecture is recognizing the limitations and capabilities of the region's climate; in fact, a direct response to existing contexts and resources includes the materials and techniques. The architecture of warm and humid climates also has a particular architectural style, previously used to achieve a sustainable architecture. However, few studies have been conducted to identify vernacular architectural features and their role. The southern edge of Iran has one of the most critical climates in the world. So, cognition and extraction of similarities and differences between the vernacular architecture of Bushehr region with similar climatic zones in other countries in passive cooling techniques, provides suggestions for improvement in this area. In conclusion, these techniques are compared with Bushehr in two categories of natural ventilation and radiation and heat control in areas known to be warm and humid in four countries including Iran, Vietnam, Oman and Malaysia.

Keywords: Passive Cooling Technique; Hot Humid; Bushehr; Vernacular

1. Introduction

There is a close link between energy consumption and environmental degradation. Consider strategies such as climate-responsive and passive solutions, among the most efficient ways to

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achieve a reduction in energy consumption in the building, which lead to 40% -50% in energy savings (Topfer, 2009).

Environmental protection and reduction in the use of natural resources are one of the major world-wide concerns today (Kamal, 2012); 40% of this giant energy consumption is related to buildings (Givoni, 1994). Building cooling using natural mechanisms (passive cooling) is one of the sustainable architectural approaches (Oliver, 1997). This strategy involves limiting the effect of heat received, in order to provide the right temperature and less ambient temperature (Bhamare, Rathod, and Banerjee, 2019). Since the potentials in each region vary, it should therefore be considered in the area concerned.

It is generally believed that vernacular buildings have been successful in using passive systems over time and across generations; as well, responding to human needs regarding thermal comfort and regional climates (Santamouris, 2012). The condition of human comfort is a set of conditions that are suitable for at least 80% of the people with respect to the temperature regime.

2. Literature Review

Lim (1987): Traditional Malaysian houses are the best example of ventilation since they have the best air circulation through windows, doors, roofs, etc.

Ziah (1994), in his studies on passive cooling performance in traditional Malaysian houses and comparing them to modern houses, found out that traditional Malaysian houses kept less heat inside them than modern ones.

Roslan (2005) has investigated traditional Malaysian houses techniques such as installing openings in pitched roofs with respect to the wind direction and using reflective ceilings, while also explores application of the above procedures as a proper solution for modern houses to achieve comfort temperature and thus less energy consumption.

Gribble (2009) examined natural ventilation in underground Egyptian tombs, where cooler night air replaces the past day’s old air and fit to be used during the following day.

Rihan, Abdelsalam (2012), examined and analyzed sustainability of elements in the native architecture of Arab cities, and their role in forming those cities according to today's style.

Kubota, Toe, and Ossen, (2014) studied the feasibility of applying cooling strategies in indigenous dwellings to modern houses to reduce energy consumption in Malaysia. They compared two traditional Malaysian wooden houses with two traditional Chinese houses and empirically measured differences relative to their passive cooling.

Victoria et al, (2017) explored the bioclimatic† solutions of aisleway-like houses such as Dayak, on the Bourneo Island, where daylight and natural ventilation are used by horizontal and porous openings located at the top of each residential unit entrance door, as well as roof openings (camban), empty under-roof (loft) space; used materials may be considered as design solutions and operational in the design of modern houses.

Prieto (2017), in a traditional simulated house, found out that the house, for 24 hours of a hot summer day needed mechanical air conditioners. However, use of passive cooling in the building, eliminated the need for mechanical air conditioning up to 8.5 hours, and the canopy shading may reduce the need for mechanical air conditioning by 10 to 50 percent.

† Bioclimatic

Moshiri (2009) studied sustainable design strategies in the two Bandar Abbas, Iran, and Belem, Brazil, cities and considers stereotypical design in one single climate and in two different geographical areas as wrongdoing or erroneous judgement.

Nikghadam (2015) explored the differences between the open and semi-open space patterns of three Bushehr, Bandar-Lengeh and Dezful areas; and considers them applicable in today's housing to achieve thermal comfort.

3. Vernacular Architectural Approaches to Passive Cooling in Hot and Humid Climate

The term passive cooling systems is used for a variety of simple techniques that are able to keep the building's interior temperature lower by natural energy sources.

Several classifications have been done based on main and natural sources from which cooling energy is derived:

-Cooling is done by the following schemes: natural ventilation, nocturnal ventilation, radiant cooling, direct and indirect evaporative cooling, Soil cooling and cooling through outdoor spaces (such as greenhouses) (Bhamare, Rathod, and Banerjee, 2019).

-Climatic site design and microclimate, radiation control, building form and plan, thermal insulation, residents' behavioral and residential patterns and interior heat absorption control (Al-Obaidi, Ismail, and Rahman, 2014).

- Protection against and control of the solar radiation and heat (insulation, microclimate, shading canopy and radiation protector, etc.) (Eddisford, and Carter, 2017).

-Heat modulation (thermal mass, nocturnal ventilation, etc.)

-Heat dispersal technique (natural cooling and ventilation, evaporative cooling, wind cross-ventilation, etc.)

Vernacular architecture is an important resource in the sustainable architecture field, energy in architecture and climate responsive architecture (Bee, 2010).

Energy conservation and passive cooling / heating are the most effective and inexpensive options for conventional energy sources. Most studies in hot climates have shown that the areas with the highest energy efficiency are those that use passive methods for cooling (Al-Obaidi, Ismail, and Rahman, 2014). According to experts, architectural goals of the hot and humid regions are directed toward moderation of the region's most important climate components, namely temperature and high humidity. These goals have led to the solutions that constitute the region’s architecture.

The strategies employed in vernacular architecture in hot and humid regions have three general objectives:

1. Solar radiation control and the resulting heat, through shading
2. Natural ventilation by applying natural airflow
3. Attention to local morphology, such as proximity to water and plants (Nikghadam, 2015).

Thus, vernacular architectural strategies to generate passive cooling, according to the above definitions, may be examined by two general approaches: natural ventilation and radiation control.

4. Zoning of the Hot and Humid Climate Study Areas

-Bushehr: Bushehr is located at 28.59 latitude, in tropical and semi-arid mega-climates on the brim of the Persian Gulf, Iran, where temperature difference between summer and winter is quite high (Victoria et al., 2017). The lowest temperature in the region is 10 degrees and its maximum reaches 36 degrees Celsius. The city needs to be cooled in two months of the year. Relative humidity is high in summer and winter, but the rainfall is low in winter and not raining in summer (Nguyen et al., 2011). (Fig 2)

-Vietnam: The Vietnam country is located in Southeast Asia at latitude 13-18, and is generally a tropical region with high annual rainfall. Climatic features of the three Hochiminh, Danang and Hanoi regions in this country are severe sunlight, high relative humidity, high temperatures, absence of cold seasons and the need for cooling. The minimum temperature in these areas is 5 degrees and the maximum reaches 40 degrees Celsius (Kubota, Toe, and Ossen, 2014). (Fig 2)

-Malaysia: Malaysia's climate can be classified as tropical hot and humid. The air temperature in this region reaches 32 degrees and relative humidity more than 75%. Rainfall in this region is high. The Malacca city, which lies at 2.16 latitude is the only region in Malaysia that has a general architecture with special features (Victoria et al., 2017). Dayak longhouses in sarawak state and Chinese shophouses in Malacca are good examples, of passive cooling techniques of the past (Victoria et al., 2017; Al-Hinai, Batty, and Probert, 1993). (Fig 2)

-Oman: Oman's coastal region, located north of 22.32–23.35 degrees, include: Muscat, Sur, Batinah. Due to its proximity to the Persian Gulf, Oman has a hot and humid climate with very low rainfall, but a relative humidity of 100%. The air temperature in the area is also 49.5 degrees Celsius (Dabbaghiyan et al., 2016). (Fig 2)

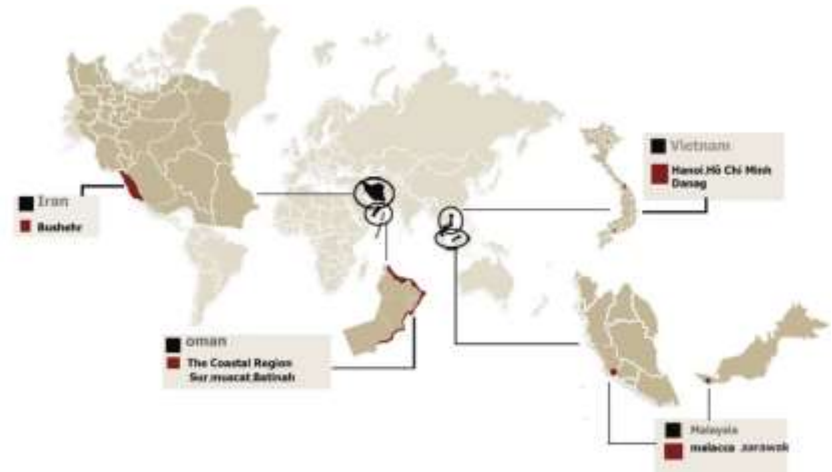


Fig 1 Zoning of the hot and humid climates under study (Source: Kubota, Toe, and Ossen, 2014; Victoria et al., 2017; Dabbaghiyan et al., 2016)

4.1. Comparison of Climate Components

a) Received Radiation: Despite Malaysia and Vietnam's closer proximity to the equator than Bushehr and Oman, the highest amount of radiation received in Oman, Bushehr, Malaysia and Vietnam is due to high cloud cover in the sky, which prevents direct radiation. (Fig 3)

b) Temperature: The rise in temperature from April to November is usually observed in three areas of Bushehr, Vietnam and Oman; the temperature difference in Bushehr and Oman is very high as compared to that of Vietnam as the temperature in Malaysia is almost constant throughout the year Oman's temperature is higher than in other regions.

c) Wind speed: The highest wind speeds are felt in Bushehr and Oman, much higher than Vietnam and Malaysia. Wind speeds in Malaysia and Vietnam are roughly the same throughout the year. (Fig 3)

d) Relative Humidity and Rainfall: Comparison of relative humidity and rainfall in the study areas shows that despite high annual rainfall difference between Bushehr and Oman (coastal areas) with Malaysia and Vietnam, due to proximity to the sea, their relative humidity is slightly different; the highest is in Malaysia and the least in Oman. (Fig 3)

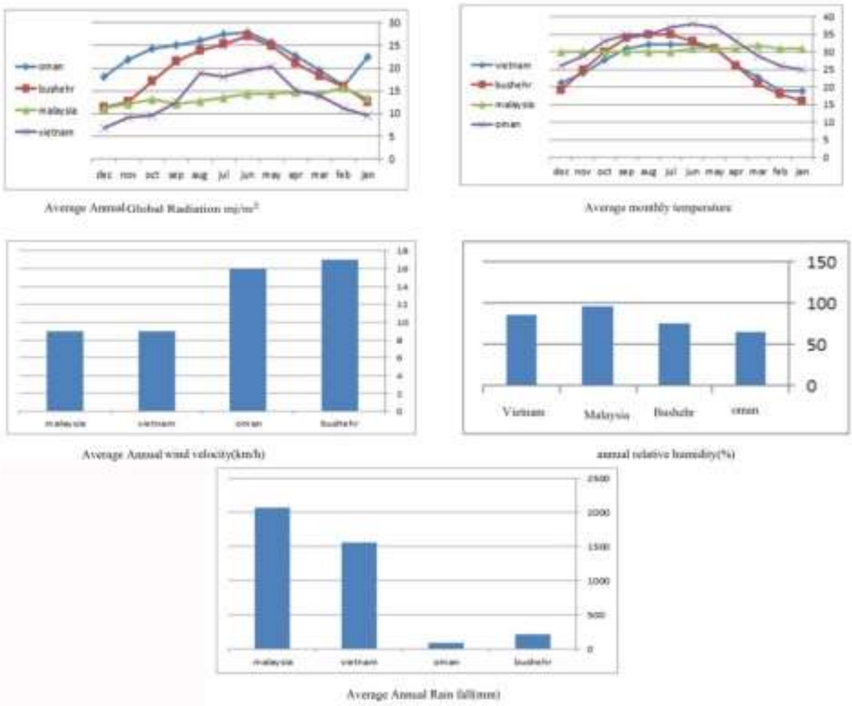


Fig 2 Comparison of climatic components (Source: Keskin, and Erbay, 2016)

5. Methodology

In this study, passive cooling techniques are compared with Bushehr in two categories of natural ventilation and radiation and heat control in areas known to be warm and humid in countries including, Vietnam, Oman and Malaysia. (Fig1)

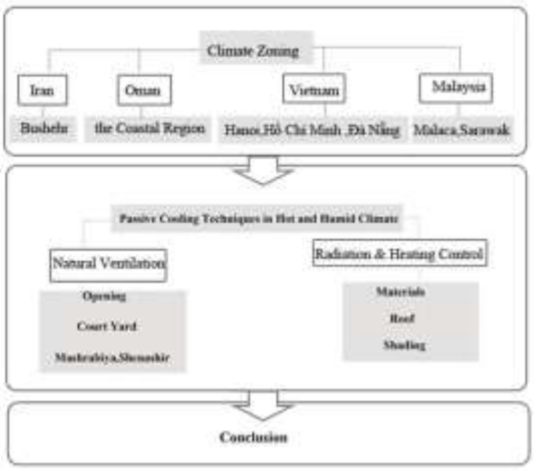
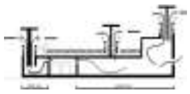
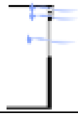
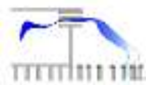
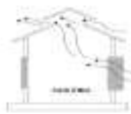
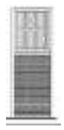
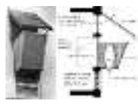
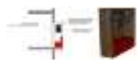
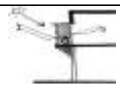


Fig 3 Research objective and methodology

6. Natural Ventilation

Table 1 Natural ventilation

Elements		Region	Cooling technique	Image	Source
Openings	Clustra, Shabak, Goljam	Gheshm, Oman	-Provide natural ventilation in the interiors -In combination with funnels and roof louvers		Brian, 2002; weatherbase.com
		Bushehr	-In combination with extended widows for optimum sea breeze and moisture absorption		
	Fixed transom on top of the wall	Malaysia	-Cool air suction from under buildings by interval bamboos off the ground by stack ventilation		Al-Hinai, Batty, W. & Probert, 1993
	Roof opening	Malaysia	-Provide natural ventilation in two ways: stack ventilation and wind flow ventilation	 	
		Vietnam	-Creating funnel-shaped gutters under attic for sucking hot air and Moving it out		Kubota, Toe, & Ossen, 2014
	- Extended windows -Louver	Bushehr	-Vertical extended windows - In some cases with pores to absorb moisture		weatherbase.com
	–Utilization of window at height	Oman	-To get the desired breeze at higher altitudes from the sea		Dabbaghiyan et al., 2016; Kubota, Toe, & Ossen, 2014
	-Raise buildings off ground level	Vietnam - Malaysia	-To get high speed wind at higher altitudes and away from moisture		
Courtyard		Malaysia	-Providing cross-ventilation between central courtyard and the back yard -Tornado formation in the central courtyard for air exchange with outside (skimming flow)		Zakaria, Kubota, & Toe, 2018
		Vietnam	-Large and long courtyard helps enhance natural ventilation and reduces humidity. - Side corridor induces wind into the courtyard.		Kubota, Toe, & Ossen, 2014

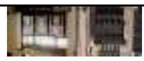
	Bushehr	-Trapping sea driven desirable wind currents and creating turbulent flow in the central courtyard -Providing two-way ventilation for closed spaces around the yard - Creating so-called single-layer spaces around the central courtyard -High wall height and small yard dimensions to enhance air turbulence		weatherbase.com; Shahin, & Sh,2006
	oman	-The two or three storey central courtyard -Take in the sea driven desired breeze at higher speeds at higher altitudes -Tunnel function such as entrance corridors and central courtyard ventilation		Husin, 2016
Shenashir	oman	-Cooling the air by evaporative cooling		Schiano-Phan, 2010; ALSHAMASI, 2015
		–Help the wind flow and to spread around –Help the wind flow and to spread around		
	Bushehr	-Moisture attraction -Wind flow control -Shading -Provide cross- ventilation	 	Hedayat, & Eshrati, 2017

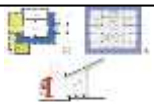
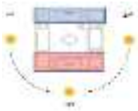
7. Radiation and Heating Control

Thermal envelope of the building are walls, windows, doors and other building components that separate the interior from outside. The building envelope may affect many environmental aspects. The building envelope geometry and physical properties of the materials used in it may have great impact on daylighting, heating, cooling and ventilation. Thus, by focusing on the building envelope geometry and the composition of the materials, designers can reduce the scope of air conditioning and energy systems needed for lighting systems and ultimate energy consumption. Many factors must be taken into account in designing the building envelope: floor-to-ceiling height, window size, window orientation, interior wall size and angle.

Table 2 Radiation and heating control system

Elements		Region	Cooling technique	Features	Source
Material	Bamboo	Vietnam -Oman- Malaysia	- Passing the wind through the intervals between bamboos - High strength - High tensile capability - Does not create heat bridge - In combination with woven cane and palm create a kind of beam (Denshal) - Create a kind of beam (Denshal) by combining woven cane and palm	Floor- Wall- - Truss Column- Beam- -Stand (to raise floor from ground level) -Provide meshes for floor, wall and roof -Provide a decorative motif	Qobadian, 2006; Sun, 2013; Mitra, & Bose, 2017; Nikghadam, 2015; Dodoo, Gustavsson, & Sathre, 2010; Singh, Mahapatra, & Atreya, 2009; Majid, Shuichi, & Takagi, 2012; Dabbaghiyan et al., 2016 Mazraeh, & Pazhouhanfar, 2018;

			- Reusable after building demolition - Span cover 2.5-3m		Chandel, & Sarkar, 2015; Karimi, 2012; Nikghadam, 2015
	Iron-like wood or belian (in timber form)	Malaysia	-Low heat capacity -Hot and cold insulation -Has relatively good mechanical strength of elastic ability against impact -Able to clean, color acceptance and shear -The possibility of making modifications such as water-proof, fire-proof and antifungal -Does not create heat bridge	Main Structure- Roofing cover- Truss-	
	Teak wood chandelier	Bushehr	-Light, hard, red, stays on the water, is bitter so that termite does not eat it, with the ability to become a narrow board	- For roof beams and door shutters, windows - Building door, window and canopy	
	Palm (Metoxylone)	Oman-Malaysia	-Less maintenance required -Air stream passage -Has waterproof property		
Straw-mat	Bushehr-Oman		-Does not provide heat bridge	-Use in damp places such as baths	
Limeston e	Bushehr		-High strength against moisture -Low strength to heat	-Use lime moulding decorations instead of plaster moulding -Use in damp places such as baths	
Soil (clayey and sandy)	Bushehr		-This loose soil to semi dense and relatively viscous	Making calcareous mortar-	
Roof	-Sloped roof -Insulation of roofs	Malaysia		-A mass of cooled air descends from the sloping roof into the yard -Reduced temperature of indoor spaces	Victoria et al., 2017
	-Wooden roof -Flat roof -Thick roof	Bushehr		-Heat scattering on the roof surface	Mazraeh, & Pazhouhanfar, 2018
	-Sloped roof Use Loft- -Use of porous materials on the roof High roof (up to 5m) -Thick roof	Vietnam		- High rainfall -Provide insulation -Provide ventilation - Moisture absorption at night Roof cooling during the day	Kubota, Toe, & Ossen, 2014
	-Use palm stems	Oman		-air-leaky panels facilitate ventilation	Dabbaghiyan et al., 2016
Shading Element	-Porous openings -Eaves projection Orientation-	Malaysia	-Provide sufficient light in the interior spaces with shading -East orientation so that less interior space is exposed to direct solar radiation		Hidayahtuljamil ah Ramli, 2012
	-East-west extension	Oman	-Achieve the desired breeze -Shading		ALSHAMASI, 2015

	-Semi-open spaces (balcony, Dahreez) -Mashrabiya -Windows sills				
	-Semi open spaces (Tarmeh) -Orientation -Roof top parapet -Shenashir -Louver - locating entrance	Bushehr	-Shading -Location on the south -East-west extension -Moisture attraction -Shading -The main building entrance protected interior spaces against solar radiation		Hedayat, & Eshrati, 2017; Mazraeh, & Pazhouhanfar, 2018
	-Eaves projection -Louver -South orientation -Locate the corridor to surround the building	Vietnam	-Shading -protect against direct solar radiation		Kubota, Toe, & Ossen, 2014
	- summer spaces	Bushehr	The summer residence is located on the south side of the courtyard to avoid direct sunlight in the summer, and the main axis is usually a semi-open space		Shahin, & Sh,2006
		Oman	summer part of the house was made from palm-frond panels or had several large windows in its outer walls.		Dabbaghiyan et al., 2016

8. Findings

8.1. Natural Ventilation

Central courtyard

The element of a central courtyard is common in all four climates of Bushehr, Oman, Vietnam and Malaysia, though they differ over its functioning to produce ventilation. Two regions, i.e., Bushehr and Oman, have managed to achieve a similar function to produce ventilation. Also, the central courtyard enclosure by high walls in Bushehr and the multi-story enclosure in Oman have caused the turbulent airflow to trap in the central courtyard. In the next stage, this turbulent airflow is directed to the internal spaces (Table 1).

In Malaysia, the entrapped airflow in the central courtyard is repelled by the backyard, which thus produces necessary ventilation. In Vietnam, unlike the three mentioned regions, the airflow is not only entrapped by the central courtyard, as corridors adjacent to the courtyard contribute to the entrapment.

There is a specific orientation toward the sea to receive the desired breeze that rises from the sea in coastal areas of Oman and Bushehr due to the special geography of these areas and restricted access to the desired breeze. An analysis and comparison of the relative wind velocity in these areas indicates that despite the higher relative velocity of the gust of wind in Bushehr compared to the other three regions, there is no sign of the normal wind flow direction into the spaces, and elements such as wind towers noted in Oman are absent in Bushehr.

8.2. Openings

A comparison of opening elements in the four climates reveals that this element in Oman and specifically in Bushehr not only receives the desired breeze but also controls humidity. Table 1, shows that no such measure is seen to control humidity despite the higher relative humidity in Malaysian and Vietnamese regions. In these regions, openings are just aimed at ventilation and airflow. This is also seen in Oman. Table 1, shows that evaporative cooling is used despite the higher relative humidity in this region.

In Vietnam and Malaysia, since the building floor has a distance from the ground, the airflow is vertical between the ground and the ceiling, while no such flow is noted in Oman and Bushehr (Table 1). The use of airflow created on the back front facing the wind is noted in Malaysia and Vietnam; however, this flow is made by the element of a wind tower in Oman. No such measure is seen in Bushehr due to the lack of tendency to receive flows other than those rising from the sea.

8.3. Control of radiation and heat

The control of radiation and heat can be classified into three categories as follow:

Materials: Lower thermal capacity, non-creation of a thermal bridge resistant to humidity and humidity absorber

Spaces: Rooftops, semi-open spaces, space location for greater shading (projected roof and wide-open corridors in the surrounding) and lower reception of the sunlight (summer and winter residence) and semi-open spaces

9. Conclusion

An examination of passive cooling techniques in the four hot and humid regions has the following outcomes: The four regions have adopted a similar approach but different instruments to control radiation and heat. For ventilation, although the measures are the same, considerable differences are noted due to the level of rainfall in the said areas. It is thus concluded that despite available sources and considering all regions to be under the hot and humid category, it is not suggested to include areas of different rain in one climate.

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