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Passive Architecture in Very Hot Climate: a Simple and Flexible Bioclimatic Approach for Architects

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Abstract: The last 25 years have been ground-breaking in architectural design on low energy consumption in cold climate, mainly in north-western cultures. For an architect today, the method to design a passive house in cold weather and the choice of the Architectural Actions (AA), are clearly established. When the question comes to how to build a passive house in warmer, hot, and very hot climates, the strategies are poor and often results of a combination of western strategies with a local relook. From several visits in Middle East countries, Saudi Arabia, UAE, Oman, Palestine, Qatar, we concluded that the strategy for low consumption houses is not established yet and poorly grasped. The lack of training on low energy consumption in hot climate and the low price of energy, force designers and owners to relay on over usage of air-conditioning systems as measures to catch up on poor bioclimatic design. This paper proposes a new approach on bioclimatic design for hot climates from an architect point of view. It is based on a Cooling Degrees Days approach, a state of art of contemporary architecture and professional experience. Local climates are classified according to passive strategies: cold/cold, cold/cool, temperate/temperate, cold/hot, warm/hot, and hot/hot.

Keywords: Hot climate architecture, early design stage, passive architecture, low energy consumption architecture, cooling degrees day method.

Introduction

The low energy consumption tendency and know-how in hot climate countries is awakening from a dark period on high energy dependency, even though still much work is to be developed and promoted: methodologies, tools, labels, training... etc. Today more than 80% of people in the world live under a warm-hot climate, and millions of them under very hot climate, and so far in recent and modern construction, buildings follow a model of architecture called "international" with little efforts on architectural principles for low energy consumption. Finally the comfort is achieved relying on technical equipment, including air conditioning with high energy consumption.

Today, the international comfort standards cannot avoid the massif use of air conditioning systems, and its omnipresence and over-use has become a fact in the everyday life of the middle class in developed or emerging countries in hot climates. However in hot climate, like in cold climate, we find extreme contexts, countries that have shortages of access to electricity as some cities in Palestine or many countries in Africa and those who have an important energy access situation, as in Saudi Arabia or the United Arab Emirates. Paradoxically in both cases reach the low energy consumption is now a priority in national strategies for different reasons: one is designed to minimize the energy shortage, while rich countries aim to reduce exorbitant spending on subsidies in energy sold at prices below the cost of production for reasons of social solidarity.

In this paper we aim to explore a simple method for architects to produce well founded architectural solutions which could help to improve the comfort and the future quality of life of low-income families in hot climates combining a passive thinking but high flexibility on design without neglecting the use of newest construction technologies.

“Very hot climate” definition for designers.

The term "hot climate" is often too general in western and European cultures. Wladimir Köppen defined "hot desert climate" as Bwh, where “B” meant a climate defined by little precipitation, “W” indicating an extreme arid one with annual precipitation under a certain threshold, and “h” meaning low latitude climate with temperatures average annual temperature above 18ºC, which basically means hot arid weather. This term covers all Saharan Africa, Arabia, south of the United States and the center zone of Australia. However In this classification not all countries undergo the same need to use air conditioning, specially the countries of the Arabian Peninsula and around the Red Sea and the Persian Gulf, where record-breaking temperatures are often measured. In 2004 the ASHRAE and IECC (International Energy Conservation Code) agreed to create a common classification more accurate, standard 90.1.: Zone 1: very hot and wet (1A)/very hot and dry (1B). A climate is rated 1B "very hot and dry climate" if it has more than 5000 Cooling Degree Days (CDD) at a temperature of 10ºC.

By this method, the city of Riyad with 6026 CCD at 10ºC would be largely in this category. However with the same criteria, a city like Karachi in Pakistan with 6119CDD to 10ºC would be in the same category of hot climate even if it does not represent a climate as severe as the climate of the cities of the Arabian Peninsula. A higher temperature threshold would be more judicious to establish criteria to classify cities in extreme desert climates.

Table 1. Classification of cities based on their COOLING DEGREE DAYS at 26ºC

Celsius-based 2-year-average (2014 to 2015) cooling degree days for a base temperature of 26,0C in airports															**Source www.degreedays.net**
CDD 26ºC			Year	Month											
			TOTAL	**J**	**F**	**M**	**A**	**M**	**J**	**Jl**	**A**	**S**	**O**	**N**	**D**
EUROPE	**FRANCE**	NICE	**40**	0	0	0	0	0	3	**23**	13	1	0	0	0
		PARIS	**29**	0	0	0	0	0	5	**16**	8	0	0	0	0
	SPAIN	SEVILLA	**305**	0	0	1	4	35	54	**99**	84	21	6	0	1
		MADRID	**253**	0	0	0	0	12	44	**108**	71	17	1	0	0
	GREECE	ATHENES	**293**	0	0	0	0	8	40	**97**	108	38	2	0	0
MIDDLE EAST	**SAUDI ARABIA**	RIYADH	**1630**	1	6	22	102	218	272	**327**	326	223	123	10	0
		DJEDDAH	**1509**	21	28	61	99	159	177	**240**	261	198	154	76	35
		MEDINAH	**2061**	6	16	64	136	249	314	**333**	392	322	189	34	6
		MAKKAH	**2324**	44	59	115	182	271	308	**340**	338	290	221	104	52
	UAE	DUBAI	**1769**	1	12	26	100	221	259	**334**	339	249	179	45	4
	IRAN	ANWAZH	**1840**	0	1	8	85	232	340	**402**	388	266	115	3	0
	OMAN	MASCATE	**1541**	0	14	18	144	272	283	**248**	197	180	143	40	2
		SALALAH	**586**	3	6	25	70	118	117	**26**	15	48	80	57	21
	PALESTINE	NABLUS	**156**	0	0	0	5	17	19	**28**	50	29	8	0	0
		JERICHO	**1102**	0	2	16	55	123	158	**228**	259	174	76	10	1
	ISRAEL	JERUSALEM	**315**	0	1	3	11	29	31	**59**	93	66	19	3	0
AFRICA	**SUDAN**	KHARTOUM	**2056**	45	76	167	215	294	292	**231**	173	204	220	100	39
	CHAD	N'DJAMENA	**1543**	53	100	191	219	254	206	**108**	53	73	133	113	40
	NIGER	AGADEZ	**2008**	28	64	139	212	298	322	**240**	170	214	214	92	15
		NIAMEY	**1776**	58	104	190	249	270	224	**128**	81	111	188	130	43
AMERICA	**USA**	PHOENIX	**1222**	0	3	20	41	99	263	**287**	263	178	64	4	0
ASIA	**INDIA**	NAGPUR	**1154**	8	35	93	187	284	192	**88**	65	64	75	44	19
	PAKISTAN	KARACHI	**1035**	2	8	43	108	152	193	**143**	107	109	110	50	10
OCEANIA	**AUSTRALIA**	ALICE SPRINGS	**658**	108	99	90	23	3	0	0	3	18	88	112	**114**

If we consider that heat discomfort starts at 26º, under relative humidity conditions around 50%, and most of the air conditioning equipment starts also at 26º, then CDD26º is a good reference to classify the “hunger” for energy on active cooling of a climate. The choice of 26ºC is an arbitrary one and it depends on cultures and lifestyles. Cultural and social factors can have strong influence on the accepted “hot temperature” that we will not study in this paper.

Based on this method, Table 1 shows a classification on cooling energy needs based on a start of the cooling needs at 26º (considering that most of the existing air conditioning systems do not consider relative humidity parameters). It is clear that the GCC countries (Saudi Arabia, UAE…) are way far ahead on cooling needs that any other zone in the world.

Classification of a city climate by using the concept of “Climatic Seasons”

The approach of the climate of a city by a designer is not systematic and it is frequently neglected in projects of private houses and small collectives. In order to classify a site from the point of view of bioclimatic strategy we defined three simple situations that represent the broad majority of cases, and imply very different bioclimatic design strategies. These generic situations are described as follows:

Situation 1 - It is cold outside, and the vector [temperature, humidity] is unpleasant: users prefer to close doors and windows and reduce exchange with the outside. They try to get as much as possible of sun inside of the house.

Situation 2 - It is temperate outside, cool or warm, the vector [temperature, humidity] is pleasant: users prefer to open doors and windows to generate cross ventilation.

Situation 3 – It is hot outside; the vector [temperature, humidity] is unpleasant: users prefer to close doors and windows and reduce exchange with the outside. The sun-rays are blocked as much as possible.

Several of these three situations can arrive during one same day, making appear different day-types: 1-1, 1-2-3, 1-2, 2-3, and 1-3. The designer will then need a passive strategy for different day-type. The impression of cold, cool, warm and hot, can vary a lot depending on cultures. We chose the most usual range in Europe of 19ºC to 26ºC, but it could be adapted to any culture. With this range of comfort temperature and these three situations, we define a new concept named “CLIMATIC SEASON”, which are periods that can last several months with the passive strategy remains the same (fig.1)

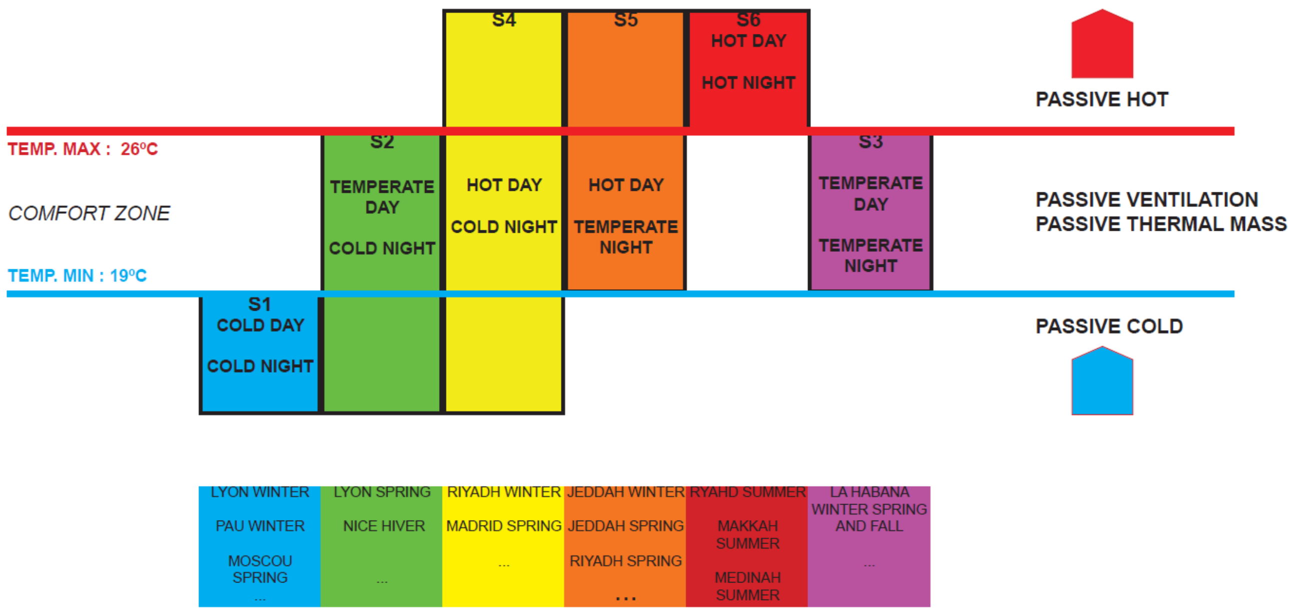


Figure 1. Diagram of “climatic seasons” with some examples of cities and their seasons.

These "climatic seasons" are defined as follows:

Climatic Season S1: cold days and cold nights. This season is the coldest of all, and it is characteristic of many cities in Northern Europe during winter. The temperatures are low, and even though they may not be extreme they are permanently under the cold temperature threshold. People do not want to have exchanges with the exterior.

*Climatic Season S2: cool days and cold nights.*This season combines daily temperatures that are comfortable and night temperatures that are below the comfort threshold.

Climatic Season S3: temperate days and nights. This season is always comfortable in terms of temperature, because the maximum temperature and minimum daily remain always within the thresholds of comfort. These conditions are often associated with tropical cities close to the sea with high relative humidity values and a low daily temperature fluctuation.

Climatic Season S4: hot days and cold nights. Daily maximum temperatures are above the upper threshold of comfort and the daily minimum temperatures are below the low threshold of comfort. An important part of the day temperatures are comfortable but at peak hours we either feel too hot or too cold.

Climatic Season S5: hot days and warm nights. Daily maximum temperatures are above the upper threshold of comfort and daily minimum temperatures stay in the range of comfort. A large part of the day exterior conditions are uncomfortable and late in the evening they become confortable for some hours.

Climatic Season S6: hot days and hot nights. This is the hottest season of all, temperatures are high all the time, and even though they may not be extreme they are permanently over the high threshold of comfort temperature. It is characteristic of many cities in the Middle East during spring, summer and fall.

Degrees-days for architectural passive strategy

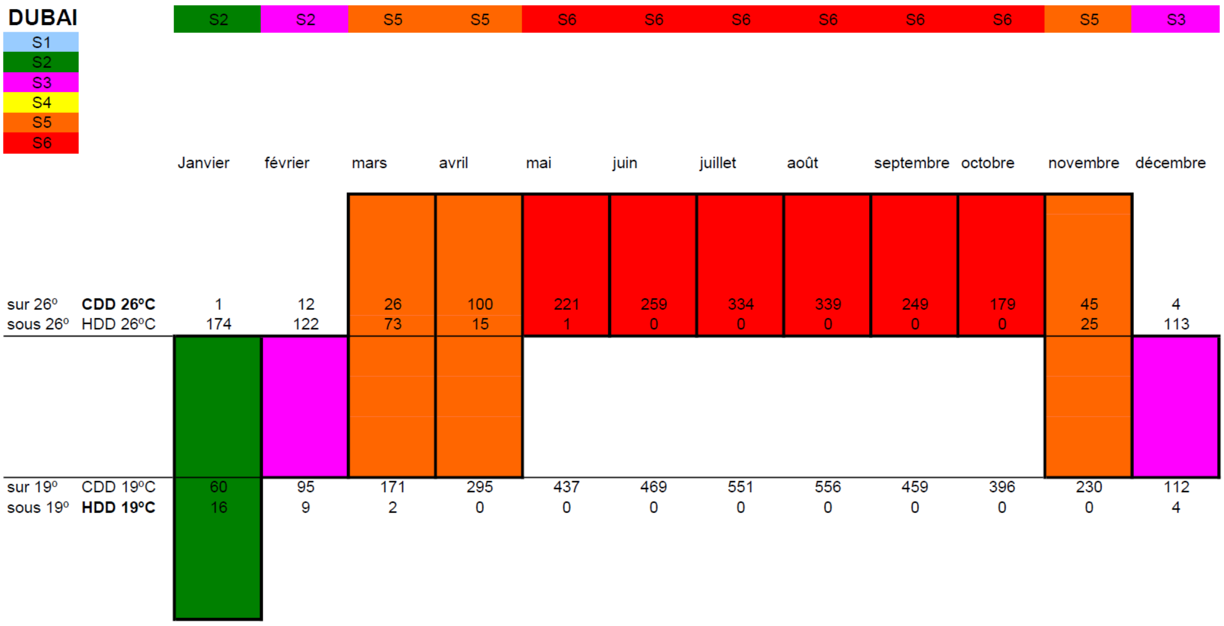
To be able to organize the year of a city in Climatic Seasons we will use a widespread and relatively accessible index in all the bibliographies and websites: the heating degree-day (HDD) and cooling degree-day (CDD). We will use two values associated with the high temperature threshold of 26ºC: HDD26 and CDD26, and two values associated with the low temperature threshold of 19ºC: HDD19 and CDD19.

In order to determine to which Climatic Season (S1, S2,... S6) belongs a particular month of the year of a city, we need to establish criteria based on a established threshold:

Season 1: HDD19>0 CDD19=0 heating- no air conditioning- no exterior
Season 2: HDD19>0 CDD26=0 heating- no air conditioning- some exterior
Season 3: HDD19=0 CDD26=0 no heating- no air conditioning- lots of exterior
Season 4: HDD19>0 CDD26>0 heating- air conditioning- some exterior
Season 5: HDD19=0 CDD26>0 no heating- air conditioning- some exterior
Season 6: HDD26=0 CDD26>0 no heating- air conditioning- no exterior

However we need to allow a certain overtaking on these values to dismiss extreme values: it will be enough in a very cold day (S1) with an outside temperature of one degree over the comfort level to consider it as a temperate-cold season (S2). To allow this over threshold we will use a percentage of the "monthly comfort allowance", MCA, representing the total degree-day located between the comfort thermal range. For a 7º degrees range the MCA value is 217, for a 31-days month, 210 for a 30-days month and 196 for the 28-days month. We will consider that if the DD value divided by MCA is less than 5%, it will be consider as 0 in terms of Climatic Seasons classification.

Figure 2 shows the comparison between the Climatic Season classification and the maximum and minimum daily temperatures of a average journey in Dubai in 2005 climate data, the result shows that from May to October the temperatures are too high to open the windows at night time, as shows the Season 6 with the “Climatic Season” method. In January, the temperatures are low, especially at night time, so a Season 2 strategy can be carried out.



jours par mois	31	28	31	30	31	30	31	31	30	31	30	31
Somme DD	217	196	216	210	217	210	217	217	210	217	210	217
somme DD/jours mois	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
CDD26/Somme DD	0,5%	6,1%	12,0%	47,6%	101,8%	123,3%	153,9%	156,2%	118,6%	82,5%	21,4%	1,8%
HDD26/Somme DD	80,2%	62,2%	33,8%	7,1%	0,5%	0,0%	0,0%	0,0%	0,0%	0,0%	11,9%	52,1%
CDD19/Somme DD	27,6%	48,5%	79,2%	140,5%	201,4%	223,3%	253,9%	256,2%	218,6%	182,5%	109,5%	51,6%
DD/Somme DD	7,4%	4,6%	0,9%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	1,8%
date 2005	14/1	18/2	16/3	9/4	18/5	10/6	13/7	8/8	13/9	15/10	17/11	14/12
Temp max	23	25	27	32	35	42	45	45	41	37	30	27
Hum min	53%	34%	42%	31%	22%	14%	11%	12%	15%	27%	20%	28%
Temp min	16	16	23	22	25	32	34	34	30	28	23	19
Hum max	82%	82%	83%	64%	54%	59%	59%	34%	70%	66%	65%	64%

Figure 2. Comparison of Climatic Season method with a temperature-humidity values of 2005 for Dubai.

The climatic year

The combination of the Climatic Seasons of a particular city over a year is named 'Climatic Year', the diagram in figure 3 shows all the different combinations of climatic seasons for different cities. These combinations allow us to define several types of Climatic Years:

-Temperate cold Climatic Year: S1 + S2 + S4 (Paris, Bordeaux)

-Temperate hot Climatic Year: S1 + S2 + S4 + S5 (Madrid, Valencia, Sevilla, Jericho)

-Very hot and dry Climatic Year: S2 + S4 + S5 + S6 (Riyad, Medinah)

-Very hot and humid Climatic Year: S2 + S3 + S5 + S6 (Dubai) and S2 + S5 + S6 (Doha)

-Extreme hot Climatic Year: S5 + S6 (Jeddah, Makkah)

Architectural strategy based on Climatic Seasons

Both, hot/cold, bioclimatic strategies have similar approaches organized in five general axes:

1-External hot/cold protection

2-Inner heat management
3-Heat evacuation/capture
4-Cold/heat production
5-Heat/cold adaptation

PARIS	S1	S1	S1	S1	S1	S2	S4	S2	S2	S1	S1	S1
BORDEAUX	S1	S1	S1	S2	S2	S4	S4	S4	S2	S2	S1	S1
MADRID	S1	S1	S1	S2	S4	S4	S5	S5	S4	S2	S1	S1
JERICHO	S1	S1	S2	S2	S4	S5	S5	S5	S5	S4	S1	S1
VALENCIA	S1	S1	S2	S2	S2	S5	S5	S5	S5	S2	S2	S1
SEVILLA	S1	S1	S2	S2	S4	S5	S5	S5	S5	S2	S2	S1
RIYAHD	S2	S2	S4	S5	S6	S6	S6	S6	S6	S5	S2	S2
DOHA	S2	S2	S5	S5	S6	S6	S6	S6	S6	S6	S5	S2
DUBAI	S2	S3	S5	S5	S6	S6	S6	S6	S6	S6	S5	S3
DJEDDAH	S5	S5	S5	S5	S6	S6	S6	S6	S6	S6	S5	S5
MEDINAH	S2	S4	S5	S6	S6	S6	S6	S6	S6	S6	S5	S2
MAKKAH	S5	S5	S5	S6	S6	S6	S6	S6	S6	S6	S5	S5

Figure 3. Climatic year of different cities by combination of climatic seasons

Once a site is classified in Climatic Seasons, we must combine (fig.4) Architectural Actions to clearly define the spirit of the passive strategy for each Climatic Season. An Architectural Action is a decision taken by the designer having an impact on the architectural shape of the building to bring down the energy consumption of the building,

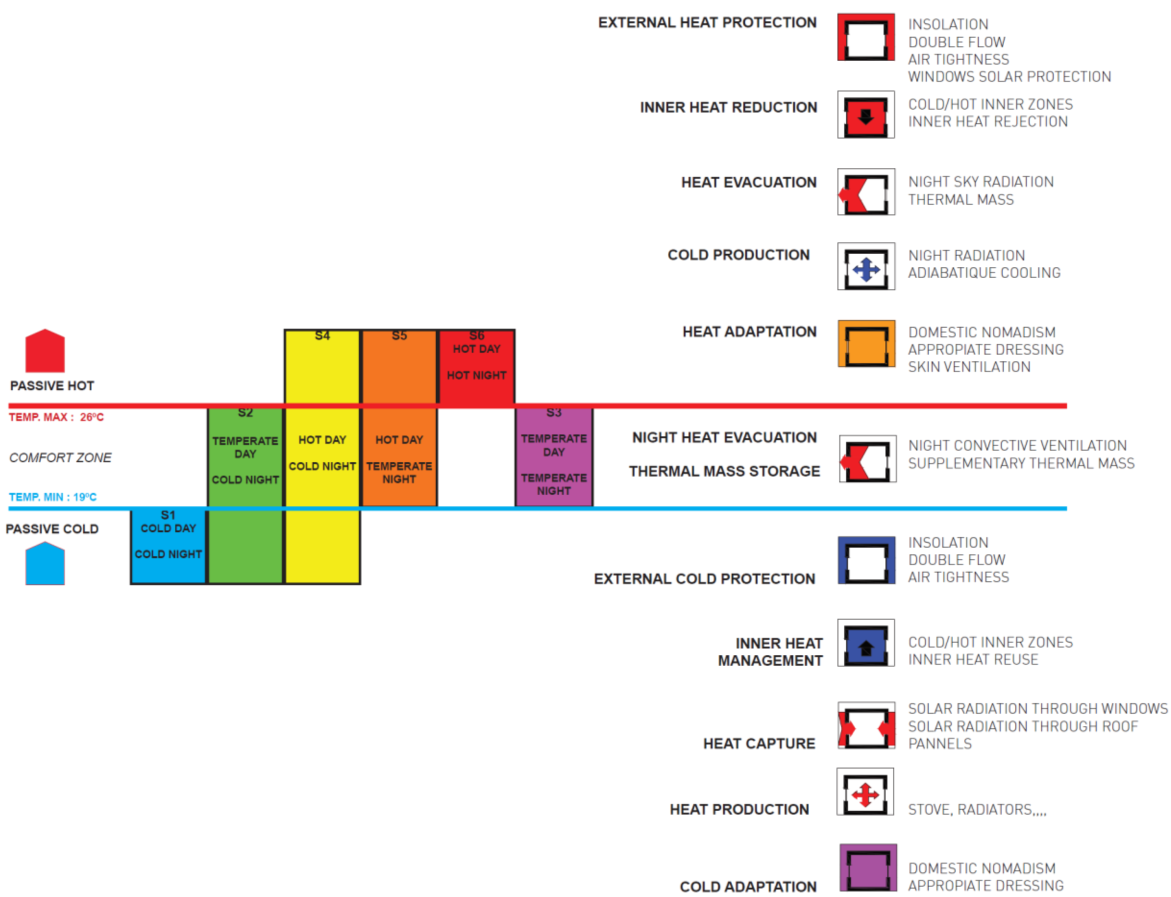


Figure 4. Strategic directions and the most common architectural actions

Classification of architectural Actions (AA) for a very hot climate

We classified all the Architectural Actions extracted from the scientific literature of the last 50 years and real practice in contemporary construction under hot climates fig.6. They are grouped by five main axes, and several sub-groups:

AXIS 1: External hot protection

1. Heat reduction coming through glazed openings in housing: Reduction of glass surface exposed to the sun. Reduction of the surface of glass-not-exposed-to-the-sun. Preferably N-S orientation. External brise-soleils. Inner opaque curtains. 2. Heat reduction coming through the opaque parts: Strong thermal insulation. No thermal bridges. Low emissivity on exterior walls. Ventilated double skin. Albedo reduction by peripheral shading. 3. Reduce the heat entering the house through ventilation: high-performance air sealing. Double flow thermal exchanger. Partial cooling of the air by underground pipes.

AXIS 2: Inner heat reduction

1. Energy efficiency label, position and management of the cooking appliances in the kitchen, thermal zoning of the area of the kitchen that produces a strong residual heat (fire and oven). Specific air extraction in areas with strong heat production. 2. Energy efficiency label of the computers, small appliances and lighting. Electrical switches for complete disconnection of appliances out of charging periods. 3. Position and management of domestic hot water in the bathroom and distribution: Extraction of water steam with strong latent heat storage.

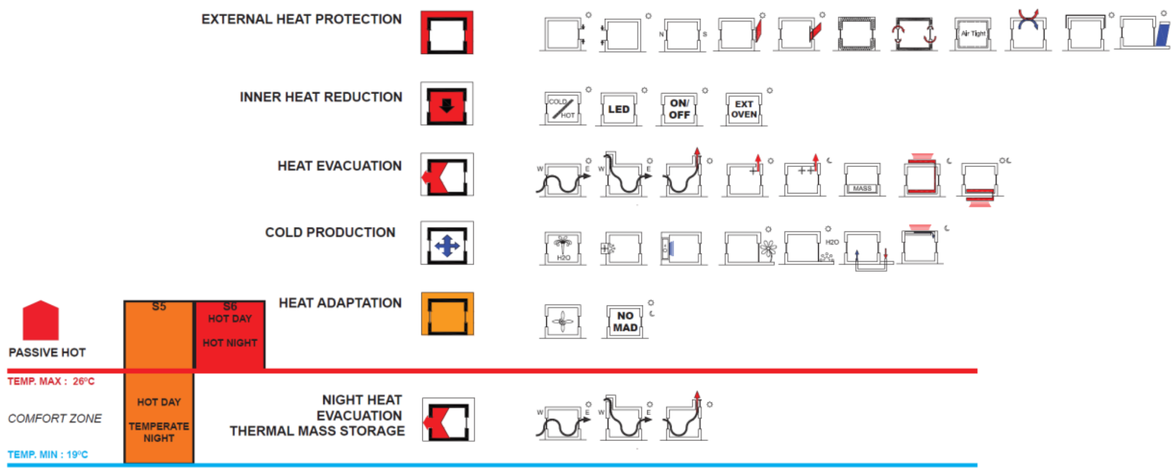


Figure 6. Architectural Actions associated to a very hot climate year as Jeddah or Makkah

AXIS 3: Inner heat evacuation

1 - Convective Evacuation by air: natural cross-ventilation air currents. Wind catcher towers. Thermic gradient towers or walls. 2. Night radiant heat discharge of thermal load by the facades and roof with specific thermal mass storage. 3. Heat storage in the thermal mass of the building. Delete ground insulation to facilitate the evacuation of heat to the ground.

AXIS 4: Cold production

1 - Adiabatic cooling: Direct or indirect adiabatic cooling. 2. Radiant night sky cooling with specific thermal mass storage. 3. Night recovery of the lower temperature air under radiant plate orientated towards the sky.

AXIS 5: Heat adaptation

This axis is to identify all architectural, social and cultural elements that can improve the comfort, without involving measures that change the inner temperature:

1 - Facilitate the natural mechanisms of regulation of the human body: no air-conditioned mechanical ventilation, fans.

2. The use of space: nomadism inside and outside.

3. Wearing appropriate clothing that helps other measures to work well.

Discussion

This simple method can be carried out by anyone having a low internet connection to get the degrees-day data, a simple worksheet program, and some basic principles on bioclimatic architecture. Thus, any young designer can understand the main bioclimatic challenges of a project site and propose a solid bioclimatic based project to their clients. However, the choice of an Architectural Action is associated with logic of investment and a pay-back period, which is associated with three factors: 1. The contribution of the Architectural Action to decrease the energy consumption. 2. The cost of construction and maintenance over the years of the Architectural Action. 3. The price of energy. The first and second factors, the energy saving and the price of the action will depend on climate and the geographical context of the site. According to local context, energy prices and the construction cost will depend on factors such as the hourly cost of labor, the lack of access to electricity, the cost of building materials. The combination of these values must create a hierarchy in the possible Architectural Actions based on the pay-back period of each that will invite the designer and clients to implement it or not

To quantify these parameters we modeled on Design Builder model with a hot climate house-type, and created a digital model by different architectural action variants. We quantified the influence of each action per day. In parallel we have evaluated the additional cost of each one of these actions on the cost of construction of the House. These elements define the payback period in function of the electricity cost and allow a hierarchy on the choice according to local context.

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