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Towards Low Energy and Thermal Comfort of Buildings Through Passive Cooling or Heating Strategies in Hot Arid Climates

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ABSTRACT

Due to strong urban expansion and population growth, the residential sector is the main consumer of electricity and gas, especially the arid region of Algeria. This situation produces enormous energy consumption while the application of thermal regulations was not valid for the entire construction. This article aims to use passive strategies inspired by vernacular architecture, to arrive at passive and ecological houses. Initially, this work consists of knowing the different traditional or current systems used specifically in arid and semi-arid regions. Then, the methodology followed based on a dynamic simulation of the strategies applied in an existing apartment located in the south of Algeria (case study). Afterwards, we will provide a multi-criteria and cost-benefit analysis, to validate an appropriate optimal model, based on energy savings and investment cost. In conclusion, it was observed that using the waterspout wall with night ventilation could reduce energy consumption by 50% and maintain thermal comfort.

1. Introduction

Improving the environmental and energy quality of building envelopes is one of the major challenges with a view to global warming of the planet. It was interesting both to maintain the well-being of the occupants on the one hand and to reduce energy consumption related to heating and cooling. This problem was not only for Algeria, but also for all the countries of the world. In fact, with climate change, we have a cold and dry winter season, followed by an extreme and hot very harsh summer season. In addition, the increase of average temperatures on the globe surface is the direct and expected result of massive greenhouse gas emissions [1].

Today, the residential sector represents in our country's major global energy consumer, 60% of final consumption, and 23% of cooling energy demand [2]. Currently, the maximum of building is often poorly adapted to the hot dry climate, thermally uncomfortable, and energy consuming. According to this situation, the question is how one design can improve and reduce the massive need for cooling

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in hot, arid climates. Therefore, the answer is moving towards original passive cooling or heating systems to maintain the thermal comfort and energy efficiency of the residential building.

In hot arid climates, the current problem of housing situations is characterized by absolute insufficiency, which is explained by both demographic and socio-economic factors with underdevelopment of the productive forces [3]. Currently, these constructions had non-insulated, with conventional air-conditioning systems, no thermal regulations applicable for design or envelope construction. The internal temperatures are increasing during the daytime and into the nighttime. Over, these residential buildings had not provided adequate shelter in these extreme conditions and specific for a very hot summer period, may have resulted in situations of discomfort of human life [4].

The study on the passive cooling/ heating strategies of a country is not recent; several researchers produced important work in this area. Regarding some passive systems, they showed a direct passive impact of traditional constructions cooling strategies on the comfort level of architectural design, such as courtyard with the use of adequate and specific materials.

This research contributes to research some passive strategies of cooling and heating to think about passive houses or Eco houses for hot arid regions. Overall, different passive designs based on vernacular architecture characteristics for decades. For a less energy consuming, this study should take into account a bioclimatic comfort and climate indicators of the principles recommended.

The main objective is to evaluate the thermal comfort, energy consumption in a standard residential building (traditional and actual housing) located in Bechar city (south of Algeria). This study analyses and compares of some passive cooling/heating strategies of residence building with multi criteria's analysis and benefits cost.

2. Vernacular Passive Cooling Strategies in Arid Region in Past and Today

In hot areas, particularly in Sub-Saharan Africa, no research has yet been carried out, to evaluate thermal comfort and efficiency energy of using passive strategies in buildings, combining experimentation and simulation. It is clear that buildings located in these regions with are not adapted to the extreme climate. In African countries, the research of energy efficiency into practice is poorly documented. It has should be carried out, to help the countries located in hot zones to better implement the concept of sustainable development. The continent is struggling to take off towards globalization, because of the lack of initiative of this kind of research of new researchers coming from this region [13].

The vernacular houses of South West Algeria present a good example of adaptation with extreme climate. These constructions used objectively natural and sustainable passive cooling techniques. This work can provide valuable assessment of the thermal performance of an existing home in hot and dry climates. In this context, we will identify the main of passive cooling in these traditional houses, and examine how architectural elements such as central courtyards, passive walls and vaults can contribute to the provision thermal comfort in vernacular houses.

Passive cooling systems, inspired by vernacular architecture have been the main design driver in bioclimatic architecture, especially in hot climates. These constructions have been designed to adapt to climatic and local conditions and they provide occupants with optimal comfort all the year. Also, the usefulness of local materials and respectful of the environment. Vernacular approach is one of approaches founded on original and local architecture by promoting environmental elements such as solar radiation and natural ventilation. This approach has become a practical solution to maintain thermal comfort without involving mechanical or electrical devices. The quality of performance of this approach is very dependent on the design's interaction with environmental factors, such as sunlight, ambient air temperature, wind, and humidity, to achieve an energy balance.

"Cooling" methods are simply active, passive or hybrid types, which provide natural or mechanical cooling. For vernacular cooling systems, the climatic conditions are taken into account to be obtained in the premises must be favorable all year round, for the lives of the occupants, their health and their well-being.

There are passive cooling actions, must understanding to avoid heat gains, slow down the heating process or to store cold air. For that, it is necessary to appreciate passive cooling actions as follows:

i. Storage with Courtyards, basements. -soils, earthen are spaces [4], can be keeping a cold mass or air in the building envelope, away from direct heat gains to provide spaces to cool air before entering interior space.
ii. The external heat gains should be avoided from direct solar radiation. This action is carried out taking into consideration the location of the building. The use shade windows and glazing surfaces to avoid the entry of solar rays.
iii. Eliminate some of the unwanted heat that could not avoided.
iv. Slow down external through efficient insulation casing and double glazed windows.

In this present, we will establish the effectiveness of various vernacular passive cooling techniques, in arid region (south of Algeria). These techniques have a big effect at the microclimate of conventional homes, such as the courtyards, natural ventilation, or nighttime, ignored the heat in hot dry climatic houses.

2.1 Natural Ventilation with Courtyard

Many strategies were practiced in vernacular architecture such as the courtyards, coupled with the usage of thermally massive materials walls, can be reduced a heat of temperature in summer. This important strategy may be useful mitigating the heat in Saharan houses and could be supplied by the energy of the solar collector in winter.

2.2 Thermal Envelope

A thermal envelope is envelope as a barrier against unwanted heat or mass transfer between the building interior and exterior conditions. The effectiveness of the thermal envelope depends on the insulation levels of the walls, ceiling and floor or basement, including factors such as moisture condensation and thermal bridges that affect insulation performance. With thermal properties of windows or doors; and the indoor and outdoor air exchange rate, which in turn depends on the airtightness of the envelope and driving forces such as wind, indoor-outdoor temperature differences and differences in air pressure due to mechanical ventilation systems or heat / cool air distribution [16].

2.3 Factor of Compactness

Buildings in hot arid climates are usually compact and dense with narrow streets and small squares and with tall vegetation for shading. This layout provides optimal protection against solar radiation. Buildings are compact and close to each other shadowing each other’s façades [3].

2.4 Insulation with Natural Material

The choice of insulation material needs to maximize long-term thermal performance of the building element overall. As mentioned previously, this involves consideration of remaining thermal bridges and any water ingress, or other factor, which could result in deterioration of performance over time. For existing buildings, space may be at a premium and the most efficient insulation materials may be needed to minimize thicknesses required.

2.5 Trombe Wall

In dry climate zones, the technique of Trombe wall is a very old technique used in vernacular construction with is a large thick and massive material. These walls are massive for blocking the heat during day peaks by dense materials such as stone and brick reduce thermal fluctuations. Traditional buildings with thick earthen or stone walls rarely need to be cooled artificially. Actually, using lighter materials with thermal insulation through heavy exterior walls and roofs. It is highly important to keep the temperature constant for a longer time and to create a natural barrier between the interior and exterior temperatures.

the use of Adobe bricks. With a high thermal mass performance and high heat capacity, this material can be reducing the heat transfer from inside to outside of construction, by absorbing sun's radiation for all day, and avoiding the heat from getting interior spaces.

2.6 Roof Cool

The roofs used in these regions have a great thermal insulation, reducing the heat flow to the interior are naturally ventilated below [4]. The use of natural material can offer thermal conditions for interior spaces. In the night summer, the high capacity of roof can be cooling the interior spaces [11].

2.7 Night nocturne ventilation

With Night ventilation used, the construction could absorb heat gains during the morning and reducing the temperature rise. These constructions can be cold night air to cool down of a building, so that it can be optimize the daytime cooling capacity of thermal mass. The use of courtyard practices a ventilation at night to allow relatively cool night air to remove heat absorbed in the mass during the day.

In order to induce natural ventilation, three main principles should understand very well: includes stack ventilation, Bernoulli's effect, and the Venturi effect.

2.8 Passive solar heating

Passive solar heating can involve large glazing exposed to the sun, with solar air collectors on the wall or on the roof. A double facade wall construction with ventilation windows and massive walls behind, buried pipes can preheat or precool the ventilation air [17].

Toward concluding, Vernacular cooling strategies can be improved modern means, using excellent effectiveness principles. The effects of natural ventilation design where have a less investigated for low-cost housing [10].

3. Materials and Methods

In this research, the method is based on new approach allowing analyzing the energy efficiency of passive cooling/heating, TRNSYS V16 software package was used, which provides all the tools needed for internal temperature and load consumption. The selected of traditional house was simulated in this software to analyze comfort and energy consumption as well as determining inside and outside temperature of floor and walls of houses.

This paper describes investigation of applying vernacular passive cooling in hot climates. Next, we will achieve a comparative of the relative technical efficacy, and cost effectiveness, of various passive strategies and combined between them. This comparative based multi criteria analysis appears to be significantly cost benefits analysis needing to be done.

3.1 Selected building of Study

To appreciate how passive cooling strategies has contributed to housing in hot and dry climatic conditions: this study has analyzed many traditional buildings of Saharan areas of Algeria. Figure 1 shows case study of residential building plan.

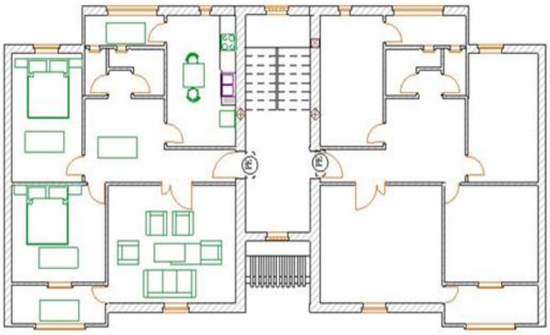

Fig. 1. Plan of residential building case study

3.2 Climate Data of Arid Region

In this research, current data of Bechar city is according to the Algerian National Center of Studies and Researches Integrees of the Building (CNERIB: Centre National d'Etudes et de Recherches Integrees du Batiment) and the thermal regulation (DTR C3- 2), for residential buildings, Algeria has six distinguished climatic zones:

- Zone (A): in the north of Algeria, including the coastal zone;
- Zone (B): in the south of zone (A), including the plain behind the seashore;
- Zone (C): in the south of zone (B), including the highlands;
- Zone (D): in the south of Algeria, including the desert; and the climate zones (B') and (D'), representing subzones within the main zones (B) and (D), respectively [18].

In this research, we will study various strategies of passive or cooling, applying for existing housing, located in South-west of Algeria. The Table 1 present theses strategy and components of each strategy with thickness of wall and U factor.

Table 1
Components of each strategy cooling/heating applying in existing building

	Compositions	Thickness (m)	Total thickness	U (W/m^2. K)
Initial	Exterior plaster	0.015	0.25	0.89
	Concrete brick	0.10		
	Air blade	0.02		
	Concrete brick	0.10		
	Cement plaster	0.015		
Trombe wall	Inside plaster	0.02	0.25	0.41
	Brick wall	0.10		
	Air vacuum	0.02		
	Stone brick	0.30		
	Outside plaster	0.02		
Roof pond	Insulation	0.04	0.32	0.53
	Steel frame	0.02		
	Input air	0.05		
	Fan	0.05		
	Cement roof 15cm	0.15		
Nocturne ventilation	-	-	-	-
	Small opening	Windows (50cmx50cm)	S/V (M2/M3)	0.50
Thermal insulation	Plaste	0.02	0.44	0.39
	Exterior	0.02		
	Finish coat	0.08		
	Insulation	0.20		
	Plate	0.02		
	Red brick	0.10		
	Blade of air			
	Hollow Brick			
Passive solar heating	A double facade wall with ventilation windows and massive walls behind, buried pipes can preheat or precool the ventilation air	0.20 0.04 0.20	0.50	0.45

4. Results and Discussions

4.1 Cooling/Heating Energy Consumption of Building

According to this study, the traditional architecture of the desert region illustrates an example of excellent principles for adapting to the arid climate through passive strategies. Habitually, in hot and dry climates, one of the fundamental tasks is the interior space, presented by a central courtyard with little opening.

Design strategies for energy-efficient buildings include reducing loads, selecting systems that make the most effective use of ambient energy sources and heat sinks and using efficient equipment and effective control strategies. An integrated design approach is required to ensure that the architectural elements and the engineering systems work effectively together.

We had carried out to calculate energy consumption and an environmental analysis in an existing housing located in Bechar, using global warming potential and energy as indicators. In this study, the Table 2 shows the results of energy consumption of nocturne ventilation and thermal insulation strategies is 100 and 125 KWh/m2 and while 71.42% of saving energy for nocturne ventilation as shown in Figure 2.

Table 2
Energy consumption and Cep Eco of each strategy

Strategies	Initial	Passive solar	Trombe wall	Thermal insulation	Nocturne ventilation	Optimal
IPS min	0.15	0.30	0.40	0.60	0.75	1
Q Heating KWh/m2.an	270	200	100	100	73	35
Qcooling KWh/m2.an	80	50	50	25	26	15
Cep max KWh/m2.an	350	250	150	125	100	50
Factor Eco	-	150	200	225	250	300
Energy saving %	-	42.85%	57%	64.88%	71.42	85.71

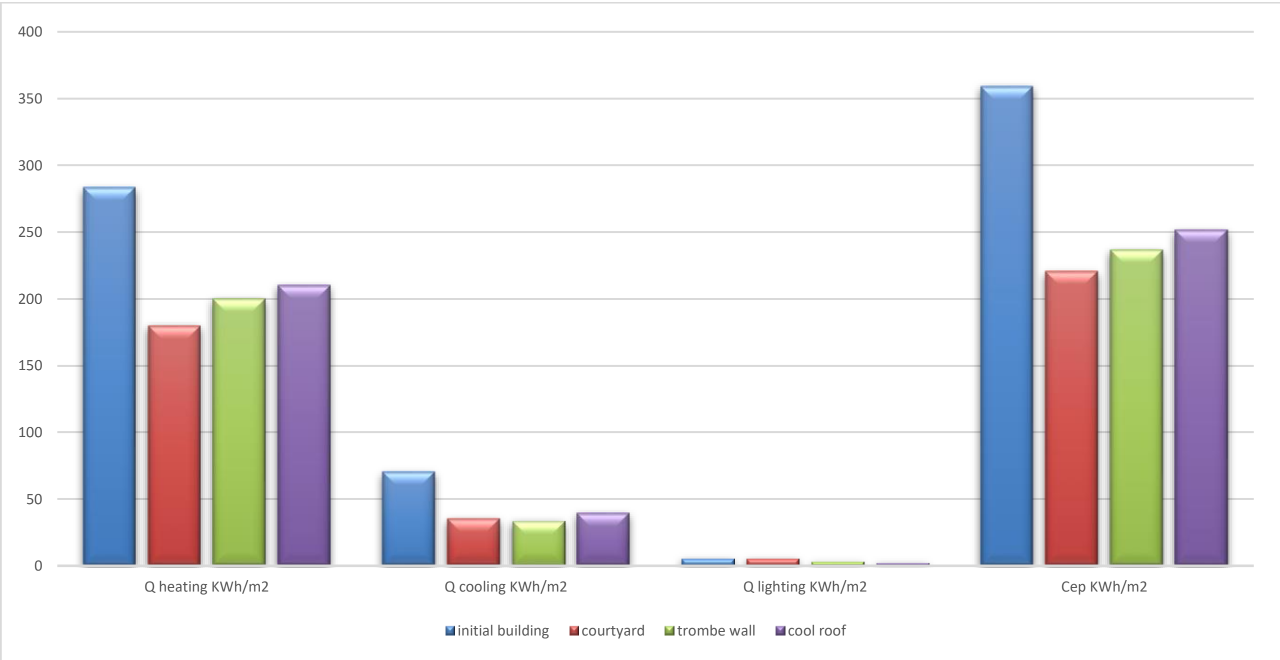

Fig. 2. Cep Energy consumption for each scenario KWh/m^2
With: -Cep= Cep heating + Cep -cooling+ Cep –lighting+ CepECS + Cep-auxs+ Cep-auxv (Cep auxs= cep auxv=0 et cep éclairage= 4.5 KWh/m2 et cep ECS= 4.5KWh/m2

4.2 Multi criteria's Analysis and Benefits Cost

However, our study does consider multi-criteria analysis of different strategies representative in Table 3. Both energy certification and energy rating provide certain criteria's such as:

- Criteria n°1: Environmental: _ CO_2 emissions for heating, cooling and hot water and also for lighting (kg CO_2/m2 per year
- Criteria n°2: CRITERE COMFORT: factor
- Criteria n°3: Bioclimatic: S/V losses surface to volume ratio or shape factor or loss compactness [m-1] and Bbio (points) [indicator bioclimatic
- Criteria n°4: economical; Energy coast "L'éco" and cost investment TR
- Criteria n°5: energetically; Final energy consumption for heating, cooling and hot water (also for lighting,), Cep it is necessary to Identical Weighting/scoring for all criteria [12].

We have shown the benefit of using courtyard and adapting in building, by specifically spaces, all the resource requirements of this analysis on our study case, due to the limit and current with source of water and impact of humidity. The evaluation of the energy consumption of the Reference has made possible to significantly reduce energy consumption and improve comfort in arid and semi-arid regions.

It remains that the bibliographical study suggests that passive solutions inspired by vernacular architecture has not been applied as modern solutions for buildings located in dry and hot climates. These techniques are local and economical, at low cost.

In our research, we investigated the comparative or cumulative effectiveness of different strategies monitored in Table 3.

The effect of courtyard or a waterspout wall can reduce the demand for air conditioning and provide natural and passive cooling. The most effective solution was developed in the past, to maintain the well-being of the occupants by effective, local means and easy to apply in this context. This is essential information for engineers, and therefore emphasizes advice on the strategies to be favored. It is common to provide features of a bioclimatic design, which appear to be favorable and adequate for the environment (Table 3).

Table3
Multi criteria's analysis of each passive cooling/heating strategies studies

Criteria's	Strategies	Initial	Passive solar	Trombe wall	Thermal insulation	Nocturne ventilation	Passive optimal
Comfort	IPS min	0.15	0.30	0.40	0.60	0.75	1
Energy	Cep max KWh/m2.an	>450	250	150	125	112	<50
Economic	Investment costs DA/m2	15000-20000	10000 - 15000	5000-10000	1000-5000	0-1000	0
	Temps de retour TR	0	0-3 month	1- 2 year	2-4 years	4-8 years	8-10 years
	Cost electricity DA	>60000	48000-60000	36000-48000	36000-24000	24000	12000
Environmental	Emission CO_2 per/kg	15000	12000-15000	9000-1200	6000-9000	6000	3000

5. Conclusion

In hot, arid climates, energy consumption has increased rapidly in recent years. There is great potential to improve design passively (assisted by traditional techniques in new and existing housing.

The results show that the passive cooling strategy of the courtyard with natural ventilation is appropriate for arid regions; however, a high thermal mass would be suitable for construction. This study made it possible to choose a passive cooling strategy suitable for all types of construction in hot and dry climates. In this work, we can offer recommendations for future buildings in arid climates.

These recommendations in this study can be generalized to different climates with conducting the same procedure:

i. For passive heating, while the effective summer solution to ensure a comfortable construction in winter is more practical for heating by using a Solarium. By a trombe wall system with double glazed openings results a 50% reduction in heat gain and a 49% reduction in losses compared to the roof cool. The trombe wall must be trapping the maximum solar radiation inside the room with a minimum U value.

ii. For passive cooling, the combination of cooling from the internal courtyard and hardening of trombe walls is very effective and can reduce the temperature by up to 7 ° C. Cooling a cool roof is the least economical concept for cooling a building.
iii. For passive heating / cooling, the combination of a Trombe wall, with thermal insulation achieves savings of 50% and 80% respectively in summer.
iv. the hybrid system between these studied systems gives better results in terms of efficiency, thermal environment, heating and electricity consumption. Photovoltaic systems are among the most promising alternative energy sources.
v. A 50.65% reduction in annual energy consumption can be achieved through the use of courtyard and trombe wall like optimal solar passive cooling strategies. Using the optimal solution can reduce the building's energy needs by 50% compared to current design practices adopted in the arid region of Algeria

The proposed model was determined for courtyards and trombe wall correlations between properties materials was identified. As conclusion, it was shown that decreasing energy consumption of cooling and heating and obtains greater comfort in designing passive houses in hot-dry climate, it means that passive cooling strategies inspired of vernacular architecture performs better than actives systems today.

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