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Numerical assessment and optimization of a low-energy residential building for Mediterranean and Saharan climates using a pilot project in Algeria

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A B S T R A C T

The awareness for energy efficiency in buildings increasingly expands in Algeria, where a legal framework exists for promoting the utilization of regenerative energies. However, models of best practice are still relatively few. As a contribution, this paper reports on a study, which aims at finding out the best design strategies for affordable energy efficient residential buildings. The focus is put on the Mediterranean Algiers and the Saharan Ghardaia. Dynamic energy modelling was carried out using TRNSYS 17 to assess a residential house built as a MED-ENEC pilot project. The simulation is executed at two sequential stages: the reconnaissance stage where the building is compared to a typically non-insulated conventional construction and then the assessment stage, in which the pilot project already designed to low energy standards is investigated in an attempt to increase its energy efficiency further. By means of a parametric study, the most efficient passive design measures for minimizing heating and cooling energy demands were delineated and their dimensioning fixed. The results confirm i) the easiness to save energy in comparison to the local inappropriate conventional building type, and ii) possible additional energy savings in the pilot project, so that almost no heating is required and the cooling visibly further reduced.

1. Motivation and objectives of the work

In the southern emerging countries, such as Algeria, the awareness of energy issues and the goal for more energy efficiency via the application of regenerative energy grow increasingly. Renewable energies are becoming one of the major elements of the country's energy policy given the considerable potentials available in particular for solar energy with the aim being to reach by 2030 a share of renewable energy of between 30% and 40% in the national energy balance [1–4].

A legal framework has been developed for promoting the utilization of regenerative energies. With the “Program for regenerative energy and energy efficiency”, Algeria as hydrocarbon producer is preparing itself for a future of green growth. The official program supports amongst all the solar energy and energy conservation in the building sector and sets as milestone that energy use for heating and cooling in residential buildings should be lower than 40% by 2030 since 42% of energy consumption accounts for this sector [5]. Several background laws do exist, e.g. N° 99-09 (1999) on energy savings, N° 02-01 (2002) on electricity and gas, and N° 04-09 (2004) on renewable energy and sustainable development [6] as well as a building thermal regulation i.e. Document Technique Réglementaire DTR C3.2 [7] and DTR C3.4 [8].

However, in spite of this legal framework and mandatory thermal regulation, most buildings, especially residential ones, are not climatically responsive designed and remain very energy consuming. Typically, the buildings are not thermally insulated, use double hollow brick cavity as external walls and single glazing windows. Consequently, a substantial need for heating, cooling or for both is observed depending on the climate zone since Algeria accounts several very contrasting climate regions. Indeed, the implementation and commitment to the available directives is still insufficient and requires more incentives and exemplary actions. A focus on low-cost passive strategies and affordable active measures using renewable energy technologies, easily understandable and differentiated according to the climate zone is therefore crucial to

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guarantee an extensive implementation.

Such guidelines for locally adapted energy-efficient building design would support some current initiatives underway. For instance, the ECO-BÂT project, recently initiated by the local authorities, which consist of 600 low-energy housing units distributed across the country under different climate zones, is an initial start-up for this program. The new city of Hassi Messaoud in the Algerian Sahara is another example of a voluntary green action with potential for such implementation (see [5]).

Moreover, regional projects like the EU-funded MED-ENEC (Energy Efficiency in the Construction Sector in the Mediterranean) implemented different procedures via demonstration projects to show ways for solving the challenges in the construction sector in the south Mediterranean [9]. The aim of these pilot projects was to increase the local awareness for energy issues and provide examples of best practice for improving energy efficiency and the use of regenerative energy within buildings in southern and eastern Mediterranean countries.

To make these single initiatives feasible for wider replication in the country, it is necessary to provide the architect and the engineer with design guidelines that help at early design stages towards energy efficiency in the sense of the mandatory thermal regulation in force. As one contribution, the present paper reports on a research following this objective [10]. It uses the pilot project of MED-ENEC as object of study, a residential house built as pilot project in the suburbs of Algiers, involving the local research centres CNERIB [11] and CDER [12] for its design and construction.

The objective of this study is to find out the best design features for the latitudes under study, which could make residential buildings in Algeria energy efficient at best economical levels. The focus is put on two climate regions: the Mediterranean Algiers (warm and humid, 36.75°N, 3.00°E) and the Saharan Ghardaia (hot and dry, 32.40°N, 3.80°E). First, the energy performance of the object of study is assessed at its real location in Algiers and subsequently for an assumed location in Ghardaia. Then, further variants of this reference building are investigated in order to delineate the most efficient building design parameters and best combinations of these parameters which could yield optimal energy savings for both heating and cooling.

2. Building design priorities in hot climate regions

Warm to hot climate regions, either subtropical or tropical, are manifold. They range from mild climates like the Mediterranean to harsh arid desert climates such as the Sahara. Differences in air temperature extremes and amplitudes, sun paths and amounts of solar radiation, air humidity ratios, precipitation rates etc., imply adaptation solutions, which must be accordingly differentiated. Designing for warm or hot climate regions is qualitatively well documented, either based on intuitive traditional or pragmatic contemporary building design e.g. Saini [13], Fathy et al. [14], Givoni [15], Hindricks and Daniels [16], Lechner [17], Konya and Vanderberg [18], Saldanha et al. [19]. The advised guidelines for climate-sensitive and energy-saving building design deal with various features:

i. Control of climate elements including solar access or solar protection, shading, ventilation, glare protection and daylight.
ii. Site planning including topography adaptation, use of vegetation and water.
iii. Building's envelope construction (roof, façade, windows, etc.), building materials (thermal insulation, thermal mass, etc.), building form and orientation.
iv. Specific climate-related solutions such as wind catchers, evaporative coolers, windbreaks, etc.

Some general design strategies from these references are summarized below.

In the winter, the goal is to ensure sufficient heat gains and limit the heat losses. Passive solar heat gains can be enhanced by maximizing window surface area in the southern façade and from heat gain from equipment, artificial light and occupants of a building. By contrast, to avoid heat loss, compact building envelope and small window surface area in façades other than south are advisable. It is also important to improve the thermal insulation of the opaque elements of the envelope and the thermal insulation of the transparent elements by using double or triple glazing with low U-value. The thermal insulation is more critical where the winter is colder.

In the summer, the issue is to prevent excessive heat gains and overheating due to the typically high solar irradiances. Massive construction should be used in order to enhance the heat storage. The undesirable heat is charged in the building materials in the daytime and leads to lower magnitudes and amplitudes of the indoor air temperatures. This heat is then discharged and transported away at night using natural, cross or shaft ventilation. The thermal inertia is more crucial for the Saharan climate. Extensive shading help reduce the absorbed solar radiation. Roof overhangs or adjustable exterior shading devices e.g. above the windows are typical solutions. Vegetation also enhance shading and water sources temperate the temperatures by providing more latent heat. Ceiling fans could be used in hot days to allow cooler air movement indoors while windows remain closed. Light-coloured building materials with a high degree of reflection should be used to minimize the heat gain during the summer. Wind protected porches and arcades can extend the stay outside by providing a better microclimate.

Thermal conservation via building compactness is beneficial the year round. The building should be compact, i.e. with low surface to volume ratio (S/V) in order to limit the heat transport via the envelope with the surroundings either in the winter (heat loss) or in the summer (heat gain). The floor plan should be organized in a way that provides the living areas with sufficient natural light during the day, i.e. south or near south and orientates the secondary rooms in the other directions.

Depending on the climate type, whether humid or dry, the solutions may vary, especially in relation to the use of water as evaporative cooler or the ventilation for dissipating excessive heat.

Such guidelines as general rules of thumb at early stages of design are useful, but accurate and reliable design recommendations are better achievable by quantitative means such as experimental investigations or robust numerical modelling as undertaken in this study. This is because the multiple combinations between all decisive parameters have to evaluated in a systemic approach including their interactions. This method is the one followed in this study and is explained in the next sections.

Moreover, selected references with some common features with this research are briefly summarized hereafter for later comparison (see Sections 7 and 8). Climate-sensitiveness and energy-efficiency of residential buildings were investigated by Rosenlund [20], Rosenlund et al. [21] for the Saharan climate, Johansson and Ouahrani [22] for the east Mediterranean, Schnieders [23] for the south-west Europe whereas Derradji et al. [24], Derradji et al. [25] Imessad et al. [26] addressed the same object of study as the one considered here.

Rosenlund [5] reports on experimental and numerical studies of housing buildings in hot and arid regions in the North African Ghardaia, Tozeur and Tamerza locations. The focus was put on