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Energy performance analysis of a solar-cooled building in Tunisia: Passive strategies impact and improvement techniques

Meriem Soussi [b], Moncef Balghouthi [a,*], Amenallah Guizani [a]

[a] Research and Technology Center of Energy (CRTEn), B.P. 95, 2050, Hammam Lif, Tunisia
[b] Energy in Buildings and Solar Energy, National Engineering School of Tunis (ENIT), B.P. 37, 1002, Tunis-Belvédère, Tunisia

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ABSTRACT

The energy performance of a solar cooled office building located in Tunisia is studied using the TRNSYS software. The simulations assessed the real case study and analysed the impact of its architectural characteristics and passive techniques on its energy requirements. The impact of solar passive heating techniques already implemented in the envelope is studied in order to take advantage of them in winter and prevent their overheating effect in summer. Besides, additional passive cooling solutions are proposed and studied aiming to decrease the cooling requirements. The results showed that the insulation of the walls and the cool roof guarantee important savings of 46% in winter and 80% in summer compared to an ordinary building. The study was also focused on the impact of the trombe walls and showed that the heating requirements are raised by 20.7% if the storage walls are omitted from the construction. The integration of internal curtains in the windows and movable solar overhangs shading the storage walls and the low-emissive Argon coatings allowed a relevant reduction in total energy demands: 60.3% for heating demands and 47.7% for cooling demands. The peak cooling load has decreased from an initial value of 14.09–8.68 kW. Thanks to this relevant reduction, a technical improvement solution consisting in a cooling storage was proposed to increase the solar cooling performances.

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1. Introduction

Several studies carried out during the last years, highlighted the high contribution of buildings in primary energy consumption all around the world and especially in developed countries where this contribution reaches 20–40% of the total energy use [1]. Heating, ventilation and air conditioning systems (HVAC) are the most energy-consuming amongst the buildings services. For these reasons, the conception of energy-efficient buildings has become a priority and the integration of cooling and heating passive techniques is increasingly encouraged by international regulations.

Passive cooling relies on the use of techniques that enable controlling and dissipating the solar radiation and thermal gains during summer. Contrarily, heat passive features take advantage of sunlight and its heating effect thanks to their high capacity of absorbing solar radiation, storing and releasing heat inside the building. Hence, low-energy or 'zero-energy' buildings incorporate efficient passive features that guarantee indoor conditions within comfort range without consuming any primary energy.

Reducing energy consumption in buildings can be guaranteed, first by designing envelopes passively taking into account the climatic conditions in order to choose the best orientation, walls and windows compositions. Second, by improving the efficiency of the building equipments, especially cooling and heating systems and supplying them if possible by renewable resources rather than electrical or fossil energy.

A large number of researches and experimental studies have been performed in residential and non-residential buildings analysing passive heating and cooling techniques and their effect on the comfort conditions inside the edifices. These researches led to the production of numerous experimental and numerical studies mainly using the reference simulation program TRNSYS (Transient System Simulation Program).

Chel et al. [2] experimented and modelled the effect of using a trombe wall in a honey storage building located at Gwalior in India. They replaced an electrically driven room air heater by the passive heating technique of storage wall and studied its effects on heating load and the amounts of CO_2 released. Their experimental and numerical study (using TRNSYS program) showed that the trombe wall can ensure the adequate temperature for the building with a potential of energy conservation up to 3312 kWh/year and a reduction in CO_2 emissions of 33 tonnes/year. Besides, the implementation of the trombe wall was also sustained by an economical study that showed its viability.

* Corresponding author. Tel.: +216 97570277; fax: +216 430934.
E-mail addresses: balghouthi_moncef@yahoo.fr, moncef.balghouthi@crten.rnru.tn (M. Balghouthi).

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Nomenclature

SHGC, g	solar heat gain coefficient (%)
COP	coefficient of performance
SCOP	solar coefficient of performance
TW	trombe wall
U	thermal transmittance (m^2 K/W)

Greek symbols

τ	transmission coefficient
ρ	reflection coefficient
α	absorption coefficient
ε	thermal emittance

Subscripts

amb	ambient
m	mean
tr	trombe

Passive cooling by means of a green roof was tested by Castelloti et al. [3] in a hospital in Vicenza, Italy. This technique consists of a roof covered with vegetation that limits the heat transfer through the roof and reduces the thermal load of the building. The potentiality of this kind of roof in lowering heating and cooling loads is evaluated by an experimental and a numerical study. The experimental data and the TRNSYS numerical model results were in concordance and showed that the green roof allows a reduction of the thermal heat gain of about 60%.

Bouden [4] has studied the possibility of integrating curtain glass walls in Tunisian buildings. A series of simulations using TRNSYS program were carried out to investigate the impact of glass curtain walls implementation with different glazing sizes (different values of the ratio of the glazed area to the total area) and different glass types on a typical administrative building thermal performance. The numerical study showed that glass curtain walls could be used in Tunisian buildings if the appropriate orientation and glazing type are selected. This passive solar gaining technique can perform even better than ordinary masonry walls when small windows covering 20% of the total wall area are used in the glass curtain wall.

Passive solar systems and natural ventilation in an industrial factory in restoring phase were discussed by Ballestini et al. [5]. The archaeology factory is located in Cavaso del Tomba, Venice, Italy. In order to increase thermal performance of the walls, a glass double-facade was attached to the existing wall surface separated by an air gap (0.65 m), this constitutes a passive heating technique in winter thanks to the glass solar gain transferred to the building. Besides, several openings were created in the secondary skin of the walls and in the doors of each floor in order to guarantee cooling effect and natural ventilation from sunspace to rooms and back again. TRNSYS simulations showed satisfying results if the upper and the lower louvres of the glass skin wall are properly opened in summer to avoid overheating by greenhouse effect. In addition, Ballestini et al. concluded that the glass double-skin wall is considered to be a valuable solution to building restoring since it helps avoiding the intervention in the old wall layers which is a difficult and expensive operation, but the appropriate glass type and ventilation process should be selected to avoid overheating problems and guarantee optimal comfort conditions.

Abundant literature dealt with the investigation of the solar heating and cooling passive strategies, optimising other specific building characteristics such as the building form, orientation, HVAC systems, windows and walls composition [6–10]. Each one of these studies reported the analysis of the considered technology, its efficiency, the gains it provides as well as its limitations.

In the current work, we studied a building laboratory located in the Research and Technology Centre (CRTEn) at Borj Cedria (Tunisia). The building is cooled by a solar cooling system that consists of a double effect water–Bromide absorption chiller coupled to parabolic trough solar collectors. The best functioning of this solar cooling system and the highest efficiency rates could not be reached unless the total building energy consumption is reduced. It is important to note that the studied building was built with a bioclimatic design, as a prototype to test passive solar systems. Its particular geometry and its orientation as well as the trombe walls and the important glazed area in its south and southwest facades are solar passive strategies that have deeply reduced the heating demands in winter. However, they have increased the cooling requirements by their overheating effect in summer. For these reasons, series of simulations are conducted in this work in order to assess the case study and analyse the effect of passive techniques implemented in the edifice in order to take advantage of them and prevent their overheating effect in summer. The possibility of applying new passive cooling features is also studied aiming to reduce the energy requirements and reach a higher level of comfort inside the building especially in summer. The architectural scenarios consider the construction geometry, orientation and composition (walls insulation, cool roof) as well as windows types. Moreover, the study will be focused on analysing the efficiency of the storage walls implemented in the building, three extreme scenarios are shown: building with storage walls, building with storage walls and solar overhangs and building without storage walls.

2. Building description

2.1. Description

The building studied in this work is a 126 m^2 research laboratory located in the Research and Technology Centre of Energy in Borj Cedria, Tunisia. It consists of four offices and a meeting room (Figs. 1 and 2). The four offices have respectively the following surfaces: 15.16 m^2, 15.21 m^2, 15.26 m^2 and 14.57 m^2. Besides, each one of the four offices has a single glazed window of 1.48 m^2 on its southwest facade. As for the meeting room, it is the most spacious zone of the building (36 m^2) containing five 1 m^2 windows on its south facade and three 1.2 m^2 windows on the southwest facade.

The construction of the building is also characterised by five storage walls (also called trombe walls) located on the southwest facades of each office of the building. Every wall storage has the following dimensions: 2.3 m of height, 1.2 m of width and 0.3 m of thickness.

2.2. Storage wall

The storage wall is a passive heating technology that consists of a block of strong inertia material (concrete) placed in front of a window (Fig. 3), it is able to store the amount of energy provided by solar radiation and restores it during the night. The glazed window creates a greenhouse effect to warm the ambient air, reduces heat loss and allows more heat transfer to the inside space. Heat transfer from solar radiation to the office is guaranteed by conduction, radiation and convection.

First, the solar radiation heats the surface of the trombe wall, then heat slowly passes through the massive wall stroked by sunlight, and arrives at the inside surface of the wall several hours later to provide heat in the evening. The solar radiation impact is also optimised by the black paint of the wall. In addition to the thermal conduction inside the massive wall layers, air between the

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