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Experimental study of the thermal behavior of a direct solar floor

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Abstract

E Solar radiation constitutes a source of free and non-polluting energy, so it is worth to promote it locally using various technologies. The building sector seems to be quite favourable for several reasons.
Technically, important surfaces (roofs, walls) can be used for solar collecting.
Economically, the over costs can be reduced providing a suitable architectural integration. Socially, the reduction of heating costs is an additional asset.
The aim of this research consists on:

- *The investigation on materials and components improvement, for example the search for insulating and transparent materials which make it possible to collect the radiation with minimum thermal losses;*
- *The search of suitable integration of these technologies in an architectural envelope, in order to obtain good performance and to minimize costs;*
- *The realization of experimental operations (a direct solar floor) and proposal for national project for a solar house realization.*

Thus, this study consists on developing this technique, which deals with habitat heating using solar energy in general and direct solar floor particularly, by investigating the thermal behaviour of the system in the site of Bouzaréah (Algiers).

Keywords: *Solar energy, flat plat collector, thermal storage, heating floor, heating of buildings*

1. INTRODUCTION

Active solar thermal makes it possible to recover the radiation heat within a fluid, using solar collectors. The direct solar floor (DSF) technique results from a very important simplification of the active solar heating techniques used up to now. Indeed, the fluid heated by solar collectors circulates directly in a floor without passing through a storage tank.
The concrete mass provides the energy storage functions and its restitution to the heated volume. Connected to a low temperature distribution, the flat plat collectors operate with a

better output, since all the intermediate losses (exchangers, storage) are eliminated. The thermal use of solar energy has advantages such as:

- Technologies using solar thermal energy are easily controllable and adaptable to all areas. The techniques and materials used are similar to those employed in traditional heating sector. Labour requires only little further training.
- It is a flexible form of energy production that can be adapted according to needs.
- The costs of maintenance are reduced. If maintenance should not be neglected, its expenses and thus operation are however relatively low.

Solar thermal energy has however some limits:

- It is variable in time. Under moderated climates, this variation is especially important according to seasons. This involves a need for storing this energy, which increases considerably the installation cost.

- It is a diffuse energy. The power available per unit of area is relatively limited; this makes difficult the response to important needs (great sets of apartments, for example).

2. DESCRIPTION OF THE SYSTEM

The prototype was constructed in the site (CDER), the system dimensions were set up in order to have best possible performance (floor thickness/collecting area ratio).

The experimental apparatus is composed of a concrete slab of 3,2 m² and 17 cm thick, traversed by a copper serpentine 16/18 mm diameter and 13m length. A water flat plat solar collector of 1,8 m² whose absorber consist on a radiator. The water transfer is ensured by a circulating system (composed of a 3 speeds pump, a safety valve, a fluid expansion tank and a non-return valve).

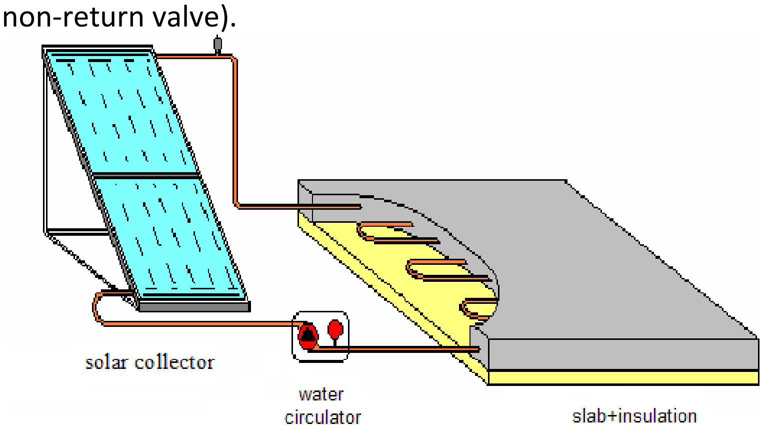

Figure.1. diagram of the whole system

3. TESTS AND MEASUREMENTS

The test bench was carried out within the CDER's experimental platform (Centre de Developpement des Energies Renouvelables).
To study the thermal behaviour of the slab, the following parameters are measured:

- Global solar radiation.
- Ambient temperature.
- Slab floor temperatures.
- The slab inlet/outlet water temperatures.

For temperatures measurement, a set of 17 thermocouples are placed in various points of the slab as shown in fig .2, in addition two measurement a taken at inlet and outlet positions of the serpentine (18;19).

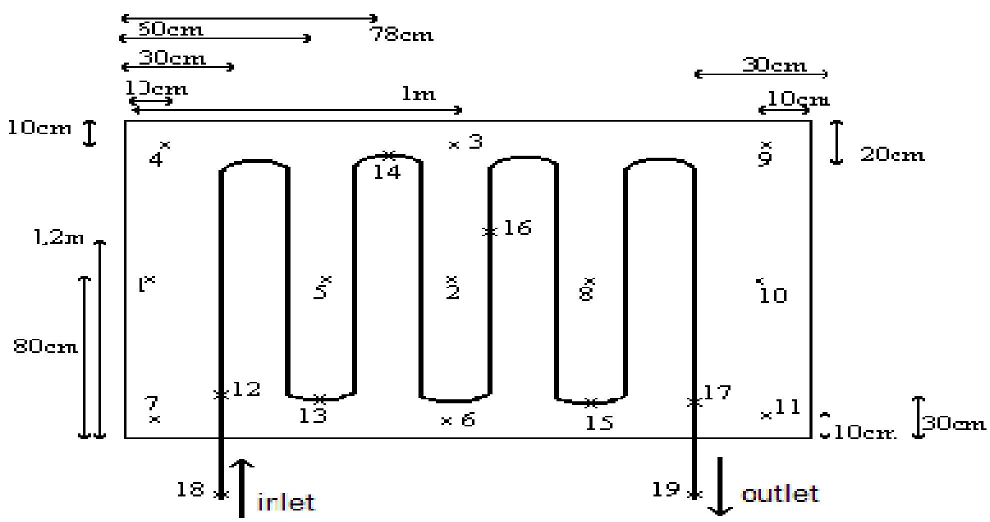

Figure.2. Thermocouples positions in the slab

4. MATHEMATICAL FORMULATION

The model used for the flat plat collector is a one model temperature, it is considered that at a given time and in an infinitesimal section dx, there is only one temperature very close to that of the fluid (the absorber and the fluid have the same temperature).

The heat balance of the section dx in transient state is given by the HOTTEL & WHILLER equations [4].

$$dQ_c \cdot dt = \left[I - UL\left(T - T_{am}\right)\right] \cdot \frac{A_C}{L} .dx.dt \quad \{1\}$$

In general, the following equation is used [5]: $Q_c = m.c_p.\left(T_{out} - T_{in}\right) \qquad \{2\}$

By supposing negligible thermal losses between collector and the slab, the energy received 'Qc' by the collector (useful output) is equal to the heat yielded 'Qy' to the slab, one can thus write:

$$Q_y = Q_c \qquad \{3\}$$

The energy stored by the slab is written as follows: $E_s = \int_{t_i}^{t_f} Q_y.dt \quad \{4\}$

The trapezoids method is used for the integral calculation, which is given by the following relation:

$$\int_{x_{j-1}}^{x_{j+1}} f(x).dx = \frac{\Delta X}{2}\left[f_{j-1} + 2f_j + f_{j+1}\right] \quad \{5\}$$

It is obtained from calculation that an amount of energy reaching 10624, 5 kj is stored during the day of March 05th 2000 from 6.00 AM to 6.00 PM.

5. EXPERIMENTAL RESULTS

The following curves are plotted using the recorded data:

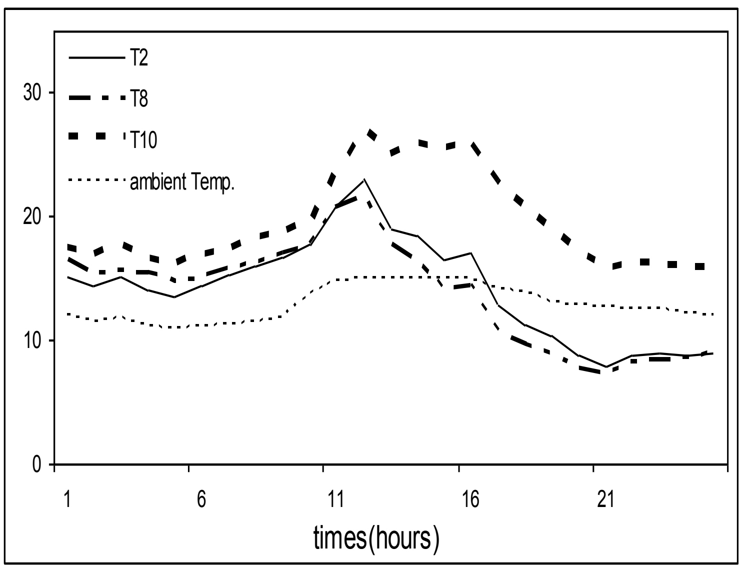

Figure.3. Internal slab temperatures evolution after one week

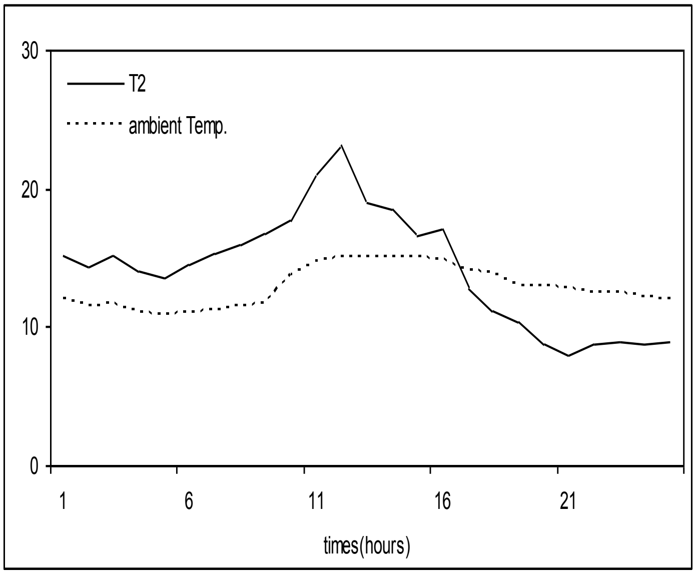

Figure.4. Slab/ambient temperature evolution

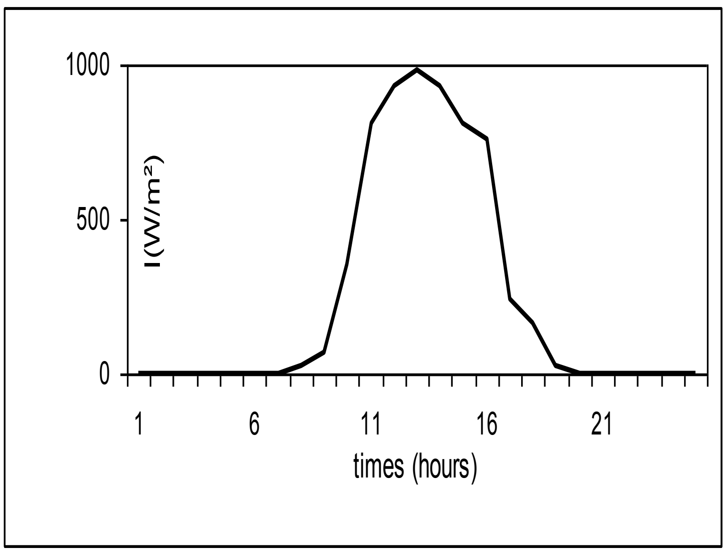

Figure.5. Evolution of global solar radiation on the collector area (W/m²)

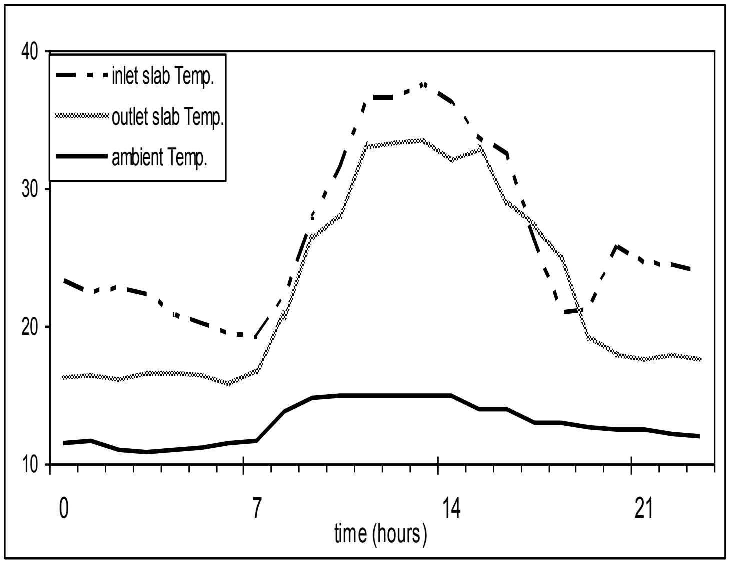

Figure.6.The slab inlet and outlet temperatures.

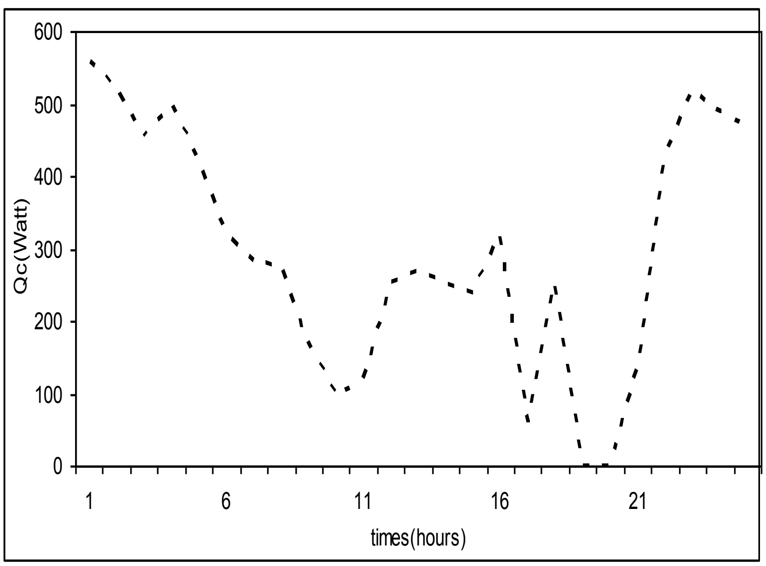

Figure .7.The collector useful output Qc Evolution.

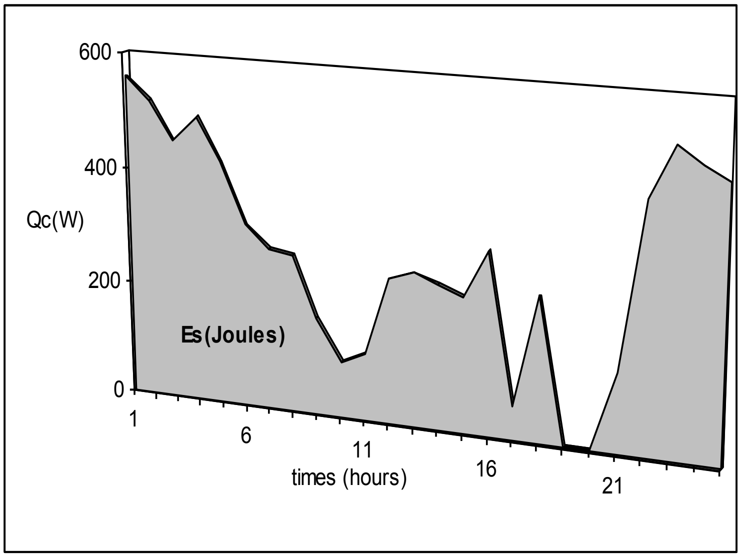

Figure.8. Energy stored by the slab

6. INTERPRETATION OF THE RESULTS

The global solar radiation represented in figure -5- on the day of March 05th 2000 varies according to a bell shape, which reaches its maximum (984,14 W/m²) by 12h30.
The slab inlet temperature (figure-6) which corresponds to the collector outlet temperature reaches its peak (36,5°C) at the same time.
The slab inlet and outlet temperatures difference varies from 3 to 8 °C, the temperature loss recorded at the slab outlet reflects the effect of the heat stored (fig 6.7 and 8).
One can note that the curves have the same shape; the temperatures in different nodes in the slab tend to be uniform after one week of heating (thermal inertia of the slab).
The average slab temperature ranges at 22-24°C, this shows that a certain thermal comfort is obtained. It is noted, on the other hand, that during the night, the recorded temperatures drop slightly at the edges, which is due to the poor slab edge insulation (edge effects).
The collected useful energy output Qc, which corresponds to the energy yielded to the slab, lies from 60 to 560Watts, see fig -5-.
The energy stored “Es” by the slab is calculated by the trapezoids method, by neglecting the thermal losses in the collector/slab connections (collected heat equals yielded heat).
During the day of March 05th, the slab stored from 6 am to 6 pm more than 10000 kilojoules.

7. CONCLUSION

Over one week of experimentation, the temperatures in various points of the slab tend to have a uniform trend. The relatively low temperatures recorded at the slab sides are explained by the fact of high thermal losses at the edges due to the poor insulation on this part of the floor (edges effect).
The main goal would be to design buildings which are, on one hand, energy saving (by collecting and accumulating the maximum direct solar radiation during the heating period) and, on the other hand, comfortable in summer (by avoiding overheating without resorting to expensive air-conditioning apparatuses). This goal can be reached by complying with design architectural rules (opening positions, insulating materials, accumulating materials, protection from dominant winds....).
These tests enable us, in conclusion with a two-dimensional heat transfer study, to evaluate the advantages of such a system (thermal comfort, heat storage ...).
It is worth improving this type of system in order to make it more attractive by investigating the possibilities of reducing its disadvantages (as thermal losses ...).

NOMENCLATURE

m: water mass flow circulating in the collector (kg/s).
Cp: Calorific capacity of water (J/kg. °C).
Qc: useful output of the collector (W).
I:l': global solar radiation (W/m²).

UL: thermal losses (W/m²°C)
Ac: collector surface (m²).
L: collector length (m)
Qy: The heat yielded by the collector (W).
Es: The heat stored by the slab (Joules)
T_{in},T_{out}: inlet and outlet temperatures of the collector (°C)
t_i,t_f: initial and final time taken for the calculation of stored heat (hours).

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