COUPLED UTILIZATION OF SOLAR ENERGY AND LOCAL MATERIALS IN BUILDING

H. Kazeoui, A. Tahakourt*, A. Ait-Mokhtar**, R. Belarbi***

*Laboratory of Technology of Materials and Engineering Process (LTMGP), University A. Mira
Targa Ouzemour, Bejaia, 06000, Algeria
Tel: 00 213 34 21 45 01; Fax: 00 213 34 21 60 98; E-mail: hkazeoui@yahoo.fr

**Laboratory of Study of Transfer Phenomena Applied to Buildings (LEPTAB), University of La Rochelle
Av. Michel Crépeau 17042 La Rochelle cedex, France
Tel: +33 (0) 5 46 45 72 39; Fax: + 33 (0) 5 46 45 82 4; E-mail: karim.ait-mokhtar@univ-lr.fr

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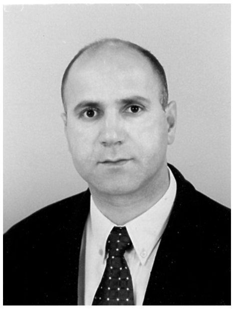
The aim of this study is to present possibilities of associating the solar energy with local materials in buildings under the Mediterranean climate since the solar energy is a renewable, economical and not pollutant energy, the local materials offer comfort to users, protect the environment and have a low price. The performances of the Direct Solar Floor (DSF) are presented. This method of proceeding is one of the most used solutions in the solar heating field. The application of this method in the south Mediterranean side could bring about interesting results with respect to the importance and availability of the solar bearing. The effects are not only relevant to the energy saving or the thermal comfort that the DSF procures, but include also the environmental aspects of quality. One example of study carried on an experimental cell equipped with the DSF in the west of Algeria is presented. A behavior model of DSF was realized and integrated in the computing simulation system TRNSYS. The results obtained are very promising because the heating and the warm sanitary water needs are satisfied at more than 60 % with an area ratio captor/ground = 0.1. These results are then compared to the other results obtained from equipment realized in France in order to estimate the solar bearing influence on this type of system.
On the other hand the incorporation of local materials, especially those based on the stabilized clay in cold conditions, in the building is an important element of thermal comfort. Simulations were carried out on a building of a given design by changing the building materials. These simulations show clearly the supply of comfort in terms of thermal stability, surrounding conditions and building energetic needs. Thus, the coupling system DSF/ local materials will certainly allow to improve the building energy performances, hence the reduction of the user's energy bill.

Keywords: solar buildings, heating, direct solar floor, heating needs, local materials, thermal comfort



Abdelkader Tahakourt

Diplome: Doctorat Thesis at The National Institute of Applied Science, (INSA) Rennes, France, July, 1992.
Education: Professor of Bejaia University since 1993.
Main range of scientific interests: reinforced concrete, heat transfer, thermal modelling in building.
Experience: Head of "Construction Materials team" at the LTMGP laboratory.
Research fields: heat transfer in building and local materials.
Publications: in Revue Générale de Thermique (now: International Journal of Thermal Science).

Abdelkarim Ait-Mokhtar

Diplome: Doctorat Thesis at The National Institute of Applied Science, (INSA) Rennes, France, January, 1993.
Education: Professor of La Rochelle University since 1994.
Main range of scientific interests: construction materials, behaviour laws of materials, diffusion through porous media.
Experience: Head of "Construction Materials team" at the LEPTAB laboratory.
Research fields: mass and aggressive agents transfer in porous materials, with application to the durability of materials and constructions. Development of new construction materials.
Publications: Publications in many international scientific journals.

Introduction

The European energetic bill in the building sector represents 40.7 % of the total energetic expenses. Besides, the heating of the residential premises represents the biggest part of the energy consumed for the house keepings of the European state members (57 %) followed by the production of domestic hot water needs (25 %) [1]. Also, the improvement by one point per year (1 %) of the energetic intensity in the final consumption will lead into more than 55 Mtep of economy over the whole energy consumption in the building sector. This leads to avoid 100 million tons of CO_2 emission per year; a quantity representing 20 % of EU commitment kept in Kyoto.

In order to reduce the energetic consumption in buildings and to improve the quality environmental aspect and the thermal comfort, several studies have been carried out [2-6]. To contribute to this research work, the energetic performance of a direct solar floor (DSF) system and local materials in building in the south-Mediterranean climate has been analysed. The reasons of our interest in the heating techniques by DSF are the large advantages such as availability of the solar energy in Algeria [7]; a uniform temperature so there is no cold or hot area [8], simple and not encumbering system contrarily to the classical solar heating systems, free energy.

Furthermore, the use of local materials known for their thermal and hygrometrical properties (absorption and adsorption of steam present in the ambient medium) allows to the indoor ambient conditions to be regulated (temperature, moisture), thus providing comfort for the occupiers [9].

The present work constitutes the first step of the study centred on the evaluation of a DSF performance using local materials. The aim of this phase is to show the impact of these two processes on the building comfort, the air quality and the energy consumption.

On one hand, an evaluation of DSF performance was realized (through a comparative study over two sites with different climates); on the other hand, an evaluation of the influence of using local materials was carried out (through a study on two buildings; one commonly used in current constructions with standard materials such as concrete and the other with bioclimatic architectural design in which the envelope is made of local materials.

Direct solar floor

The technique of heating using heating floors with hot water is particularly well adapted to low temperatures generators (high output boiler, condensation boiler, heating pump, solar collectors). In France, more than 20 % of the new houses use this technique for domestic hot water needs. However, this proportion remains small compared to other European countries (40 % in Germany and 50 % in Switzerland) [1].

The physical phenomena governing the thermal behaviour of the solar direct heating floor are difficult to approach, because of the inertia emitter and the coupling between the direct solar floor input and radiance input of transparent surfaces. In order to conduct this study, a bidimensional model of the DSF was developed [10, 11] and integrated in the TRNSYS environment [12]. The model is obtained after dividing the floor into a multitude of unites and nodes. The writing of equations of thermal assessment for the different nodes leads to a complex system of non linear equations. The problem solving is done by using thermal response factors method. The meshes system adopted is the one of a bidimensional model with finite differences (Fig. 1). This method considers linear thermal exchanges (conduction, convection and radiation) and assumes invariant character of the couple excitations/responses where the same reasons produce the same effects.

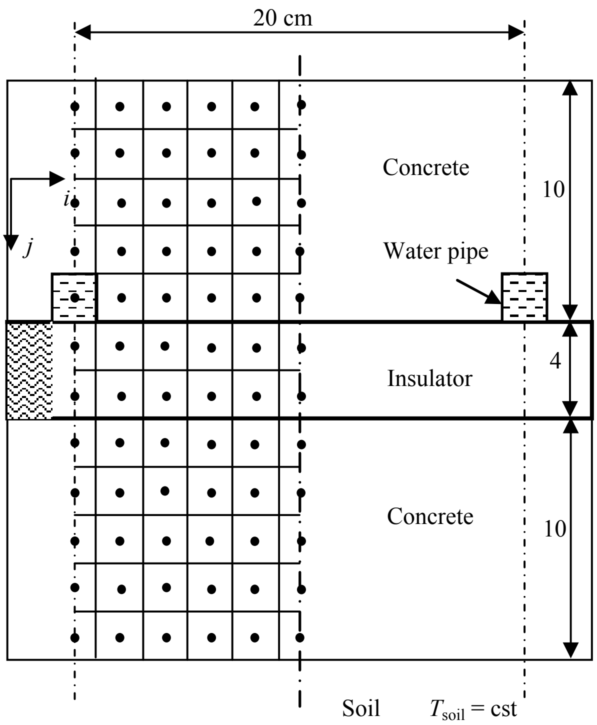


Fig. 1. *Meshing scheme of the model*

The response factors method principle consists in following the evolution of the system response to a triangular or rectangular excitation (Fig. 2). The unitary triangular excitation response is sampled following a time step taken usually equal to an hour.

So, we obtain a series of discrete values. Since the system is linear, the superposition of effects is adopted. Thus, each sollicitation can be decomposed into a series of discrete triangular elements and the system response will be the sum of responses corresponding to each triangular solicitation. For the direct solar floor, the excitations to consider are of four types: air temperature, floor surface temperature, injected power in pipes and absorbed solar flow on surface. The response factors are numerically calculated using the differences method with

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alternated directions (ADI) [13]. In this method, Δt is divided to two time steps. In first time step, $T^{t+\Delta t/2}$ is calculated, implicitly according to x and explicitly according to y. In the second one, $T^{t+\Delta t}$ is calculated implicitly according to y and explicitly according to x. Such a method is unconditionally convergent.

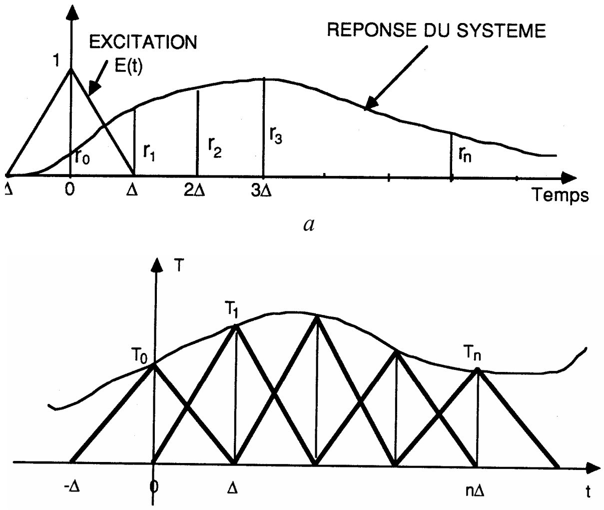


Fig. 2. *The principle of the method of the response factors: a – sampling of the response to a triangular unitary solicitation; b – decomposition of the solicitation into triangular elements*

Theoretical analysis

An orthogonal mishe of Δx and Δy dimensions is used (Δx and Δy variable). Thermal energy balance equations are written for the different floor nodes.

The basic equation of heat transfer in bidimensional model is written:

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}=\frac{1}{a}\frac{\partial T}{\partial t};$$

$$\frac{\partial^2 T}{\partial x^2}=\frac{1}{\Delta x}\left[\frac{T^t_{(i+1,j)}-T^t_{(i,j)}}{\Delta x}+\frac{T^t_{(i-1,j)}-T^t_{(i,j)}}{\Delta x}\right];$$

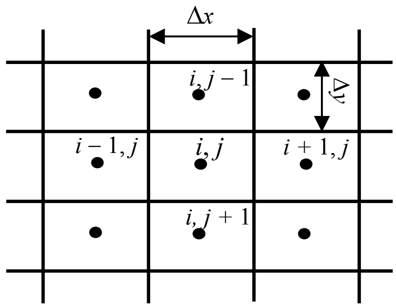
$$\frac{\partial^2 T}{\partial x^2}=\frac{1}{\Delta x^2}\left[T^t_{(i+1,j)}-2T^t_{(i,j)}+T^t_{(i-1,j)}\right];$$

$$\frac{\partial^2 T}{\partial y^2}=\frac{1}{\Delta y^2}\left[T^t_{(i,j+1)}-2T^t_{(i,j)}+T^t_{(i,j-1)}\right];$$

$$\frac{\partial T}{\partial t}=\frac{T^{t+\Delta t}_{(i,j)}-T^t_{(i,j)}}{\Delta t},$$

where a – material diffusivity: $a = \lambda/\rho c$, where λ – thermal conductivity, c – specific heat, ρ – density, Δt – time step.

**** Interior nodes (concrete, insulator, soil)***



For (i, j) node, the following equation is obtained:

$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}= =\frac{a}{\Delta x^2}\left[T_{(i+1,j)}-2T_{(i,j)}+T_{(i-1,j)}\right]+ +\frac{a}{\Delta y^2}\left[T_{(i,j+1)}-2T_{(i,j)}+T_{(i,j-1)}\right]; \qquad (1)$$

n values are 1 then 2.

$\underline{n=1}$:

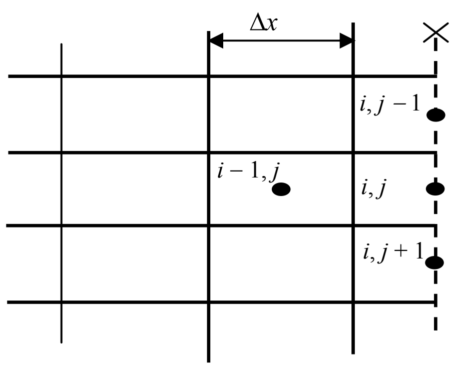
$$-\frac{a}{\Delta x^2}T_{(i+1,j)}\left(t+\frac{\Delta t}{2}\right)+\left(\frac{2a}{\Delta x^2}+\frac{2}{\Delta t}\right)T_{(i,j)}\left(t+\frac{\Delta t}{2}\right)- -\frac{a}{\Delta x^2}T_{(i-1,j)}\left(t+\frac{\Delta t}{2}\right)=\frac{a}{\Delta y^2}T_{(i,j+1)}(t)+ +\left(\frac{-2a}{\Delta y^2}+\frac{2}{\Delta t}\right)T_{(i,j)}(t)+\frac{a}{\Delta y^2}T_{(i,j-1)}(t),$$

$\underline{n=2}$:

$$-\frac{a}{\Delta y^2}T_{(i,j+1)}(t+\Delta t)+\left(\frac{2a}{\Delta y^2}+\frac{2}{\Delta t}\right)T_{(i,j)}(t+\Delta t)- -\frac{a}{\Delta y^2}T_{(i,j-1)}(t+\Delta t)=\frac{a}{\Delta x^2}T_{(i+1,j)}\left(t+\frac{\Delta t}{2}\right)+ +\left(\frac{-2a}{\Delta x^2}+\frac{2}{\Delta t}\right)T_{(i,j)}\left(t+\frac{\Delta t}{2}\right)-\frac{a}{\Delta x^2}T_{(i-1,j)}\left(t+\frac{\Delta t}{2}\right).$$

**** Nodes on symmetry axes:***

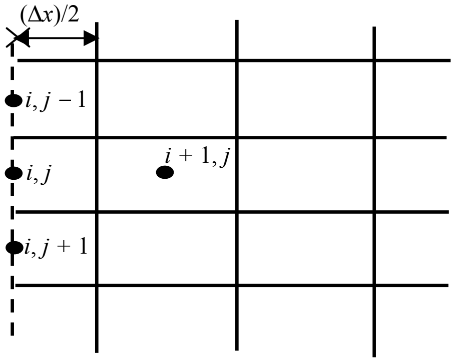
Nodes on axis of symmetry of pipes



$$\frac{T(i,j)\left(t+\frac{n\Delta t}{2}\right)-T(i,j)\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}=$$

$$=\frac{a}{\Delta x^2}\left(T_{(i-1,j)}-T_{(i,j)}\right)+\frac{a}{\Delta y^2}\left(T_{(i,j-1)}-2T_{(i,j)}+T_{(i,j+1)}\right)$$

Nodes along pipes



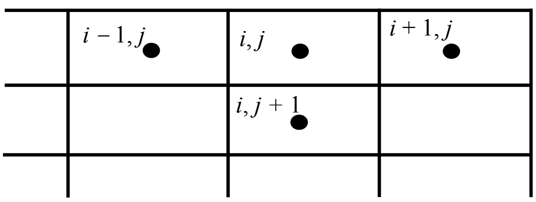
$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}=$$

$$=\frac{a}{\Delta x^2}\left(T_{(i+1,j)}-T_{(i,j)}\right)+\frac{a}{\Delta y^2}\left(T_{(i,j-1)}-2T_{(i,j)}+T_{(i,j+1)}\right)$$

**** Surfaces floor nodes***

These nodes are characterized by a limit condition of Dirichlet (imposed surface temperature) or of Fourier (imposed ambient temperature and conductance). When the floor rests on soil, the temperature of soil is considered constant.

Upper surface



$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}=$$

$$=\frac{a}{\Delta x^2}\left[T_{(i+1,j)}-2T_{(i,j)}+T_{(i-1,j)}\right]+$$

$$+\frac{1}{\Delta y}\left[\frac{a}{\Delta y}T_{(i,j+1)}-\left(\frac{a}{\Delta y}+\frac{2a}{\Delta y+2\frac{\lambda}{h}}\right)T_{(i,j)}+\frac{2a}{\Delta y+2\frac{\lambda}{h}}T\right], \quad (2)$$

where T − imposed temperature (surface temperature or ambient temperature).

When a surface temperature is imposed, the equation (2) remains valid on condition to take a large value of h ($\lambda/h \rightarrow 0$).

Surface below

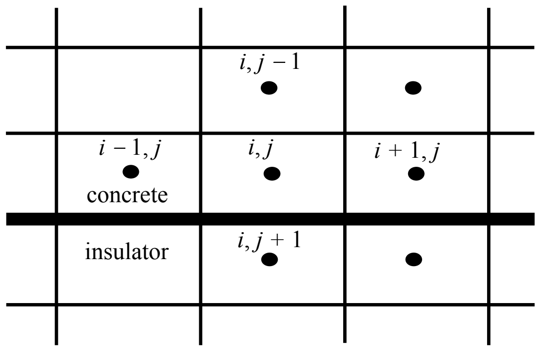
$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}=$$

$$=\frac{a}{\Delta x^2}\left[T_{(i+1,j)}-2T_{(i,j)}+T_{(i-1,j)}\right]+$$

$$+\frac{1}{\Delta y}\left[\frac{a}{\Delta y}T-\left(\frac{a}{\Delta y}+\frac{2a}{\Delta y+2\frac{\lambda}{h}}\right)T_{(i,j)}+\frac{2a}{\Delta y+2\frac{\lambda}{h}}T_{(i,j-1)}\right].$$

**** Nodes in concrete-insulator interface***

It concerns the nodes situated in concrete (or insulator) which change heat with the nodes situated in insulator (or in concrete). The case of nodes in concrete is developed below.



Thermal resistance concrete-insulator:

$$R_1=\frac{\Delta y/2}{\lambda_1}+\frac{\Delta y/2}{\lambda_2}=\frac{\Delta y}{2}\left[\frac{1}{\lambda_1}+\frac{1}{\lambda_2}\right]=\frac{\Delta y}{2}\frac{\lambda_1+\lambda_2}{\lambda_1\lambda_2},$$

where λ_1 − thermal conductivity of concrete, λ_2 − thermal conductivity of insulator.

The conductance K_1

$$K_1=\frac{1}{R_1}=\frac{2\lambda_1\lambda_2}{\Delta y(\lambda_1+\lambda_2)}.$$

The energy balance for these nodes:

$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}\rho_1 c_1\Delta x\Delta y=$$

$$=\frac{\lambda_1}{\Delta y}\Delta x\left[T_{(i,j-1)}-T_{(i,j)}\right]+\frac{2\lambda_1\lambda_2}{\Delta y(\lambda_1+\lambda_2)}\Delta x\left[T_{(i,j+1)}-T_{(i,j)}\right]+$$

$$+\frac{\lambda_1}{\Delta x}\Delta y\left[T_{(i-1,j)}-2T_{(i,j)}+T_{(i+1,j)}\right],$$

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$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}=$$

$$=\frac{a_1}{\Delta y^2}T_{(i,j-1)}-\left[\frac{2a_1\lambda_2}{\Delta y^2(\lambda_1+\lambda_2)}+\frac{a_1}{\Delta y^2}+\frac{2a_1}{\Delta x^2}\right]T_{(i,j)}+$$

$$+\frac{a_1}{\Delta x^2}\left[T_{(i-1,j)}+T_{(i+1,j)}\right]+\frac{2a_1\lambda_2}{\Delta y^2(\lambda_1+\lambda_2)}T_{(i,j+1)}.$$

**** Nodes in contact with water pipe***

The water temperature T_F is considered constant $T_F=\frac{T_E+T_S}{2}$, where T_E, T_S are respectively inlet and outlet water temperature in pipe.

These nodes change heat with water through the pipe. The expression of the conductance K_1 between water and the node (i, j) in concrete (or in insulator K_2) is given as a function of convection coefficient in water h and concrete (or in insulator) thermal resistance R.

$$K_1=\frac{1}{R_1},\quad R_1=\frac{1}{h}+\frac{e_t}{\lambda_t}+\frac{\Delta x}{\lambda_1},\ h=\frac{Nu\cdot\lambda_3}{D},$$

where e_t – pipe thickness, λ_t – pipe conductivity, Nu is Nusselt number which is calculated as a function of Reynolds Re and Prandt Pr numbers, pipe length and internal diameter.

The thermal balance for (i, j) node in concrete is:

$$\frac{T_{(i,j)}\left(t+\frac{n\Delta t}{2}\right)-T_{(i,j)}\left(t+\frac{(n-1)\Delta t}{2}\right)}{\Delta t/2}\rho_1 c_1\Delta x\Delta y=$$

$$K_1\Delta y\left[T_F-T_{(i,j)}\right]+\frac{2\lambda_1\lambda_2}{\Delta y(\lambda_1+\lambda_2)}\Delta x\left[T_{(i,j+1)}-T_{(i,j)}\right]+$$

$$+\frac{\lambda_1}{\Delta x}\Delta y\left[T_{(i+1,j)}-T_{(i,j)}\right]+\frac{\lambda_1}{\Delta y}\Delta x\left[T_{(i,j-1)}-T_{(i,j)}\right].$$

Local materials

The thermal behaviour of traditional houses using clay-based local materials "adobe" was analysed [9]. So, the thermal and mechanical characterization of these materials was realized, in addition a simplified model of the material behaviour was used. The traditional material characteristics used in the simulation were measured in the laboratory on the adobe samples with the following composition; 100 g of clay, 10 g of ACP-CEMI 52.5 (stabilizing agent) and 2 g of straw with a ratio water/clay = 50 %.

The performances of this type of house were compared to those obtained with a "modern" house using brick walls.

Results and discussion

Direct solar floor

For a better approach of the feasibility of the DSF, we have compared its performance using two climatic sites; Oran (Algeria) and Carpentras (France) sites [14, 15]. The simulated building represents an experimental cell composed with two rooms of the same dimensions but only one is equipped with DSF, the second one is considered as a reference room. Concerning the floor, we used two heating slabs of reinforced concrete (10 cm) separated with a layer of polystyrene (4 cm) where the network of pipes is put directly on the insulating material [10].

The simulations results show that in Oran, the rate of the solar coverage is about 64 % (heating HEA and domestic hot water DHW) with a collecting ratio about 0.1. In this case, the additional energy to supply is only about 36 % of the needs (Fig. 3). This coverage goes up to 89 % with a collecting ratio equal to 0.2 against 45 % for the French climate; that is to say about 50 % fewer (Fig. 4).

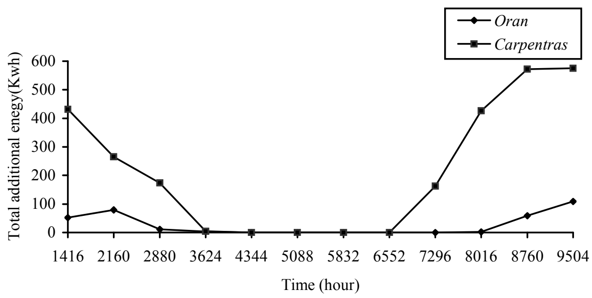

Fig. 3. *The evolution of the necessary additional energy quantity in the two regions; Oran and Carpentras*

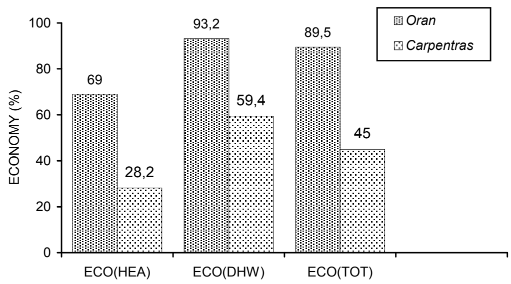

Fig. 4. *The evolution of the solar coverage in the two regions (collecting ratio = 0,2)*

Concerning free temperature evolution (without auxiliary system), we notice that the internal temperature close the comfort temperature (Fig. 5). So, we can forward that DSF heating technique applies in the southern Mediterranean climate.

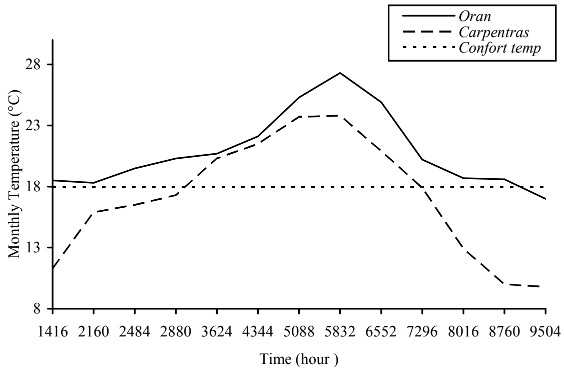

Fig. 5. *Free evolution of internal temperature with DSF only*

Another installation which has been realized in "Chartres de Bretagne" (west of France) [12], shows that for oceanic climate, where the diffused radiance is predominant, the energetic bill is covered at 40 %. The follow up of the installation performances was realized for two consecutive periods of heating on a house built on earth platform and having one floor under roof. The south façade consists of 15 m^2 glasshouse. The DSF system was installed in both floors (platform and floor). The solar collectors are of 12.15 m^2 (collecting ratio equal to 0.1) and are built-in the south roof. The Fig. 6 summarizes the installation energy balance. In summer, the installation supplies 100 % of domestic hot water, so, the annual thermal production is about 416 Wh per 1 m^2 of collectors.

The results show the influence of solar potential on the energetic needs cover of buildings, hence the interest in the use of DSF as an alternative heating solution.

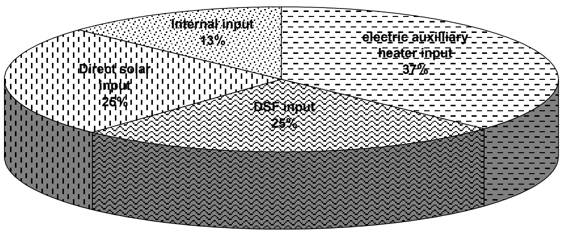

Fig. 6. *Repartition of different sources of energy contributions*

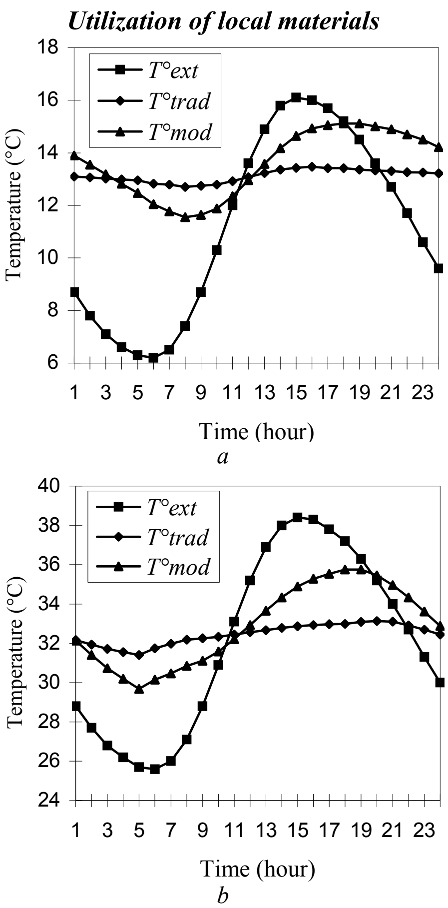

Fig. 7. *Temperature evolution in the two buildings: a – typical January day; b – typical August day*

Simulations were carried out on two buildings with the same habitable area, one with a traditional architecture using local materials like adobe, the other one with a modern architecture (classic flat) [9]. The results are presented for two typical days: wintry and summery. It is necessary to point that no heating system was used.

Analysing the free external and internal temperatures evolution (Fig. 7), we have observed that the traditional house presents better insulating and thermal comfort in summer. However, it is necessary to heat in winter in order to reach the comfort temperature.

he humidity evolution (Fig. 8) is more stable in summer. Its level, lower than the one in modern house, shows the possibilities of utilization of passive cooling systems.

We conclude that, by using local materials, the internal temperatures and relative humidity are almost constant and are close to the building comfort conditions.

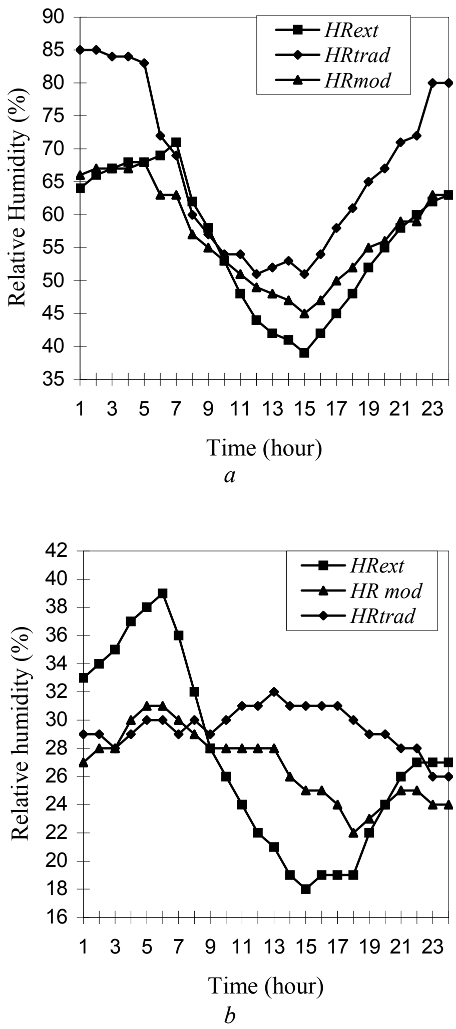

Fig. 8. *The evolution of relative humidity in the buildings: a – typical January day, b – typical August day*

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Coupled utilization of direct solar floor and local materials

The interesting results on the solar cover rate of DSF system with a ratio of 0.1 on one hand, and the thermal comfort without conditioning during summer and a small contribution of heating during winter using local materials on the other hand, lead us to the idea of coupling both systems to assure the thermal comfort with lesser cost and above all to protect the environment. We test this system by using the DSF in a building with local materials (traditional building) on one hand and with brick walls (modern building) on the other hand. The data used are those of Bechar city.

Internal temperatures and thermal comfort

The temperatures obtained in the traditional building change very little. The difference between the maximal temperatures and the minimal one is about 2 °C during the coldest week compared to 4 °C in the second building (Fig. 9, *a*). During the very coldest day where the average external temperature recorded is 4.75 °C, we noted 16.16 °C in the modern building and only 11.96 °C in the other one (Fig. 9, *b*).

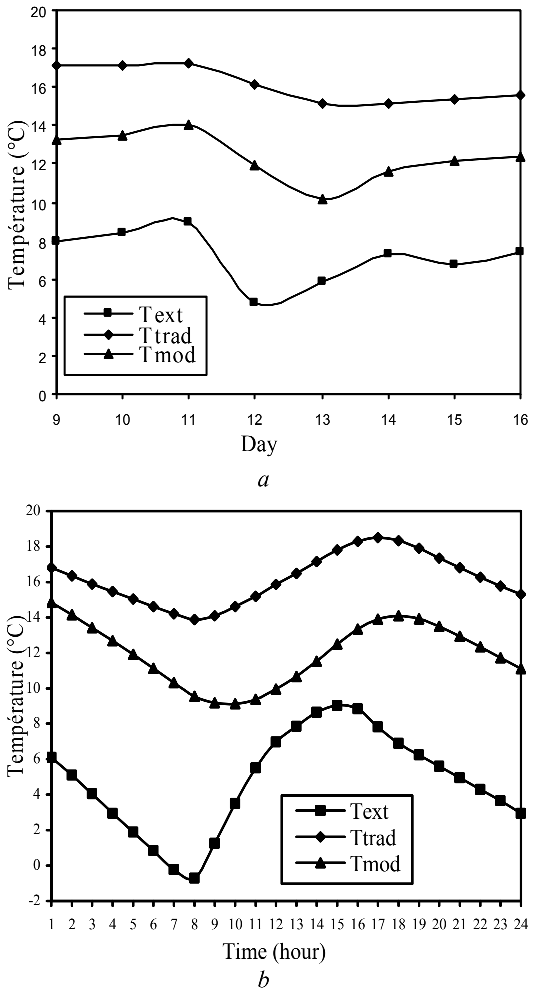

Fig. 9. *Temperature evolution in the two buildings with DSF: a – 9 to 16 January week, b – 12 January day*

We also compared internal temperatures before and after using DSF in both buildings (Fig. 10). We saw that the DSF brings a distinct improvement of comfort conditions in the traditional house (Fig. 10, *a*) where the increase in temperature reached 6 °C against only 3 °C in the second one (Fig. 10, *b*). This is due to the inertia effect of the adobe which has an important storage potential. This permits it to accumulate heat and to release it to the internal ambiance when the external temperature decreases. With bricks materials, the internal temperature evolution follows, without redemption, the external temperature fluctuations.

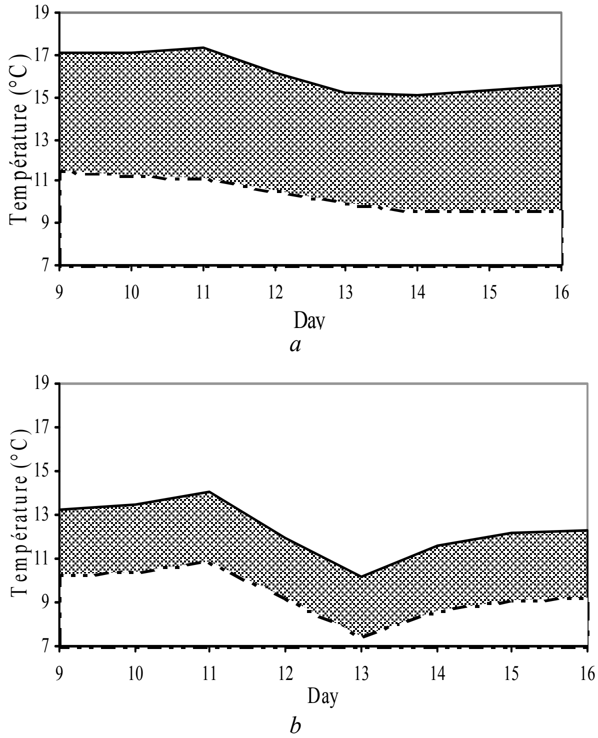

Fig. 10. *Temperature evolution in the two buildings before and after DSF incorporation: a – traditional building, b – modern building*

Performance and energetic saving

We also analysed the influence of coupled utilization of DSF and local materials on energy saving. We noted solar cover rates (COS) varying from 60 to 100 % (Fig. 11). During April month, the difference noted is about 47 % between the tow buildings. In the same way, cooling needs during summer were evaluated. Concerning the hottest month, the needs are three times as big in modern building (Fig. 12). We come back to the storage capacity of adobe which stores coolness during night and releases it during day. This particularity shows that the construction with adobe walls is particularly adapted to climates which have great difference between diurnal and nocturnal temperatures.

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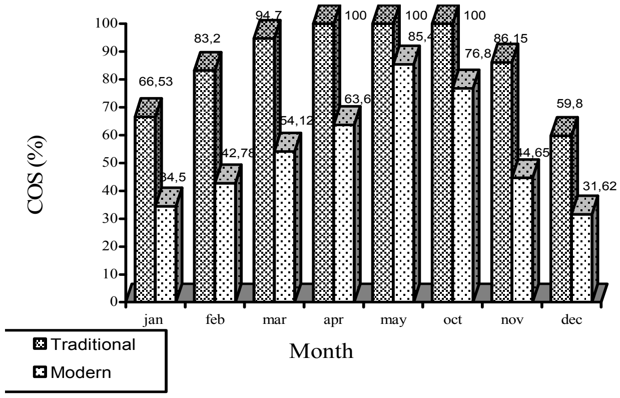

Fig. 11. Evolution of heating saving brought by using DSF in the two buildings

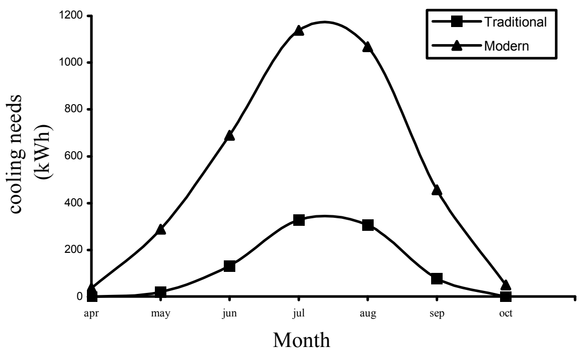

Fig. 12. Evolution of cooling needs in the two buildings

Conclusion

The results obtained for systems, direct solar floor and the utilization of local materials, put in evidence a lot of information. Indeed, in desert regions, construction using local materials offers better insulation and comfort during summer than the modern materials.
Also, the passive systems of cooling seem to adapt easily this type of construction.
The results obtained on the three installations of the same type showed the important role played by the solar bearing in the case of the direct solar floor heating. Excellent performance was obtained in Algeria with solar cover rates reaching 90 %. The simultaneous use of the two techniques underlined the interest of this solution in order to reduce energy use in buildings and ameliorate comfort conditions in hot climates. Also, it is imperative to pay attention to the choice of materials according to climatic data in the conception phase of buildings.

References

1. CEE report, Directive proposition European parliament and council about the energetic performance of buildings, Brussels 11/05/2001.
2. Sockolay S.U. Climate analysis based on the psychometric chart // International Journal of Ambient Energy. Vol. 7, No. 4. October 1986. Australia.
3. Givoni B. Man, climate and architecture. Second edition // Applied Sciences Publication, London, 1976.
4. Santamouris M. (Coordinator). Natural Cooling Techniques. Design Methodology and Application to Southern Europe. Pascool Final Report, European Commission, Directorate General XII For Science Research and Development, edited in 1995.
5. Belarbi R., Allard F. Atlas of natural cooling techniques application of evaporative cooling system. Second European Conference on Energy Performance and Indoor Climate in Buildings (EPIC'98), Lyon, November 1998.
6. Belarbi R. Développement d'outils méthodologiques d'évaluation et d'intégration des systèmes évaporatifs pour le rafraîchissement passif des bâtiments. Thèse de Doctorat Université de La Rochelle (France), July 1998.
7. Lalonde B. Du neuf sous le soleil // Solar systems revue. 64-65 (1991).
8. Jean A., Papillon P. Direct solar floor development. Journeys "Thermal Solar". Paris, October 1994.
9. Benhabib R., Ait-Mokhtar A., Allard F. Bioclimatic analysis of traditional houses in the north-Sahara regions.
10. Kazeoui H. Direct solar floor influence on the conditioning of buildings in Maghreb context. Magister Thesis, USTO (Algeria) 1997.
11. Tahakourt A. The study of the thermal behaviour of direct solar floors in the transient regime using the response factors method: experimental validation. Doctorate Thesis, INSA Rennes, France, 1992.
12. TRNSYS, Transient simulation system. Software of thermal simulation of buildings. University of Madison (Wisconsin, USA).
13. Larbi Youcef M.H. Contribution à l'étude d'un PSD sur terre-plein. Thèse de Doctorat, INSA Toulouse, 1987.
14. Kazeoui H., Mokhtari A., Achard G., Boukezzi Y. Climatic conditioning of buildings in the Maghrebin context: Direct solar floor for heating / Hydraulic floor for cooling. 8th international days of thermic (JITH), Marseille, July, 1997.
15. Papillon P. Contribution to the amelioration of direct solar floor technique. The analyses of thin slabs solution and optimized management of auxiliary heating. Doctorat thesis. University of Savoie, 1992.

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