Study Of Air Solar Collectors Systems For Habitations In Madagascar

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Abstract: A air solar collector is a thermic system that uses the solar energy to produce heat warming up a fluid circulating inside the system. There are two types of solar collectors that can be used as an air conditioning system in a habitation: water solar collectors and air solar collectors. In this work, we studied air solar collectors which is based on the circulation of heated air inside a serpentine for warming or cooling a house. A new analytical approach based on the F-chart method have been proposed to calculate the solar covering rate of the heating air requirements in the habitation. Besides, the overall efficiency of the system depends especially on the quantity of heat stored by time unit in the storage tank of the installation.

Index Terms: Air conditioning, air solar collectors, cooling, efficiency, habitation, solar energy, thermic system, warming.

1 Introduction

Solar energy belongs to renewable energy category. It constitutes a green energy and is accessible to everyone. For Madagascar, air conditioning takes an important part in domestic energy consumption. Furthermore, due to climate change, needs of cooling will be increase in the near future. Thus, houses built for present or next generations require much energy at a lower cost. In this context, we propose solving problems about habitation's energy autonomy by using solar energy while giving preference to thermal comfort inside the house. Hence, this work is devoted to study air solar cooling system for a habitation. For that, we will see in the first section of this article a short syllable introduction of the direct use of the solar energy. Then, a deep study of air solar collectors will be done. It includes especially the description of the functioning of the thermal system, the thermal balance of each parts of the collector and the calculation of the solar covering. Finally, we will present the habitation modelling.

2 Direct Use Of Solar Energy

In this study, two distinct categories of solar energy are implemented to rationalize this renewable energy: thermic solar energy and photovoltaic solar energy.

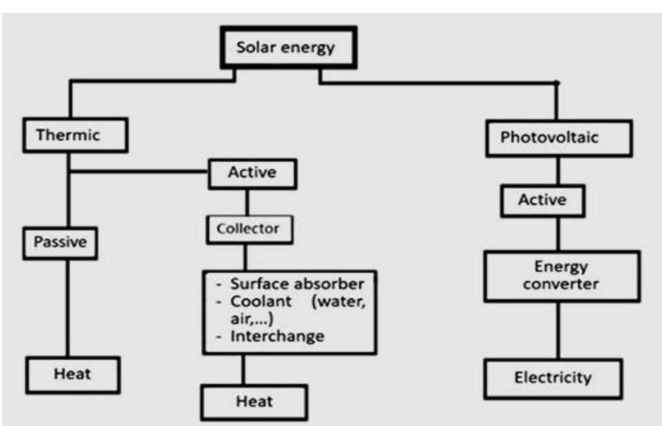

Fig. 1. Synoptic scheme of the direct use of the solar energy

The thermic system uses the solar energy to produce heat by warming up a fluid at a lower or higher temperature. One can see this concept with thermic solar collectors. For the photovoltaic solar system, it transforms a part of radiations from the sun into electric energy.

3 Air Solar Collectors

Air solar collectors are sensors in the form of panels placed on a roof. Ordinary roof tiles can be replaced with special sensor tiles as sensor. It is also possible to capture directly the heat under ordinary slates. The performance of these sensors depends on the used materials, the shape of the tiles, the used coating and the treatment of the rear force of the absorber (Fig. 3.). This last is an important element of the studied system.

3.1 Functioning of the air solar collector

In a air solar collector, a fluid which is the air circulates inside metallic serpentine welded to a black plate called absorber. For best performance, the set is placed in a glazed insulating frame. With a good sunniness and if the ambient temperature is not too low, a simple network of serpentine can constitute a panel with a good performance.

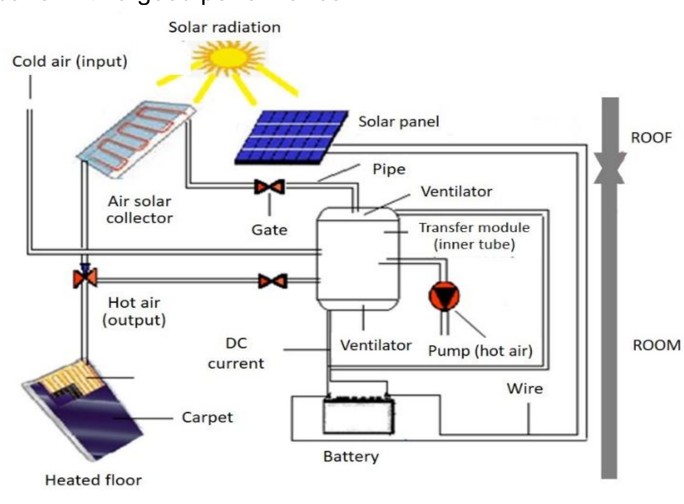

***Fig.2.** Descriptive scheme of the studied system*

The absorber is warmed up by solar radiation and transmits its heat to the fluid circulating inside the serpentines. The absorber is painted in matte black to capture a maximum of light energy. The radiation warms the glass which dissipates a part of this energy outside by convection and radiation. This phenomenon increases the losses and decreases the yield. That's why it is interesting to use chromium-treated absorbers that emit much infra-red radiation. In this case, one talk about the selective surface of the system. This surface absorbs the visible radiation where most of the energy coming from the sun is located. The principle of the heating system or the solar cooling studied in this work is insured by adequate thermal sensors, oriented towards the sun. The storage of the heat allows to warm up the house with or without sunlight, it also allows the fair distribution of hot air according to the needs of each room of the house. In the southern hemisphere, sensors must be exposed towards the north to maximize energy efficiency during the winter and not to overheat the rooms during the summer. The heat is stored in the inert element of the frame like the slab or the floors… This system minimizes the use of solar thermal energy because it facilitates the circulation of the fresh air inside the room. It requires a very precise choice of materials to optimize the energy productivity, but it is a simple and less expensive system. The coolant circulating in the air sensor placed on the roof allows the redistribution of captured calories, the heating and the air conditioning of the house. This sensor is connected to a heat transfer module or an inner tube. The room is heated by the pump which distributes the heat captured via the coolant that circulates inside. The air solar collector is a system of both heating and cooling according to the adjustment of the gates. In this system, the inner tube becomes an energy regulator. The battery is powered by the solar energy captured by the solar panel, it provides the necessary energy to the fans.

3.2 Characteristics parameters of a solar collector

We will present here the characteristics parameters to take into account for the functioning of the solar collector. They can suit to two types of solar collectors: water solar collector and air solar collector. We can see below the different temperatures that intervene in the plane collector operating:

1. T_c: Temperature of the sky.
2. T_a: Ambient temperature.
3. G_n: Total energy received in a point of the globe by a surface that is perpendicular to the solar radiations.
4. T_V: Temperature of the glass of the collector.
5. T_1: Temperature reached by the glass.
6. T_2: Temperature of the absorber into the glass.
7. T_f: Temperature of the fluid.
8. T_{1f}: Inlet temperature of the coolant inside the collector.
9. T_{2f}: Outlet temperature of the coolant.

The external parameters that refer to the collector are the sunniness parameter that is the global lighting energy due to the global radiation, the sun position, the sunstroke duration, the dry outlet temperature, the relative humidity and the wind speed on the collector.

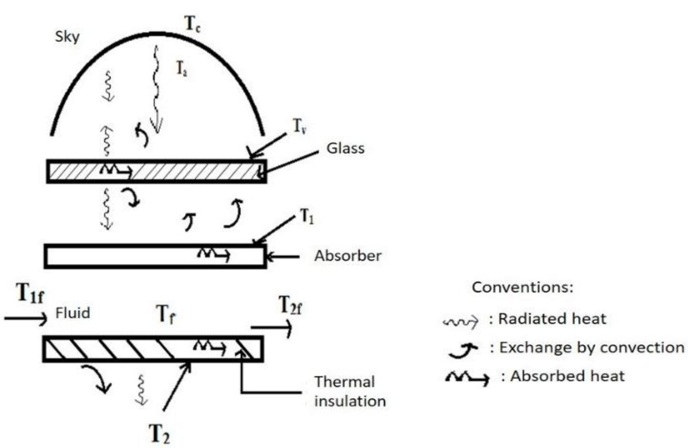

Fig.3. *Operating principle of a solar collector*

For the internal parameters, they are the position parameters including the inclination and the orientation of the collector, and the dimensions of the different parts of the collector: thickness, length and width. We also have to take into account the following parameters:

1. A: Area of the used collector. It's the sum of the surfaces of the sensor, the glass and the frame.
2. A_a: Inlet area. It is the area of the section that is perpendicular to the direct radiation being able to reach directly or by reflection the volume containing the absorber.
3. SP: Passage section of the coolant. It's the internal surface of the section that is perpendicular to the direct radiation reaching directly or by reflection the volume which contains the absorber.
4. $\dot{m}_f$: Flow of the coolant.
5. The temperatures of various parts of the collector.

Among these all characteristics parameters, the two following parameters allow to make a choice among various types of collectors: the outlet temperature of the coolant T_{2f} and the quantity of heat produced by the system.

3.3 Operating parameters of the solar collector

3.3.1 Yield of the system

The yield of the studied solar sensor is as follow:

$$\eta_c = \frac{\dot{q}_c}{A \cdot G_n} \qquad (1)$$

With, $\dot{q}_c$ the losses in storage tanks and pipes.

$$\dot{q}_c = \dot{m}_f \ C_f \left(T_{2f} - T_{1f}\right) \qquad (2)$$

With, C_f the specific heat of the coolant.

The overall efficiency of the air conditioning system can be calculated with the following equation:

$$\eta_g = \frac{\dot{q}_r}{A \cdot G_n} \qquad (3)$$

With, $\dot{q}_r$ the quantity of heat stored by time unit in the storage tank.

3.3.2 Thermal inertia of the sensor

The thermal inertia of the sensor is defined as its ability to store a heat and then to release it in a diffuse way. So, we use the parameter "a" called thermal diffusivity of the system to calculate the amount of heat transmitted by conduction into the coolant. Its value is given by:

$$a = \frac{\lambda_a}{\rho_a \cdot C_a} \qquad (4)$$

λ_a: Thermal conductivity of the absorber
ρ_a: Volumetric weight
C_a: Specific heat of the absorber

It is noticed that experimentally, in one hand, the inlet temperature T_{1f} of the fluid and the flow $\dot{m}_f$ of the coolant are fixed, on the other hand, the temperature of the sensor varies according to the sunniness.

3.3.3 Thermal balance of the glass

Equations corresponding to the energy balance [4] of the glass, the absorber, the coolant inside the collector, and the inner tube are as follows:

$$M_v C_V \frac{d\,T_v}{dt} = \sum_{j=1}^{3} Q_j - \left(\sum_{j=4}^{5} Q_j\right) = Q_1 + Q_2 + Q_3 - Q_4 - Q_5 \quad (5)$$

The amount of heat Q_j are:

1. The amount of heat Q_1 absorbed by the glass is defined by:

$$Q_1 = AG_n\alpha_v \quad (6)$$

With α_v is the factor of absorption of the glass.

2. The amount of heat Q_2 radiated from the absorber to the glass is:

$$Q_2 = A\,\sigma\epsilon_v\,(T_1^4 - T_v^4) \quad (7)$$

σ : Constant of Stefan-Boltzmann or factor of sunstroke
ϵ_v : Emission factor of the glass

3. The amount of convective heat Q_3 from the absorber to the glass is as follow:

$$Q_3 = Ah_{C1V}.(T_1 - T_V) \quad (8)$$

With Ah_{C1V} is the coefficient of exchange by convection

4. The amount of heat Q_4 radiated from the glass towards the sky is defined by:

$$Q_4 = A\,\sigma\epsilon_v\,.(T_1^4 - T_v^4) \quad (9)$$

5. The amount of convective heat Q_5 from the glass towards the outside is:

$$Q_5 = Ah_{cva}.(T_V - T_A) \quad (10)$$

3.3.4 Thermal balance of the absorber

The thermal balance of the absorber is as follow:

$$M_1 C_1 \frac{dT_1}{dt} = G_n\tau_v - Q_2 - Q_3 - Q_6 \quad (11)$$

τ_v : Factor of transmission of the air that traverses the sensor.
M_1 : Energy emittance by the glass
C_1 : Massive heat through the glass
Q_6 : Amount of convective heat from the absorber to the coolant.

$$Q_6 = Ah_{c1f} \times (T_1 - T_f) \quad (12)$$

Admitting that:

$$T_f = \frac{(T_{1f} + T_{2f})}{2} \quad (13)$$

the instant yield becomes:

$$\frac{\dot{q}_c}{A} = [\,G_n\tau_v\alpha_1 - K\,(T_1 - T_a)] \quad (14)$$

$\frac{\dot{q}_c}{A}$: Amount of heat received by the coolant per unit of time and per receiving surface unit.

K: Load factor of the thermal loss

The average temperature of the absorber T_1 is experimentally much more difficult to reach than the temperature of the coolant, hence we set by convention [1].

$$\frac{\dot{q}_c}{A} = F.\left[\,G_n\tau_v\alpha_1 - K\,(T_1 - T_a)\right] \quad (15)$$

Where F is defined as the ratio between the quantity of heat really extracted and the amount of heat extracted if the absorber was at the temperature of the fluid which is defined by:

$$T_f = \frac{T_{1f} + T_{2f}}{2} \quad (16)$$

If $T_f \leq T_1$ hence $F \leq 1$

Hence, we have the instantaneous efficiency of the studied solar collector:

$$\eta_c = F\left[\tau_v\alpha_1 - \frac{K\,(T_1 - T_a)}{G_n}\right] \quad (17)$$

For an ideal sensor F≈1, that means $T_1 \approx T_f$
.

3.3.5 Thermal balance of the coolant

For the coolant circulating inside the sensor, the thermal balance is defined as follow:

$$M_f C_f \frac{dT_1}{dt} = Q_6 - Q_7 - Q_8 \quad (18)$$

Q_7 : Amount of heat interchanged by convection between the coolant and the exterior.

$$Q_7 = h_{cfa}\,A\,(T_f.\,T_a) \quad (19)$$

Q_8 : Amount of heat interchanged by conduction between the fluid and the exterior.

$$Q_8 = \dot{m}_{cfa}\,A(T_f.\,T_a) \quad (20)$$

3.3.6 Thermal Balance of the inner tube

By neglecting the radiated heat towards the exterior, the thermal balance of the inner tube is:

$$\dot{m}_u\,C_u \cdot \frac{dT_u}{dt} = Q_8 - Q_9 - Q_{10} \quad (21)$$

Q_9 : Amount of heat lost by convection at the periphery of the inner tube.

$$Q_9 = A_r h_{cra}\,(T_r - T_a) \quad (22)$$

T_r : Average temperature inside the inner tube.

A_r : Exterior area of the inner tube.

Q_{10} : Amount of heat used and drawn from the inner tube.

$$Q_{10} = \dot{m}_u \, C_u \cdot (T_u . T_{ap}) \quad (23)$$

$T_u \approx T_r$
$\dot{m}_u$: Mass flow

3.3.7 Thermal equilibrium of the system

The following equations should be applied to have a thermal equilibrium of the system. For the glass which is assimilated to a transparent covering, the corresponding equation is:

$$U_t \; (T_v - T_e) = h_r(T_c - T_v) + h_1(T_f - T_v) \quad (24)$$

T_e: Room temperature
U_t: Heat transfer coefficient between the glass and the ambient air
h_1: Transfer coefficient between the glass and the air of the sensor
h_r: Coefficient of transmission by radiation between the glass and the absorber
For the absorber, we have:

$$\eta_0 \, G_t = U_{ar}(T_c - T_v) + h_2(T_c - T_f) + h_r(T_c - T_v) \quad (25)$$

η_0: Optical efficiency of the sensor
U_{ar}: Rear loss coefficient
h_2: Transfer coefficient between the absorber and the air of the sensor
For the coolant (air):

$$h_2 \; (T_v - T_f) = \frac{1}{l}\frac{dq_u}{dy} + h_1(T_c - T_f) \quad (26)$$

l: Sensor width at a given point of the sensor
dq_u: Amount of heat extracted by the air
dy: Length element of the sensor
The three equations (24), (25) and (26) give:

$$dq_u = F' \, [G_t \eta_0 - U_c(T_f - T_e)] l . dy \quad (27)$$

With,

$$U_C = \frac{U_{ar} \, U_t(h_1 + h_2) + (U_t + V_{ar}) \, (h_r h_1 + h_r h_2 + h_1 h_2)}{h_2 U_t + h_r h_1 + h_r h_2 + h_1 h_2} \quad (28)$$

$$F' = \frac{h_2 U_t + h_r h_1 + h_r h_2 + h_1 h_2}{(V_{ar} + h_2 + h_2)(V_t + h_1 + h_2) - h_r^2} \quad (29)$$

The equation of energy conservation for an element of volume located between the glass and the absorber length dy following the direction of the flow of the fluid is:

$$\dot{m}_{cp} \frac{d \, T_e}{dy} = l \, F'[\eta_0 G_t - U_c \, (T_f - T_e)] \quad (30)$$

Where F' is the efficiency of the absorber.

$$F' = \frac{U_F}{U_c + U_f} \quad (31)$$

U_f: Fluid flow
U_c: Heat transfer coefficient inside the absorber
The power absorbed by the sensor is:

$$q_u = AF_r[\eta_0 G_f - U_c(T_{fi} - T_e)] \quad (32)$$

T_{fi} : Inlet temperature of the fluid
F_r : Factor of conductance of the sensor. $F_r \approx 0.95$ [3]

$$F_r = \frac{\dot{m}.C_p}{A.V_c}\left[1 - \exp\left(-\frac{F'.A.V_c}{\dot{m}.C_p}\right)\right] \quad (33)$$

The temperature of the air inside the tube can be calculated via the following equation:

$$T_{F0} = T_{fi} + \frac{q_u}{\dot{m}C_p} \quad (34)$$

3.4 Solar heating – solar covering

In this work, we study two systems associating solar collectors with a short-term storage: "*air solar systems*", for which the sensors are air circulation and the storage is inside the inner tube; the "*direct solar floor*", for which the sensor is circulating air and the storage of the floors is directly used for the heating. The solar covering is the relative part of the heating needs and covered by the solar energy. It is determined by the raw solar covering which corresponds to a fictitious storage and which supposes that the factor of intermittency and the yield of the solar system are equal to one. The corrected solar covering corresponds to the studied storage and takes into account real values of the factor of intermittency and the yield of the solar heating.

3.4.1 Raw solar covering

The parameters to take into account for the study of the raw covering solar are the surface A (m²), the orientation and the inclination of the collector which are characterized by the coefficient C1. This last is defined as the ratio between the effective solar energy received during the winter by the considered area (kWh) and the solar energy received by a vertical surface (m^2) faces to the North. The following table gives the values of C1 according to the orientations of the sensors and their inclination compared to the horizontal.

TABLE 1.
VALUES OF THE COEFFICIENT C1

Inclination of the collectors (°)	Orientations of the collectors				
	N	NNE and NNW	NE and NW	ENE and WNW	E and W
75 to 90	1	0.90	0.80	0.60	0.35
65 to 80	1.15	1.10	0.95	0.75	0.50
55 to 70	1.20	1.15	1.00	0.85	0.60
35 to 50	1.15	1.10	1.00	0.85	0.65
25 to 40	1.05	1.00	0.95	0.80	0.65
0 to 20	0.85	0.80	0.80	0.70	0.65

The raw solar covering F_{chb} is calculated according to the climatic zone and X which is the ratio between the available solar contribution and the needs during the heating period. Hence, X can be calculated by:

$$X = \frac{A . F_{ts} . F_e \cdot C \cdot G_n \cdot C_{Cl}}{B_{ch}} \quad (35)$$

C: Coefficient of the direct solar floor
C_{Cl}: Local climatic factor, (dimensionless number). $C_{cl} \approx 1.2$
B_{ch}: Heating needs of the home

F_e: Sunniness factor
F_{ts}: Solar transparency factor of the walls. Its expression is:

$$F_{ts} = \alpha . ECP \left(1 - C_p \frac{A.\beta+\beta_t}{A\,\alpha}\right) \quad (36)$$

ECP: Efficiency of the primary circuit
C_p is a "loss coefficient" expressed in (m^2°C /W). For air solar system, C_p is equal to 0,035 m2°C /W. For direct solar floors, the value of Cp is 0,018 m2°C /W.

Hence, the raw solar covering can be expressed as follow:

$$F_{chb} = \frac{0{,}77 \cdot X^3}{1.47+1.89X^2+X^3} \quad (37)$$

3.4.2 Efficiency of the primary circuit or ECP

The efficiency of the primary circuit is the exchange efficiency between the sensor and the storage. ECP is a dimensionless number and its value can be calculated via the formula:

$$ECP = R'\left(1 - \frac{\beta.A+\beta t}{2m.Cp}\right) \quad (38)$$

$m.C_p$ (W/°C): mass flow of the air. For the studied system, we will suppose that $m.C_p = 40A$.

R': Efficiency of the device of control. For our case, we will take the unique value R' = 0.9.

3.4.3 Corrected solar covering

For the corrected solar covering F_{ch}, it is defined by:

$$F_{ch} = F_{chb}.C_s.C_d.C_{ri} \quad (39)$$

C_s: Storage correction which is a function of the storage capacity and the insulation of the system.
C_d: Flow correction.
C_{ri}: Yield and intermittency correction. C_{ri} depends on the efficiency of the heating and, possibly, its intermittency factor.

3.4.4 Eventual shades

Eventual shades, taken into account via the factor of sunshine F_e, vary according to the average height on the horizon of the obstacles bearing shadow on the sensors. Here are the values of F_e:

TABLE 2.
VALUES OF THE FACTOR F_e ACCORDING TO THE AVERAGE HEIGHT OF THE HORIZON

Average height of the obstacle (°)	0 to 7	8 to 12	13 to 17	18 to 22	23 to 27	28 to 32	33 and more
Values of F_e	1	0.9	0.8	0.7	0.6	0.5	Not taken into account

3.4.5 Thermal loss

Knowing the thermal loss allows to quantify the quality of the heat transfer between the sensor and the inner tube. For that, two parameters intervene:

- The thermal loss coefficient βt (W/°C) of the primary circuit connecting the sensors to the storage is expressed as follow:

$$\beta t = 6 + 3.4\,A \quad (40)$$

- The emission coefficient β (W/m°C) which is considered as to be a thermal coefficient of a wall of the sensor:

$$\beta = \frac{1}{0.15+R} \quad (41)$$

Where R is the thermal relation of the wall of the passage or the caisson (m^2 °C/W). It is noticed that for direct solar floor, the coefficient βt is calculated as for a water solar system [2]. So, we will adopt the following value for βt:

$$\beta t = 5 + 0.5.A \quad (42)$$

3.4.6 Proposed analytical method for the calculation of the solar covering

To calculate the solar covering rate F of the heating air requirements in the dwelling we will use the f-chart method. For that, we have the following equation:

$$F = C_w(aZ + bY + cZ^2 + dY^2 + eZ^3 + fY^3) \quad (43)$$

a, b, c, d and f: Coefficients that depend on the type of storage: air storage; solar floor, ...
C_w: Corrective coefficient of emission of storage. For the hot air, its value tends to 1.
Y: Ratio between the lost solar energy and the needs.
Z: Ratio between the absorbed solar energy and the needs.

If the result of (43) is negative, the value of F is zero, if it is greater than 1, then, one take F = 1. In this study, to calculate the solar covering rate, we will work on a new analytical method which is as follows:

$$F = F_1 + F_2 \quad (44)$$

$$F_1 = \mathrm{Cosh}(x) + \mathrm{Sinh}(x) - u_1 \quad (45)$$

$$F_2 = \mathrm{Cosh}(y) + \mathrm{Sinh}(y) - u_2 \quad (46)$$

$$u_1 = u_2 = 1 \quad (47)$$

x: Heat loss during the heating period.

$$x = D_P \times V(T_a - T_{ex}) \text{ (W)} \quad (48)$$

y: Supply of hot air in the house.

$$y = 0.34 \times D_{ac}(T_{sa} - T_e) \text{ (W)} \quad (49)$$

T_e: Ambient temperature ≈ 20°C
T_{ex}: External temperature (°C)
T_{sa}: Blowing temperature of the air (°C)
D_p: Loss coefficient (W/m^3 °C)
D_{ac}: Flow of hot air inside the house (m^3 /h)
V: Volume of the house (m^3)

3.5 Thermal solar collector

The study of solar installations allows to calculate hour by hour the contributions of the solar collector for the needs of the heating and the energy consumption of the system. In the scope of energy consumption, we consider that solar collectors operate all the year. Hence, contributions are free and exempt of total needs of the building. The following data are used for the calculation of the solar covering: heat requirements, specific data provided by the user and the characteristics of the different components of the system. The calculation will be done with an installation having a null sensor surface and devoid of solar installation. We should notice that it is also possible to adapt the installation of the heating on numerous heating floors inside the house. The short-term storage tank may be collective (that is, a storage tank for housing) or individual, for each room Henceforth, we will assimilate the optics yield to a parameter α, and the loss coefficient to ε. If we do not know the thermal characteristics of the sensor, we will adopt the following default values (Norm: NF EN 12976-2):

α = 0.6;
ε = 10 W/(m^2 K) (glazed collector)
ε = 30 W/ (m^2 K) (unglazed collector)

It'd be noticed that the energy balance of the system as it is defined here includes the following elements: the transmission losses and the renewal of air from the indoor environment towards the outside, the heat used from the internal sources, the used solar inputs and the heat losses generated by the distribution, the emission and the regulation of the heating system.

4 HABITATION MODELLING

4.1 Permanent regimen modelling of a habitation

The permanent regimen is represented by the thermal equilibrium between external and internal exchanges of the whole walls of the building. This modelling is designed for the expression of the heating load according to the external demands: sunniness duration, external temperature… The thermal balance equation sheet in accordance with the simple energy signing method [6] for the habitation is as follow:

$$\mathrm{Q} = \mathrm{a} + \mathrm{b}\,(\mathrm{T_{int}} + \mathrm{T_{ext}})^{+} \qquad (50)$$

With Q: Heating charge

In this equation, only the thermal period (or heating period) are taken into account, so we have:

$$(\mathrm{T_{int}} + \mathrm{T_{ext}})^{+} \mathrm{m_{ax}}(\,(\mathrm{T_{int}} + \mathrm{T_{ext}}), 0)$$

$\mathrm{T_{int}}$: Average of the internal temperature of the house (°C)
$\mathrm{T_{ext}}$: Average of the external temperature (°C)

This balance equation sheet can be simplified with the hypothesis of the very low variations of the internal temperature of a housing environment. When the heat balance of a housing environment requires no more measures of the internal temperature, (50) becomes:

$$\mathrm{Q} = x_r + \mathrm{y}_r \mathrm{T_{ext}} \qquad (51)$$

Coefficients x_r and y_r are estimated by a linear regression from the clouds of points of the daily, weekly or monthly data collected in the housing environment.

4.2 Model to study the external temperature variation and the period of sunniness

We apply a model which takes into account the variation of the solar flow because of the influence of the outside temperature. So the regression straight line can take the following form [5]:

$$\mathrm{Q} = \mathrm{x_r} + \mathrm{y_r T_{ext}} + \mathrm{z_r l'} \qquad (52)$$

With l' : sunniness duration.

Parameters x_r, y_r and z_r are calculated by square least regression. One suppose that a sample of average values of the entries and the outgoings is known. The energy signing methods are used for monthly, weekly or daily observation scale. These methods determine the useful behavior for a more detailed knowledge of the building. They do not take into account the thermal behavior of the building in transitory regimen. Hence, (52) serves to establish a consumption diagnosis by detecting the atypical consumption points compared to the regression line.

4.3 Thermal models

Parameters used for the elaboration of the thermal models are: the external temperature and the received, diffuse or direct solar energy. Here are the thermal phenomenon that intervene in the elaboration of the thermal models:

- Convection: the circulation of the coolant inside the serpentine produces a convection phenomenon at the level of the tube side. The difference compared to the conduction consist in the fact the convection is a phenomenon of energy or heat transfer by the transport.
- Radiation: it is a thermal transfer of the energy radiated by the sun.

So the thermal balance of energy conservation is determined from the following equation:

$$(\,\rho\mathrm{C})_\mathrm{i}\ \mathrm{V_i}\ \frac{\mathrm{dT_i}}{\mathrm{dt}} = \sum_\mathrm{k} \varnothing_\mathrm{ik}(\mathrm{t}) + \mathrm{P_i}(\mathrm{t}) \qquad (53)$$

$\mathrm{V_i}$: Elementary volume of the building
$(\,\rho\mathrm{C})_\mathrm{i}$: Calorific capacity of the material with which the volume $\mathrm{V_i}$ is done.
$\mathrm{P_i}$ (t): Group of external solicitations (external energy)
$\varnothing_\mathrm{ik}(\mathrm{t})$: Exchanged flow with $\mathrm{V_i}$ interface

4.4 Storage methods of the heat

Storing energy on the building roof serves to diminish the variations of the temperature by thermal inertia. Indeed, we can notice for example that a building having received sun radiations all the day and sheltered of the wind remains hot long after the sunset. This heat storage can be done directly or indirectly.

4.4.1 Direct storage

When the sensor is struck by solar radiations, part of the received energy is stored quasi instantly by the system. One say direct storage in this case. This phenomenon allows to spread the effects of solar radiation capture over time and to prevent overheating.

4.4.2 Indirect storage
The indirect storage can mature through two techniques. The first is done naturally (or natural storage) via a heat exchange by convection and radiation. The second is set up voluntarily in the context of solar systems of different styles because it uses a mass accumulator and a heat transfer mode.

4.4.3 Thermal inertia of a home
The thermal inertia of a home is its ability to store the heat and then to restitute it in a diffuse way when it's necessary. It can be a tool for favoring the exploitation of the solar energy. Besides, the thermal inertia is used to consider indicators of exploitation of the passive solar energy exploitation: instantaneous of exchanges. The efficiency indicators for passive solar energy exploitation can be defined by: the exploitation rate ($\tau_{exploit}$) over a given period is the rate of production of residual needs (τ_{gen}). In case the exploited potential is integrated over a given period, the exploitation rate of residual needs generates a negative result.

We reason on a given period P:

$$\begin{cases} \tau_{exploit} = \dfrac{\int_p P_{exploit}(t)dt}{\int_p P_{Conc}(t)dt} \\ \tau_{couv} = \dfrac{\int_p P_{exploit}(t)dt}{\int_p |q_{syst,as}(t)|dt} \\ \tau_{gen} = \dfrac{\int_p P_{exploit}(t)dt}{\int_p |q_{syst,ss}(t)|dt} \end{cases} \quad (54)$$

τ_{couv} : Coverage rate of needs
$P_{exploit}(t)dt$: Exploited potential that assesses the heating (or cooling) needs and that prevents the cold by the presence of the solar resource.

$$P_{exploit}(t) = |q_{syst,ss}(t)| - |q_{syst,as}(t)| \quad (55)$$

$q_{syst,ss}(t)$: Heat needs without solar contributions (W)
$q_{syst,as}(t)$: Heat needs with solar contributions (W). If $q_{syst,as}$ is negative, the cooling set point temperature is not respected.
$P_{conc}(t)$: Concomitant potential (W)

$$P_{conc}(t) = \begin{cases} P_{tot}(t) \text{ if } |q_{syst,ss}(t)| > 0\text{: Normal temperature respected} \\ 0 \text{ if not: Normal temperature not respected} \end{cases} \quad (56)$$

For the exploitation of the solar energy, there is also the adjusted potential $P_{ajust}(t)$ representing the maximum amount of exploitable resources [4] to fill the need when the resource is absent.

$$P_{ajust}(t) = \min\left(P_{tot}(t); |q_{syst,ss}(t)|\right) \quad (57)$$

Where $P_{tot}(t)$: total potential equal to $P_{conc}(t)$.

The thermal inertia allows to have phase difference compared to the outside temperature. When a room is warmed up, elements with high inertia like slabs, floors, wall ... will accumulate heat and then will return it for hours even if the heating system is cut off. The thermal inertia is dependent on the density and the thermal capacity of the materials that make up the interior of the system (floors, partitions ...). The more these materials are heavy, the greater their thermal inertia is important. To have a good efficiency, the choice of the physics properties of the used materials is important. These properties are the diffusivity, emissivity and the time constant.

The diffusivity can be calculated by the formula:

$$a = \frac{\lambda}{c \cdot \rho} \quad (58)$$

c: Specific heat (Wh/kg°C)
ƛ: Thermal conductivity (Wh/ (m.K))
ρ: Density of the material (kg/m^3)

The emissivity influences the internal atmosphere conditions. Its value can be calculated by:

$$a_d = ƛ \cdot c \cdot \rho \quad (59)$$

The time constant $\mathcal{T}$ affects internal and exterior relations of each system component. It allows to define the amortization or the phase difference of the thermal flux.

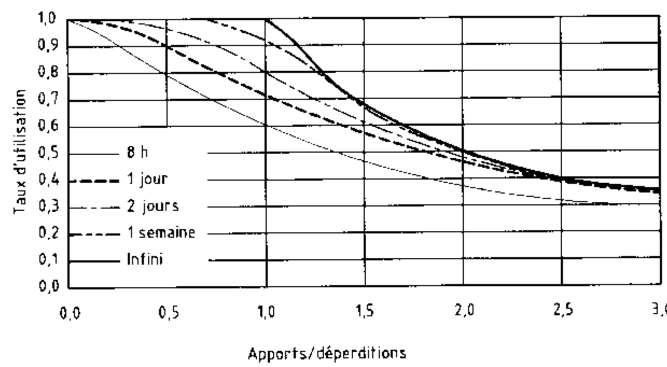

Fig.4. *Materials usage rate for time constants: 8hours, 1day, 2days, one week and infinite*

The time constant $\mathcal{T}$ can characterize the thermal inertia of a heated room. In this case, this parameter is conceived as a time-varying system in contact with two thermal environments: the indoor and outdoor environments.

5 CONCLUSION
The work presented in this article highlights the energy performance of two combined systems that lead to a house's energy self-sufficient. They are the thermic system and the photovoltaic system. Air solar collector, studied in this article, belong to the first system and use solar energy to produce heat to warm up a habitation. The functioning of this air conditioning system have been detailed in this work. We have seen especially how to evaluate the yield and the thermal inertia of solar collectors and done the thermal balance of each component of the system: glass, coolant (air), absorber and inner tube. An important parameter of the system has been studied separately: the solar covering. This last is a relative part of the heating needs and covered by the solar energy. To calculate the solar covering rate, we proposed a new method that is based on the F-chart approach. Besides, we predicted the performance of an air solar collector according to the sunniness and the external temperature. The choice of used matters is also important to optimize solar

collectors operating. Hence, methods and mathematical models proposed in this work can make headway research and applications of the solar energy in the air conditioning. Our next work is focused on the realization of experimentations by taking into account climatic factors and geographical parameters of a place. Results will be introduced in analytical models to be able to use for the simulation of the instantaneous behavior of the system.

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