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Complementarity of the trombe wall effect and air distribution in passive air conditioning of a single-zone building

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ABSTRACT

The work in this article presents the study of the Complementarity of the trombe wall effect and the distribution of air to the passive air conditioning of a single-zone building by simulating the thermal behavior of a habitat located in Madagascar, in Antananarivo. The practical recommendation of the heat flow exchanged by thermocirculation is done in an ingenious system. The first part of the work will be based on the installation of a solar capture system, a vertical wall in heavy masonry facing north and equipped with two holes. It allows and facilitates the simulation of an air circulation system between this building and the greenhouse formed by the receiving surface of the wall and the glazing that precedes it. The second will develop the physical modeling of the system obtained by assembling simplified thermal models of the wall elements, glazing and air volume constituting this zone. The analysis of the system will be able to receive a well-air-conditioned home.

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1. INTRODUCTION

In Madagascar, many homes use an air conditioning working with fossil energy that expensive and harmfull environment. The one if solution proposed is the application of trombe wall working with solar energy that free and renewable and inexhaustible. To this topic, F. Crou et al **[1]** have done an analysis on the improvement of the thermal exchange of air very used in habitat. They put in evidence that whatever the external climate, the thermal comfort is assured. For this research, it is about the installation recommendation equipment convenient of the heat flux exchanged by thermal circulation in an ingenius system.

This article concerns the use of solar air conditioning, a solar thermal collector and an exchanger that transforms incident solar radiation into energy or heat. The energy available by the experiment is evacuated by the thermal circulation of a fluid such as air. The result of coupling the trombe wall collector and a single-zone dwelling taking into account the use of materials with high thermal inertia: black slate, glass, wood, polystyrene, And preventing convection heating. A passive system applied in a room in Madagascar tends to obtain natural air conditioning by limiting an energy power captured by optimization. The aims of this article are as follows: to carry out new research on the evacuation of the air distribution in a vertical wall in heavy masonry facing north, equipped with two channels or orifices. Look for the air circulation between a single-zone building and a greenhouse formed by the physical modeling of a system by energy reception by assembling thermal models and a simplified method of their specific elements used.

2. SYNOPTIC OVERVIEW OF SYSTEM OPERATION

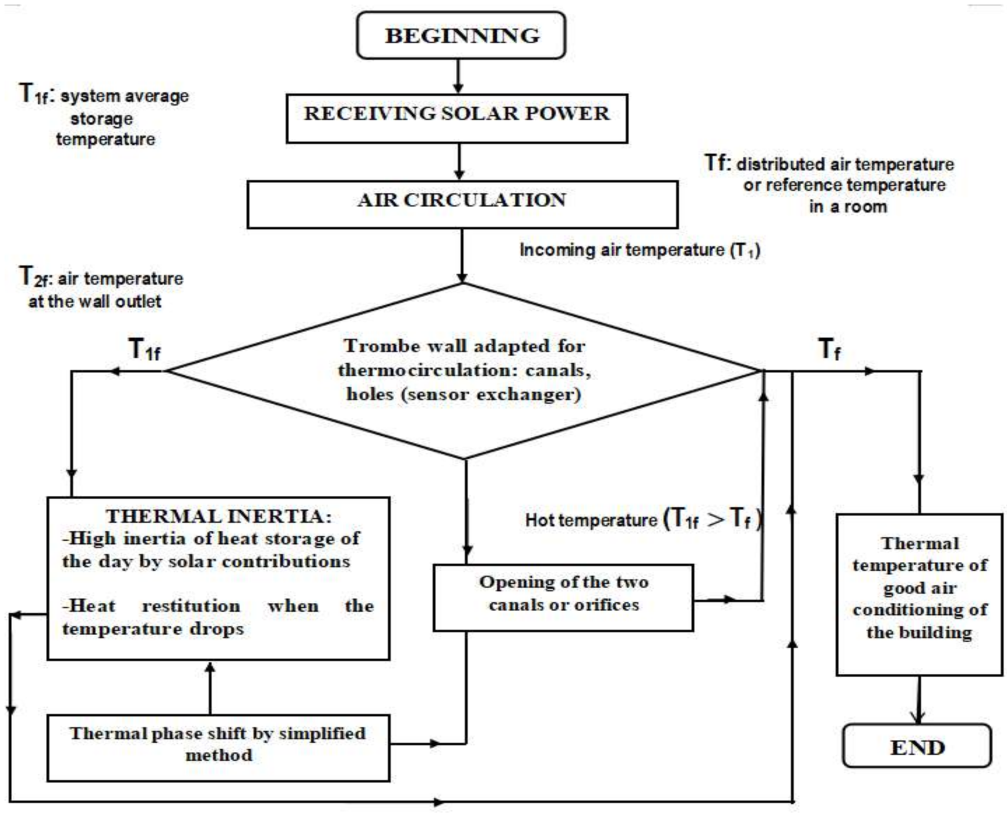

Figure 1. Synoptic overview of system operation

3. OPTIMIZATION OF A SYSTEM TROMBE WALL AS AN EXCHANGER-SENSOR OF A BUILDING

3.1. Regulation of the system

The trombe wall and the walls of the building in complementary are used to obtain best results. However, they do not have the same dimensions and the same functions. The wall of a habitat has four faces of the same construction materials and having the same function in the air conditioning of a room. On the other hand, the trombe wall is arranged on only one face of the walls of the habitat. Efficient physical materials are used for energy optimization with air conditioning in Madagascar. This complementarity is reflected in the following formulas **[2].**

$$\boldsymbol{T_f = T_1 - (T_1 - T_{1f}) Exp\left[\frac{-K'S}{\dot{m}_f\ C_f}\right]} \qquad \textbf{(1)}$$

With

K' : Overall exchange coefficient $[Wm^{-2}K^{-1}]$

$$\boldsymbol{K' = \frac{1}{h_1} + \frac{e}{\lambda} + \frac{1}{h_2}} \qquad \textbf{(2)}$$

h_1: convection coefficient outside the wall $[kcal\ m^{-2}\ h^{-1}\ K^{-1}]$

h_2: convection coefficient inside the room $[W\ m^{-2}K^{-1} ou\ kcal\ m^{-2}\ h^{-1}\ K^{-1}]$

e: wall thickness (≈ 2.2 cm)

λ: conductivity coefficient of the material constituting the exchanger (λ ≈ $0.03 Wm^{-1}°C^{-1}$)

S: surface of the trombe wall (exchange surface$[m^2]$)

$\dot{m}_f$: Air flow rate$[K\boldsymbol{g}h^{-1}]$

$\boldsymbol{T_{1f}}$**:** Average system storage temperature level ($°C\ ou\ K$)

C_f: Specific heat of the air Cp=$50 Wm^{-2}°C^{-1}$

T_f : Distributed air temperature per room ($°C\ ou\ K$)

T_1 : Average temperature of the wall waterspout or absorber.

3.2. Heat flow exchanged by thermocirculation

The quantity of heat $\dot{\boldsymbol{q}}_{\boldsymbol{r}}$ given up for a wall has the following value:

$$\boldsymbol{\dot{q}_r = \dot{m}_f\ C_p\ (T_{2f} - T_{1f})} \approx \dot{q}_c [kcal\ \ l^{-1}] \qquad \textbf{(3)}$$

$\dot{q}_r$= heat received by the heat transfer fluid air per unit of time;

T_{2f}= air temperature at the wall outlet.

$$\boldsymbol{\dot{q}_r = G_n A\ \eta_c} \qquad \textbf{(4)}$$

With

G_n: Incident flux or global solar radiation

A: building area $[m^2]$

η_c : Trombe wall efficiency [%]

The thermal sensor or the system studied has a very good efficiency with the temperature below 30°C (low temperature). The air in contact with the absorber is at low temperature and therefore the storage is also at low temperature.

For the system studied,

h_1= 25 $\boldsymbol{Wm^{-2}°C^{-1}}$

h_2= 75 $\boldsymbol{Wm^{-2}°C^{-1}}$

The quantity of heat $\boldsymbol{q_r(t_1, t_2)}$ stored by the wall at time t_1 and t_2 from a well-defined exchange surface is expressed as follows:

$$\boldsymbol{q_r(t_1 - t_2) = \int_0^H \rho_r . S_r . C_r [T_r(z, t_2) - T_r(z, t_1)]\, dz} \quad \textbf{(5)}$$

S_r = Wall section –storage, $\boldsymbol{S_r = S}$

C_r = Specific heat body

H: distance between two orifices

$T_r(z, t_1)$: Temperature distribution on the vertical of the wall at time t_1

$T_r(z, t_2)$: Temperature distribution on the vertical of the wall at t_2

ρ_r = density of the heat transfer fluid air masse.

3.3. Thermal inertia (TI) of the studied system

For the simple analytical method for good air conditioning, thermal inertia of the system is determined by the following relation **[3].**

$$\boldsymbol{IT = \frac{\sum M_C\, C_C}{a}} \quad \textbf{(6)}$$

With

a: thermal diffusion

$$\mathbf{a} = \frac{\lambda_a}{\rho_a\, C_a} \quad \textbf{(7)}$$

λ_a : Thermal conductor of the trombe wall

ρ_a : Mass volume of air at normal pressure

$\rho_a = 1.2\ kgm^{-3}$

C_a : Specific heat of air

$C_a = C_f$

M_C : Mass of the collector (≈ 800 kg)

C_c : Specific heat of the collector (insulating absorber glass)

If $\sum M_C\, C_C$ is low so we have a low inertia system

During the winter, the cooling of the wall will slow down, so that the outside temperature will not affect the inside and the heat stored by the walls during the day will be recovered at night. In the summer, the wall heating will slow down, so the outside temperature will not affect the inside atmosphere the freshness stored by the walls at night will cool the room during the day.

3.4. System Performance

3.4.a. Trombe wall performance **[3]**

$$\boldsymbol{\eta_C = \frac{\dot{q}_c}{S.G_n}} \quad \textbf{(8)}$$

3.4.b. overall performance of the installation **[3]**

$$\boldsymbol{\dot{q}_r = \frac{\dot{q}_r}{A.G_n}} \quad \textbf{(9)}$$

$\dot{q}_r = \dot{q}_c$ – Pressure losses in the path **(10)**

$\dot{q}_c = G_n A\eta_c[W]$: Heat flow **(11)**

3.5. Loss of loads in the path

The studied system is a sytem of flow forced convection therefore the knowledge of heat loss is necessary to determine the power of the energy used for the circulation of the air.
They are to be known so that this circulation is carried out naturally. The equation after determined the loss of load in energyΔP *(according to the Julius Weisbach formula)* **[4]**

$$\mathbf{\Delta P = \frac{\lambda_c}{D} \times \rho_a \frac{V^2}{2} L} \qquad \textbf{(12)}$$

ΔP: $[Nm^{-2}\ ou\ m\ d'air]$

λ_c : Pressure loss function

ρ_a: Air mass

V: Air flow velocity

L: Air flow path length

D: Sun path diameter

$\rho_a = 1.2\ kgm^{-3}$

$V = 10m\ S^{-1}$

$D = 0.02m$

$L = 4m$

Application, for the system studied

$$\boldsymbol{\Delta P = \frac{0.03}{0.02} \times 1.2\ \frac{10^2}{2} \times 4} \qquad \textbf{(13)}$$

$\Delta P = 360\ Nm^{-2}$= 0.036 m d'air ≈ 0.04 m d'air.

4. APPLIED PATH POWER

$$\mathbf{q_{ch} = q_v \times \frac{\Delta P}{\eta}} \qquad \textbf{(14)}$$

q_v : Mass flow

$q_v = S_2 \times 2$

S_C : Passage section where circulation takes place (≈ 0.02m^2)

v: Air speed (≈10 m s^{-1})

η : Flow efficiency

$$\boldsymbol{\eta = \rho\tau \times \alpha - C_p \frac{\theta_p - \theta_a}{C \times G_n}} \qquad \textbf{(15)}$$

τ = 1: the transmissibility of the trombe wall sensor system

C: constant allowing to know the capture surface of the trombe wall or geometry of the trombe wall

$$C = \frac{S}{s} \tag{16}$$

S: capture surface$[m^2]$;

s: absorbent surface of the trombe wall sensor (s = $4m^2$)

$\rho = \alpha \approx 0.9$

C_p : Specific heat of the air$[Wm^{-2}°C^{-1}]$

$[C_p \approx 50\ Wm^{-2}°C^{-1}]$

θ_p: Average temperature of the absorber system

θ_a: Ambient temperature in a building

$\theta_a \approx 18°C$

$$\theta_p = \frac{\rho\tau\alpha\, C \times G_n}{C_p} = T_1 \tag{17}$$

$\rho = \alpha = 0.90, \quad \tau = 1, C = 2.25$

G_n : Global Solar Energy$[Wm^{-2}]$

Application:$\eta = 70\%$

$$P_{ch} = \frac{S_c\, v \times \Delta P}{\eta} \approx 87\ W \tag{18}$$

5. THERMAL PHASE SHIFT:

Enhances the air flow system in order to reduce existing pressure losses in the path. It is a physical parameter regulating the characteristic of the orifices. The trombe wall can thus absorb low thermal inertia.

In the cooling phase, a necessary phase shift is determined by the simplified method:

$$\varphi' = \frac{m_e C_e\,(\theta_S - \theta_a)}{C_p(\theta_p - \theta_a)} \tag{19}$$

Application :

$\varphi' = \frac{800 \times 4 \times 3}{50(22-18)}$

$\varphi' = 48\ s$

Near heating, this thermal phase shift is expressed by the following relationship:

$$\frac{m_e C_e\,(\theta_S - \theta_a)}{\varphi} = \alpha g S\, R_v - C_p(\theta_p - \theta_a) \tag{20}$$

$$\varphi = \frac{m_e C_e\,(\theta_S - \theta_a)}{g\alpha S.R_v - C_p(\theta_p - \theta_a)} \tag{21}$$

C_e : Specific heat ≈ $4W/m^2\,°C$ for our experience

m_e = 800kg (sensor mass)

θ_S =21°C

θ_a = 18°C

$\varphi = 0.9$:Reflectivity of reflective surfaces in a room studied (s or min)

$S = 9m^2$

$C_p = 50\ W/m^2\ °C$

$R_v = 300W/m^2$ (Solar energy)

g=0.45

θ_p : Average temperature of the absorber system

6. RÉSULTATS

Thermal power has a significant influence on the behavior of the wall and its performance; this influence is expressed mainly by the evolution of solar irradiation or global energy and the reduction in the quantity of heat.

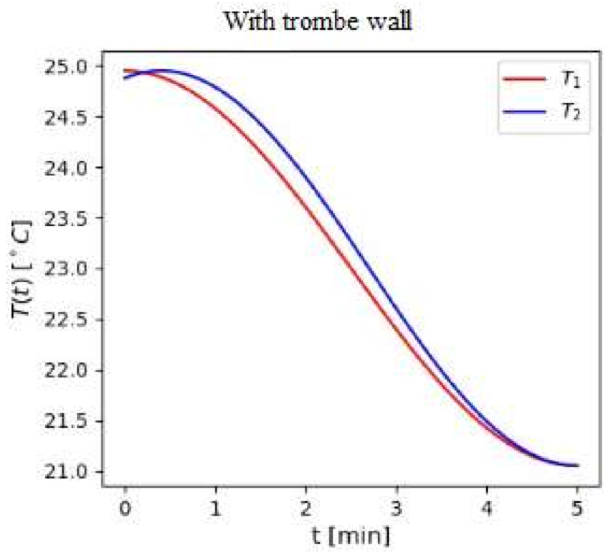

Figure 2: impact of the trombe wall with thermal regulation

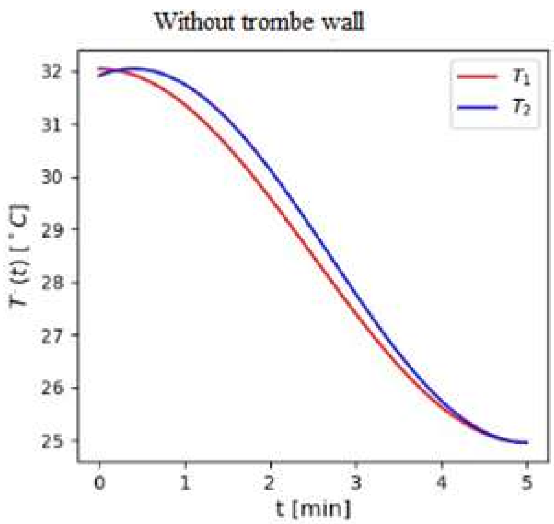

Figure 3: thermal regulation without the impact of the trombe wall

Figure 2 and 3: The numerical simulation was made for the qualitative study of the dynamic aspect of the trombe wall. We determined the most efficient type that meets the climatic needs of a home. The results obtained evaluate the distribution of air in the vertical wall equipped with two holes. In these figures, we see that the inlet and outlet temperature of the wall system are equal at night. And after sunrise, we notice that the outlet temperature follows the increase up to 21 ° C because of the trombe wall that captures heat and heats the air. The energy quality of the environment of a room and the qualification of the resources useful to cover the needs of the building are evaluated.

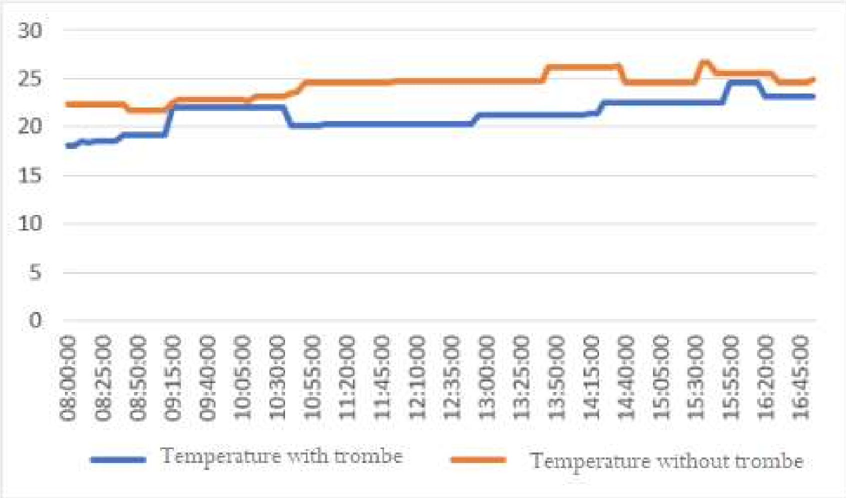

Figure 4: temperature curve with trombe wall and without trombe wall

Figure 5: humidity curve with trombe wall and without trombe wall

Figures 4 and 5: they show the influence of thermocirculation on the internal temperature of a room.

The choice of the orientation of the trombe wall is made in relation to the desired thermal environment. For Madagascar, the North wall is the most beneficial because it represents more cooling conditions to compensate for a long very hot summer period in tropical countries. In Figure 4, we notice this influence of decreasing the temperature in the room equipped with a trombe wall.

7. DISCUSSION

The trombe wall is adaptable to the bioclimatic construction of a room with the installation of an optimal way of the captured clean energy. The creation of an air flow can be generated by the opening of the upper orifice of the glazing and the lower orifice of the wall so that it creates the effect of solar chimney to have a thermal balance between humidity and heat in a room.

8. CONCLUSION

In short, the trombe wall system represents an organized air circulation so that losses in front of the collector wall are minimized. The devices reducing these losses are also exchange surfaces. The thermal inertia of the system has been confirmed. The trombe wall or the air insulator can be used as a high-performance passive air conditioning system in hot countries such as Madagascar. This system has several advantages: it always restores the heat stored during the day and night, it is a good insulator to provide acceptable indoor air quality and it can also be a good thermal regulator to achieve the desired thermal comfort in a room. The thermal simulation of heating or cooling loads by a collector exchanger will subsequently be used to calculate the thermal comfort rates within the building studied.

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