MODELLING OF A BIOCLIMATIC ROOF USING NATURAL VENTILATION

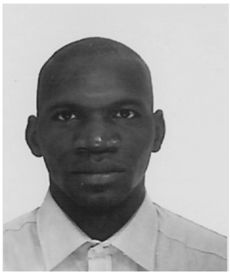
I. Ouédraogo, A. Ouédraogo*, K. Palm*, B. Zeghmati***

*Laboratoire de Chimie Organique et Appliquée UFR\SEA Université de Ouagadougou BP 7021 Burkina Faso.
Fax: (+226) 50 30 72 42, e-mail: issaka.ouedraogo@univ-ouaga.bf
**Laboratoire de Mathématiques et Physiques de Systèmes Université de Perpignan
66860 Perpignan France

Received: 11 Oct 2007, accepted: 7 Nov 2007

The traditional techniques of air-conditioning present considerable disadvantages of the point of view of the energy consumption and especially of the environmental pollution. So the promotion of new technologies of air-conditioning to low fuel consumption of energy and the improvement of the energy effectiveness of the habitats prove to be essential. The air-conditioning passivates which minimizes the thermal energy of the sun by various techniques and which exploits the architectural characteristics of the buildings is very promising. Thus, the bioclimatic term refers to some guiding principles where the design and construction of the buildings take account of the environment to create an interior environment in conformity with thermal comfort.

Keywords: solar buildings, natural ventilation, bioclimatic roof, thermal comfort



Issaka Ouedraogo

Master degree at ISFRA of Bamako (Mali), 1999.
Teacher of physique to the college Zinda of Ouagadougou, 1999-2002.
Master degree at University of Perpignan (France), 2002.
Assistant monitor in charge of undergraduate Physics lab at University of Ouagadougou, 2004.
Scientific interests: modelling and heat transfer.

Alioune Ouedraogo

Laboratoire de Chimie Organique Appliquee UFR/SEA University of Ouagadougou.
Pr, Head of Physics Department of IMP, 1981-1984.
Coordinator of Physics-Chemistry section, 2004, UFR/SEA.
Decoration: Chevalier of Academic Palm, 2002.
Fullbright grant (USA) 1986-1987 at UC-Davis, and UGa-Athens CIUF grant for 3 months training (Belgium), 1999-2002, at ULB.
Scientific interests: solid state physics, ferroelectrics, essential oils and aromatic plants.
Publications: 4 in Mechanics (BUP); 6 in Solid State (Journal de Physique, Ferroelectrics and European Physical Journal); 2 in Journal of SOACHIM; 2 on Essential Oils (Journal of Applied Sciences and Annals of UO).
2 scientific projects.

Nomenclature

T = Temperature (K)
t = Time (s)
L = Length (m)
l = Width (m)
H = Height of the channel (m)
S = Surface (m^2)
k = Thermal conductivity (W·m^{-1}K^{-1})
Ep = Thickness (m)
M = Mass (kg)
Cp = Specific heat constant (J·kg^{-1}K^{-1})
hr = Radiation transfer coefficient (W·m^{-2}K^{-1})
hc = Free convection transfer coefficient (W·m^{-2}K^{-1})
F = Geometrical factor form
γ = Roof thermal absorptivity (W·m^2)
ε = Emissivity
α = Angle inclination (°)
η = Flux density collected by Absorber (W·m^2)
Pu = Flux puissance (W·m^2)
ϕ = Solar flux (W·m^2)

Indices

be = External roof
bi = Interior roof
a = Air of the channel
p = Absorber
is = Insulator
amb = Ambient
ν*c* = Vault of heaven
amp = The air enters the insulator and the ceiling
pl = Ceiling

Introduction

In the world and particularly the emerging countries like Burkina Faso, energy is a factor very determining to ensure a minimum of the economic and social activity. The problem of energy is essential to reduce the great consumption related to the HVAC (Heating Ventilating and Air Conditioning) by the techniques of passive air-conditioning. So it is allowed that the combination of various techniques passive air-conditionings decreases the energy loads considerably and to improve comfort of the buildings [1]. Our model of bioclimatic roof designed to trap the solar radiation involves local materials [2]. Plexiglas and clay tiles, a channel where circulate the air of the enclosure, and a sheet painted in black being the absorber. Finally an insulator is constituted of *Ceiba Pentandra* fibres. In this work the model is compared to a plane sensor of air of rectangular and tilted section. Distribution of the temperatures of various materials of the roof, and the air flow depends on the coefficients of heat transfer by natural convection and radiation [3]. However these coefficients are characterized by the number of Nusselt for a given geometrical configuration. We retain the number of Nusselt proposed by Holland et al [4]. The air flow is estimated by the equation of Bansal, Mathur and Bhandari [5]. Finally we numerically simulate the performances of the model of a bioclimatic roof in a hot and dry tropical climate, in order to optimize the dimensional parameters of buildings.

Description of the model

The roof model is similar to that studied by Khedari et al [6] in a hot and wet climate (Thailand). The process consists in making the air inside the building circulate by natural convection in the roof by creating temperature gradients between the components of the roof made up of local materials (Fig. 1).

On one hand it is possible to act on dimensions of bricks and their sites and on the other hand on the optical properties of these bricks. The study of this roof can be performed primarily according to two steps:

1. The first takes account of the space-time evolution of the temperature of all the speed and roofing units, to which the air circulates in this roof. This method requires the resolution of the equations of transfers by natural convection coupled with the equation of transfer of heat by conduction in various materials (Table 1).

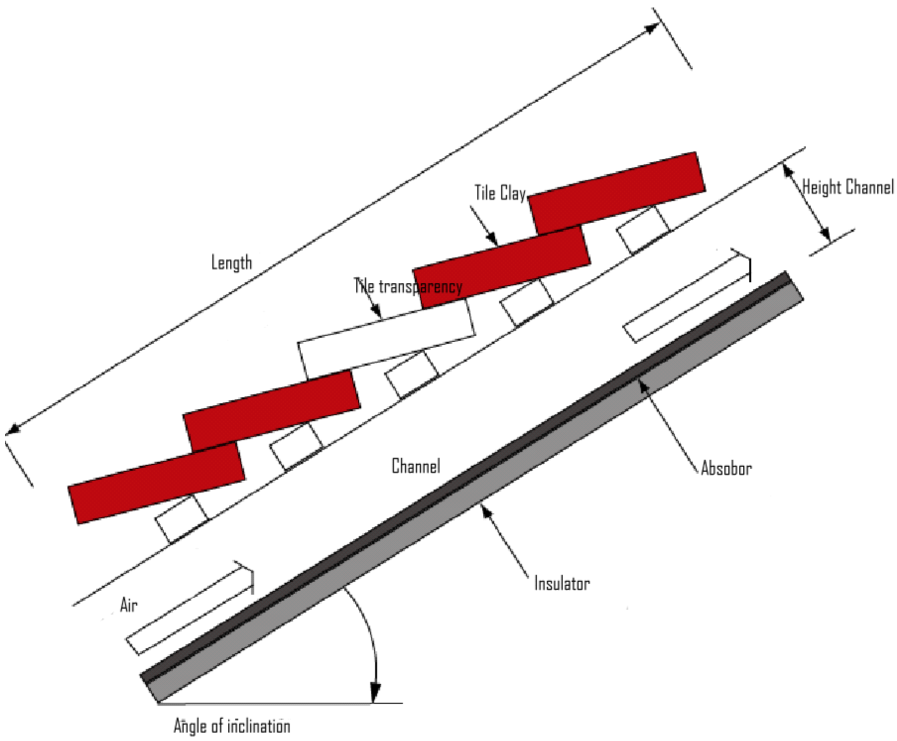


Fig. 1. *Bioclimatic roof model*

Table 1

Thermal properties of materials

Materials	Density, ρ (kg/m^3)	Specific heat, C_p (J/kg/K)	Absorptivity, γ	Thermal conductivity, K (W·m^{-1}K^{-1})	Emissivity, ε
Clay tiles	1800	780	0.485	0.685	0.834
Plexiglas tiles	1200	800	0.128	0.752	0.010
Absorber	2700	920	0.945	180	0.880
Insulator	530	950	0.237	0.016	0.15

2. The second consists in allotting to the various roofing units arbitrary average temperatures. It allows gives an account of their temporal evolution, and evaluates the air flow which circulates in the roof. This method rests on the use of the analogies between the thermal and electric transfers.

For modelling, the following simplifying assumptions were made:

1) The constituent materials of the roof are homogeneous.

2) The physical properties of materials and the air are supposed to be constant.

3) The transfers are one-dimensional.

4) The thermal inertia of the air is negligible.

Mathematical formulation

The method consists in cutting out the roof in fictitious sections in the direction of the air flow. To write the heat balances in each section we use analogies which exist between the thermal transfers and the transfers of electricity. The application of the Ohm's law to each section leads to the following heat balances:

The external

$$\frac{M_{be}CP_{be}}{S}\frac{\partial T_{be}}{\partial t} = \varepsilon\gamma_{be}\eta_{be} + \frac{k_{be}}{EP_{be}}\left(T_{bi} - T_{be}\right) + hr_{be}\left(T_{vc} - T_{be}\right) + hc_1\left(T_{amb} - T_{be}\right) + hr_{amb}\left(T_{amb} - T_{be}\right). \quad (1)$$

The internal

$$\frac{M_{bi}CP_{bi}}{S}\frac{\partial T_{bi}}{\partial t} = \frac{k_{bi}}{EP_{bi}}\left(T_{be} - T_{bi}\right) + hc_2\left(T_a - T_{bi}\right) + hr_{p\to bi}\left(T_p - T_{bi}\right). \quad (2)$$

Air channel

$$\frac{M_a CP_a}{S}\frac{\partial T_a}{\partial t} = +hc_2\left(T_p - T_a\right) + hc_3\left(T_{bi} - T_a\right) + Pu\,. \quad (3)$$

Absorber

$$\frac{M_p CP_p}{S}\frac{\partial T_p}{\partial t} = \varepsilon\gamma_p\eta_p + \frac{k_p}{EP_v}\left(T_p - T_{is}\right) + hc_2\left(T_a - T_p\right) + hr_{p\to vc}\left(T_{vc} - T_p\right) + \sum_{i=1}^{3} hr_{i\to t_p}F_{i,t_p}\left(T_i - T_p\right) + \Phi\,. \quad (4)$$

Insulator

$$\frac{M_{is}CP_{is}}{S}\frac{\partial T_{is}}{\partial t} = \frac{k_{is}}{EP_{is}}\left(T_p - T_{is}\right) + hc_4\left(T_{amp} - T_{is}\right) + \sum_{i=1}^{2} hr_{i\to pl}F_{i,pl}\left(T_i - T_{is}\right). \quad (5)$$

Resolution algorithm

The discretization using an implicit method with the finished differences of the equations (1 to 5) led to a system of algebraic equation which is solved, in each section of the roof, by using the method "Diabolo Sablier". An iterative calculation is necessary because the heat transfer coefficients by convection and radiation are a function of the roof temperatures.

Results and discussion

The space-time knowledge of the distributions of the temperatures of the whole of materials of the roof of the building and the air flow to ventilate by natural convection proves to be necessary to determine optimal dimensions. Thus we study the influence of the physical properties of materials of the roof (B = tiles out of clay and P = plexiglass tiles). Of sound inclination (α) compared to the horizontal one for values ranging between 30° with 75° and of sound geographical orientation on the distributions of the temperatures of the air in the roof and the enclosure of the building. We consider the influence height (H) of the channel where the air flow circulates. We present them below numerical results with the following parameters: $\alpha = 50°$, $H = 0.15$ m, $L = 2$ m, $l = 0.3$ m. For our calculations we used the weather data of the town of OUAGADOUGOU (in the center of Burkina Faso) [7] standard day of June, May, July.

While comparing the profile of the temperatures of air and of different materials (Fig. 2) it is noticed that the temperature of the air is (T_a) is higher than that of other materials of the roof, except the one of the absorber (T_p). This seems to be in contradiction with the concept of passive air-conditioning. It can be explained by the presence of the plexiglas tiles which cause an increase in the solar flow collected by the elements of the lower part of the roof which is accompanied by an increase in the intensity of the radiative exchanges inside the roof.

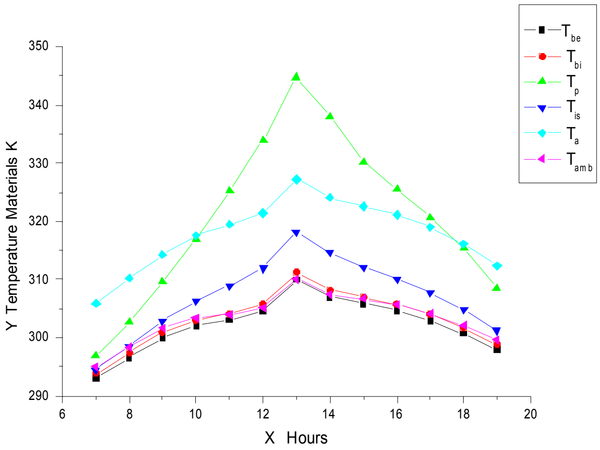


Fig. 2. *Space-time evolution of the temperatures of materials of the roof*

To follow the evolution of the air flow to the course time, and to seek an optimal flow in conformity with the Adaptive Standard Comfort (ACS), we planned several types of roof. It is about the higher part of roof contacts some with the ambient conditions. As illustrated by Fig. 3, when this part is completely covered with the clay tiles (BBBBB), one notes very week air flow, therefore a thermal discomfort inside the building. While an entirely covered roof of plexiglass tiles (PPPPP), the air flow is very appreciable but for the reason of expensive cost of the materials, we did not consider this case in practice.

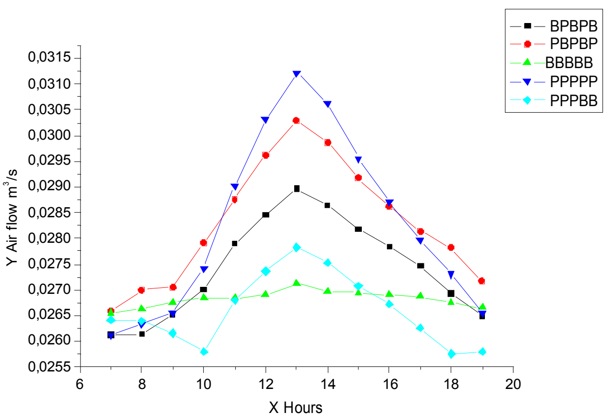


Fig. 3*. Space-time evolution of the flow circulating in the roof*

While varying the height of the channel $H = 0{,}12$ m (Fig. 4) and 0,15 m, we notice in (Fig. 5) when one intercalates the tiles out of clay and plexiglas that the air flow decrease and increases. However the temperature of the air (T_a) is not very sensitive to this variation.

The angle of inclination influences considerably the temperature and the air flow which circulates. When the angle of inclination is higher than 45°, the intensity of the flow collected by the roof decreases. For an angle of inclination α = 50°, we observe that the average temperature of the air inside is lower than that of ambient. Let us add that other parameters influence the environment of the enclosure of the building, such as the thickness of the walls and the height of the windows. In order to validate our numerical results, we compare these results with the works of Jompob Waewsak [8] on a similar roof in Thailand and those of Richard J. de Dear and Gail S. Brager [9] on the thermal index of satisfaction of Adaptive Comfort Standards (ACS).

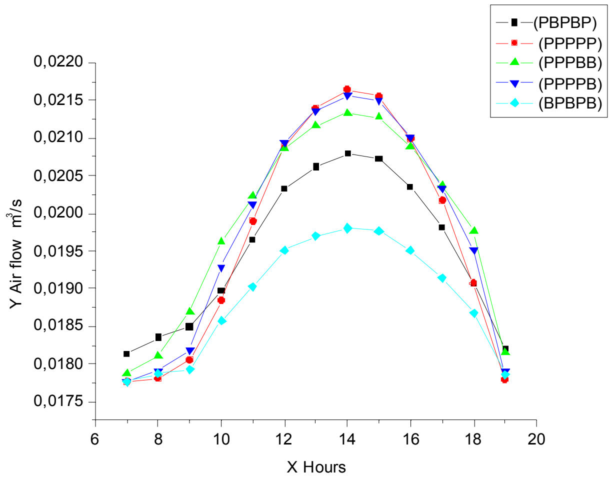


Fig. 4. *Space-time evolution of the flow circulating in the roof an influence height of the channel*

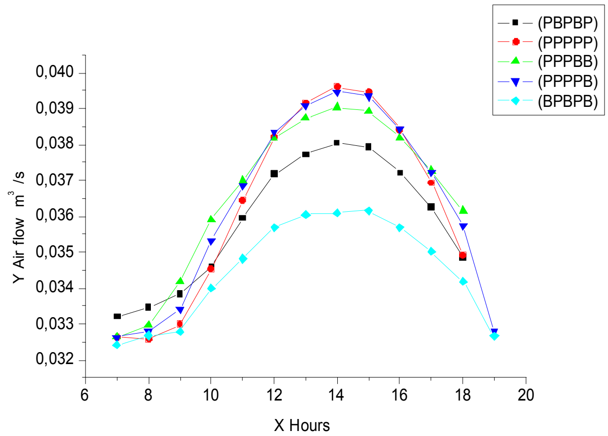


Fig. 5. *Space-time evolution of the flow circulating in the roof an influence height of the channel*

Conclusion

Our study explores the effects of natural ventilation in a hot and dry tropical climate inside a building to save energy in a city like Ouagadougou in Burkina Faso. It comes out from our calculations to reach an optimal flow in the enclosure of a building, synonymous with satisfactory thermal feeling: the building must be directed in North-South and the roof should be inclined with an angle of 50° with a maximum of the influence of channel for an height of 0.15 m. In spite of that the thermal feeling depends also on the relative humidity of the city, the clothing and finally of the psychological factor of the occupants of the building.

Aknowlegements

The authors wish to thank the CUD (Belgium) for the grant (CIUF/UO/06) to Mr. Ouedraogo Issaka.

References

1. Depecker P. et al. Design of building shape and energy consumption // Building and environment. 2006. No. 36 (5). P. 627-635.
2. Awbi H. B. Design consideration for naturally ventilated buildings, Renewable Energy. 1994. No. 5. P II. P. 1081-1090.
3. Rodigues A.M., Canha da Piedade A., Lahellec A., Grandpeix J. Y. Modelling natural convection in heated verticale channel for room ventilation // Building and Environment. 2000. No. 35. P. 455-469.
4. Duffie J. A., Beckman W.A. Solar Engineering of thermal Processes. 2nd edition. New York: John & Sons Inc., 1991. P. 919.
5. Bansal N.K., Mathur R., Bhandari M. S. Solar chimney for Enhanced Stack Ventilation // Buildings and Environment. 1992. No. 28. P. 373-377.
6. Khedari J. et al. New configuration of a roof solar collector maximizing natural convection // Buildings and environment. 2001. No. 36. P. 383-391.
7. Lui B.Y.H., Jordan R.C. The interrelationship and characteristic distribution of direct diffuse and total radiation // Solar Energy. 1961. No. 4. P. 1-19.
8. Waewsak J. These de doctorat. Designing of an original Thai-Bioclimatic Roof. 2001. University of Perpignan.
9. Richard J. de Dear, Gail Brager S. Thermal comfort in naturally ventilated buildings: revision to ASHRAE standard 55 energy and building. 2002. No. 36. P. 549-561.
10. Fange P.O. Thermal comfort-Analysis and Application in Environmental Engineering, Danish Technical Press Copenhagen. 1970.
11. Agrawal P.C. A review of passive system for natural heating and cooling of buildings // Solar and wind Technology. 1989. No. 6. P. 557-567.