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Study of the influence of local materials insulation on cooling loads of a house made of breeze block or laterite in a dry tropical climate

D. Toguyeni and O. Coulibaly

UO-UFR/SEA, Laboratoire de Physique et de Chimie de l'Environnement, LPCE
03 B.P. 7021, Ouagadougou, Burkina Faso

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Abstract - *In this paper, we study the influence of local materials for insulating roof and fiber-reinforced mortar coatings on cooling loads of a home in dry tropical climate. The wall of the housing is made of cinderblock or laterite and the insulating material of a roof panel is made with lime (24%), cement (6%), water (50%) of vegetable fibers hibiscus sabdariffa (16%), tree widespread in Burkina Faso and sugar cane bagasse (4%). This panel roof insulation and the fiber-reinforced mortar were characterized at the Laboratory of Physics and Chemistry of the environment by the hot plate method. The building is modeled in TRNSYS using climate data from the city of Ouagadougou. The results obtained show that in the warmer months of the year, that is to say in March and April, the relative differences between heat gains configurations the configurations "breeze block-coating mortar and roof not insulated" and 'laterite- fiber-reinforced mortar coating and insulated roof' vary between 15.6 % and 16.8 %. Configuration 'laterite- fiber-reinforced mortar coating and insulated roof allows a reduction of annual heat gains of 15.5% compared to the configuration 'breeze block-coating mortar and roof not insulated'.*

Résumé - *Dans cet article, nous étudions l'influence des matériaux locaux pour le toit et les revêtements de mortier renforcé de fibres d'isolation sur les charges d'une maison en climat tropical sec de refroidissement. La paroi du boîtier est réalisé en parpaing ou en latérite et le matériau isolant d'un panneau de toit est fabriqué avec de la chaux (24%), du ciment (6%), eau (50%) de fibres végétales Hibiscus sabdariffa (16%), l'arbre répandu au Burkina Faso et la bagasse (4%) . Cette isolation de la toiture du panneau et le mortier renforcé de fibres ont été caractérisées au Laboratoire de Physique et Chimie de l'environnement par la méthode de la plaque chaude. Le bâtiment est modélisé dans TRNSYS en utilisant les données climatiques de la ville de Ouagadougou. Les résultats obtenus montrent que, dans les mois les plus chauds de l'année, c'est-à-dire en Mars et Avril, les différences relatives entre les configurations des gains de chaleur la configuration 'brise mortier bloc de revêtement et le toit pas isolés' et 'mortier latérite renforcé de fibres revêtement et toiture isolée' varient entre 15,6% et 16,8%. Configuration' revêtement de mortier de latérite renforcé de fibres et isolation du toit permet une réduction des gains de chaleur annuels de 15,5% par rapport à la configuration 'de mortier brise bloc de revêtement et le toit pas isolés'.*

Keywords: Hot-plate approach - Laterite fiber-reinforced mortar - TRNSYS model - Cooling load.

1. INTRODUCTION

The importation in Burkina Faso manufactured goods related to construction sector (cement, sheet, rebar) now represent 45 % of the total volume of imports: where a major outflow of currency. Burkina Faso, because of its climate is tropical hot and dry, with global solar flux of about 5700 (W/m^2/d) the hottest months (March-April), must cope with high cooling loads for operators not aware of the rational use of energy. As otherwise this country is among those whose price per kWh is higher, it is easy to assume that any improvement in thermal properties of the building envelope is relevant socio-economic role. Studies on the distribution of global heat gain caused by the different parts of a building in warm tropical climate [11] show that 31 % is attributable to the roof (sheet metal), while 25 % and 44 % are due to walls and windows respectively.

When you know that almost systematic recourse, in 90 % of the buildings of the cities of Burkina, a material unsuitable for roofing sheet that constitutes the major causes of currency outflows, should be sought locally effective solutions and thus energy-consuming more economical, making eco-design of roofing insulation boards. This is why we use insulation board made from natural fibers of Burkina Faso (Hibiscus sabdariffa) and lime-cement mixtures.

Given that the laterite is a building material with low embodied energy (of about 0.3 MJ/kg: European natural stone/local [13]) very abundant use for the erection of walls considered here one of the consequences if its use becomes routine will drastically reduce the use of cement and rebar, which are materials with high embodied energy. 25% of heat gain that goes through the walls, improving the thermal performance of building envelopes must also pass through an appropriate thermal insulation by using high-performance coatings such as cement mortars incorporating local plant fibers especially, hibiscus sabdariffa.

Few studies on the estimation, through the use of dynamic codes, energy performance habitats manufactured using local materials were produced. It is in this context that this study was undertaken.

Initially, experiments to determine the effusivities and thermal conductivities using a device such as hot plan have been completed. Then, based on the work of Al-Ajmi *et al.* (2008) [2], Annabi *et al.* (2006) [3], Diez-Webster U. *et al.* (2006) [4], a cinderblock house or block of laterite was modeled in TRNSYS to determine the influence of insulation and roof coatings mortars bundles on cooling loads.

2. SAMPLE CHARACTERIZATION BY THE HOT PLATE METHOD

A uniform heat flux is imposed on the interface of two symmetrical samples equivalent to semi-infinite environments, that is to say that the ratio of their length to the thickness of the heating element is greater than 20. Moreover, the side faces of the two samples are isolated and the transfer can be considered unidirectional. The temperature response over time is measured in the plane of heating by a thermocouple.

The method for characterization and estimation is based on the work of Jannot *et al.* [5]:

- a complete modeling of the system by the method of quadrupoles;
- use of the method for calculating Sthefest inverse Laplace transforms;
- use of Newton's method for minimizing the squared deviations between experimental and theoretical thermograms.

Jannot *et al.* [5] showed that after the modelling by the method of quadrupoles and application of the method of Sthefest, for a semi-infinite, the temperature difference $T_0(t) - T_0(0)$ can be calculated by:

$$T_0(t) - T_0(0) = \frac{\phi_0}{2} \times \left[R_c - \frac{m_c}{2(E \times S)^2} \right] + \frac{\phi_0}{E \times S \times \sqrt{\pi}} \times \sqrt{t}$$

Variables are defined in the nomenclature.

The plot of $T_0(t) - T_0(0)$ according to the square root of time is a right which the determination of the slope to calculate the thermal effusivity E. The inertia of the probe and the contact resistance does not affect the temperature after a while. However, to apply this estimation method, we must ensure that the assumption of semi-infinite medium is valid on the range of estimates chosen. The principle of the estimation method is to use the beginning of the thermogram [0, T_1] to determine the parameters E, R_c and m_c.

By plotting $T_0(t) - T_0(0)$ as a function of t, the time t_1 at which time the line is no longer linear. Steady, the temperature difference does not vary between the different faces. Can then estimate the thermal conductivity (λ) by the following equation:

$$\lambda = \frac{\varphi_0 \times e}{S \times \Delta T}$$

The hypothesis of semi-infinite medium has been validated using modeling and simulation in COMSOL [9] a two-dimensional heat transfer in a three-layer composite medium (sample, air, insulation). It should be noted that research conducted at ECPA allowed comparison of the thermophysical properties of the panels from the experiment and those calculated with the assumption of semi-infinite medium and an inverse method [7] based on minimizing a standard thermograms between experimental and analytical; the relative differences are of the order of 8 %.

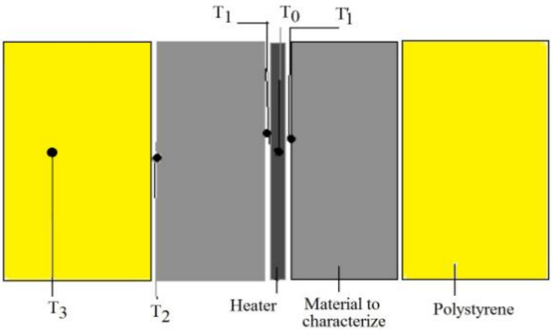

Fig. 1: Schematic of the experimental set-up

The average values of thermo physical properties of materials characterized using the method described above are given in **Table 1**. This is the fiber-reinforced mortar and insulation board. Both materials were formulated in Burkina Faso with a goal of reducing the embodied energy associated with them.

The uncertainties on the thermal conductivities and effusivities are estimated at 14% and 7%, including systematic biases caused by uncertainty in the electric flux [8]. These results are comparable with those of Izard [10].

Table 1: Material properties and simulation data in TRNSYS 16.1

Building component	Materials	Thickness (m)	Thermal Conductivity (W/mK)	Density (kg/m^3)	Thermal capacity (J/kgK)
Coating	Fiber-reinforced cement mortar	0.025	0.54	1735.25	1870.14
	Cement mortar coating	0.025	0.87	2200	1050
2 types of wall	Case1- Wall in breeze block	0.20	1.75	2100	653
	Case2- Wall in laterite	0.20	0.61	1935	897
Reference roof	Concrete	0.22	1.75	2100	653
	Roof seal (bitumen)	0.005	0.17	1050	1000
Improved roof	Insulating slab (LPCE)	0.02	0.13	349	705
	Concrete	0.22	1.75	2100	653
	Roof seal (bitumen)	0.005	0.17	1050	1000

3. MODELING IN TRNSYS 16.1

The thermo physical properties of the coating of cement, concrete and asphalt are found in the literature [11]. The influence of two insulated roof (white wood and insulation board) on cooling loads for a common insulation thickness of 1.5 cm was studied.

Modelling with TRNSYS 16.1 [7] is that of a house for residential use and about 50 sq whose facade faces south. It was built as part of the 10,000 housing project by the Centre for estate management (CEGECI) in Ouagadougou, Burkina Faso. This is a building with two bedrooms, living room and a toilet. The configuration of the building is represented by Figure 2.

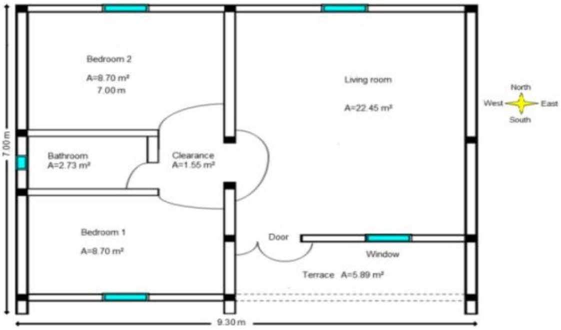

Fig. 2: Floor plan of the investigated building with orientation, dimensions, and surface areas

The floor consists of a concrete slab 15 cm thick. The doors are wood frame with double iron frame. The glazing is simple and 4 mm thick with an iron frame, a conductance outside surface resistance equal to 5.7 W/m^{2}K and solar gain factor of 0.85. The roof is a concrete slab 22 cm thick with a sealing layer of bitumen. The walls of the habitat are supposed to cinderblock or laterite with an interior and exterior coating of cement mortar or cement mortar bundle. The exterior is coated in cement mortar. The effects of insulating foam board on what the cooling loads are analyzed.

The simulations are performed on the year with a time step of 1 hour (0 to 8760 h) using the multi-zone building module (type 56). Weather data Meteonorm the city of Ouagadougou, proposed in TRNSYS 16.1 are used for simulation. The parameter set is air conditioning a temperature of 26 °C at a relative humidity of 50 %. Ventilation and infiltration are set at a volume per hour. Usage scenarios on weekdays and weekends corresponding to the rooms and residence were created [12]. The number of occupants is 4 for the stay and 2 per room. For lighting, a fluorescent lamp whose heat is 8 w is used by local. The living room has a television and a fridge 60 W – 70 W with a duty cycle of 100 % and a DVD player with a 150 W load factor is 40 %.

4. SIMULATION RESULTS AND DISCUSSIONS

Calculations based on thermophysical properties from experiments show that the building has good thermal inertia which varies between 1.06×10^6 J^2/m^4K^2s and 2.4×10^6 J^2/m^4K^2s. This induces a capping amplitudes of internal temperature with a phase shift thereof relative to those from the outside.

Table 2: Overall annual heat loads

	Overall annual heat gains in the house (kWh)	
	Insulation of the roof with a slab	
	Non-existent	Present
Breeze block	17794.25	15376.23
Breeze block with Fiber-reinforced mortar	17659.56	15260.12
Laterite and mortar	17614.61	15230.97
Laterite with fiber Reinforced mortar	17463.35	15089.78

Table 2 shows that if this important in reducing heat gain is from the roof insulation, the compositions of the walls play a secondary role. The use of insulating panels causes a relative reduction of maximum heat gains of 13.6 % compared with the case where one does not use. The appropriateness of this type of insulation board in Burkina Faso formulated and manufactured with local inputs, rather than a ceiling made of white wood has been shown by Toguyeni *et al.* [8].

When using the panel for the roof insulation to reduce heat gains relative maximum is 1.86 % (Column 2 of **Table 2**) it is 1.87 % (column 3 of **Table 2**) in the absence of insulation board. Comparing cases where the roof is insulated to cases where it is not, there is a relative reduction of maximum heat gain of 15.2 %.

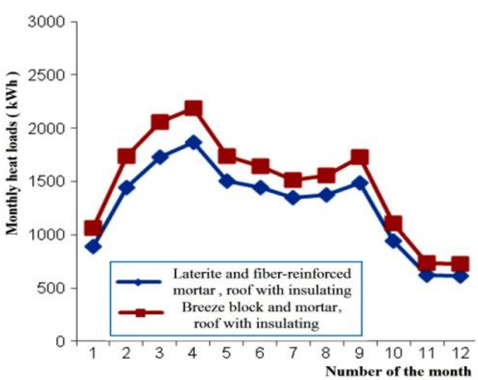

Fig. 3: Monthly heat loads for each configuration of the house

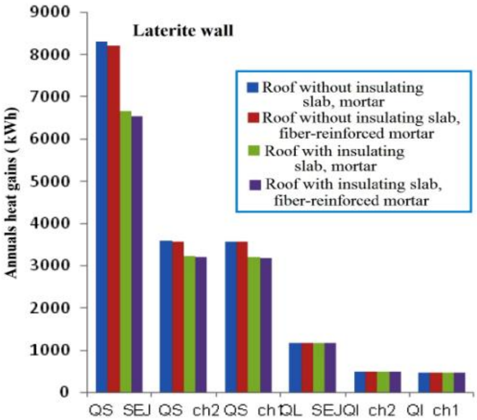

Fig. 4: Annual heat gains in the different rooms of the house for the laterite wall

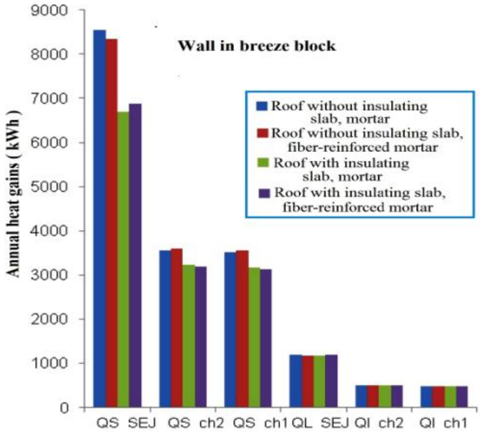

Fig. 5: Annual heat gains in the different rooms of the house to the cinderblock wall

The reduction of annual expenses is around 1.3 % between the laterite wall and the concrete block. The results have shown that the best isolation is obtained for the insulation board. Figure 3 shows the monthly charges for the building cinderblock walls and laterite. The house has a concrete block in cement mortar coating and has no insulation, the house laterite however has a fiber-reinforced mortar coating and an insulated roof with the insulation board.

As expected, the months of March and April, which are the hottest months of the year (average high temperature of 41.6 °C and 41.8 °C respectively), are those for which the overall gains in heat the building and consequently cooling loads are greatest. For these two months, the relative differences between the cases 'breeze block-mortar coating and roof not insulated' and if 'laterite- fiber-reinforced mortar coating and insulated roof' vary between 15.6 % and 16.8 %.

Figures 4 and 5 show the annual heat gain in the different rooms of the house. Sensible heat gain in the living room alone account for between 44.71 % and 48.02 % of total earnings for the breeze-block house, varying between 43.40 % and 47.16 % for the house made of laterite.

5. CONCLUSION

The influence of a local roofing insulation material on cooling loads of a breeze-block or laterite house was investigated. Initially, the thermophysical properties (conductivity, thermal effusivity, density) of these materials were determined using a method such warm terms with an analysis of thermograms in stationary and unsteady, the results are of the order of magnitude values from the literature [10] when the method is applied to the case of cement mortars or bundle of the insulating panel.

In a second step, simulations in TRNSYS 16.1 allowed to retain first only the warmer months, that is to say in march and april, the relative differences between heat gains between the case ‘breeze block-mortar coating and roof not insulated’ and the case **‘**laterite-fiber-reinforced mortar coating and insulated roof’ vary between 15.6’% and 16.8’%.

However it appears that the use of laterite instead of breeze-block when insulation is present (or absent) led to a reduction of around 1.3% this study demonstrates the great potential of using local materials in order to improve the thermal insulation of buildings.

However, much remains to consider alternative approaches. Indeed, one can easily imagine that by using fiber reinforced concrete with the insulating properties are enhanced due to the addition of vegetable fibers we will further reduce heat gain through the roof and at the same time cooling loads. Similarly, the use of an air space built into walls, stucco and clear eaves would possibly further improve the thermal performance at low cost [8].

NOMENCLATURE

E , Effusivity, $J/Km^2s^{1/2}$	mc , Heat capacity of thermocouple, J/K
e , Sample thinckess, m	R_c , Contact resistance, W/m^2K
HRSG , Heat recovery steam generator	T , Temperature, K
t , Time, s	φ_0 , Power dissipated in the hot plate, W/m^2
λ , Thermal conductivity, W/mK	ΔT , Temperature difference, K

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