JCSE International Journal of Computer Science and Engineering Open Access
Research Paper Volume-2, Issue-2 E-ISSN: 2347-2693

Modeling of a Building With The Aim of The Evaluation of its Energy Consumption Application to a Typical Building in Morocco

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www.ijcaonline.org

Received: 02 Feb 2014 Revised: 10 Feb 2014 Accepted: 22 Feb 2014 Published: 28 Feb 2014

***Abstract*—** The building sector accounts for 36% of total final energy consumption in the country, with 29% at the residential level and 7% at the tertiary level. Due to that, the building is considered as a potential of energy saving. Reliable and complete data on the energy consumptions of buildings are lacking in Morocco. Our work aims at contributing to cover these deficits and to optimize the energy consumptions of buildings in Morocco.

The work presented in this article describes a representative simplified dynamic model of a building, established from the meteorological data and the thermo physical properties of the building materials the most used in Morocco. This model will serve to predetermine the energy consumption of the building. This model will be confronted with the experimental statements to validate and correct at the need to use it then in the optimization approaches.

***Index Term*—**Thermal Modeling; Simulation; Energy Consumption; Thermal Comfort

I. INTRODUCTION

Morocco, country very weakly endowed in fossil energy resources, presents very strong energy dependence from the outside (About 94, 6 % in 2009) [1].

It is therefore necessary to reduce the energy needs while improving the energy efficiency, in particular in the sector of the building which represents the first consumer sector of electricity and the second for the fossil fuels (After the transport).

This energy consumption is expected to increase quickly in the future years for two reasons [1]:

- The important evolution of the park of buildings
- The significant increase in the rate of equipment household appliances due to the improvement of the standard of living and the lower prices of these equipments (heating, air conditioning, heating of the water, the refrigeration, etc.).

The purpose of this study is to evaluate the current situation of energy consumption of the building, including air conditioners and different internal loads. On that point, we have developed a dynamic model of the building based on equivalent circuit model. We simulated the dynamic behavior of the building using Matlab / Simulink. We then presented and discussed the solutions to reduce energy consumption.

Motivation

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II. THERMAL MODEL OF A BUILDING

It is assumed that each part of the building is equipped with an air conditioning system. It will be represented by a model [2] based on the physical principle of operation of the air conditioner and simulated by an electric model dependent on several factors such as the structure (chamber surfaces, height and materials of walls and insulation ... etc.), the outside temperature and sunlight. The figure 1 shows this model:

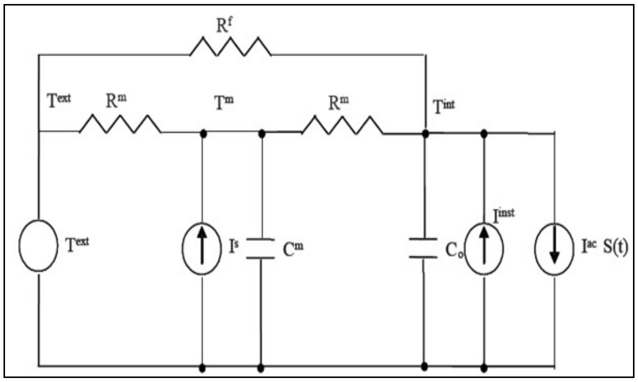

Fig.1: Electric model of an air conditioned room

With:

- R^m : thermal resistance of conduction of the room
- C^m : effective heat capacity of the constructions
- R^f : thermal resistance of conduction of the infiltration averages of air (window, glass …)

- C_o : internal heat capacity
- T^{int} : indoor air temperature
- T^m : wall temperature
- T^{ext} : external temperature
- I^s : the current source of solar radiation
- I^{inst} : the current source heat generated by equipment, people and the lighting system ...
- I^{ac} : the current source of the heat produced by the air conditioner

S (t): The switching function that takes the value 1 when the compressor is turned on and 0 when the compressor is off.

Applying Kirchhoff's law to the nodes, the following differential equations system is obtained:

$$\frac{dT^m}{dt} = \frac{I^s}{C^m} + \frac{T^{int}}{R^m C^m} + \frac{T^{ext}}{R^m C^m} - \frac{2T^m}{R^m C^m}$$

$$\frac{dT^{int}}{dt} = \frac{I^{inst}}{C_o} - \frac{I^{ac} S(t)}{C_o} + \frac{T^{ext}}{R^f C_o} + \frac{T^m}{R^m C_o} - \frac{T^{int}}{C_o}\left(\frac{1}{R^m} + \frac{1}{R^f}\right)$$

Where T^m and T^{int} are unknown.
In this study we did not take into account the thermal sources of equipment and people.
The equation (1) can be written as following state equations [3], [4]:

$$\begin{cases} x^{\cdot} = Ax + Bu \\ y = Cx + Du \end{cases}$$

Where:
$x = [T^{int} \quad T^m]$ is the vector of states;
$y = T^{int}$ is the output of the system, Corresponding to the room air temperature;
u= is the input vector of the model (External temperature, solar radiation, air conditioner power);

$$A = \begin{bmatrix} -\left(\frac{1}{R^m Co} + \frac{1}{R^f Co}\right) & \frac{1}{R^m Co} \\ \frac{1}{R^m C^m} & -\frac{2}{R^m C^m} \end{bmatrix} \text{the state matrix;}$$

$$B = \begin{bmatrix} \frac{1}{R^f Co} & -\frac{1}{Co} & 0 \\ \frac{1}{R^m C^m} & 0 & \frac{1}{C^m} \end{bmatrix} \text{the input matrix;}$$

C= [1 0], D= [0 0 0]. The C matrix relates the state vector directly to the output vector and the D matrix allows for direct connection of inputs to outputs;

III. CALCULATION OF THE THERMAL RESISTANCE AND HEAT CAPACITY OF BUILDING

Thermal resistance of the wall
The thermal resistance depends on the size and also the thermal conductivity of the material used.
The thermal resistance of a wall consisting of several layers is the sum of the individual thermal resistances in each layer [5]:

$$R = \Sigma\, Ri$$

The thermal resistance of a homogeneous solid layer Ri, is calculated from the following formula [5]:

$$R_i = \frac{ei}{\lambda i}$$

Where ei(m) denotes the thickness and λi (W/m°K) the thermal conductivity of the layer i.

Heat capacity of the construction
The effective heat capacity of the constructions, Cm, depends on the specific heat capacity and density of material used, and also of its dimensions. In the simple model it can be evaluated as the sum of the dynamic heat capacities of the constructions as [6]:

$$C^m = \sum C_{m,i} \cdot A_i$$

Where $C_{m,i}$ (J/kG-°K) denotes the specific internal dynamic heat capacity and A_i the area for surface i.
$C_m = \sum \rho_j \cdot c_{l,j} \cdot d_j$ where ρ_j (kG/m3) is the density of material, $c_{l,j}$ (J/kG-°K) the specific heat capacity of material layer j and d_j the thickness of the layer.

Heat capacity of the air
The heat capacity of the air within the room:

$$C_o = \rho_c c_o V^c$$

- ρ_c = air density (1.225 kG /m3)
- c_o = specific heat of the air (1005.4 J/kG-oK)
- V^c = room volume (m3)

IV. DESCRIPTION OF THE APARTMENT OBJECT OF OUR STUDY

Typology of construction:
The study concerns an apartment of 80 m ². The figure 2 shows the mass plan of this apartment.
The simulated building corresponds to typologies of construction the most used in Morocco [7], [8].

The external walls are constituted by hollow bricks double skin spaced out by an air space (10 cm) according to the diagram of the figure 3.

The internal walls consist of simple partitions, the ceiling is constituted by 2 cm of tiles, 5 cm of mortar and 20 cm of the heavy concrete (Figure 3), while the floor is made of concrete 30 cm thick.

The glazing has a coefficient of surface transmission U = 3.3 W/m2k [9]. The table 1 illustrates the composition of the walls of the building with the values of the heat loss coefficient U.

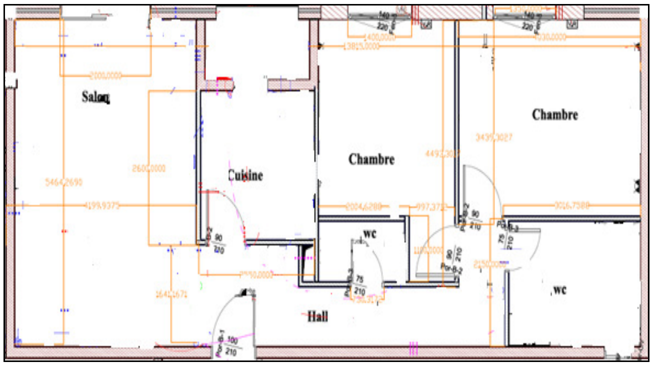

Fig. 2: Mass plan of the apartment

Wall	Constitution (Inside to outside)	U (W/m^2.K)
External wall	Interior plaster (1,5 cm) + Hollow brick (7,5 cm) + Air space (10 cm) + Hollow brick (7,5 cm) + Exterior plaster (1,5 cm)	0,68
Floor	Concrete de 30 cm	6,66
Ceiling	Heavy concrete (20 cm) + Mortar (5 cm) + Tiles (2cm)	6,66

Table 1: Wall composition and heat loss coefficient U of the building

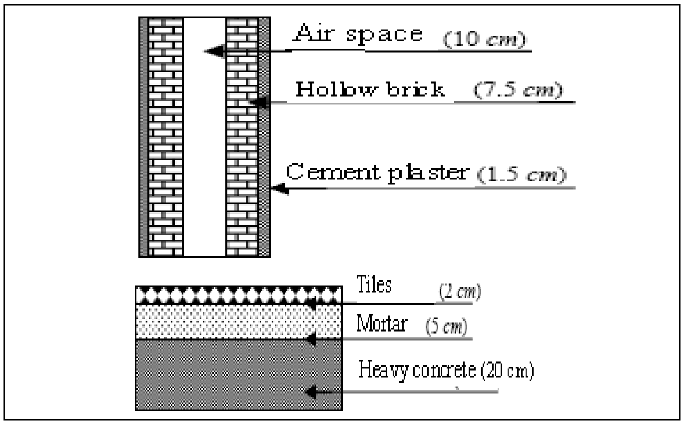

Fig. 3: Structure of the external wall and ceiling

Meteorological data

Meteorological data used are those of Casablanca taken from the average data of NASA (Surface Meteorology and Solar Energy) [10].

The minimum temperature reached is 23 ° C and the maximum temperature is 31 ° C while the average temperature is 27 ° C (Month of August). The average horizontal insolation is considered 6 kW/ m^2/ day.

V. SIMULATION OF THERMAL BEHAVIOR OF THE APARTMENT

The overall model of the apartment

The simulations were performed assuming that:

- The air conditioner is started when the internal temperature rises above 23 ° C.
- The temperature setpoints rooms are identical, which implies that there is no heat transfer between adjacent rooms. In this case, account is taken only of the room walls that are in direct contact with the outside air.
- The external temperature during a day varies according to a sinusoidal function with the average value of 27°C and the amplitude of 4°C.

The implementation of the model in the environment MATLAB / SIMULINK is realized according to the block diagram of the figure 4:

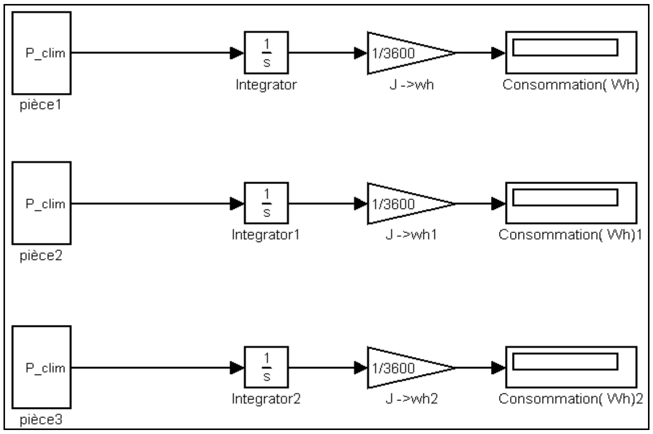

Fig.4: Representation of the model in Matlab / Simulink

The detailed model of each block is as follows:

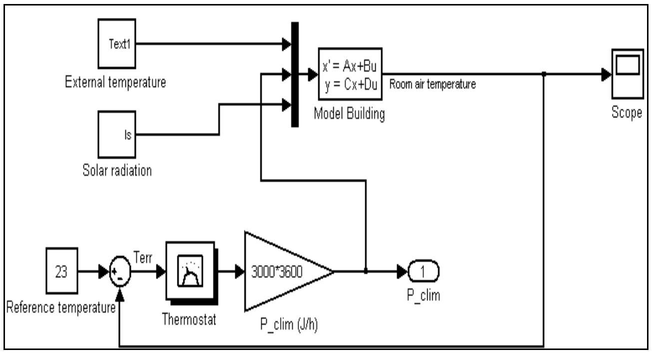

Fig. 5 : Model of each block

The model of the room is inserted into the block "Model Building". The control command "all or nothing" is very largely used in thermal building systems.

In this study, a block 'thermostat' is used to simulate the control command "all or nothing" of the air conditioner. This is a system with two positions: If the measured temperature is below the setpoint, it controls the maximum power, if the ambient temperature exceeds the setpoint, it stops completely the air conditioning.

VI. SIMULATION RESULTS

Evolution of the internal temperature

Figures 5, 6 and 7 show, over a period of 24 hours, the variation of the outside temperature and the temperature of internal air around the value of the setpoint. The setpoint temperature is fixed at 23 °C, accompanied by a hysteresis (variation around the point) of 1 °C: the air conditioner is thus switched on in 24 °C and stopped in 22 °C.

We observe that:

- The model describes correctly the evolution of the internal temperature.
- The expected comfort is assured.
- The results are in accordance with previous work ([2], page 129), [3].

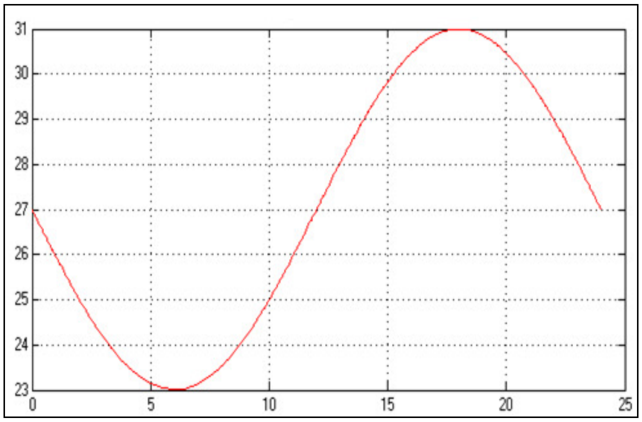

Fig.5: Exterior temperature

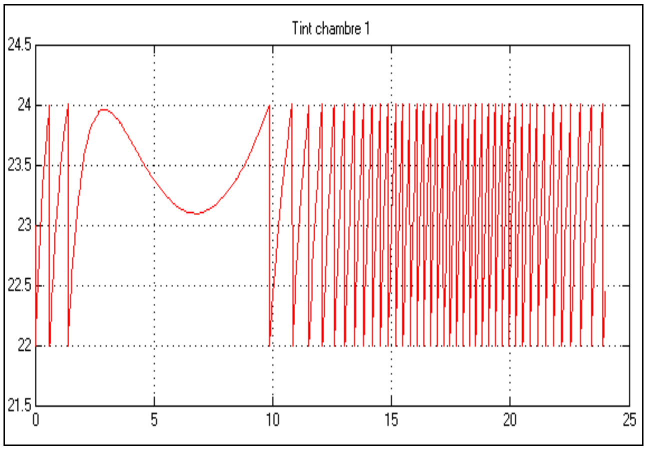

Fig.6: Temperature inside the room 1

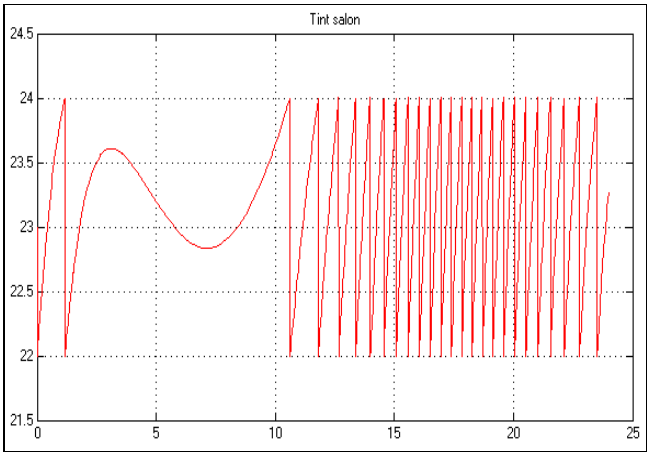

Fig.7: Temperature inside the living room

Behavior of the power consumption:

The figure 8 shows the behavior of the air conditioner. The need for cooling of rooms 1 and 2 is around 900 Wh / J for a power conditioner of 3 KW, while the living room is around 1.2 kWh / J for a cooling power of 6KW. High consumption of the living room is due to its large surface area (22 m^2) and that of the window (4.4 m^2). So a lower thermal resistance of conduction of the infiltration of air: 0.069K / W against 0.098 K / W of the room 1; it follows a need for higher cooling.

In [7], they used TRNSYS "Transient System Simulation Program" to model a single zone of 20 m^2, the characteristics of the wall are the most commonly used in the construction of buildings in Morocco. Meteorological data are those of Casablanca during the month of August.

They estimated an energy need for air conditioning which varies between 9.48 kWh and 26.57 kWh according to 6 variants of compositions of walls the most used in Morocco. In our case, the monthly consumption of the air conditioner in the living room (22m^2) (For a reference temperature of 25°C, the same as in the study of [7], is of the order of 18.85 kWh, value which agree with the results of [7].

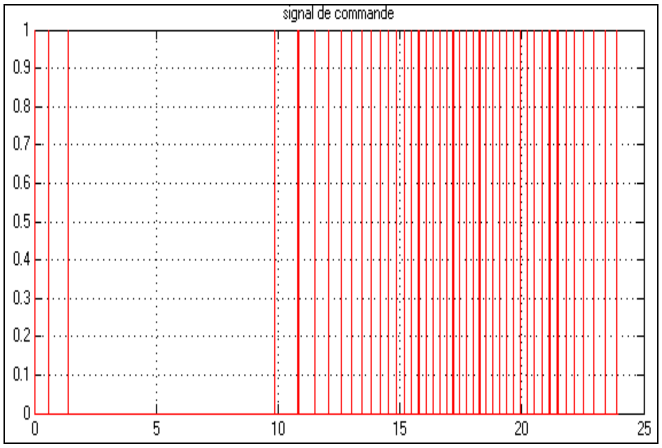

Fig.8: Fonnctionement signal of the air conditione

VII.DISCUSSION OF RESULTS & PERSECTIVES

In its current form, our thermal model allows to simulate the thermal behavior of buildings. It allows to represent in a satisfactory way the temporal evolution of the air temperature inside a local and to estimate the energy requirements for air conditioning. Indeed, the found results are consistent with those of similar works.

The established model is therefore considered at this stage, right to use it later in the work. These include the study of optimization of energy consumption in buildings, taking into account the need for cooling and demand comfort.
To this end, our ongoing work consists in:

1. Taking account the current source of heat produced by the equipment, people and the lighting system.
2. Confronting the results obtained from the simulations with the experimental measurements on pilot sites.
3. Studying the various options to reduce the consumption and assess the impact of each of the solutions on the energy balance and the required comfort.
4. Optimizing the systems retained to achieve the best possible efficiency.

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