$16^{èmes}$ Journées Internationales de Thermique (JITH 2013)
Marrakech (Maroc), du 13 au 15 Novembre, 2013

A New Modelling Approach of a Multizone Building, Influence of the Compactness Index in Hot Climate

S.M.A. Bekkouche [a], T. Benouaz [b], M.K. Cherier [a], M. Hamdani [a], M.R. Yaiche [c] and N. Benamrane [a]

[a] Division: Application of Renewable Energies in Arid and Semi Arid Environments /Applied Research Unit on Renewable Energies/EPST Development Center of Renewable Energies, URAER & B.P. 88, ZI, Gart Taam Ghardaïa, Algeria
[b] University of Tlemcen, BP. 119, Tlemcen R.p. 13000 Algeria
[c] Development Center of Renewable Energies, CDER & B.P 62, 16340, Route de l'Observatoire, Bouzaréah, Algiers, Algeria.
Email : b_tayeb@yahoo.com

Abstract: Some variables that are related to building shape and which influence heating and cooling requirements are the following: compactness index; the height of walls, climate; and the characteristics of the building envelope. These characteristics are crucial variables that should be taken into account because they are relevant to the energy requirements for maintaining the building at a comfortable temperature. This article provides studies of some building criteria that can reduce the energy demand for the heating and cooling of residential buildings. These criteria are based on the adoption of envelope system, and the building compactness. The result proves that proper use of compactness index and building geometry parameters will noticeably minimize building energy and improve the internal temperature of the building. The compactness is better when the compactness index is lower.

Keywords :

Multizone Model – Nodal Method – Temperature Compactness – Hot climate.

1. Introduction

The most often preferred modelling approach for architects is to emphasise on the outer shape of the building. Constructing a model of thermal dynamics of a multi-zone building requires modeling heat conduction through walls as well as convection due to air-flows among the zones. Constructing building thermal dynamics is a challenging task since it requires modeling heat exchange through convection, conduction and radiation among all the rooms. The thermal dynamics in a multi-zone building can be thought of as an interconnected system of many subsystems [1]. A network model of thermal dynamics of a multi-zone building will have nodes corresponding to the temperatures in zones and edges corresponding to reduced order models of dynamic interaction between the variables connected by the edge.

The compactness of a building, indicated by the S/V ratio (S: area of building envelope surface, V: volume of the building) has a considerable influence on the heating energy demand of buildings, regardless of the level of fabric insulation. This paper provides a simplified analysis method to predict the impact of the shape (compactness index) for a building on its instantaneous temperature. A proposed model is developed based on detailed simulation analyses utilizing several combinations of building geometry, orientation, thermal insulation level, glazing type, glazing area and climate. The present paper wants to emphasize the importance of this factor in the estimation of a building energy performance on the base of an analysis of a building in hot climate.

2. Multizone building modelling

Most of the research papers dealing with this topic present the temperature identification of either a single-zone building, or a single building sub-system. On contrary, we proposed a novel approach combining a detailed modeling by a building-design simulation program. This section formulates the problem precisely and describes the proposed method. The main equations as well as the structure of the new model environment have been described.

2.1. Conduction model coupling with superficial exchanges

We can find a simplified approach allows representing the multilayer system by a model based on an electrical analogy proposed by Rumianowski et al in 1989, and then it was taken by Con et al. in 2003 [2]. It is often used when we intresse to the determination of the temperature of any node inside a wall. The following figure is an illustration of the decomposition principle.

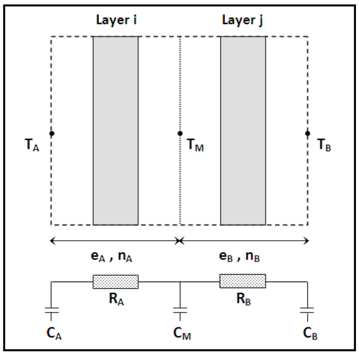


Figure 1: Wall spatial discretisation and conduction model

The equivalent resistances are calculated by the following formulas:

$$n = n_A + n_B \qquad R_A = \sum_{k=1}^{n_A} \frac{e_k}{\lambda_k S_k} \qquad R_B = \sum_{k=n_A+1}^{n} \frac{e_k}{\lambda_k S_k} \qquad (1)$$

$$C_A = \sum_{k=1}^{n_A} \rho_i Cp_i e_i S_i \left(1 - \beta_i\right) \qquad C_B = \sum_{j=n_A+1}^{n} \rho_j Cp_j e_j S_j \delta_j \qquad (2)$$

$$C_M = \sum_{k=1}^{n_A} \rho_i Cp_i e_i S_i \beta_i + \sum_{j=n_A+1}^{n} \rho_j Cp_j e_j S_j \left(1 - \delta_j\right) \qquad (3)$$

$$\beta_i = \frac{\frac{e_i}{2 \lambda_i S_i} + \sum_{k=1}^{i-1} \frac{e_k}{\lambda_k S_k}}{R_A} \qquad \delta_j = \frac{\frac{e_j}{2 \lambda_j S_j} + \sum_{k=n_A+1}^{j-1} \frac{e_k}{\lambda_k S_k}}{R_B} \qquad (4)$$

The energy balance of the building for surfaces is represented by equations 5-7:

$$C_A \frac{d T_A}{dt} = \frac{T_M - T_A}{R_A} + \sum S \ F_{Surf-i} \, \sigma \left(T_i^4 - T_A^4\right) + S \ h_{conv} \left(T_{air} - T_A\right) \qquad (5)$$

$$\begin{aligned} C_B \frac{d T_B}{dt} &= \alpha \ S \ G + \frac{T_M - T_B}{R_B} + \varepsilon \ S \ \frac{1 - \cos\beta}{2} \left(T_{Ground\ outside}^4 - T_B^4\right) \\ &+ \varepsilon \ S \ \frac{1 + \cos\beta}{2} \left(T_{Sky}^4 - T_B^4\right) + S \ h_{conv\,amb} \left(T_{amb} - T_B\right) \end{aligned} \qquad (6)$$

$$C_M \frac{d T_M}{dt} = - \frac{T_M - T_A}{R_A} - \frac{T_M - T_B}{R_B} \qquad (7)$$

$$h_{conv\,amb} = 2.8 + 3.3 \ V_{Wind} \qquad (8)$$

$$T_{Sky} = 0.0552 \ T_{amb}^{1.5} \qquad (9)$$

e : thickness (m)
n : number of node
α : absorption coefficient
ε : thermal emissivity
G : the incident global irradiation on the surfaces (w m^{-2})
S : surface (m^{2})
λ : thermal conductivity (w K^{-1} m^{-1})
Cp : specific heat (j kg^{-1} K^{-1})
ρ : density (kg m^{-3})
F : form factor between the exchange surfaces
σ : Stephane-Boltzmann constant (w m^{-2} K^{-4})
V_{vent} : wind speed (m s^{-1})
h_{conv} : coefficient of heat flux exchanged by convection (w)

In the multizone-zone model a given building is made up with a certain number of rooms, walls, doors and also glass windows. The physical model of the building is obtained by assembling thermal models of each element. The different zones' temperatures (principal variables) are linked together through heat conduction and air movement.In this paper, we make a coupling between the equations proposed by Rumianowski et al [2,3] and equations of a building thermal energy model found in the TRNSYS user manual [4]. The building energy balance for a zone is a balance model with one air node per zone, representing the thermal capacity of the zone air volume. The building power balance for a zone is shown as equation 10 representing the variation of the power energy of the air in the zone in the time interval dt:

$$\rho_{air}\, C_{air}\, V_{air}\, \frac{d\,T_{air}}{dt} = Q_{Gain} + Q_{Surf} + Q_{\text{heating}} + Q_{\text{cooling}} + Q_{Inf} + Q_{Vent} \qquad (10)$$

With thermal powers are algebraic values

T : temperature (K)
ρ_{air} : air density (kg m^{-3})
C_{air} : the specific heat of air, it is assumed constant and estimated at 1008 (m^{2} s^{-2} K^{-1}, j kg^{-1} K^{-1})
V_{air} : air volume (m^{3})
$Q_{heating}$: thermal power provided by heating equipment (w)
$Q_{cooling}$: thermal power provided by cooling equipment (w)
Q_{Inf} : thermal power gain due to air infiltration (w)
Q_{Vent} : thermal power gain due to air ventilation (w)
Q_{Surf} : thermal power due to exchange between the air and, (i) walls inner surfaces and (ii) windows and doors, (w)
Q_{Gain} : direct solar gain due to openings (w)

The boundary conditions of the system include the nodes of the inner surface for all surfaces of the zone, including radiative energy flows. We also note that the energy of an active layer and the energy stored in the walls are not part of this energy balance, but they are part of detailed balance for surfaces. The transfer rates of thermal energy of infiltration and ventilation air flow are respectively calculated by equations 11 and 12.

$$\dot{Q}_{Inf} = \dot{m}_{Inf}\, C_{air} \left(T_{air} - T_{out}\right) \qquad (11)$$

$$\dot{Q}_{Vent} = \dot{m}_{Vent}\, C_p \left(T_{Vent,out} - T_{Vent,\text{int}}\right) \qquad (12)$$

$\dot{m}_{Inf}$: the air flow due to infiltration (kg/s)
$\dot{m}_{Vent}$: the air flow due to ventilation (kg/s)
T_i : air temperature inside the building (K)
T_{out} : air temperature outside the building (K)
$T_{Vent,out}$ and $T_{Vent,in}$: air temperature at the outlet and inlet ventilation respectively (K)

Thermal energy due to exchange between the air and walls inner surfaces are calculated by equation 13:

$$Q_{Surf} = \sum S\, h_{Conv} \left(T_{Surf} - T_{air}\right) \qquad (13)$$

T_{Surf} : air temperature walls inner surfaces (K)
h_{Conv} : the convective transfer coefficient (w m^{-2} K^{-1})

Surface description	Flow regime	Condition	Expression
Vertical wall	Laminar regime	$10^4 < Gr\,Pr < 10^9$	$h_{Conv} = 1.42\,(\Delta T/L)^{1/4}$
	Turbulent regime	$Gr\,Pr > 10^9$	$h_{Conv} = 1.31\,(\Delta T/L)^{1/3}$
An upper surface of an hot horizontal plate or an underside surface of a cold plate	Laminar regime	$10^4 < Gr\,Pr < 10^9$	$h_{Conv} = 1.32\,(\Delta T/L)^{1/4}$
	Turbulent regime	$Gr\,Pr > 10^9$	$h_{Conv} = 1.52\,(\Delta T/L)^{1/3}$
An underside surface of a hot plate or an upper surface of an cold plate	Laminar regime	$10^4 < Gr\,Pr < 10^9$	$h_{Conv} = 0.59\,(\Delta T/L)^{1/4}$
	Turbulent regime	$Gr\,Pr > 10^9$	

Table 1: Expression of convective transfer coefficients

Gr : Grashof number
Pr : Prandtl number
L : length of the plate (m)
ΔT : temperature difference between the surfaces and volumes exchange (K)

2.2. The Nodal Structure and Description of the Building

The study was carried out on a building in Ghardaïa. A certain number of information fields are connected to a node, traducing for instance the allocation of a node to a zone or also the topology of the global electrical network associated with the building. We have been induced to assign a type to each node. Indeed, relative to the equations, the nodes are concerned with different phenomena. Then, it appears necessary to attribute a type to each node. For a given building, when the node structure is established, it is easy to fill up each element of the mathematical model. Indeed, we have just to sweep the node structure and attribute the relevant terms. Then, the structure will include six zones' numbers (figure 2).

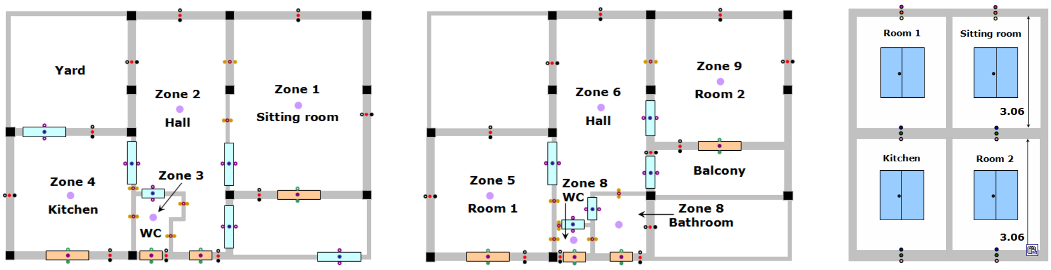


Figure 2: Types of nodes and zonal structure

The house has a habitable area of 68.3 m^2, and wall heights are equal to 3 m. The flooring is placed on plan ground to lodge the ground floor. The concrete of the flooring is directly poured on the ground thus minimizing losses. Floor tiles are inter-imposed, it is an end coating resisting to corrosion and chemical agents. Layer thickness, composition and thermal transmittance values U for walls, ground and roof are given in table 2.

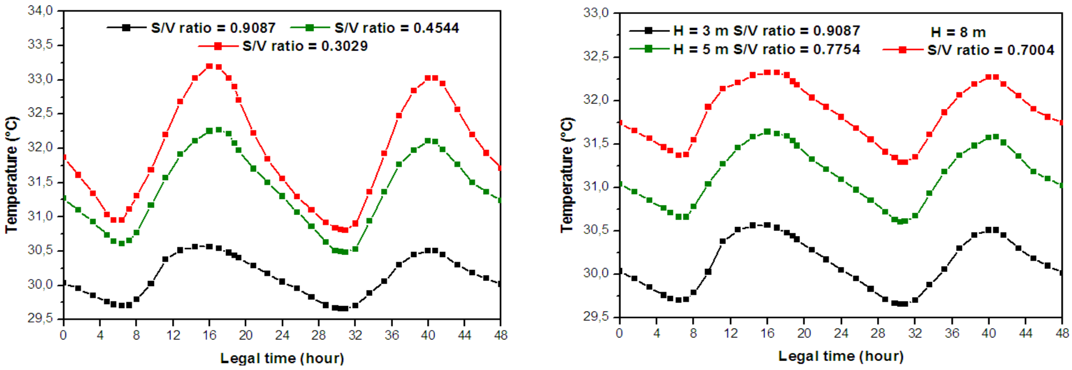
3. Compactness and computational results

The compactness of a building is measured by a ratio of surface area S to volume V, this ratio is an indication of the rate at which a building heats up during the day and cools down during the night. The building form and its compactness are relevant for the amount of heat transmission losses, which are proportional to the insulating quality and to the heat transmitting surface. In this contribution, we enlarged the plan (Vx2 and Vx3) to determine internal temperatures of the sitting room. The building is exposed on all sides (the four walls and roof) to the wind and sun. These cases took into account only thermal exchanges thus air stratification, whereas wind influence on air infiltration and water diffusion into walls body were not considered. Also states changes are not considered therefore storage of latent heat and moisture effects were neglected.

Figure 3 gives an idea of the temperature profiles obtained by numerical simulation.The obtained values correspond first to the plane of figures 2 which is relative to a height of 3 m, and secondly, correspond to the same plane and the same geometrical shape of the house but by multiplying the dimensions by 2 (respectively 3) which corresponds to a height of 6 m (9 m respectively). In what follows, we are interested in the effect of the compactness index of this construction on the temperature inside the sitting room. Figure 4 predicts the calculated temperatures using the same conditions imposed for the case of figure 3. The idea is to keep the same descriptive plan but by varying the height of the walls, which leads each time a change in compactness index.

	Composition	Thickness *(cm)*	Thermal transmittance values U $(W / m^2 K)$
Exterior walls	Plaster	1.5	1.89
	Brick	30	
	Coating plaster	1.5	
Interior walls	Coating plaster	1.5	2.4
	Brick	20	
	Coating plaster	1.5	
Ground	Tiling	2.5	0.358
	Cement	1	
	Stone	6	
	Concrete	24	
Roof	Plaster	1.5	1.048
	Slab	12	
	Mortar	3	
Flat Glass	Single pane, clear + wood blinds		3.18

Table 2: Layer thickness and U values for building envelope



Figures 3-4: Temperature of sitting room, 10-11 August.

4. Conclusion

In hot climate, a house in a large building which has only one exposed wall is characterized by a low compactness index due to the total area of exposed walls which is significantly reduced. Also, the geometry and precisely the variation of the walls height play a crucial role; the obtained temperature profiles are proportional to the heights of building walls. Increasing height walls for this construction type does not promote thermal comfort even if we consolidate the thermal insulation of the building external envelope.

In hot dry climates, the surface volume area ratio should be as low as possible to minimise heat gain and the compactness is better when the compactness index is lower.

References

[1] S. Goyal, C. Liao and P. Barooah, *Identification of multi-zone building thermal interaction model from Data*, 2011 50th IEEE Conference on Decision and Control and European Control Conference (CDC-ECC) Orlando, FL, USA, December 12-15, 2011.

[2] P. Rumianowski, J. Brau, and J.J Roux, *An Adapted Model for Simulation of the Interaction Between a Wall and the Building Heating System*, In Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings IV Conference Orlando,USA, p. 224-233, 1989.

[3] L. Mora, *Prédiction des performances thermo-aérauliques des bâtiments par association de modèles de différents niveaux de finesse au sein d'un environnement orienté* objet, Thèse de Doctorat, Laboratoire d'Etude des Phénomènes de Transfert Appliqués au Bâtiment, UFR Sciences Fondamentales et Sciences pour l'Ingénieur, université de la rochelle, Septembre 2003.

[4] TRNSYS16, TRNSYS User Annual, Solar Energy Laboratory, University of Wisconsin Madison, USA, 2004.