International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Numerical Study on the Effect of Insulation Materials on the Single Zone building Performance

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Accepted 25 Nov 2016, Available online 05 Dec 2016, **Vol.6, No.6 (Dec 2016)**

Abstract

The thermal performance of a single zone building at Baghdad city was studied under different wall construction. The building walls are insulated by expanded Polystyrene with different densities and different thicknesses. Depending on the energy balance equation, the MATLAB software is used to solve the thermal performance of the building. A number of nodes are used to simulate the building performance. To reduce the initial conditions influences, every model has submitted to three pre-simulations (warm-up) for the same day of August 21, with 25 ºC initial temperature. A fully implicit scheme with a set simultaneous linear equations is used to solve the models and building thermal performance. Outdoor temperature and solar intensity were used as input parameters, and the output were the indoor air temperature and heat flow to the building through the building structure. The results showed that using insulation within the walls reduces the mean indoor temperature and damping the indoor temperature fluctuation. The density and thickness of polystyrene affect the indoor temperature and heat flow to the building insignificantly. Insulating northern wall shows insignificant effect on the indoor temperature; it is recommended to leave the southern wall without insulation.

Keywords: *Building energy model, R C model, Thermal network*

1. Introduction

Iraq is an extremely hot arid zones, so the selecting of building design and building materials are a critical issue. The good selection of building materials reflects positively on indoor temperature, as well as on the power that consumed in air conditioning systems. Also, increasing wall thermal mass can delay the heat entering building envelope to the time when the value of outdoor condition at minimum or near minim value. As well as, increasing walls thermal mass can damp the cooling load, which leads reduce the air conditioning system capacity. There are many works related to the improving of the building performance by studying different building materials. Daily temperature fluctuations in a direct gain room were studied by (Maloney, Wang, Chen, & Thorp, 1982), the room was assumed to have losses heat on three faces and south glazing. The temperature and solar insolation values for a typical January day in Nebraska were duplicated thirty consecutive times and were used for the weather data input to the modelling program. A computer analysis in the frequency domain of multi-zone passive solar buildings was investigated by (Athienitis, Chandrashekar, & Sullivan, 1985), this method modeled the heat conduction and convection between rooms, heat flows which were often not accounted for to reduce computation time. Heat transfer through a building is modeled by a thermal network. (M.J. Jiménez, Madsen, & Andersen, 2008) Presented the application of IDENT Graphical User Interface of MATLAB to estimate the thermal properties of building components by testing the outdoors dynamic, imposing appropriate physical constraints and assuming linear and time-invariant parametric models. (Bacher & Madsen, 2011) suggested the procedure for identification of suitable models for the heat dynamics of a building. Such a method for model identification was better usage of readings from smart meters, which was expected to be installed in almost all buildings in the coming years. (Fraisse et al, 2011) presented a method for identifying the parameters of RC network models by illustrating the case of 1D conduction in a wall.

The parameters of the RC model were identified by the optimization method of genetic algorithms. Nodes representing exterior surfaces, whose temperatures do not have to be explicitly determined, were eliminated by the Norton theorem. (Bueno, Norford, Pigeon, & Britter, 2012) presented an urban canopy and building energy model based on a thermal network of constant resistances and capacitances (R C). The RC model represented the physical relations between buildings and their urban environment, retaining the sensitivity to the design parameters typically used in building

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energy and urban climate studies. (Park, Martaj, Ruellan, Bennacer, & Monmasson, 2013) proposed a low-order dynamic model of a building system to predict thermal behavior within a building and its energy consumption. The building system includes a thermally well-insulated room and an electric heater. It was modeled by a second order lumped RC thermal network based on the thermal-electrical analogy. The relationship between commonly RC-network models and the parametric models proposed was deduced. (BOND, 2014) that used an electrical analogy to model one-dimensional heat conduction using RC circuits. A frequency response analysis was conducted based on a period of one day. For a fixed wall thickness, four features were optimized: materials, proportion of materials, layers number , and distribution of material.
In this work the performance of a single zone building, at Baghdad city was studied at August 21. The effect of adding insulation at building walls, density and thickness of insulation materials on the indoor temperature, and heat flow to the building envelope are analyzed numerically. The walls, roof, floor, door and window are simulated as resistance capacitance network. MATLAB software is used to solve the final building model.

2. Building model description

The building under study is unconditioned single zone building with dimensions of 10 m wide, 10 m long and 3 m height. The wall that is having the door and window is facing the west.

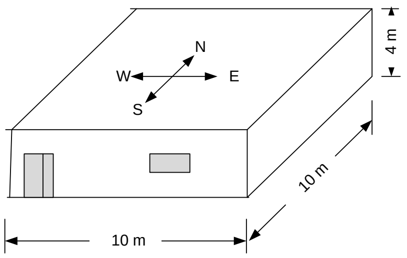


Fig.1 Schematic diagram of building under study

The traditional building wall is built from 240 mm common brick, with 10 mm external cement plaster and 10 mm gypsum plaster. The roof layers from outer to the inner surface are 25 mm cement tile, 150 mm sand, 150 mm poured concrete and 10 gypsum plaster. The floor consists of 25 mm cement tile, 100 mm Light concrete, asphalt singles and 100 mm poured concrete. The 3 m^2 outer door is of wood of 25 mm thickness, and there is a 2 m^2 southern window of 8 mm glass thickness with steel sash. To study the effect of insulation on the indoor temperature and heat flow to the building envelop, the outer walls of the building are replaced by a modified walls, that built from 120 mm double common brick, the 25 mm space thickness between the two walls are filled 25 mm expanded Polystyrene of densities of 15, 20 and 30 kg/m^3. All walls, roof, door and windows are exposed to the ambient conditions and solar radiation. The building in Baghdad city, the longitude and latitude are 33.3128° N, 44.3615° E, respectively. The elevation from sea level is 34 m. The thermal properties of building materials are shown in table (1). While the schematic diagram of the building is shown in Fig. (1).

3. Modeling of building

The inside air temperature of the direct gain building is a function of outdoor conditions, solar intensity, building thermal mass and glazing area. One method that used to solve such combination of variables is the Resistance – Capacitance RC thermal network. The simplest RC model is shown in Fig. 2a. The heat balance of the RC network is as follows (Kreider, Curtiss, & Rabl, 2002)

Heat stored with the capacitance = heat flow through the resistance + Solar incidence

$$C.\frac{dT}{dt} = \frac{T_2 - T_1}{G} + I \tag{1a}$$

Where:
G: Wall thermal resistance (m^2. Hr. K/kJ)
I: Solar intensity (kJ/hr. m^2)
C: Wall capacitance and can be calculated as follows:

$$C = \rho.Cp.x.A \tag{2}$$

Where:
ρ: Plane density (kg/m^3)
Cp: Specific heat of the plane (kJ/kg K)
Re arrange Eq. (1a), yields:

$$\tau.\dot{T} + T_1 = T_2 + I.G \tag{1b}$$

Where, τ is the time constant for the first order differential equation, and equals to (G.C). If the solar intensity and free node temperature are assumed to be constant, then the derivative of Eq. (1 a) is as follows(Kreider et al., 2002):

$$T_{(t)} = T_{1(t)} - T_2 - G.I \tag{3}$$

Substituting Eq. (1 b) into Eq. (3) yields:

$$\tau.\dot{T} + T = 0 \tag{4}$$

The solution of Eq. (4) is:

$$T_{(t)} = T_0.e^{\left(\frac{-t}{\tau}\right)} \tag{5}$$

Where T_0 is the initial temperature of the node.

If two nodes model are used as shown in Fig. 2b, the heat balance of the two nods are:

$$C_1.\frac{dT_1}{dt} = \frac{T_n - T_1}{G_1} + I \tag{6a}$$

$$C_2.\frac{dT_n}{dt} = \frac{T_1 - T_n}{G_1} + \frac{T_2 - T_n}{G_2} \quad (6b)$$

When the solar intensity and the free node temperature (T_2) are constants, then the solution of Eqs. (6a) and (6b) is:

$$T_{(t)} = T_{1(0)}.e^{\left(\frac{-t}{\tau}\right)} \quad (7)$$

And the time constant for Eq. (7) should be satisfy

$$\tau^2 - (C_1.G_1 + C_1.G_2 + C_2.G_2)\tau + C_1.G_1C_2.R_2 = 0 \quad (8)$$

Generally for a slab divided by N layers, the RC thermal network is shown in Fig. 2c, thus the heat balance equation for the internal node is (Kreider et al., 2002):

$$C.\frac{dT_n}{dt} = \frac{T_{n-1} - T_n}{G} + \frac{T_{n+1} - T_n}{G} \quad \text{for } 2 \leq n \leq N\text{-}1 \quad (9)$$

While the thermal balance for the external nodes are:

$$C.\frac{dT_1}{dt} = \frac{T_i - T_1}{G_i} + \frac{T_2 - T_1}{G} \quad (10\ a)$$

$$C.\frac{dT_N}{dt} = \frac{T_{N-1} - T_N}{G} + \frac{T_o - T_N}{G_o} \quad (10\ b)$$

It can be seen from the figure that the values of G_i and G_o can be written in terms of plane thermal resistance (G), outer and inner film surface conductance (hi) and (ho) as, $G_i = \frac{R}{2} + \frac{1}{h_i.A_{Plane}}$, $G_o = \frac{R}{2} + \frac{1}{h_o.A_{Plane}}$ and $G = \frac{x}{k_{Plane}.A_{Plane}}$.

From above, the building walls, under study, can be represented as RC thermal networks, as shown in Table (2).

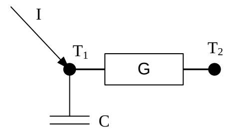


Fig.2a Single RC thermal network

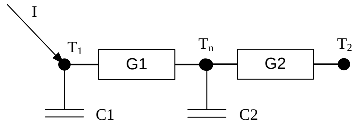


Fig.2b Double RC thermal network

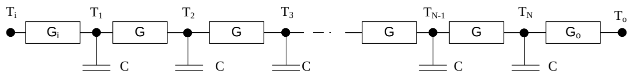


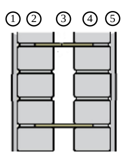
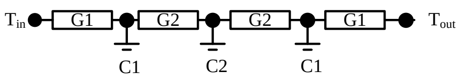
Fig.2c N number RC thermal network

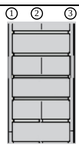
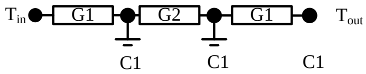
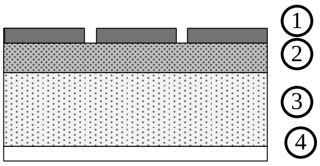
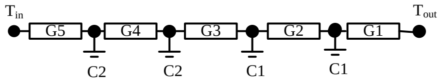
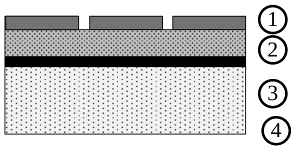
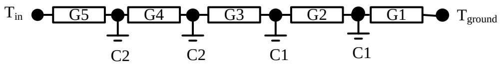
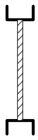
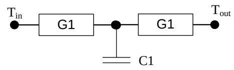
Depending on the energy balance equations, the MATLAB software is used to solve the thermal performance of the building. A number of nodes are used to simulate the building. In order to reduce the initial conditions influences, every model has submitted to three pre-simulations (warm-up) for the same day of August 21, with 25 °C initial temperature.

Table 1 Thermal properties of selected building materials

Materials	Thermal conductivity (kJ/ hr. m .K)	Specific heat (kJ/ kg)	Density (kg/ m³)
Cement Plaster	2.59	0.836	1856
Cement tile	6	0.65	1800
Clear glass	21.4	--	--
Common Brick	2.848	0.84	1600
Gypsum Plaster	1.69	0.8	1680
Light Concrete	6.1	0.62	1800
Polystyrene			
Density 15 kg/m3	0.144	1500	15
Density 20 kg/m3	0.1224	1500	20
Density 30 kg/m3	0.1188	1500	30
Poured Concrete	6.1	0.62	1800
poured Concrete	6.12	0.652	2300
Sand	0.9	0.8	1500
Wood	0.396	544	1.42

Table 2 Walls and roof construction materials and R-C thermal network

Wall type	Construction materials and RC model
 Insulated Wall	1 10 mm Gypsum Plaster 2 120 mm Common Brick 3 25 mm Polystyrene 4 120 mm Common Brick 5 10 Cement Plaster 

 Common Wall	1 10 mm Gypsum Plaster 2 240 mm Common Brick 3 10 Cement Plaster 
 Roof	1 25 mm Cement tile 2 150 mm Sand 3 150 mm poured Concrete 4 120 mm Common Brick 5 10 Gypsum Plaster 
 Floor	1 25 mm Cement tile 2 150 mm Light Concrete 3 Asphalt single 4 100 mm poured Concrete 
 Window or door	Window 6 mm clear glass Door 25 mm wood 

A fully implicit scheme with a set simultaneous linear equations were used to solve the models and building thermal performance. Outdoor temperature and solar intensity were used as input parameters, and the output were the indoor air temperature and heat flow to the building. The RC thermal network of the whole building is shown in Fig. 3

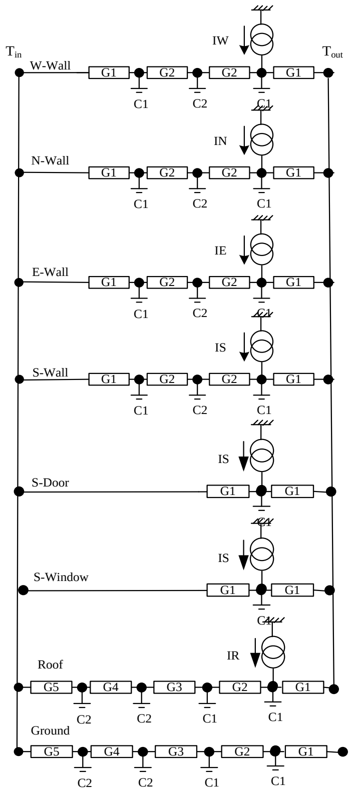


Fig.3 R- C thermal network for whole building

4. Results and discussion

The effect of adding an insulation within the traditional walls on the thermal performance of a single space building are introduced and discussed in this paragraph.

Fig. 4 shows the ambient temperature and solar radiation for a selected hot day, at August 21, the data were derived from Meteonorm 7 software. Main data periods were 1991-2010 for solar radiation parameters and 2000-2009 for temperature, humidity, wind speed and all further parameters.

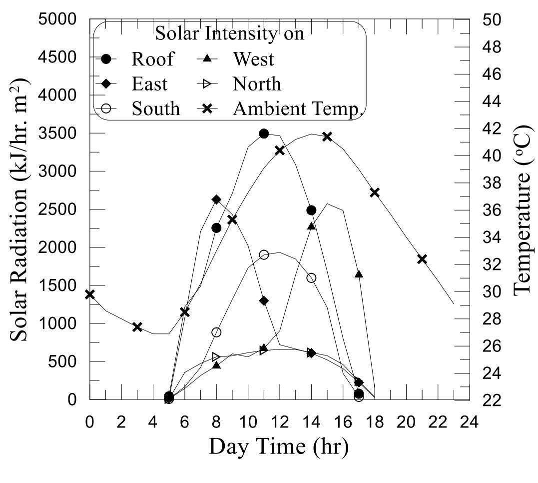


Fig.4 Variation of ambient temperature and solar radiation for Baghdad at August 21

Fig. 5 shows the effect of expanded polystyrene densities, namely 15, 20 and 30 kg/m^3, on the fluctuation of indoor temperature, it can be seen from the figure that the polystyrene density has insignificant effect on the indoor temperature, since the difference between thermal conductivity for the three densities are small. So, the polystyrene density of 15 kg/m^3 is used for the this work.

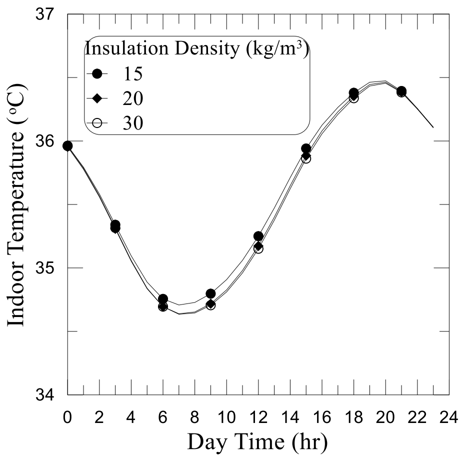


Fig.5 Effect of polystyrene density on the indoor temperature

6 shows the effect of adding insulation to the walls on the indoor temperature, it can be seen from the figure that adding insulation to the four building walls reduced the mean indoor temperature, as well as damping the indoor temperature fluctuation, this is due to that, adding thermal insulation between the walls increases the wall thermal mass, which leads to consume the heat flow to the building in rising the outer layer of the wall. This tends to reduce the heat flow to the building. Using insulation to that northern wall is absolute, as shown in the figure. So, from the economic point of view, it is recommended to leave The northern wall without insulation.

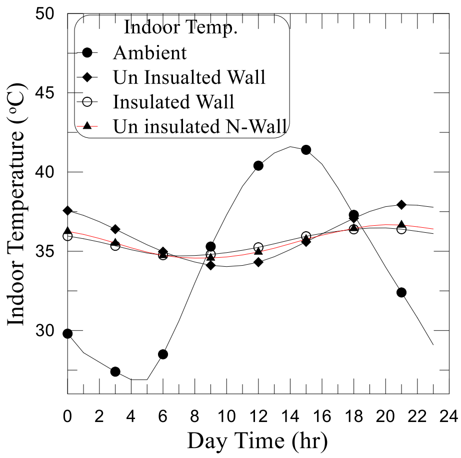


Fig.6 Effect of insulation on the indoor temperature.

Fig. 7 shows the variation of outer surface temperature of the traditional walls, as it can be seen from the figure that, the maximum wall temperature reach its maximum value at about 18 hr due to the storage of heat within wall materials. As it can be seen from the figure that the maximum temperature is for the western wall due to the long duration of wall to solar radiation. As the insulation added to the walls, the maximum and the mean outer surface temperature increases, as shown in Fig. 8, this is due to the that the insulation obstruct a portion of heat that flow through the wall, this portion of heat tends to rise the wall temperature.

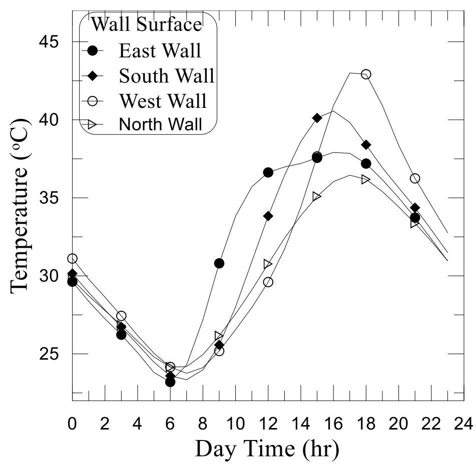


Fig.7 Variation of outer surface temperature

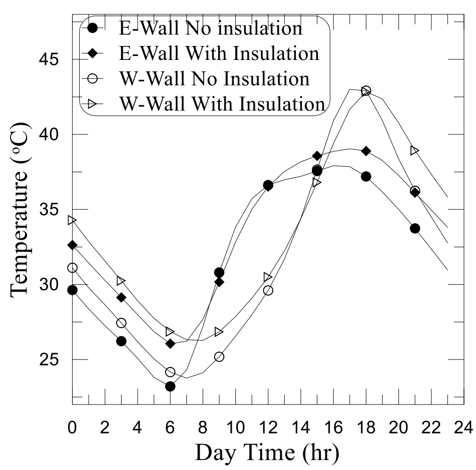


Fig.8 Effect of insulation outer surface temperature of eastern and western walls

Fig. 9 shows the variation of heat flow to the building from different orientation walls, it can be seen from the figure that the maximum heat flow is from the western wall, and the maximum amount of heat flow from all walls occurs after 14 hr due to the walls thermal mass. As insulation is used with walls the heat flow reduces rapidly, as shown in Fig. 10, this is due to two reasons, the first one is that using insulation tends to impede the heat flow through the wall, and the second one is that the impediment heat through walls materials rises the outer surface temperature of the wall, so, a significant part of stored heat within the wall flows to the outside instead of to the building.

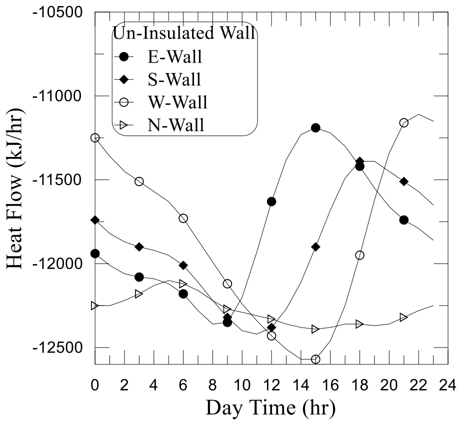


Fig.9 Heat flow to the building from different orientation walls

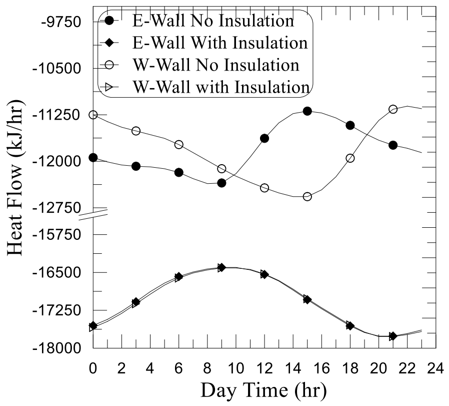


Fig.10 Effect of insulation on the heat flow from eastern and southern walls to the building

Fig. 11 shows the effect of 15 kg/ m³ density polystyrene thickness on the indoor temperature, it can be seen from the figure that, the insulation thickness has insignificant effect on the indoor temperature. So, selecting the insulation thickness of 25 mm by the manufacturers are due to get the appropriate mechanical durability.

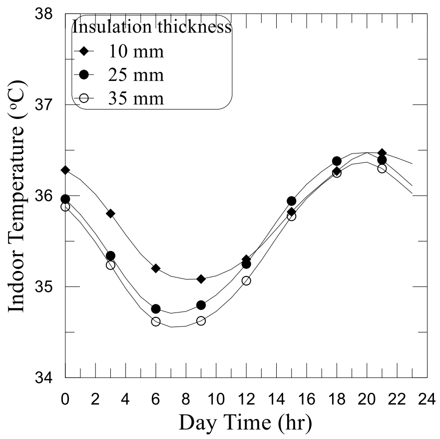


Fig.11 Effect of insulation thickness on the indoor temperature

Conclusions

1) Using Insulation within the walls reduces the mean indoor temperature and damping the indoor temperature fluctuation.
2) The density and thickness of polystyrene affect the indoor temperature and heat flow to the building insignificantly.
3) Insulating northern wall shows insignificant effect on the indoor temperature, it is recommended to leave the southern wall without insulation.

Symbol

A	Area (m^2)
C	Wall capacitance (m. K. hr/kJ)
Cp	Specific heat of the plane (kJ/kg K)
G	Wall thermal resistance (m^2. K. hr/kJ)
hi	inner film surface conductance (kJ/ hr. m^2 K)
ho	outer film surface conductance (kJ/ hr. m^2 K)
I	Solar intensity (kJ/hr. m^2)
k_{Plane}	Plane thermal conductivity (kJ/hr m. K)
RC	Resistance capacitance
ρ	Plane density (kg/m^3)

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