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A STUDY ON A PASSIVELY HEATED SINGLE-ZONE BUILDING USING A THERMAL STORAGE WALL

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ABSTRACT

The thermal performance of a passively heated zone is predicted by calculating the transient temperature variation of each node in the system using a finite-difference model. The sensitivity of the zone air temperature to the change in some of the zone features is examined. Some of these parameters included; the thickness of the walls, using constant and variable heat transfer coefficients, having controlled and uncontrolled thermocirculation in a vented storage wall.

KEY WORDS

Passive systems; thermal storage wall; simulation; solar heating.

INTRODUCTION

Passive system is one which uses the design features such as shading, orientation, insulation, thermal mass, etc., of the building to reduce or eleminate the heating and cooling requirements of the zone. In contrast to the active system, passive system doesn't normally need any active devices (such as pump, blower, etc.) to achieve the heating or cooling process. One of the most common methods used in passive heating is the utilization of a massive wall for heat storage. The performance of the wall is affected by many factors such as the thickness of the wall and the media used for heat storage. The present study aims at examining analytically the performance of a zone heated by a thermal storage wall and how the zone temperature is affected by the change in some of the building features.

The effect of the following parameters were examined:
-The thickness of the thermal storage wall and other insulated walls of the zone.
-The use of vented thermal storage wall with controlled and uncontrolled thrmocicrulation flow.
-The use of auxiliary heat with the passive system.
-The use of variable and constant interior and exterior heat transfer coefficients.

To acheive the goal of the study a dynamic simulation computer model is developed. The program uses the hourly values of the diffuse and direct solar radiation intensity and the ambient air temperature to predict the thermal performance of the zone.

DESCRIPTION OF THE MODEL

The zone is represented by a thermal network, as shown in Fig. 1, with each thermal conductance represented mathematically in the model. The mathematical equations are solved repeatedly at each time step for the period of the simulation. The program allows for the thermal radiation heat transfer between walls of a zone and has the flexibility of using either variable or constant convective and longwave radiative heat transfer coefficients. The walls are connected to each other by surface nodes through a thermal radiative conductance and to the zone air by a convective conductance. Both are calculated at each time step.

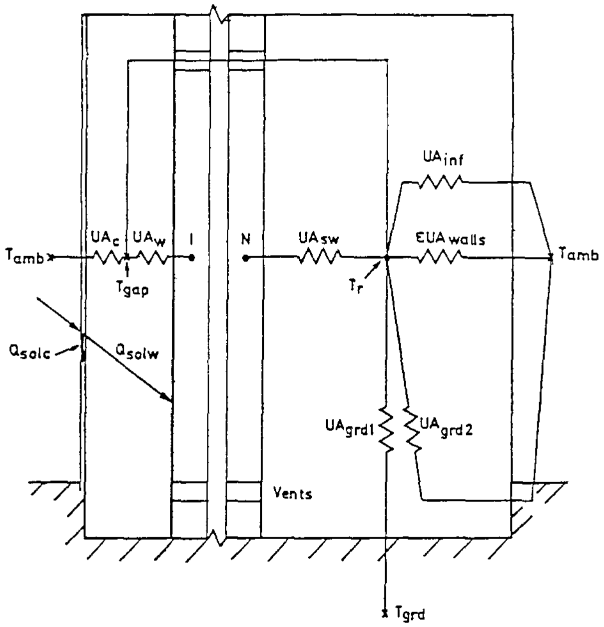


Fig. 1. Building thermal network.

The program does not model the actual distribution of the incoming solar radiation to the various surfaces of the zone. Instead, all solar radiation received by the zone is allocated to the exterior surface of the thermal storage wall. The thickness of the thermal storage wall and its thermal properties can be varied so as to reduce or eliminate the effect of the thermal storage. As a consequence, the wall can be left to act as a surface where all the incoming shortwave radiation can be allocated. That avoides the need for detailed modelling of the shortwave radiation inside the zone, which in most cases, can not be modelled accurately in a realistic room geometry. The thermal storage wall iteslf can be modelled with and without vents. In the former case a conductance due to thermocirculation is calculated at each time step.

For walls experiencing large temperature variations at the surface, such as the thermal storage wall, a node spacing of 50 mm gives accurate results (SERI-RES, 1983). The thermal storage wall is divided into five slabs with a node at the centroied of each slab. The temperature of the glazing and that of the air between the storage wall and the glazing is represented by one node each. All walls, apart from the thermal storage wall, are assumed to store no heat. All zero capacitance elements are described by steady state equations. Likewise, a steady state equation is used to calculate the temperature at the interior and exterior surface of the thermal storage wall and at all other opaque building surfaces.

A finite difference method is used to calculate the transient temperature variation at each node. The natural convective heat transfer coefficients on the different interior surfaces of the building, including the thermal storage wall, and those on the different exterior surfaces of the building are calculated by the empirical formulae given in the literature (see for example; Akbarzadeh, 1982; Khalifa et al., 1989; Khalifa et al., 1990; Morck, 1986).

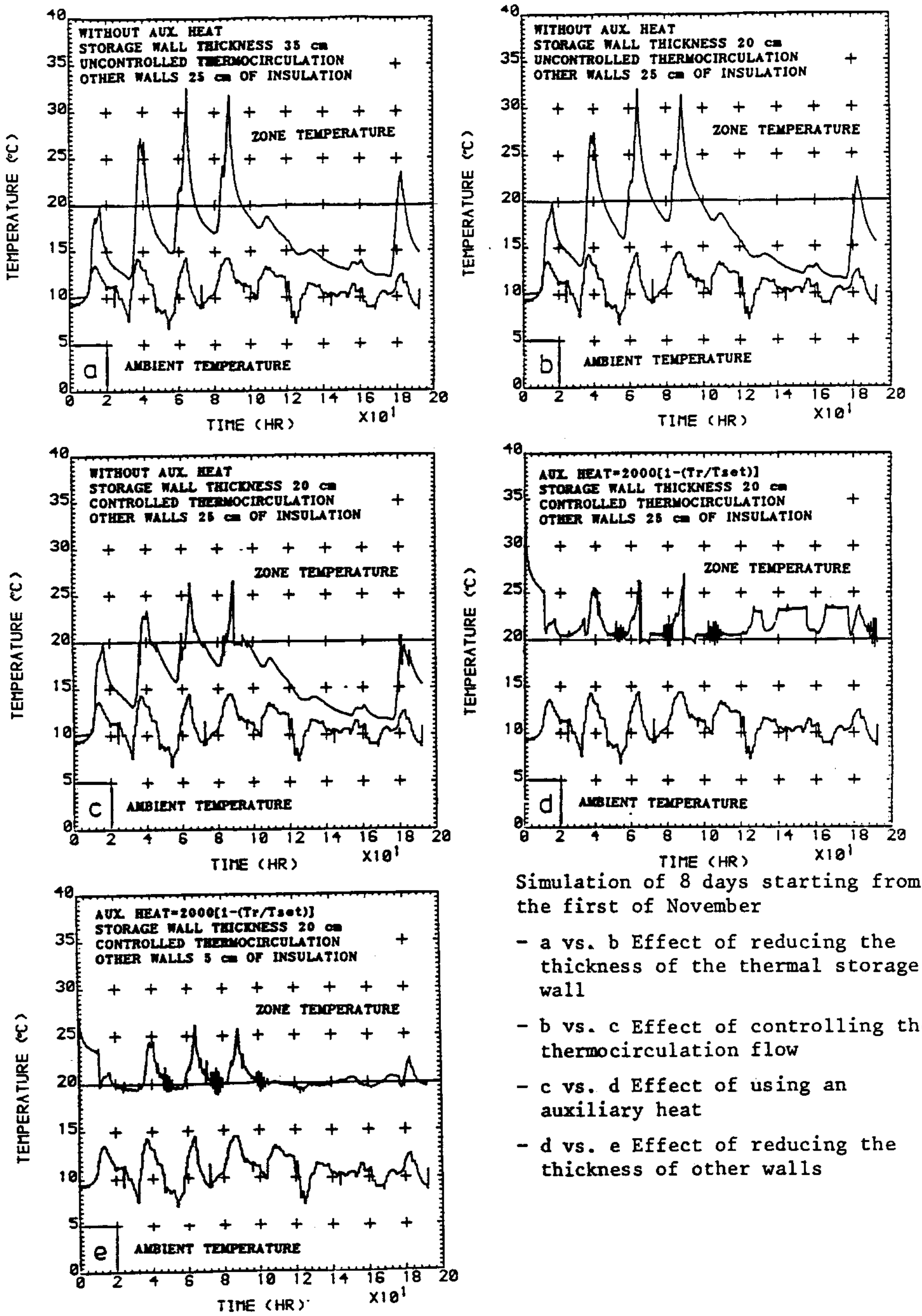
The simulation is started by setting initial system temperatures and describing the details of the building. While reading the hourly values of the solar radiation and the ambient temperature from the weather data file, the temperatures and the heat transfer coefficients of the system are updated at each time step. The total heat loss coefficient of the buildung is estimated by adding up the heat loss coefficient of the zone components such as walls, floor, roof, windows, infiltration ..etc. That coefficient is then multiplied by the ambient and zone air temperature difference to obtain the total heat loss from the building for the specified time interval.

RESULTS AND DISCUSSION

The study are carried out for a single zone building which has the details given in Table 1. An annual set of hourly weather data for a typical cold weather (that of Kew/England for 1963/1964) is used. Each simulation is started by initiating all system temperatures to the ambient temperature read from the weather data file.

The sensitivity of the zone air temperature to the change in some of the zone features are shown in Figs. 2 and 3. Figure 2 shows the simulation results for the first eight days of November using a time step length of 900 seconds. Figure 2a shows the variation of the zone air temperature when a 350-mm-thick thermal storage wall is used. Periods of underheating and overheating can be noticed which corresponds mostly to the fluctuation in the ambient air temperature. Reducing the thickness of the storage wall to 200 mm (Fig. 2b) results in no significant change. Significant reduction in the magnitude and number of the temperature peaks is noticed, as shown in Fig. 2c, when the thermocirculation flow is controlled by preventing the circulation when the zone air temperature exceeds the set point temperature. The net contribution of the thermocirculation flow can thus be judged from the comparison of Figs. 2b and 2c. To eliminate the periods of underheating, auxiliary heat may be used. Figure 2d shows the situation when a controlled auxiliary heat is used. The effect of reducing the thickness of other insulated walls is shown in Fig. 2e. Some of the temperature peaks are compensated by the increase in the heat loss through these walls. It is worth mentioning that neither the thermocirculation flow nor the auxiliary heat has contributed to the overheating of the zone since their effects have been controlled and isolated during these periods.

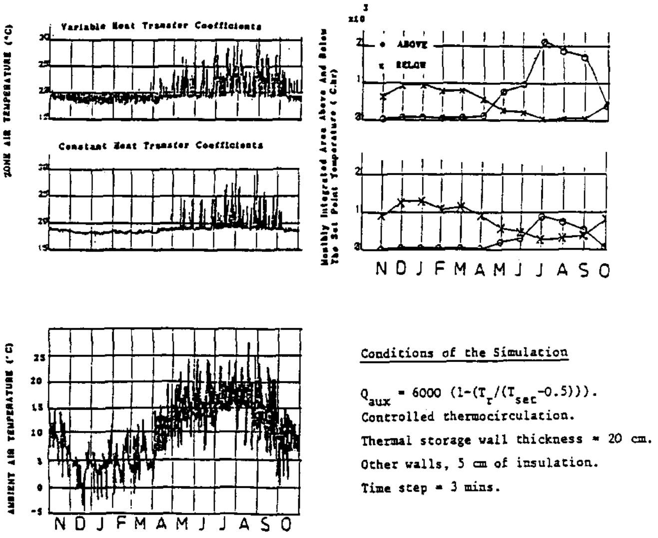
The sensitivity of the zone air temperature to the use of variable and constant heat transfer coefficients is investigated by the annual simulation of Fig. 3. In the first case, The radiative heat transfer coefficients on the interior surfaces and those due to wind and free convection on the exterior surfaces are calculated at each time step. For the second case, the constant values of Table 1 are used through the annual simulation. A time step lenght of 180 seconds is used in the simulation. The temperatures plotted in Fig. 3, however, are those representing the average values over 1800 seconds intervals and are meant only to show the general trend of the variation in the zone air temperature. To demonstarte the effcet more clearly, the monthly integrated area above and below the set point temperature (°C hr)is shown in Fig. 3 for each case. It was found that the zone air temperature predicted with constant heat transfer coefficients are lower than those predicted by the model with its variable heat transfer coefficients for most of the year. Furthermore, the time length of the overheating and underheating periods predicted by the model for each case are significantly different, especially for the summer months as for August for example where the difference is around a factor of 2.5. Such results highlight the importance of the accurate modelling of the heat transfer coefficients in building geometries. Figure 4 shows the monthly heating load predicted for the zone and the monthly solar energy collected by the thermal storage wall for the months of the year.



Simulation of 8 days starting from the first of November

- a vs. b Effect of reducing the thickness of the thermal storage wall
- b vs. c Effect of controlling the thermocirculation flow
- c vs. d Effect of using an auxiliary heat
- d vs. e Effect of reducing the thickness of other walls

Fig. 2 - Effect of Changing some of the Simulation Parameters on the Zone Air Temperature. 8-day Simulation



Conditions of the Simulation

$Q_{aux} = 6000\ (1-(T_r/(T_{set}-0.5)))$.
Controlled thermocirculation.
Thermal storage wall thickness = 20 cm.
Other walls, 5 cm of insulation.
Time step = 3 mins.

Fig. 3. Effect of Using Variable and Constant Heat Transfer Coefficients on the Zone Air Temperature and the Monthly Integrated Area (°C.hr) above and below the Set Point Temperature - Annual Simulation

Table 1. Details of the zone used in the simulation.

Wall	Material	k	Cp	ρ	Thickness
Storage wall	concrete	1.173	837	2243	50-350mm
Floor	concrete	1.173	837	2243	50mm
Other walls	insulation	0.03	1000	25	50-250mm
Glazing	window glass	0.76	8400	1750	5mm

-Outside dimensions of the zone:
Width = 2.50 m; Length = 3.00 m; Height = 2.50 m.

-The constant heat transfer coefficients used in the simulation:
Convective on interior surfaces = 3.00 W/m²K.
Radiative on interior surfaces = 5.70 W/m²K.
Combined (free+wind) on exterior surfaces = 18.20 W/m²K.
Combined (free+wind) on roof = 22.20 W/m²K.

CONCLUSIONS

1. The sensitivity of the zone air temperature to the use of constant and variable heat transfer coefficients is investigated. The zone air temperature is found to be significantly different for each case. Actual (variable) heat transfer coefficinets should be used in building simulations rather than constant values.

2. Thermocirculation through thermal storage walls should be controlled to minimize the periods of overheating of the zone.

3. For the weather conditions examined, thermal storage walls can not satisfy the daily and seasonal heating requirments of the zone. Auxiliary heat is required at the periods of underheating.

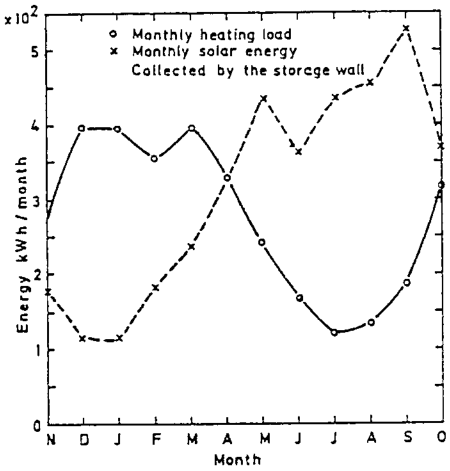


Fig. 4 · The Predicted Monthly Heating Load for the Zone and the Monthly Solar Energy Collected by the Thermal Storage Wall - Annual Simulation

NOMENCLATURE

Cp, k	Spesific heat (J/kgK) and thermal conductivity (W/mK) resp..
N	Node number.
Q_{aux}	Auxiliary heat (W).
Q_{solc}, Q_{solw}	Solar radiation absorbed by the glazing and the storage wall resp. (W).
T_{amb}, T_{gap}	Ambient and gap air temperatures resp. (K).
T_{grd}	Ground temperature (K).
UA_c	Conductance of the glazing (W/K).
UA_{grd1}	Conductance of the floor through the ground (W/K).
UA_{grd2}	Conductance of the floor through the walls (W/K).
UA_{inf}	Conductance due to infiltration (W/K).
UA_{sw}	Conductance between the thermal storage wall and zone air (W/K).
UA_w	Conductance between the thermal storage wall and gap air (W/K).
$\sum UA_{walls}$	Conductance through the walls of the zone (W/K).
ρ	Density (kg/m^3).

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