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COMPUTER MODELING OF BUILDING ENERGY CONSUMPTION IN A TYPICAL HOUSE IN OSHAWA, ONTARIO

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ABSTRACT

A mathematical model was developed to predict the building energy and electricity consumption based on several parameters including occupants' behavior as related to window opening, variation of thermostat set point temperature, window shading schemes, and use of electrical appliances. Simulation results from the computer program were verified from comparison of the building thermal load with simulation results from ESP-r, comparison of the air infiltration rates with simulation results from CFD modeling and comparison of the electricity usage with measurements reported in the open literature. Preliminary results of the total energy and CO_2 emissions of a typical house in Oshawa under different occupants' behavior schemes are also presented in this paper.

INTRODUCTION

Ooccupants' behaviors have a great impact on the building energy consumption as well as the peak loads experienced in summer time. People can open the window to use natural ventilation and reduce the cooling energy need in summer (Iwashita and Akasaka 1997), and use a higher cooling set point and a lower heating set point for energy saving purposes (Newsham 1997). Emery and Kippenhan (2006) observed that the energy need for heating the incoming outside air as a fraction of the total energy need in an occupied house built in 1980 was approximately double that of the unoccupied house (29% compared with 14%). Paateron and Lund (2006) found that if the load of household appliances is shifted by 1 hr, the daily peak loads can be reduced by 7.2%, and with more severe demand site management (DSM) schemes, the peak load at the yearly peak day can be reduced by 42%. Reinhart (2004) applied the probabilistic switching patterns for a private office with a southern façade, and found that the lighting energy demand for a manually controlled electric lighting and shading system ranges from 10 to 39 kWh/(m^2· yr). The predicted mean energy savings of a switch-off occupancy sensor in an office was 20% and the mean electric lighting energy savings due to a daylight-linked photocell control range was from 60% to zero. Bourgeois et al. (2006) found that for those occupants that actively seek daylighting rather than systematically rely on artificial lighting, the primary energy expenditure on lighting can be reduced by more than 40%, when compared with occupants who rely on constant artificial lighting. Al-Mumin et al. (2003) conducted a survey on occupancy patterns and operation schedules of electrical appliances in 30 houses in Kuwait. The computer simulation using the survey data results showed an increase of 20% of the annual energy consumption compared with the results using default values of occupancy patterns from the program.

Lam et al. (1997) used the simulation results from DOE-2 to generate a regression model to predict the energy consumption of a high rise air-conditioned office building in Hong Kong. Twelve input design parameters were suggested including: window-to-wall ratio, space air temperature, equipment load, lighting load, occupant density, fan efficiency, fan static pressure, thermal stat temperature in summer, outdoor air flow rate, chilled water supplied temperature, chiller COP, and shading coefficient of windows.

Ali (1999) developed a regression model to predict the energy consumption in multi-family housing area in College Station, Texas. The model was based on interviews and measurements of 176 apartments. The following variables were incorporated into the model: the floor area, number of occupants, length of shared wall, length of exterior wall, floor level, appraised value, age of the building, construction material, marital status, education of the household, rent, occupation of the head, race, air-conditioner type, energy audit, thermo-stat type, summer thermal stat setting, winter thermo-stat setting, number of fans, cooling slope (the amount of energy required for cooling per degree of change in the average outdoor air temperature), heating slope (the amount of energy required for heating per degree of change in the average outdoor air temperature), and base load.

Chirarattananon and Taveekun (2004) used DOE-2 simulation to develop an overall thermal transfer value (OTTV) for four types of commercial buildings. Paateron and Lund (2006) suggested an approach to generate the household electricity load profiles based on the probability function derived from public reports and statistic data from Finland.

Olofsson et al. (1998) used a neural network method and principle component analysis (PCA) to predict the annual space heating demand for 10 small single family buildings in the north of Sweden. The neural networks method is also used for the prediction of building energy consumption (Aydinalp et al. 2002; Yang et al. 2005; Karatasou et al. 2006). For example, Aydinalp et al. (2002) used neural networks to simulate the energy consumption of houses in the survey of household energy-use (SHEU) database and extrapolated to estimate the average energy consumption of all Canadian houses. Yang et al. (2005) presented two adaptive artificial neural networks models, namely the accumulative training and the sliding window models, for an office building in Montreal. Karatasou et al. (2006) applied neural networks to predict the energy consumption for an office buildings located in Athens, Greece.

The aim of this paper is to develop a thermal energy simulation model and to study the occupants' behavior impact as well as looking for new ways for the development of a correlation model for the prediction of energy consumption of residential buildings in Canada.

MATHEMATICAL MODEL

Heat Transfer through the Wall/Roof of a House

The wall is assumed to have four layers and there are two boundary nodes and one internal node for each layer; thus there are nine nodes for each wall/roof.

The governing equation for the transient heat transfer process is:

$$\frac{\partial T}{\partial t} = \alpha_h \frac{\partial T^2}{\partial x^2} \tag{1}$$

where α_h is the temperature diffusion coefficient for each layer of the wall (m^2/s), and x is the thickness of the layer (m).

Heat Balance over the External Wall Surface

The heat balance over the external wall surface is written as follows:

$$-k_1 \frac{\partial T}{\partial x}\Big|_{x=0} + q_{sol,l,out} + q_{conv,l,out} + q_{surf,l,out} = \rho_1 \cdot \frac{1}{4} dx_1 \cdot c_{p1} \cdot \frac{dT}{dt} \tag{2}$$

where k_1 is the thermal conductivity of the first layer of the wall/roof (W/m·ºC); $q_{sol,l,out}$ is the absorbed solar radiation at the outside wall surface (W/m^2); $q_{conv,l,out}$ is the convective heat transfer over the outside wall surface; $q_{surf,l,out,t}$ is the net surface-to-surface radiation leaving the outside wall surface; ρ_1 is the density of the first layer of the wall (kg/m^3); dx_1 is the thickness of the first layer of the wall (m); c_{p1} is the specific heat of the first layer of the wall (J/kg·°C).

Internal Nodes between Two Surfaces

For internal nodes between two different layers (e.g., 1 and 2), the following equation is written, as an example for the surface between layers no.1 and no.2:

$$\frac{1}{4} \cdot \left(\rho_1 \cdot c_{p1} \cdot dx_1 + \rho_2 \cdot c_{p2} \cdot dx_2\right) \cdot \frac{dT}{dt} = -k_1 \cdot \frac{dT}{dx}\Big|_{x=\frac{3}{4}dx_1} + k_2 \cdot \frac{dT}{dx}\Big|_{x=dx_1+\frac{1}{4}dx_2} \tag{3}$$

where $-k \cdot \frac{dT}{dx}$ is the conduction heat flux at the interface of two layers (W/m^2); k_1 is the thermal conductivity of layer 1 of the wall; ρ_1 is the density of layer 1; dx_1 is the thickness of layer 1; c_{p1} is the specific heat of layer 1.

Heat Balance Over the Inside Wall Surface

The heat balance over the inside wall surface is written as follows:

$$-k_4 \cdot \frac{\partial T}{\partial x}\Big|_{x=th} + q_{sol,l,in} + q_{conv,l,in} + q_{surf,l,in} + q_{rad,ihg} = \rho_4 \cdot \frac{1}{4} \cdot dx_4 \cdot c_{p4} \cdot \frac{dT}{dt} \tag{4}$$

where k_4 is the thermal conductivity of layer 4; $q_{sol,l,int}$ is the absorbed solar radiation at the inside wall surface; $q_{conv,l,in}$ is the convective heat transfer over the inside wall surface; $q_{surf,l,in}$ is the net surface-to-surface radiation leaving the inside wall surface; $q_{rad,ihg,l}$ is the radiation heat flux due to internal heat gain; and th is the thickness of the wall.

Window Model

As the window contains very little thermal mass, it is considered to behave in a quasi-steady state mode.

Infiltration Model

The infiltration through an opening of windows can be calculated by the crack method (ASHRAE 1992):

$$\dot{m} = C_d \cdot \rho \cdot A \cdot (\Delta p)^n \quad (5)$$

where C_d is the flow coefficient, taken as 0.83 (Wurtz et al. 1999; Haghighat 2001); ρ is the density of the outflow air; A is the area of the opening, in m^2; Δp is the pressure difference between the house and the outdoor air, in Pa; n is the flow exponent, n=0.5 for turbulent flow.

$$\Delta p_{w,i} = \frac{1}{2}(C_{p,i} - C_{p,a})\rho_o v_w^2 \quad (6)$$

where $C_{p,i}$ is the C_p value at the ith window surface; $C_{p,a}$ is the C_p value of the inside surface; v_w is the wind speed over the window surface (m/s).

For more than one opening with stack effect and wind-driven infiltration, a zonal model approach is applied:

$$\sum_{i=1}^{N} \dot{m}_i = 0 \quad (7)$$

where N is the number of openings.

Electrical Appliances Power Input Model

The operating electric energy consumption for the electric appliances working on multi-stage operating conditions is:

$$E_i = f_{h,i} * AVG_i \quad (8)$$

Where $f_{h,i}$ is the hourly probability on the usage of the electrical appliance; AVG_i is the average power input per cycle, W.

$$AVG_i = \frac{\sum_{j=1}^{N} P_{i,j}\tau_j}{\sum_{j=1}^{N} \tau_j} \quad (9)$$

where $P_{i,j}$ is the power input to the electric appliance i in phase j; τ_j is the time required for phase j.

Heat Balance of the Inside Air

The indoor air of the house is assumed well mixed and therefore it is represented by one node. The indoor air temperature T_a is held at the thermostat set-point value by a heating/cooling system. The heat balance for the indoor air is written as:

$$Q_{HVAC} + \sum_{j=1}^{M} A_j h_a (T_{j,in} - T_a) + Q_{exf} + Q_{internal,conv} = 0 \quad (10)$$

where A_j is the inside wall/window surface area; h_a is the inside surface convective coefficient (W/m^2·°C); $T_{j,in}$ is the temperature of inside surface j; Q_{HVAC} is the heat addition rate by the heating system (W); Q_{exf} is the exfiltration heat loss; $Q_{internal,conv}$ is the convective part of internal heat gain, from people, lighting, and electric appliances; T_a is the room air temperature, set by the occupant i;

The electric appliances include freezer, lighting, clothes washer, dish washer, TV, and oven.

House Energy Consumption

In this system the house is heated by a forced air system and cooled by a central air conditioner unit and the same duct systems are used for heating and cooling. The following are the components of the whole system: 1) Heating: forced air heating system with heat supplied by a gas-fired furnace; 2) DHW: gas-fired hot water tank; 3) Ventilation: exhaust fan; and 4) Cooling: central air conditioning unit.

The following conditions applied:

$$\dot{Q}_{ac} = \dot{Q}_{CL} \text{ (in summer)} \quad (11)$$

where $\dot{Q}_{CL}$ is the cooling load of the house (W).

$$\dot{Q}_{furnance} = \dot{Q}_{HL} \text{ (in winter)} \quad (12)$$

where $\dot{Q}_{HL}$ is the heating load of the house (W).

Total electricity demand is:

$$\dot{W}_{pp} = \dot{F}_1 + \dot{F}_2 + \dot{W}_{comp} + \dot{W}_{app} \quad (13)$$

where $\dot{F}_1$ is the electric power input to the blower fan of the furnace; $\dot{F}_2$ is the electric power input to the exhaust fan; $\dot{W}_{comp}$ is the electric power input to the compressor of the AC; $\dot{W}_{app}$ is the electric power input to the electric appliances.

Total energy need of the house is:

$$\dot{E}_{total} = \dot{E}_{pp} / \eta + \dot{E}_{furnance} + \dot{E}_{DHW} \quad (14)$$

where $\dot{E}_{pp}$ is the primary energy consumption by the power plant (J); η is generation and transmission efficiency; $\dot{E}_{furnance}$ is the primary energy consumption of natural gas by the gas-fired furnace; $\dot{E}_{DHW}$ is the primary energy consumption of natural gas by the gas-fired hot water tank.

Power Plant Model

The power plant model is used to reflect the use of primary resources. For instance, the contribution of energy sources to the off-site electricity generation and their percentage of total supply are: nuclear 10882 MW (36%), hydroelectric 7756MW (26%), coal 6434 MW (21%), oil/gas 4976 MW (17%), others 66MW (<1%)

(IESO 2005). The overall efficiencies of the power plants are as follows: nuclear power plant 30% (Rosen 2001), hydro power plant 80% (Ileri and Gurer 1998), coal-fired power plant 37% (Rosen 2001), oil-fired power plant 33% (Kannan 2004), natural gas-fired plant 43.1% (AIE 1998). The transmission and distribution loss in line is 14% which means that 86% is supplied to the end user (Zhang 1995).

The total primary energy supply for the power plant is:

$$\dot{E}_{pp} = \alpha_{nu} \dot{W}_{pp} / \eta_{nu} + \alpha_{hy} \dot{W}_{pp} / \eta_{hy} + \alpha_{gas} \dot{W}_{pp} / \eta_{gas} + \alpha_{oil} \dot{W}_{pp} / \eta_{oil} + \alpha_{ca} \dot{W}_{pp} / \eta_{ca} + \alpha_{ot} \dot{W}_{pp} / \eta_{ot} + \dot{E}_{furnance} + \dot{E}_{DHW} \quad (15)$$

where α is the contribution of electric power generated by certain type of power plant, and η is the efficiency of the power plant. $\dot{W}$ is the total demand of the house.

The annual GWP (global warming potential) produced by the house can be calculated as:

$$EQ_{CO2,total} = EQ_{CO2,nu} + EQ_{CO2,hy} + EQ_{CO2,gas} + EQ_{CO2,oil} + EQ_{CO2,ca} \quad (16)$$

where EQ_{CO2} is the equivalence CO_2 emission (kg).

The annual GWP produced by each power plant can be calculated as:

$$EQ_{CO2,i} = \dot{E}_i \cdot (\alpha_{CO2,i} \cdot 1 + \alpha_{NOx,i} \cdot 310 + \alpha_{CH4,i} \cdot 21) \quad (17)$$

where a is the pollutant coefficient (g/MJ).

NUMERICAL SOLUTION

The thermal and airflow model is written as a system of linear and nonlinear equations. Nonlinear equations are generated due to the surface-to-surface long-wave radiation in the thermal model, and due to the coupling of air movement and heat transfer between the house and outdoor environment. However, if the radiation coefficients are used to calculate the surface-to-surface radiation, then the whole system equations of temperatures can be considered as quasi-linear. The radiation coefficients are generated by using the total interchange view factor (Lin and Zmeureanu 2008). The system of equations can then be broken into two sub-systems, one system that contains the unknown temperatures and another system that contains the unknown pressure coefficients.

The convective coefficients are calculated based on the updated air temperature difference, air flow direction and air velocity. The radiation coefficients are calculated using the total interchange view factor and the updated surface temperature difference.

The system of equations of the thermal and airflow models are written in form of a matrix:

$$\begin{bmatrix} \mathbf{A} & \mathbf{O} \\ \mathbf{O} & \mathbf{C} \end{bmatrix} \begin{bmatrix} \mathbf{T} \\ \mathbf{C_P} \end{bmatrix} = \begin{bmatrix} \mathbf{B} \\ \mathbf{D} \end{bmatrix} \quad (18)$$

where **A** is the matrix containing the thermal and optical properties of the system; **C** is the matrix containing the properties of the interfaces between the indoor and outdoor; **B** and **D** contain the coefficients of the driving forces for temperature and pressure, respectively.

By using the radiation coefficient and convective heat transfer coefficient through iteration (Lin and Zmeureanu 2008), the entire system of equations is written separately as composed of a linearized part that contains the unknown temperatures only:

$$[\mathbf{A}]\ [\mathbf{T}] = [\mathbf{B}], \quad (19)$$

and a non-linearized part that contains the unknown pressures only:

$$[\mathbf{C}]\ [\mathbf{C_P}] = [\mathbf{D}]. \quad (20)$$

For a house with three double-glazed windows, the total number of unknown temperatures of the system of equation (19) is 60.

The linearized part of the system (equations for temperature) is solved by the Gauss-Seidel iteration technique, and the nonlinear part of the system (equations for pressure) is solved by the Newton-Raphson method (Press et al. 1992).

The computation time for the case presented in this paper is about 17 minutes using a desk computer configured with Intel Core 2 Duo 2.13G, 1066M Hz FSB CPU, 2M L2 Cache and 1G DDRII memory.

VERIFICATION

The simulation results (from the computer program) of the thermal load of a house located in Oshawa (Figure 1) were compared with the results from the ESP-r program (Figure 2). The dimension of the house is 10m ×10 m×4m. Three double-glazed windows are mounted on the south wall, west wall and east wall, respectively. The window-to-wall ratio of 0.15 is applied. Thermal resistance of the external walls is 3.4 $m^2 \cdot °C/W$, and of the roof is 5.5 $m^2 \cdot °C/W$. The U-value of the windows is 3.06 $W/m^2 \cdot °C$. The natural air infiltration rate for the house is set equal to 0.15 ACH (air change rate per hour). No internal heat gain is considered. The simulation results from the computer program predicted the annual energy needs of 30733 kWh, while the simulation results from the ESP-r program predicted the annual energy needs of 29766 kWh. The difference between the results from the computer program and from the ESP-r program was 3.2%. Therefore, it can be concluded that the simulation results have fairy good agreements with the results from the ESP-r program. Therefore, greater fluctuation of the predicted thermal load using the ESP-r program was observed. One reason to explain the difference in the fluctuation is that the ESP-r iterates for the first 10 days to find the initial value of the temperature for each node while our computer program iterates each day to find the initial values.

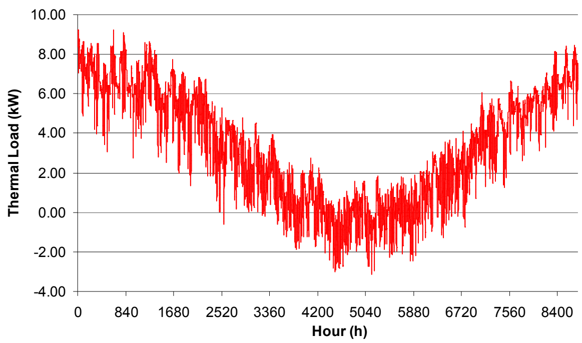

Figure 1 Model predictions of the hourly thermal load

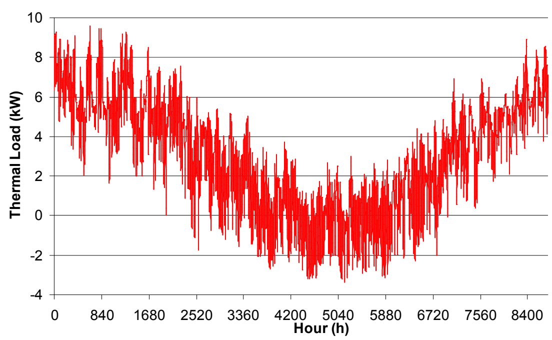

Figure 2 Prediction of the hourly thermal load using the ESP-r program

The results of the ventilation model that calculates the air infiltration through the window openings were compared with the CFD results of Asfour and Gadi (2007) for windows with two openings at opposite sides. The wind speed was 1.0 m/s, and wind direction was either normal to the window (cases No.1 and 3) or oblique to the window (case No. 2). The detail information of the three cases are presented in Table 1.The simulation results presented in Table 2 indicate that the ventilation results are in good agreement with the CFD results, with difference of less than 5%.

The results from power input model for the electric appliances were compared with the mean hourly consumption curve of a household for weekend days provided by Paatero and Lund (2006). The results are presented in Figure 3, and it is observed that the average difference between the power plant model and the mean hourly household electricity consumption is only about 6.5%.

Table 1 Information for the cases tested in this study

	Building dimension (m×m×m)	Opening Area (m^2)	Wind direction (º)	C_{p1}	C_{p2}
Case 1	5×5×5	4	0	0.7	-0.2
Case 2	5×5×5	4	45	0.35	-0.4
Case 3	4×8×4	4	0	0.6	-0.35

Table 2 Simulation results vs. CFD results

	Infiltration Rate (kg/s)		
	Model	CFD	Difference
Case 1	3.09	3.19	3%
Case 2	2.82	2.98	5%
Case 3	3.17	3.3	4%

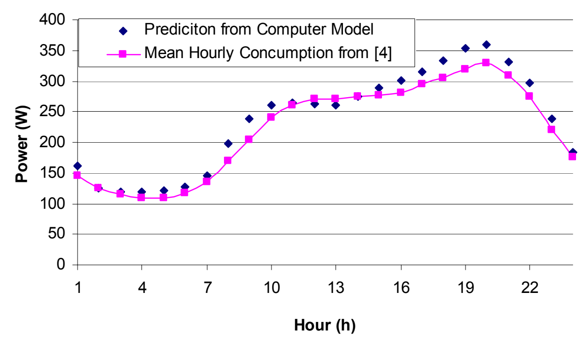

Figure 3 Comparison of the hourly household electricity consumption

In conclusion, the predictions of the ventilation model and electricity power input model are comparable with those obtained with a detailed CFD model and with the measurement data.

CASE STUDY

A house of 100 m^2 floor area and 4 m wall height, located in Oshawa (Canada), is selected as a case study. The outdoor dry bulb temperature, humidity ratio, direct normal solar radiation, global solar radiation, diffuse solar radiation, wind speed and wind direction are obtained from Energyplus weather file database (EnergyPlus 2007). The dry bulb temperature and direct normal solar radiation are presented in Figures 4 and 5. Each wall of the house is composed of 100 mm face brick, 135 mm insulation, and 20 mm gypsum board. The window-to-wall ratio of 15% is applied to three facades only (East, South and West). The natural air infiltration rate for the house is set equal to 0.15 ach for newly built house, and 0.5 for old house. The house has one stove oven, one clothes washer, one dish washer, one freezer, one color TV. The living patterns come from studies by (Al-Mumin et al. 2003; Papakostas and Sotiropoulos 1997). The occupants' living pattern and electric appliances usage are presented in Figures 6 and 7. Figure 8 presents the correlation model of the end-use energy consumption of the house as a function of accumulative degree days. Strong linear relationship with R-square value of 0.997 and relative difference between the predicted energy consumption from the correlation model and simulation results of less than 7.6% are observed. This finding will be applied to develop electricity consumption model and to compare with the smart meter readings from 270 houses in Oshawa.

Table 3 provides the results of the total end-use energy consumption, the furnace energy consumption, air-conditioning system electricity consumption, primary energy consumption, and total CO_2 emission on an annual basic. The furnace is assumed to have an energy efficiency of 0.85, and the air-conditioner has a COP of 2.0. From the results, it appears that the infiltration rate of the house has the greatest impact on the heating energy consumption, and the shading schemes appear to have the greatest impact on the A/C energy consumption. The optimum building azimuth is 0, with the front wall facing south. The electricity consumption of the A/C can be reduced to minimum by shading the window in summer, opening the window in summer when the outdoor air temperature is below the indoor air temperature and using higher thermostat set-point temperature in summer and during transitional seasons. The variables presented in the table are listed as follows: Φ =building azimuth, degree from due north; T =indoor air temperature; ACH =infiltration rate, taken as 0.15 for newly built house, and 0.5 for old house; SF =shading factor for window, 0 for no shading and 1.0 for complete shading; OF=opening factor for window, the opening area vs. the total area, dimensionless; Nlight=number of light bulbs turned on each time.

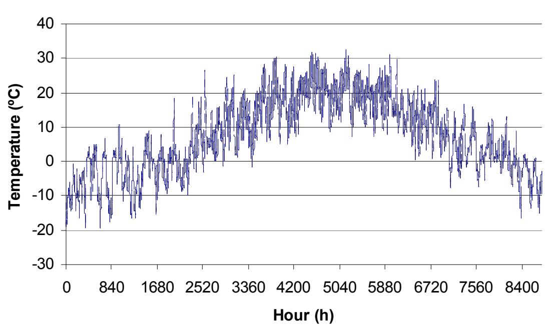

Figure 4 Outdoor dry bulb temperature for case study

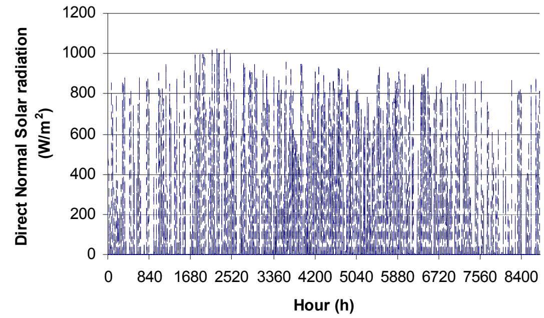

Figure 5 Direct normal solar radiation for case study

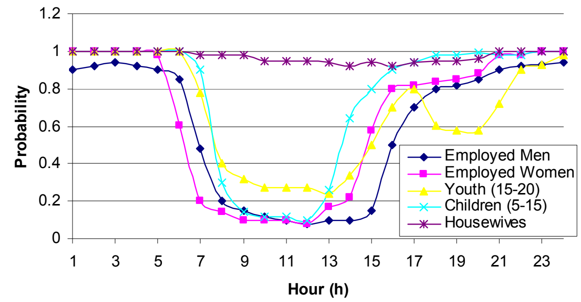

Figure 6 Probability of occupant presence

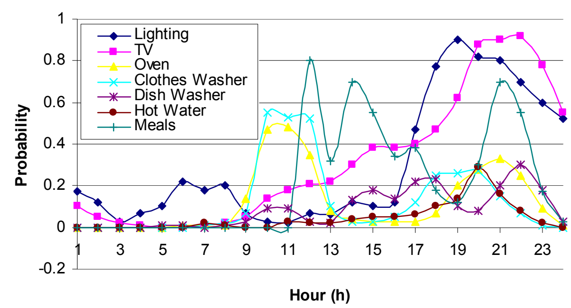

Figure 7 Electric appliance usage patterns

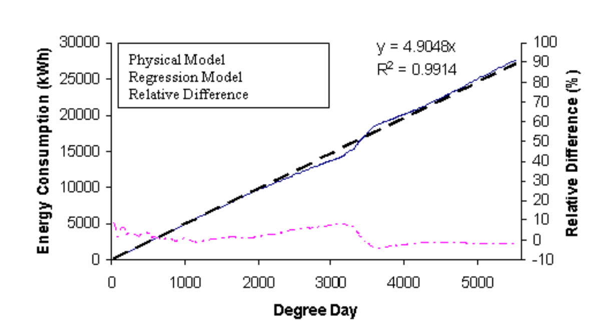

Figure 8 Rgression model derived from the simulation results, Case no.17

Table 3 Results for different cases

Case	End-use (kWh)	Heating (kWh)	Cooling (kWh)	Primary (kWh)	CO2-eq (ton)	Φ (º)	T (ºC)	ACH (-)	SF (-)	OF (-)	N_{light} (-)
1	27669.9	16329.2	1849.4	43470.4	10.6	0	22	0.15	0	0	6
2	27920.5	16884.7	1593.4	43122.7	10.5	45	22	0.15	0	0	6
3	28061.3	17230.0	1422.4	42862.1	10.5	60	22	0.15	0	0	6
4	28765.7	17703.9	1563.1	44018.8	10.8	0	23	0.15	0	0	6
5	30004.4	19143.4	1301.1	44863.5	11.0	0	24	0.15	0	0	6
6	34213.2	22415.5	1892.3	50910.3	12.5	0	22	0.35	0	0	6
7	**39282.6**	**27090.7**	**1957.6**	**56753.3**	**14.1**	0	22	0.50	0	0	6
8	28553.4	18042.2	1139.6	42726.5	10.5	0	22	0.15	0.5	0	6
9	30128.2	20157.9	620.6	43239.7	10.7	0	22	0.15	1.0	0	6
10	31085.3	19516.1	1864.3	47334.1	11.6	0	22	0.15	0	0.001	6
11	34564.3	22748.4	1890.7	51296.9	12.6	0	22	0.15	0	0.002	6
12	27340.7	16730.6	1758.1	41707.6	10.2	0	22	0.15	0	0	2
13	28185.2	**15739.2**	1992.8	46154.4	11.1	0	22	0.15	0	0	12
14	27168.5	16408.3	1452.6	41829.8	10.2	0	22,24[1]	0.15	0	0	6
15	27564.0	16880.5	1370.0	42074.9	10.3	0	22,23,24[2]	0.15	0	0	6
16	**26973.1**	17081.3	714.0	**39930.8**	**9.84**	0	22	0.15	0,0.5,1.0[3]	0	6
17	27679.0	16344.4	1843.9	43467.4	10.6	0	22	0.15	0	0,0.001[4]	6
18	27464.8	17947.8	382.6	39687.1	9.84	0	22,23,24	0.15	0,0.5,1.0	0,0.001	6
19	28009.6	18488.5	357.1	40234.0	9.99	45	22,23,24	0.15	0,0.5,1.0	0,0.001	6
20	28343.2	18820.2	**341.0**	40577.3	10.1	60	22,23,24	0.15	0,0.5,1.0	0,0.001	6

[1]22ºC in winter, 24 ºC in summer, 22 ºC for other seasons
[2]22ºC in winter, 24 ºC in summer, 23 ºC for other seasons
[3]0 in winter, 1.0 in summer, 0.5 for other seasons
[4]0 in winter, 0.001 in summer when outdoor air temperature is lower than indoor air temperature

CONCLUSION

This paper presented a mathematical model that considers the building envelop, window shading and opening schemes, and occupants' behavior regarding thermo-stat set-point temperature and also usage pattern of the electric appliances. The simulation results shows that the infiltration rate of the house has the greatest impact on the heating energy consumption, and the shading schemes have the greatest impact on the A/C energy consumption. The electricity consumption of the A/C can be reduced to minimum by appropriately applying the shading and opening schemes and control on the thermostat set-point temperature, while keeping the window closed and allowing the solar radiation to be transmitted through the window in winter to reduce the heating needs of the house.

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