

## BUILDING ENERGY SIMULATION WITH EASE

Duo Randriamiarinjatovo, Michel A. Bernier  
Département de Génie Mécanique  
École Polytechnique de Montréal  
Case Postale 6079, succursale “centre-ville”  
Montréal H3C 3A7 – Canada

### ABSTRACT

This paper describes a relatively simple software tool that has been developed to perform annual hour-by-hour energy simulation of a building. It extends earlier work performed for one-zone buildings (Bernier and Randriamiarinjatovo, 2001) to buildings that can be represented by five thermally similar zones. The simulation program has been built using a general equation solver (Klein and Alvarado, 2002). As implied by the title of this paper, the solver is easy to use both for the software developer and the user. It provides all the necessary tools (solver, plotting, graphics ...) within the same package. The program can accommodate up to five thermal zones: four peripheral zones and an inner zone. The following phenomena are modeled: transient heat transfer through walls (using finite-difference), solar heat gains through windows, internal heat gains, and longwave radiation exchange between inside surfaces. The implementation of these phenomena into the software is discussed. Finally, validation tests performed using ASHRAE's analytical test suite (Rees et al. , 2002) and the BESTEST diagnostic method (Judkoff and Neymark, 1995) are presented. These results show good agreement with other software tools.

### INTRODUCTION

The main objective of this work is to develop a simple and user-friendly software tool that can be used to obtain hourly heating and cooling loads. Although the software has been developed as a teaching aid, it could also prove to be useful to building professionals who want to fill the gap between back-of-the-envelope calculations and elaborate building energy simulation programs. The tool has been named B5EES. It stands for **B**uilding – **5** zones – **E**ngineering **E**quation Solver. It is designed to perform annual energy simulations for 5-zones buildings.

B5EES's main menu is shown in Figure 1. As shown on this figure, hourly loads are obtained through a seven step process. The first step converts a particular building into a five-zone building by grouping rooms with similar thermal behavior. In the

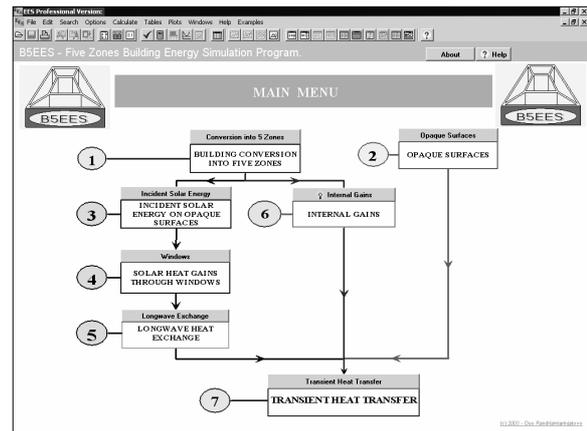


Figure 1: B5EES - main menu

second step, the user enters the characteristics of all (exterior and interior) opaque surfaces. The program then constructs the finite-difference mesh that is necessary in the seventh step. The third step involves solar radiation calculations on opaque surfaces while step four evaluates solar gains through windows. Long-wave radiation exchange among inside surfaces in each zone is evaluated in step five. The user can enter the estimated internal gains in step six. The final solution process is activated in step seven where transient heat transfer is calculated as well as the resulting heating or cooling loads.

The following sections of this paper are devoted to each of these seven steps. Each step is explained with reference to an example building whose characteristics are shown in Figure 2 and Table 1.

### MODELLING

#### Step 1: Conversion to a five-zone building

In this step, the user converts the building into a five zones building. In this particular case the user decided to have four 325m<sup>2</sup> peripheral zones and a 3600m<sup>2</sup> internal zone. The conversion module can handle non-parallelepiped buildings. B5EES assumes that there are partition walls between each zone.

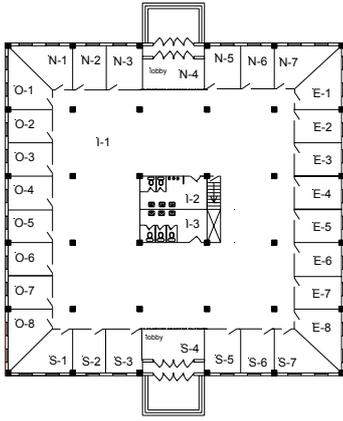


Figure 2 Example building

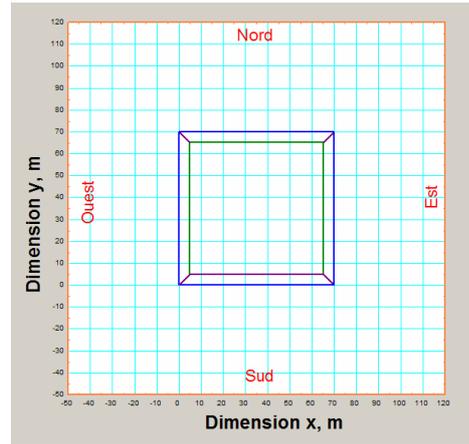


Figure 3 Schematic representation of the conversion of example building to a five zone-building

Table 1 Characteristics of the example building

Location	Montréal, Canada
Orientation	E-S-O-N
Dimension	One story, 70 × 70 × 3.3m
External walls	A0-A7-B2-C14-E1-E0 (ASHRAE nomenclature)
Windows	70 m <sup>2</sup> in each ext. wall Double-glazed -12.7 mm- Argon-clear/clear- no curtains
Partition	C8 (ASHRAE nomenclature)
Roof and floor	A0-A4-E3-B20-E5-E0
Internal gains	Occupant: 0.07 occ./m <sup>2</sup> ; 130 W/occ. Lighting: 20 W/m <sup>2</sup> Equipment: 8.9 W/m <sup>2</sup>
Occupancy schedule	100% 7a.m. to 9 p.m. weekdays 0% at night 20% during weekends

Consequently, each peripheral zone has one external wall and three partition walls and the internal zone has four partition walls. Finally, each peripheral zone can have windows. Once the user has entered all the relevant dimensions B5ESS generates, as shown on Figure 3, a schematic representation of the building.

### Step 2: Opaque surfaces

In this step the user enters the composition of each of the building's opaque surfaces. There are four categories of opaque walls: external walls, roof, floor and partition walls. An opaque wall may contain up to five layers. Each wall is built either with proposed standard layers (ASHRAE, 1997) or by user-defined layers.

Once the different layers have been entered, the user activates the grid generation calculations. The resulting grid spacing can be visualized as illustrated on Figure 4 which shows the grid spacing for the external wall of the example building.

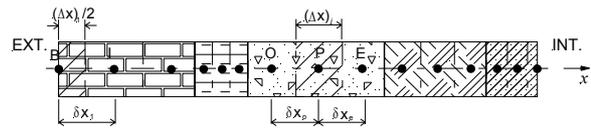


Figure 4 Grid spacing generated by B5EES for the wall of the example building.

Grids are generated according to the Type-A practice suggested by Patankar (Patanekar, 1980). Each wall has a total of 15 grid points, three in each layer. This selection is the result of a compromise between accuracy and calculation speed. Finally, B5EES assigns thermophysical properties ( $\lambda$ ,  $\rho$ ,  $C_p$ ) to each control volume. If needed, the interface thermal conductivity is also evaluated (Randriamiarinjatovo, 2003).

### Step 3: Incident solar radiation

Total solar radiation incident on each external surface is evaluated in this step. The user specifies where the building is located and the corresponding meteorological weather file is retrieved. This file contains data on total and diffuse solar radiation on a horizontal surface and direct normal solar radiation. Given these three components, B5EES proceeds with the evaluation of total solar radiation on the four vertical walls and on the horizontal roof surface. These calculations are performed using classic relationships presented by Duffie and Beckman (1980). The results are stored for use in following steps.

The heat flux at each external surface,  $q_{ext,w}$ , is evaluated using the sol-air temperature,  $T_{sol-air,w}$ , (Randriamiarinjatovo, 2003):

$$q_{ext,w} = h_o (T_{sol-air,w} - T_{s,ext,w}) \quad (1)$$

where  $h_o$  is the equivalent outside film coefficient (assumed constant and equal to 16.94 W/m<sup>2</sup>-K) and  $T_{s,ext,w}$  is the surface temperature of the exterior surface of the wall.

#### Step 4: Windows

##### Solar heat gains

The user can select different window types in each external wall. The transparent and the opaque portions (frame) of the windows are selected independently. A total of thirteen transparent surfaces, ranging from single-glazed to triple-glazed windows, can be selected while frames are selected from a list of ten frames. The properties of these windows/frame were obtained from the fenestration chapter of the ASHRAE Handbook (ASHRAE, 2001). They are stored internally using "lookup" tables which can be modified easily by the user. Once the user has chosen all the fenestration components, B5EES calculates the total solar gains,  $Q_w$ , for each window type according to the following relationship:

$$Q_w = [Q_{TR} (1 - c) + Q_{OP} c] A_w \times IAC \quad (2)$$

where,

$Q_{TR}$  = solar gains from the transparent portion (W/m<sup>2</sup>);

$Q_{OP}$  = solar gains from the opaque portion (W/m<sup>2</sup>);

$c$  = frame area/ $A_w$

$A_w$  = total window area (m<sup>2</sup>)

IAC = internal attenuation coefficient

$Q_{TR}$  and  $Q_{OP}$  are given by:

$$Q_{TR} = G_D SHGC(\theta) + (G_d + G_R) SHGC_d \quad (3)$$

$$Q_{OP} = (G_D + G_d + G_R) SHGC_{op} \quad (4)$$

where  $G_D$ ,  $G_d$ ,  $G_R$  are the direct, diffuse, and reflected incident solar radiation components, respectively. As shown in Equations 3 and 4, Solar Heat Gain Coefficients ( $SHGC$ ) are used. They represent the fraction of incident solar radiation that becomes a heat gain inside the building (ASHRAE, 2001). As shown in Equation 3, two  $SHGC$  are used to determine the solar gains from the transparent portion of the window.  $SHGC(\theta)$  is the fraction of direct solar radiation that becomes a heat gain. This fraction is a strong function of the incident angle  $\theta$ .  $SHGC_d$  is the fraction of diffuse and reflected solar radiation that becomes a heat gain. Finally,  $SHGC_{op}$  is the fraction of total solar radiation striking the opaque surface of the window (frame) that becomes

a heat gain. This value is assumed to be independent of  $\theta$ . B5EES uses values of  $SHGC(\theta)$ ,  $SHGC_d$ , and  $SHGC_{op}$  recommended by ASHRAE (ASHRAE, 2001). The effects of curtains and blinds are accounted for by using a constant interior solar attenuation coefficient (IAC). B5EES offers three choices to the user for the value of IAC: 1, 0.75, and 0.5. Finally, it is assumed that  $Q_w$  is totally absorbed by the floor. This last value becomes a boundary condition for floor transient heat transfer (see Figure 5) and, therefore, the solar heat flux incident on the floor,  $q_{win,tot}$ , is given by:

$$q_{win,tot} = Q_w / A_{floor} \quad (5)$$

where  $A_{floor}$  is the floor area.

##### Conduction heat gains/losses

In order to perform long wave radiation calculations among the various zone surfaces, the U-factor of the window is first modified to obtain  $h_l$ , the heat loss factor from the external temperature to the interior glazing surface temperature:

$$1/U = 1/h_l + 1/h_{0,int} \quad (6)$$

where  $h_{0,int}$  is the combined (convection-radiation) film coefficient on the internal side of the window. The U-factors used here are those of ASHRAE (ASHRAE, 2001). They are based on a value of  $h_{0,int}$  of 8.29 W/m<sup>2</sup>-K. The radiative portion of  $h_{0,int}$  is 5.13 W/m<sup>2</sup>-K, thus leaving a value of 3.16 W/m<sup>2</sup>-K for the convective portion. Conduction heat gains/losses from windows,  $Q_{c,win}$ , are then evaluated using:

$$Q_{c,win} = h_l (T_{ext} - T_{s,int,win}) \quad (7)$$

where  $T_{ext}$  is the external ambient temperature and  $T_{s,int,win}$  is the interior glazing surface temperature. This last temperature is unknown *a priori*. It is evaluated as a result of window conduction heat gains/losses and long wave radiation exchange among the various zone surfaces.

#### Step 5: Long wave radiation exchange

Each peripheral zone contains a maximum of seven surfaces (four walls, a ceiling, a floor, and windows on the external wall). The internal zone has a total of six surfaces since it does not contain any windows. Long wave radiation exchanges among these various surfaces are calculated using the radiosity method. With this method, the incident long wave radiation on a surface "i",  $q_{lw,i}$ , is given by:

$$q_{lw,i} = \frac{Eb_i - J_i}{1 - \varepsilon_i}$$

$$q_{lw,i} = \sum_{k=1}^n \frac{J_i - J_k}{\frac{1}{A_i F_{i,k}}} \quad \text{for } i = 1 \text{ to } n \quad (8)$$

where n equals 7 for the peripheral zones and 6 for the internal zone,  $Eb_i$  is the emissive power ( $= \sigma T_{s,int,i}^4$ , with  $T_{s,int,i}$  representing the surface temperature),  $J$  represents radiosity,  $A_i$  is the surface area,  $F_{i,k}$  is the view factor between surfaces i and k, and  $\varepsilon_i$  is the surface emissivity. The solution to equation 8 is quite straightforward once the view factors are known.

View factors can be evaluated using the well-known double integral (Incropera and DeWitt, 1990). However, when walls are not necessarily parallel or perpendicular to each other or when windows are present, the necessary bookkeeping (angles and distances between surfaces) is incompatible with the simple nature of B5EES. Instead, B5EES uses area weighting to approximate view factors. With this technique, view factors are obtained using:

$$F_{ij} = S_j / S_T; \quad F_{ii} = 0 \quad (9)$$

where  $S_j$  and  $S_T$  represent the area of surface j and the sum of all the area contained in a zone ( $\sum S_j$ ), respectively. Thus, only surface areas are needed to obtain the  $F_{ij}$ . However, under this approach, the sum of all  $F_{ij}$  is different from unity thus violating the complementary law by a quantity equal to  $(1 - \sum F_{ij})$ . It has been suggested (Allard et al., 1987) to correct the calculated  $F_{ij}$  by using the ratio  $(S_j / S_T)^2$ . This operation reduces the error but does not remove it completely. In the present study, the correction procedure has been improved one step further by implementing an iterative process to correct the  $F_{ij}$ :

$$F_{ij}^* = F_{ij} + \left( \frac{S_j}{S_T} \right)^2 \left( 1 - \sum_{j=1}^n F_{ij} \right) \quad (10)$$

As shown in Equation 10, the final value of  $F_{ij}$  ( $F_{ij}^*$ ) is obtained by updating previous values of  $F_{ij}$  by an amount equal to the error  $(1 - \sum F_{ij})$  multiplied by the factor proposed by Allard (Allard et al., 1987). Iterations are performed until successive values of  $F_{ij}$  agree within  $10^{-5}$ . At convergence, the resulting view factors respect the reciprocity and complementary laws (Randriamiarinjatovo, 2003).

### Step 6: Internal heat gains

In this step, the user enters in B5EES the values of internal heat gains associated with occupancy, lighting, and equipment. In each case, nominal

values of power per floor area are entered as well as the radiative/convective split. Hourly values are obtained using user-defined occupancy scenarios. Then the total hourly instantaneous convective and radiative heat gains ( $Q_{c,ig}$  and  $Q_{lw,ig}$ ) are calculated. The radiative portion incident on a particular wall of a zone wall,  $q_{lw,ig,w}$ , is area-weighted according to:

$$q_{lw,ig,w} = Q_{lw,ig} \times (A_{wall} / A_{total}) \quad (11)$$

where  $A_{wall}$  and  $A_{total}$  are the wall and total zone areas, respectively.

### Step 7: Transient heat transfer

This is the main calculation module of B5EES. The user can select between two scenarios: i) zone air temperatures are constant and B5EES calculates the hourly heating/cooling loads; ii) zone air temperatures are free floating. The calculation procedure is best illustrated with reference to Figure 5 where only two zones of the five possible zones are illustrated.

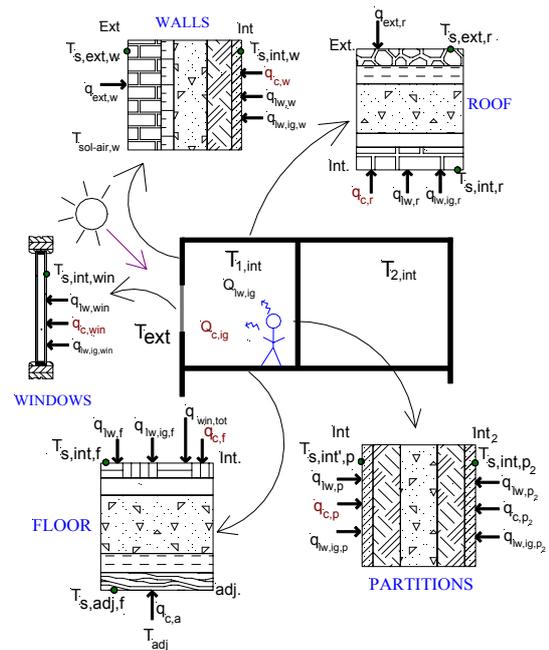


Figure 5 Illustration of the various heat transfer processes in Step 7.

Given the fact that only convective gains contribute to the load, the heating/cooling load in zone 1,  $q_{load,1}$ , is then given by:

$$q_{load,1} = q_{c,ig} + q_{c,w} + q_{c,r} + \sum_3 q_{c,p} + q_{c,f} + q_{c,win} \quad (12)$$

where the indices  $ig$ ,  $w$ ,  $r$ ,  $p$ ,  $f$ , and  $win$  refer to internal gains, wall, roof, partitions, floor, and window, respectively. The summation term reflects the fact that there are three partition walls in zone 1.

If the user selects the free floating temperature scenario, then the air temperature in zone 1 at the current time step,  $T_{1,int}^t$ , is calculated using:

$$\rho_a V C p_a \frac{(T_{1,int}^t - T_{1,int}^{t-1})}{\Delta t} = q_{c,ig} + q_{c,w} + q_{c,r} + \sum^3 q_{c,p} + q_{c,f} + q_{c,win} \quad (13)$$

where  $\rho_a$  is the air density,  $V$  is the zone volume,  $C p_a$  is the specific heat of the air,  $T_{1,int}^{t-1}$  is the zone temperature at the previous time step, and  $\Delta t$  is the time step.

Except for the convective gains associated with internal heat gains, each convective heat transfer rate ( $q_{c,i}$ ) contained in equations 12 and 13 has the form:

$$q_{c,i} = h_{c,i} A_i (T_{s,i} - T_{int}) \quad (14)$$

where the “i” index refers to convective gains on surface “i” (Figure 5). The user can select a constant value of  $h_{c,i}$  or it can be evaluated internally by B5EES using relationships developed by Alamdari and Hammond (1983). This second alternative slows down the calculations as convective coefficients are calculated iteratively based on surface temperatures.

Except for windows, where steady-state heat transfer is assumed, heat transfer in all opaque surfaces is calculated assuming one-dimensional transient heat flow which is governed by:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) \quad (15)$$

where  $\rho$  is the density,  $C_p$  is the specific heat,  $k$  is the thermal conductivity,  $t$  is the time,  $x$  is the position, and  $T$  is the temperature. Equation 15 is solved numerically using the control-volume approach proposed by Patankar (1980). With reference to Figure 4, the fully implicit form of the discretization equation for an internal node is given by :

$$a_P T_P = a_E T_E + a_O T_O + b \quad (16)$$

where

$$a_P = a_E + a_O + a_P^0, \quad a_E = \frac{k_e}{\delta x_e}, \quad a_O = \frac{k_o}{\delta x_o},$$

$$\text{and } a_P^0 = \frac{\rho C_p \Delta x}{\Delta t}, \quad b = a_P^0 T_P^0$$

$\Delta x$  is the width of the control volume,  $T_P^0$  is the temperature at point P prevailing at the preceding time interval,  $k_e$  and  $k_o$  are so-called interface conductivities which account for different thermal

conductivities between adjacent nodes (Patankar,1980). Boundary nodes require a special treatment. Taking the exterior and interior surface temperatures of the external wall as an example ( $T_{s,ext,w}$  and  $T_{s,int,w}$  in Figure 5), the values of  $a_B^0$  and  $b$  are given by:

$$a_B^0 = \frac{\rho C_p (\Delta x/2)}{\Delta t} \text{ for } T_{s,ext,w} \text{ and } T_{s,int,w} \quad (17)$$

$$b = a_B^0 T_{s,ext,w}^0 + q_{ext,w} \quad (18)$$

for  $T_{s,ext,w}$  and

$$b = a_B^0 T_{s,int,w}^0 + q_{c,w} + q_{lw,w} + q_{lw,ig,w} \quad (19)$$

for  $T_{s,int,w}$

values of  $q_{ext,w}$ ,  $q_{c,w}$ ,  $q_{lw,w}$ , and  $q_{lw,ig,w}$  are given by equations 1, 14, 8, and 11, respectively.

In summary, B5EES establishes 15 discretized equations of the form represented by equations 16-19 (one for each node) for each opaque wall in each zone. Zones are coupled via partition heat transfer. Then B5EES uses the internal solver of the equation solver to obtain converged solutions to each discretized equation. Then, either equation 12 or 13 are evaluated to obtain the desired results.

## VALIDATION OF B5EES

B5EES is validated using two approaches. First, the analytical verification test suite developed by ASHRAE (Rees et al. 2001, ASHRAE, 2002) is used to validate elementary thermal processes. Then, the BESTEST procedure (Judkoff and Neymark, 1995) is used to validate the heating/cooling load calculations as well as zone temperature predictions.

### ASHRAE's analytical test suite

Randriamiarinjatovo (2003) has conducted five tests (TC1, TC2, TC3, IntRad, IntHeatGain) using ASHRAE's analytical test suite. On average, the agreement between B5EES and the analytical solutions is very good. Three of these validation tests will now be presented.

### Transient conduction in walls

Two tests on transient conduction in walls are reported here. The first one, called TC2, is a test involving a  $3 \times 3 \times 3$  m room with 5 adiabatic walls and an external wall composed of a single homogeneous low thermal mass layer subjected to a step change in external temperature. The interior temperature is kept constant as well as internal and external convection coefficients. The second test, called TC3, is identical to TC2 except that the external wall is composed of multiple layers (1.5 m

thick) and is subjected to steady-periodic sinusoidal change in external temperature. The interior temperature is fixed at the mean external temperature. A one hour time step was used in B5EES for these tests.

Figure 6 shows result for the TC2 test. As shown on this figure the load predicted by B5EES is in excellent agreement with ASHRAE's analytical results.

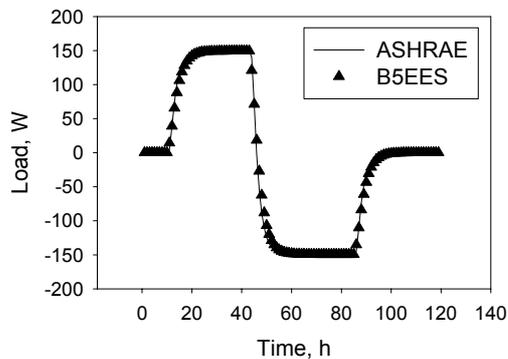


Figure 6 Comparison between ASHRAE's analytical results and B5EES for a low thermal mass wall

The results for test TC3 are shown on Figure 7. As shown on this figure, B5EES over predicts the load by approximately 32 % when compared to ASHRAE's analytical results. Furthermore, there is a 2 hour time lag in the prediction of the peak load. As shown by Randriamiarinjatovo (2003), these differences are essentially due to three factors: the relatively small number of grids (3 grids per layer), the fully implicit numerical scheme, and the relatively long time step (1 hour). In one particular test performed with a 6 minutes time step, Randriamiarinjatovo (2003) has shown that the time lag is virtually eliminated while the peak load difference is reduced from 32 % to 9%.

#### Interior long wave radiation

The objective of this test, called IntRad, is to test the treatment of interior long wave radiation. A windowless cubic room ( $3 \times 3 \times 3$  m) with one external lightweight wall (surface 1) has been selected for this test. The exterior and interior temperatures are fixed at  $30^{\circ}\text{C}$  and  $10^{\circ}\text{C}$ , respectively. The external and internal convection coefficients are set at 10 and  $5 \text{ W/m}^2\text{-K}$ , respectively. All six internal surfaces have emissivities equal to 0.9. As shown in Table 2, the agreement between B5EES and ASHRAE's analytical test suite is excellent indicating that interior long wave radiation exchange is implemented correctly in B5EES.

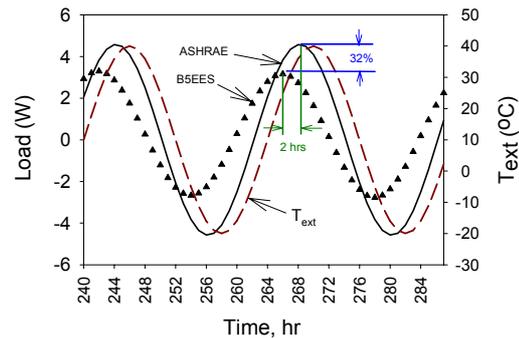


Figure 7 Comparison between ASHRAE's analytical results and B5EES for a multilayer high thermal mass wall

Table 2 Comparison between B5EES and ASHRAE's analytical test suite results for interior long wave radiation exchange

Surface	Inside surface temperature ( $^{\circ}\text{C}$ )		Radiative flux ( $\text{W/m}^2$ )		Convective flux ( $\text{W/m}^2$ )	
	ASHRAE	B5EES	ASHRAE	B5EES	ASHRAE	B5EES
1	20,494	20,495	42,582	42,580	52,473	52,470
2	11,703	11,703	-8,513	-8,516	8,513	8,517
3	11,703	11,703	-8,517	-8,516	8,517	8,517
4	11,703	11,703	-8,517	-8,516	8,517	8,517
5	11,703	11,703	-8,517	-8,516	8,517	8,517
6	11,703	11,703	-8,517	-8,516	8,517	8,517

#### BESTEST

The Building Energy Simulation Test (BESTEST) compares the results obtained from several commercially-available software for a series of test conditions. The building tested measures  $6 \times 8 \times 2.7$  m and is oriented towards the four main cardinal points. A TMY weather file corresponding to a latitude of  $39.8^{\circ}$  north and a longitude of  $104.9^{\circ}$  west is utilized. The results of five comparative tests are reported here. The first one compares the solar radiation calculation while the other four are tests 195, 270, 600FF, and 900FF (Judkoff and Neymark, 1995).

#### Solar radiation calculations

Solar radiation calculations have been compared for four cases: two dates (March 5<sup>th</sup> and July 27<sup>th</sup>) and two orientations. Results for March 5<sup>th</sup> and the west orientation are shown in Figure 8. These results show that B5EES agrees favorably well with the other programs. Randriamiarinjatovo (2003) reports that for the four cases tested the maximum difference at

noon between the average of all programs and B5EES is +6.1%.

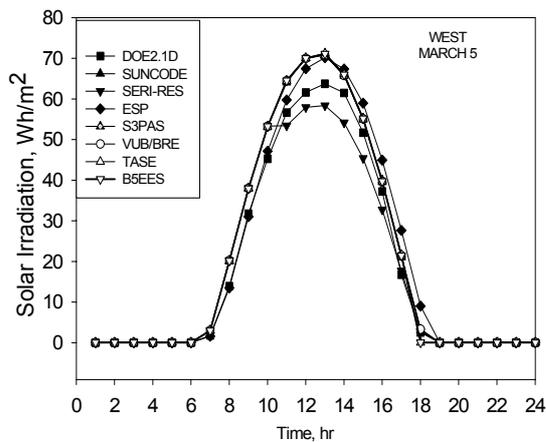


Figure 8 Comparison of the solar radiation calculations for various building simulation programs

CASES 195 and 270. These elementary cases involve hourly load calculations for the test building maintained at 20°C. The building envelope is lightweight and there are no internal gains. The building in case 270 has a 12m<sup>2</sup> window on the south face while case 195 has no windows.

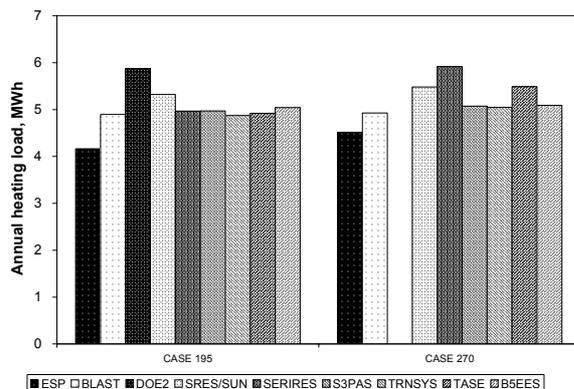


Figure 9 Comparison of annual heating loads for cases 195 and 270.

The comparison shown in Figure 9 for cases 195 and 270 indicates that the annual heating load calculated by B5EES compares favorably well with the other programs. Similar results have been obtained for the annual cooling loads. Randriamiarinjatovo (2003) has shown that the maximum difference between B5EES and the average of the other programs is less than 3% for the heating and cooling load predictions.

CASES 600FF and 900FF. BESTEST contains several so-called qualification tests. The current version of B5EES can not handle dead-band thermostats. Therefore, only free-floating temperature cases (600FF and 900FF) are considered

here. These cases are more realistic than cases 195 and 270 as they include internal heat gains and air infiltration. Case 600FF is for a low thermal mass envelope while Case 900FF is for a high thermal mass envelope.

Randriamiarinjatovo (2003) presents several comparisons between B5EES and the other programs for cases 600FF and 900FF. Figure 10 is representative of these comparative tests. It presents the results of a comparison on the prediction of the maximum annual temperature for both cases. As shown on this figure, B5EES compares favorably well with the other programs. The difference between B5EES and the average of the other programs is less than 1.3 °C for case 600FF and less than 0.7 °C for case 900FF.

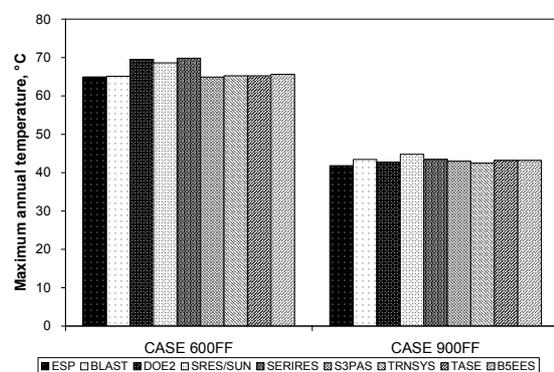


Figure 10 Annual maximum temperatures for cases 600FF and 900FF

### Concluding remarks on validation

The validation tests performed with ASHRAE's analytical test suite and BESTEST show that B5EES does not seem to have any major intrinsic error and that it gives results as accurate as other commercially-available building simulation programs.

### APPLICATION

The example building presented earlier (Figure 2, Table 1) has been simulated using B5EES. Some of the results of this simulation will now be presented. As an example, Figure 11 presents the hourly load of the internal zone for the entire year. This type of simulation requires approximately 2 hours of CPU time on a P4 computer running at 1.4 GHz. B5EES is therefore relatively slow. However, the ease of use of B5EES largely compensates this drawback. Another important feature of B5EES is that most calculated values are accessible for plotting using the internal plotting capability of the equation solver. For example, if the user wants to investigate the internal surface temperatures of the internal zone he can do it with just a couple of clicks. Figure 12 has been

drawn to illustrate this feature. It presents the temperatures of all six surfaces of the south zone

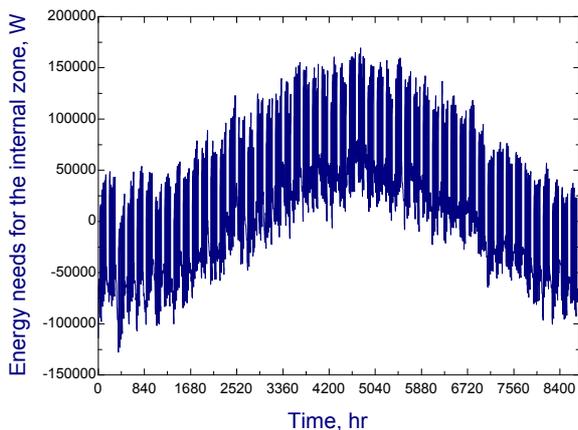


Figure 11 Hourly load of the internal zone of the the example building

of the example building for the first week of the year. This figure shows that while the air temperature is maintained at 22°C, there are significant differences in surface temperatures. The floor experiences peak surface temperatures of over 30°C because of solar gains through the south window. The interior partition walls (north, west, south) have surface temperatures below 22°C most of the time. For example, at t=24 hour, these three temperatures are close to 20.5°C. This is due to long wave radiation exchange between these surfaces and the cold surface temperatures experienced by the south wall and the roof.

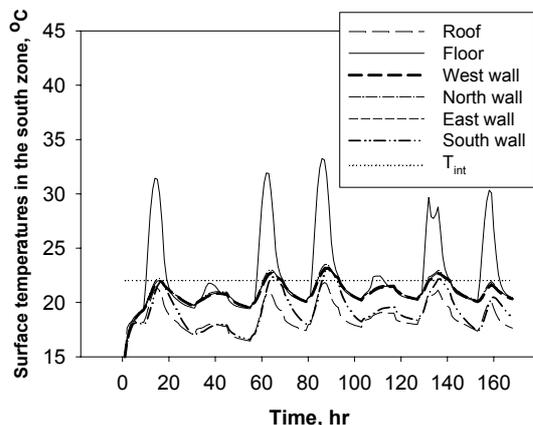


Figure 12 Internal surfaces temperatures for the south zone of the example building

## CONCLUSIONS

This paper describes a relatively simple software tool, called B5EES, which has been developed to perform annual hour-by-hour energy simulations of five-zone buildings using a commercially-available engineering equation solver. The validation tests performed with ASHRAE's analytical test suite and

BESTEST show that B5EES gives results as accurate as other commercially-available building simulation programs. The yearly simulations are time consuming. However, the ease of use of B5EES largely compensates this drawback.

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