A simplified energy model for analysis of building envelope thermal characteristics

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A SIMPLIFIED ENERGY MODEL FOR ANALYSIS OF BUILDING ENVELOPE THERMAL CHARACTERISTICS

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ABSTRACT

A new National Energy Code for Buildings has been developed in Canada. For this new code, a simplified model was developed to estimate the change in energy consumption associated with a change in envelope thermal characteristics. This energy model was derived from a set of correlations based on a large number (more than 5,000) of DOE-2.1E simulations for 25 Canadian locations. These correlations predict heating and cooling energy based on location and building envelope characteristics and internal gains from people, lights, and equipment.

This paper describes the design of the correlation equations, compares the results of correlation equations with DOE-2.1E simulation results, and briefly discusses how the energy-correlation model was used in the new energy code.

The simplified model represents a building by three basic parameters:

—heat loss parameter, U;
—solar gain parameter, V; *and*
—internal gain parameter, W.

The model for heating consists of two parts:

- *the heat-loss term, which is a linear function of* U, *with the slope and intercept dependent on climate; and*
- *modifier terms, which are functions of* V *and* W, *that reduce heating to account for solar and internal gains.*

The cooling model is similar. In this case, the two parts are a base cooling term, which is a linear function of parameters V *and* W; *and a modifier term, which adjusts the cooling as a function of heat loss parameter,* U.

These simple models produce annual values for heating and cooling energy that are within 10% of those from the DOE-2.1E runs for a wide range of parameters.

This method for predicting energy use was used in the life-cycle cost-analysis procedure to determine prescriptive requirements for the energy code. It also forms the basis for trade-off procedures that can be used to demonstrate compliance for alternative combinations of envelope characteristics that deviate from the prescriptive requirements.

INTRODUCTION

The development of a new Canadian energy code (NRCC 1994) required a simple, fast means of calculating the change in heating and cooling energy that would result from a change in building envelope characteristics. This was needed for the life-cycle costing analysis that was employed for choosing the prescriptive envelope requirements for the code. The basis of such an analysis is to minimize the sum of incremental construction cost and the present value of incremental energy cost. This procedure is described in a companion paper (Sander et al. 1995). The simple energy model also is used in the "trade-off compliance" option (Sander and Cornick 1994), which permits deviation from some of the prescriptive requirements provided others are exceeded, such that the resulting energy performance is "equivalent" to prescriptive.

Other simplified correlation-based energy models exist, but they were not appropriate for the Canadian Energy Code for Buildings. For example, Crawley (1992) describes why methods such as ASHRAE Standard 90.1 were not appropriate for Canadian climates. The gain-load method developed by Sander and Barakat (1983), (1984) did not combine the effects of solar and internal gains and was developed for houses. A new method was required.

The simple energy model described here consists of equations to predict the heating- and cooling-system loads, per m^2 of gross wall, as a function of orientation, climate, internal loads, and wall/window characteristics. The system loads, sometimes referred to as "coil loads," represent the heating and cooling energy that is provided by the heating, ventilating, and air-conditioning (HVAC) system; they do not include heating system efficiency or cooling coefficient of performance (COP). These are accounted for separately so that the equations are not dependent on the energy source (fuel).

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Because the energy-code analysis was restricted to a relatively small number of Canadian locations, the authors began by producing coefficients that were location specific for those regions for which analysis was to be done. Later, the authors found it was possible to extend the application of the model by correlating the coefficients to climate parameters.

This paper describes the design of the correlation equations, compares the results of correlation equations with DOE-2.1E simulation results, and briefly discusses how the energy-correlation model was used in the new energy code.

ASSUMPTIONS

The simple energy model was derived from a data base of 5,400 DOE-2.1E simulations for 25 Canadian locations (Crawley 1992). Four exterior zones facing the cardinal orientations were modeled. Each perimeter zone comprised a lightweight exterior wall having a layer of insulation of unit thickness and variable U-value, as well as a strip of glazing running the entire length of the wall, a medium-weight concrete floor, and adiabatic interior walls (Cornick and Sander 1995). The transient response of the envelope was calculated by DOE-2.1E. The following assumptions were made:

- no interzonal heat transfer,
- fixed infiltration rate of 0.25 L/s·m^2 (0.05 cfm/ft^2),
- internal loads on a six-day office-type schedule,
- heating setback to 15°C (59°F) and cooling off when unoccupied,
- variable-air-volume (VAV) system with terminal reheat,
- 13°C (55°F) supply air,
- free cooling (enthalpy-controlled air-side economizer), and
- minimum ventilation as prescribed by *ANSI/ASHRAE 62-1989* (ASHRAE 1989) requirements—9.4 L/s·person (20 cfm/person).

The building envelope was characterized by three parameters: a transmission parameter, U, which accounts for the heat loss or gain through the envelope; a solar parameter, V, which accounts for the solar gain through the envelope; and an internal-gain parameter, W, which accounts for internal load.

The parameters are defined as

$$U = [A_g \cdot U_g + A_w \cdot U_w]/A_t \qquad \mathrm{W/(m^2 \cdot {}^\circ K)}$$

$$V = A_g \cdot SC_g / A_t \qquad \text{dimensionless}$$

$$W = I \cdot A_f / A_t \qquad \mathrm{W/m^2}$$

where

A_w = opaque wall area (m^2);
A_g = window wall area including frame (m^2);
A_t = gross wall area, $(A_w + A_g)$ (m^2);
A_f = floor area associated with envelope, typically 4.5 m (15 ft) deep (m^2);
U_w = opaque wall U-factor (W/m^2·K);
U_g = window U-factor, including frame (W/m^2·K);
SC_g = window shading coefficient (dimensionless); and
I = design heat gain from lights, people, and equipment (W/m^2 floor area).

HEATING ENERGY EQUATIONS

The relationship between the annual heating system load, Q, and the three parameters, U, V, and W, was derived for one location—Ottawa, Ontario. Once a plausible model was found, it was tested using other selected locations chosen to reflect the climatic variation across Canada. The proposed model predicted the annual heating system loads accurately for the other locations. In the final model, the annual heating system load, Q, was calculated by modifying the annual heat loss, L, by factors to account for solar and internal gains (Equation 1). This model takes a similar approach to that proposed by Sander and Barakat (1984) and accounts for the interaction of solar and internal gains. A more complete description is given by Cornick and Sander (1994).

$$Q = L \cdot \mathrm{SGRF} \cdot \mathrm{IGRF} \cdot \mathrm{GIF} \qquad (\mathrm{MJ/m^2 \cdot yr}) \qquad (1)$$

where L, SGRF, IGRF, and GIF are as defined below.

Annual Heat Loss, *L*

The authors began by examining the annual heat loss, L, the heating when there are no internal or solar gains. L can be approximated as a linear function of U as

$$L = b_0 + b_1 \cdot U \qquad (\mathrm{MJ/m^2 \cdot yr}) \qquad (2)$$

where

U = U parameter (W/m^2· K),
b_0 = constant representing infiltration and ventilation losses (W/m^2· K), and
b_1 = relationship between U-factor and heat loss (K).

The annual heat loss was found to be only slightly dependent on orientation. The coefficients b_0 and b_1 vary only by a few percent for different orientations, indicating that solar radiation on the wall surfaces is not a major factor. As expected, values of coefficients b_0 and b_1 are dependent on location. The coefficients for Ottawa are shown in Table 1.

TABLE 1 ***L* Coefficients for Ottawa**

	East	West	North	South
b_0	728.8679	722.127	721.3787	729.1496
b_1	431.2615	444.9293	463.3301	421.1035

Solar-Gain Reduction Factor, SGRF

Next, the authors examined the reduction in heating due to solar gains. L_v was defined as the annual heating loss minus the solar gains (i.e., L - solar gains). A plot of L_v against the solar gain parameter V revealed six different curves, each representing a particular value of U. However, dividing both L_v and V by the annual heat loss L accounted for the effect of U and the six curves collapsed into a single curve.

The authors defined the ratio L_v/L to be the solar-gain reduction factor (SGRF). Fitting the curve of L_v/L against V/L produced a single equation (Equation 3) that suited all 25 data-base locations. Four sets of coefficients, one for each orientation, were produced for each location in the data base. Table 2 lists the coefficients α_1, α_2, and α_3 obtained for Ottawa.

$$\mathrm{SGRF} = L_v/L = 1/(1+\alpha_1 \cdot x + \alpha_2 \cdot x^2 + \alpha_3 \cdot x^3) \quad (3)$$

where

$x \quad = V/L.$

TABLE 2 **SGRF Coefficients for Ottawa**

	East	West	North	South
α_1	2528.154	2436.595	1396.895	3344.05
α_2	−896615	−873968	−274133	3672654
α_3	1.44E+09	1.48E+09	3.36E+08	1.6E+09

Internal Gain Reduction Factor, IGRF

Internal loads also reduce the annual heating loss for a building. The annual heating loss minus the internal gains was defined as L_w (i.e., L - internal gains). When L_w was plotted with the internal gain parameter, W, the six different curves, representing the values of the U parameter, were again apparent. In a similar manner to solar gains when both L_w and W were divided by the annual heat loss, L, all the curves collapsed into one. Fitting the curve obtained by plotting L_w/L against W/L produced a single equation (Equation 4) that suited the 25 database locations. However, because the effect of internal gains on heating was independent of orientation, a single set of coefficients resulted for a given location. Table 3 shows the coefficients β_1, β_2, and β_3 for the Ottawa location.

$$\mathrm{IGRF} = L_w/L = \exp(\beta_1 \cdot y + \beta_2 \cdot y^2 + \beta_3 \cdot y^3) \quad (4)$$

where

$y \quad = W/L.$

TABLE 3 **IGRF Coefficients for Ottawa**

	All Orientations
β_1	−15.6865
β_2	2.002871
β_3	−593.541

Solar Gain and Internal Gain Interaction Factor, GIF

When solar and internal gains are present, it was found that the annual heating system load, Q, could be approximated by the product of the annual heat loss, L, and the solar and internal gain reduction factors, SGRF and IGRF, respectively (Equation 5).

$$Q = L \cdot \mathrm{SGRF} \cdot \mathrm{IGRF} \quad (5)$$

However, to improve the accuracy of the results with both internal and solar gains interacting, an additional factor, the gain interaction factor (GIF), was introduced. GIF was introduced to account for solar and internal gain interaction and was defined as the ratio of Q obtained from DOE-2.1E to the product of L, SGRF, and IGRF calculated from the simulation results (Equation 6).

$$\mathrm{GIF} = Q_{(\text{from DOE2.1E})} / (L \cdot \mathrm{SGRF} \cdot \mathrm{IGRF}) \quad (6)$$

Another parameter, γ, was defined. This is the ratio of total gains ($L - Q$) to the sum of solar gains ($L - L_v$) and internal gains ($L - L_w$).

$$\gamma = \text{total gains}/(\text{solar gains} + \text{internal gains})$$

$$\gamma = (L - Q) / ((L - L_v) + (L - L_w))$$

$$\gamma = (1 - Q/L) / ((1 - L_v/L) + (1 - L_w/L))$$

However, L_v/L = SGRF, L_w/L = IGRF, and Q/L = SGRF · IGRF; therefore,

$$\gamma = (1 - \mathrm{SGRF} \cdot \mathrm{IGRF}) / ((1 - \mathrm{SGRF}) + (1 - \mathrm{IGRF}))$$

$$\gamma = 1 \text{ if SGRF and IGRF} = 1.$$

Several things were apparent from a plot of GIF vs. γ. First, the gain interaction factor, GIF, was not dependent on orientation. Second, GIF was not strongly dependent on location. Consequently, a universal curve was fitted for GIF vs. γ using all the orientations for all the selected locations. The result was a single correction term for all Canadian locations (Equation 7). The coefficients for the GIF are given in Table 4.

$$\mathrm{GIF} = \exp(\delta_0 + \delta_1 \cdot \gamma + \delta_2 \cdot \gamma^2 + \delta_3 \cdot \gamma^3) \quad (7)$$

where

$$\delta_0 + \delta_1 + \delta_2 + \delta_3 = 0.$$ [1]

[1]This constraint was derived from the following boundary condition: if SGRF *or* IGRF has a value of 1 then there is no interaction, γ becomes 1 and the value of GIF becomes 1. Consequently, the sum of the coefficients must be 0. The "*or*" here is inclusive.

TABLE 4 **GIF Coefficients (The Coefficients Are Independent of Location and Orientation)**

δ_1	−7.631
δ_2	24.608
δ_3	−26.340
δ_4	9.3629

COOLING ENERGY EQUATIONS

The relationship between annual cooling system loads and the three parameters *U*, *V*, and *W* was derived in a manner similar to that for heating. Annual cooling system loads, *C*, primarily are dependent on internal and solar gains rather than envelope losses. A simple two-step model was derived to estimate cooling system loads (Equation 8). First, the base cooling load, C_0, is calculated from the internal gain and solar gain parameters *V* and *W*. Then the base cooling load is corrected for the envelope transmission parameter *U*. A detailed description of the derivation of the cooling equations is given by Sander et al. (1993) and Cornick and Sander (1994).

$$C = C_0 + \Delta C_0 \qquad (\mathrm{MJ/m^2 \cdot yr}) \qquad (8)$$

where C_0 and ΔC_0 are as defined below.

Base Cooling Load, C_0

The authors began by examining how the cooling loads vary with changes in solar and internal gain. When *U* was held constant, the cooling load varied in direct proportion to the solar gain and internal gain parameters *V* and *W*. However, the cooling loads did not go below a minimum value, C_{min}, even for combinations of *U*, *V*, and *W* that produce little to no cooling load. This minimum cooling was a result of the choice of system modeled and the operational assumptions, especially the minimum ventilation requirement. The value of C_{min} was found to be climate dependent. The base cooling load, C_0, was defined as:

$$C_0 = \max\,(C_{min},\, a_0 + a_1 \cdot V + a_2 \cdot W) \quad (\mathrm{MJ/m^2 \cdot yr}) \; (9)$$

where

C_{min} = minimum cooling load for a particular climatic location and

a_0, a_1, and a_2 = climate- and orientation-dependent coefficients.

Table 5 shows the values of the coefficients for Ottawa.

TABLE 5 **Cooling Coefficients for Ottawa**

	East	West	North	South	C_{min}
a_0	22.0343	24.824	15.103	19.473	87.684
a_1	857.662	816.929	506.308	789.254	
a_2	4.076	4.111	4.175	4.115	
a_3	−41.259	−46.518	−52.063	−43.619	

Correction for Envelope Losses/Gains, ΔC_0

The effect of the *U* parameter on cooling was accounted for by applying an envelope correction term to the base cooling load, C_0. In cooler climates, such as Canada, building envelopes tend to experience net transmission loss. The DOE-2.1E simulations showed that as *U* increased, more heat was lost through the envelope and the annual cooling system load decreased. This was, in effect, *free* cooling obtained by increasing the envelope transmission. However, this *free* cooling was obtained at the cost of a substantial increase in the heating load in Canadian climates.[2]

The envelope correction term, ΔC_0, was defined as the change in cooling system load given a change in *U* from $U = 0$ to $U = U$ while holding *V* and *W* constant (Equation 10). Envelope transmission losses for cooling tend to be relatively small when compared to the base cooling load. The coefficient a_3 from Equation 10 also is climate and orientation dependent. Table 5 shows the values of the a_3 coefficient for Ottawa.

$$\Delta C_0 = a_3 \cdot U \cdot (1 - C_{min}/C_0) \quad (\mathrm{MJ/m^2 \cdot yr}) \qquad (10)$$

CLIMATE CORRELATIONS

The heating and cooling equations were derived with location-specific coefficients for the 25 Canadian locations. To permit calculation for Canadian locations not in the original data base, the method was extended so that heating and cooling loads could be predicted from basic climatic data such as heating degree-days, cooling degree-days, and the amount of solar radiation.[3] Cornick and Sander (1994) give a more complete description of the derivation of the climate correlations for the heating and cooling equations.

Cooling

Because the climate correlations for cooling are more straightforward, they will be presented first. There are five coefficients in Equations 8, 9, and 10 that need to be determined. They are

a_0 = intercept for the base cooling load,
a_1 = variation of cooling with solar parameter,
a_2 = variation of cooling with internal load parameter,
a_3 = variation of cooling with thermal transmittance, and

[2]For warmer climates, such as Australia, the envelope effect was found to be much less and, in some cases, was opposite for hot locations such as Darwin, Australia.

[3]In fact, several weather stations were selected by the provincial ministries for the Energy Code that were not among the list of locations simulated. The climate correlations were used to generate the coefficients for the heating and cooling equations that subsequently appeared in the life-cycle costing analysis procedure and trade-off specification (Sander and Cornick 1994).

C_{min} = minimum cooling load.

Straightforward regression analysis produced the following climate correlations for cooling:

$$a_0 = E_0 + E_1 \cdot CDD65 + E_2 \cdot VS_j + E_3 \cdot CDD50 + E_4 \cdot VS_j \cdot CDD50 + E_5 \cdot \sqrt{(VS_j \cdot CDD50)} \quad (11)$$

$$a_1 = L_0 + L_1 \cdot CDD50 + L_2 \cdot \sqrt{(CDD50)} + L_3 \cdot HDD65 + L_4 \cdot VS_j + L_5 \cdot VS_j \cdot CDD50 \quad (12)$$

$$a_2 = G_1 \cdot CDD50 + G_2 \cdot CDD65 + G_3 \cdot CDD50 \cdot CDD65 + G_4\sqrt{(CDD50 \cdot CDD65)} \quad (13)$$

$$a_3 = T_0 + T_1 \cdot LAT + T_2 \cdot LAT^2 + T_3 \cdot CDD50 + T_4 \cdot \sqrt{(CDD50)} + T_5 \cdot HDD65 \quad (14)$$

$$C_{min} = X_1 \cdot CDD50 + X_2 \cdot CDD50^2 + X_3 \cdot CDD65 + X_4 \cdot CDD50 \cdot CDD65 + X_5 \cdot \sqrt{(CDD50 \cdot CDD65)} \quad (15)$$

where

CDD50 = cooling degree-days at 50°F (10°C),
CDD65 = cooling degree-days at 65°F (18°C),
HDD65 = heating degree-days at 65°F (18°C),
LAT = latitude in minutes,
VS_j = vertical solar on orientation j, and
j = {north, south, east, west}.

TABLE 6 Climate Correlations for the Cooling

	East	West	North	South
E_0	−18.628	−8.00885	−11.168	−10.859
E_1	0.074	0.0821	0.0734	0.0686
E_2	0.035	0.0106	0.0302	0.0152
E_3	0.0403	0.0101	−0.0128	0.0177
E_4	−5.3E-05	−1.5E-05	1.19E-05	−1.8E-05
E_5	−0.017	0.00102	0.0237	−0.007
L_0	−521.244	−378.88	−495.692	−87.828
L_1	0.182	0.261	0.211	0.356
L_2	0.474	1.1087	13.395	−9.209
L_3	−0.008	−0.00905	0.0104	−0.0213
L_4	1.299	0.988	0.687	0.820
L_5	0.000236	8.23E-05	−0.00063	5.91E-05
G_1	0.00116	0.00124	0.0012	0.00117
G_2	−0.0118	−0.0115	−0.0119	−0.0121
G_3	7.81E-07	8.96E-07	7.42E-07	8.37E-07
G_4	0.00627	0.00589	0.00641	0.00639
T_0	−182.239	−112.926	−102.649	−161.768
T_1	0.116	0.0728	0.082	0.102
T_2	−1.6E-05	−9.9E-06	−1.3E-05	−1.4E-05
T_3	0.0146	0.00115	0.0127	0.00966
T_4	−1.825	−1.335	−2.265	−1.628
T_5	−0.00025	−0.00056	−0.00026	−0.00042
X_1	0.0242			
X_2	−1.1E-05			
X_3	−0.318			
X_4	6.92E-05			
X_5	0.171			

TABLE 7 Climate Correlations for L

	East	West	North	South
A_0	176.797	169.889	173.548	170.561
A_1	0.0609	0.0612	0.0608	0.0615
B_0	106.531	111.498	131.917	97.449
B_1	0.0379	0.0382	0.0378	0.0376

The coefficients E, L, G, T, and X for the climate correlations are shown in Table 6.

Heating

The first step in developing climate correlations for the heating coefficients involved finding a correlation for the annual heat loss, L. The next step involved predicting the solar and internal gain reduction factors for a specific location. The gain interaction parameter was found to be independent of climate.

Annual Heat Loss Like the cooling equations, the coefficients b_0 and b_1 have some physical significance; b_0 accounted for the infiltration and ventilation losses, while b_1 characterized the effect of thermal envelope transmission on the heating requirement for a given climate. As may be expected, the coefficients b_0 and b_1, which are used to calculate the annual heat loss (Equation 1), were found to be linearly related to heating degree-days (Equations 16 and 17).

$$b_0 = A_0 + A_1 \cdot HDD65 \quad (16)$$

$$b_0 = B_0 + B_1 \cdot HDD65 \quad (17)$$

Table 7 shows the climate coefficients A and B for predicting the annual heat loss coefficients.

Solar Gain Reduction Factor The coefficients for the solar gain reduction factor (SGRF) (Equation 3) were determined by a simple best fit; the authors have not tried to ascribe physical significance to the coefficients. The sign of the higher order coefficients changed depending on the data, making it difficult to correlate them to climate. Therefore, a different approach had to be used. Instead of generating climate correlations for the coefficients in Equation 3, the entire curve defining SGRF was modified to coincide with a reference curve. To calculate SGRF for a location not in the original data base new coefficients are calculated by modifying the coefficients of the reference location for the effects of climate. A climate factor, k_1, was generated to modify the SGRF coefficients for Ottawa, the reference location.

Figure 1a shows the curves for the SGRF for Ottawa and Vancouver (east orientation). The curves have the same general shape. If the curve for Vancouver is shifted along the independent axis it is possible to calculate the SGRF for Vancouver using the curve derived for Ottawa. To do this, the value of V/L for Vancouver is modified by an amount, k_1, such that the values of $k_1 \cdot V/L$ and V/L correspond to the same SGRF on the Ottawa

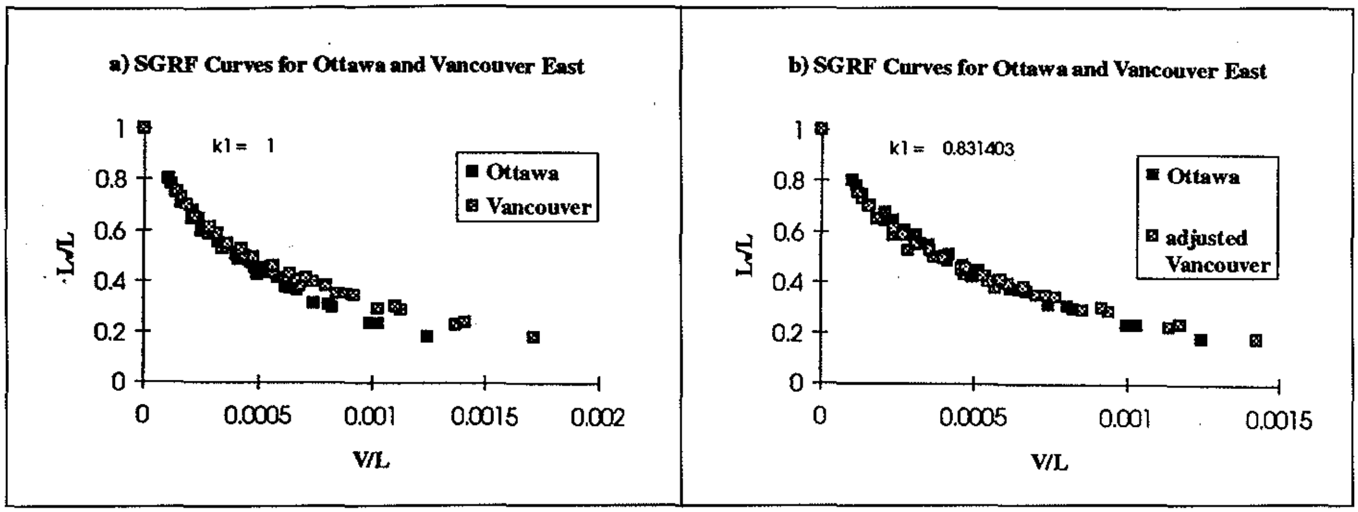

Figure 1 *Solar gain reduction factor. (a) The Ottawa and Vancouver* L_V/L *vs.* V/L *curves. (b)* L_V/L *vs.* V/L *for Ottawa and* L_V/L *vs.* $k_1 \cdot V/L$ *for Vancouver.*

and Vancouver curves. It is possible to find a value for k_1 that makes the entire Vancouver curve coincide with the Ottawa curve. This is shown in Figure 1. k_1 is found by minimizing the values, Δ_1, where

$$\Delta_1 = |L_v/L - f(k_1, V, L)|$$

where

$f(k_1, V, L)$ $= 1/(1+\alpha_{1ottawa} \cdot x' + \alpha_{2ottawa} \cdot x'^2 + \alpha_{3ottawa} \cdot x'^3)$;

$\alpha_{1ottawa}$, $\alpha_{2ottawa}$, $\alpha_{3ottawa}$ = Ottawa coefficients for the SGRF;

x' $= k_1 \cdot V/L$; and

V and L = solar parameter and annual heat loss for the location of interest.

Values of k_1 were generated for each of the 25 locations and orientations in the DOE-2.1E data base (100 in all). From these the authors were able to generate a climate correlation to predict k_1 for locations not in the original data base (Equation 18). The coefficients for the correlation equation are shown in Table 8. To calculate SGRF for a location not in the data base the value of k_1 is first calculated from Equation 18. SGRF is then calculated using Equation 3 and the following coefficients:

TABLE 8 **k_1 Climate Correlations**

	East	West	North	South
C_0	2.294	2.656	1.681	2.098
C_1	–0.00054	–0.00052	–0.00036	–0.00054
C_2	–0.00032	–0.0005	–7.6E-05	–0.00042
C_3	3.38E-07	6.61E-07	–7.8E-08	5.23E-07
C_4	0.000618	0.000167	0.00304	0.000494
C_5	–1.4E-08	–3,2E-08	–1.2E-08	–4.7E-08
C_6	2.28E-05	1.04E-05	–2.1E-05	3.21E-05

$$\alpha_1 = k_1 \cdot \alpha_{1ottawa}$$

$$\alpha_2 = k_1^2 \cdot \alpha_{2ottawa}$$

$$\alpha_3 = k_1^3 \cdot \alpha_{3ottawa}$$

$$k_1 = C_0 + C_1 \cdot LAT + C_2 \cdot \mathrm{CDD50} + C_3 \cdot VS_J \cdot \mathrm{CDD50} + C_4 \cdot VS_J + C_5 \cdot \mathrm{CDD50} \cdot \mathrm{CDD65} + C_6 \cdot \mathrm{HDD65} \quad (18)$$

Internal Gain Reduction Factor The final step was to generate a climate correlation for the internal gain reduction factor, IGRF using the same procedure used to generate a climate correlation for SGRF. The curves for the IGRF have the same general shape regardless of location. A climate parameter, k_2, was introduced such that for a specific value of k_2 the curve for a location other than Ottawa coincided with the Ottawa curve. The k_2 climate parameter was calculated by minimizing Δ_2, where

$$\Delta_2 = |L_w/L - f(k_2, W, L)|$$

where

$f(k_2, V, L)$ $= \exp(\beta_{1ottawa} \cdot y' + \beta_{2ottawa} \cdot y'^2 + \beta_{3ottawa} \cdot y'^3)$,

$\beta_{1ottawa}$, $\beta_{2ottawa}$, $\beta_{3ottawa}$ = Ottawa coefficients for the IGRF,

y' $= k_2 \cdot W/L$, and

W and L = solar parameter and annual heat loss for the location of interest.

The k_2 parameters were generated for each of the 25 locations in the data base. Using the 25 values of k_2 a climate correlation was derived (Equation 19). The coefficients for the climate correlation equation are shown in Table 9. To calculate IGRF for a location not in the data base the value of k_2 is first calculated from Equation 19. IGRF is then calculated using Equation 4 and the following coefficients:

$$\beta_1 = k_2 \cdot \beta_{1ottawa}$$

$$\beta_2 = k_2^2 \cdot \beta_{2ottawa}$$

$$\beta_3 = k_2^3 \cdot \beta_{3ottawa}$$

$$k_2 = S_0 + S_1 \cdot \mathrm{CDD50} + S_2 \cdot VS_{ew} + S_3 \cdot LAT \qquad (19)$$

TABLE 9 **k_2 Climate Correlations**

F_0	1.366	F_2	−0.00046
F_1	−0.00023	F_3	3.67E-06

RESULTS

Figure 2 shows the comparison between the simulated values and the predicted values. For typical annual heating system loads the predictions are within 10% of the DOE-2.1E simulations. Figure 3 shows how the annual heating system loads, Q, for Vancouver calculated using the climate correlations agree with the system loads obtained using DOE-2.1E. When using the

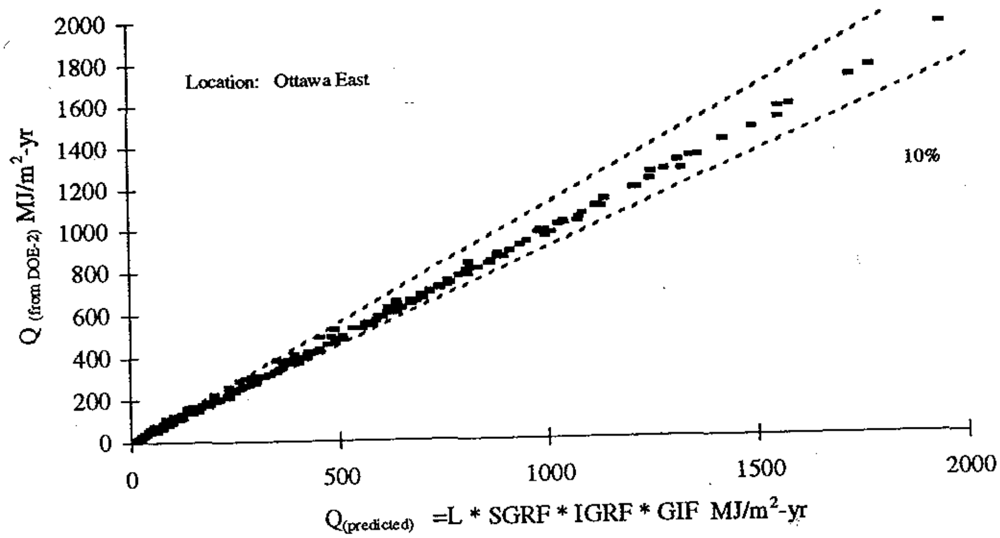

Figure 2 *Comparison of annual heating system loads, Q, calculated using heating equations with loads predicted by DOE-2.1E for Ottawa.*

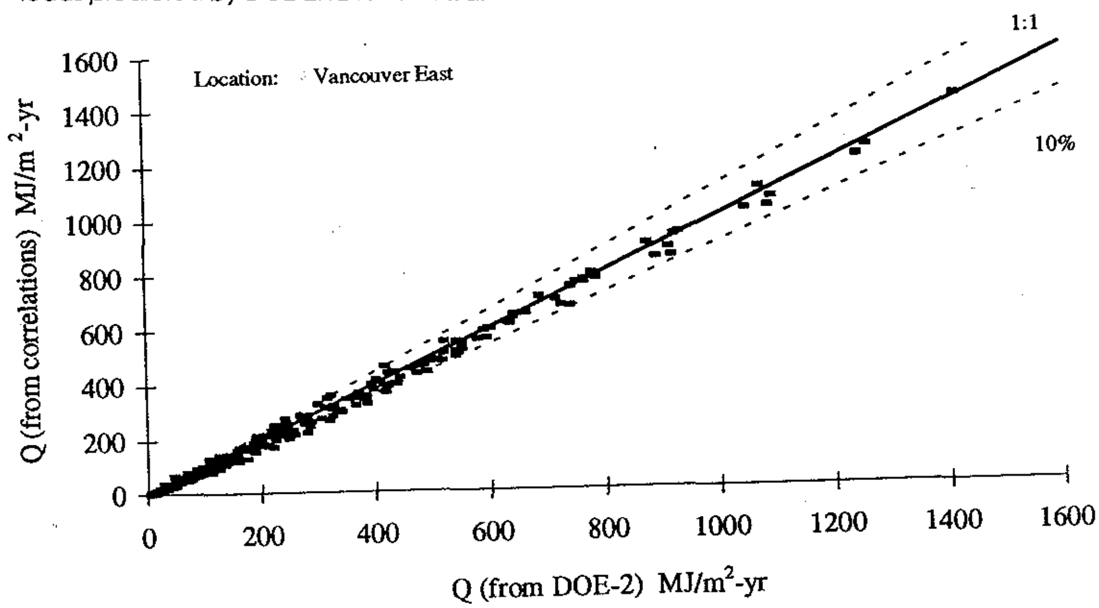

Figure 3 *Comparison of annual heating system loads, Q, calculated using climate correlations with loads predicted by DOE-2.1E for Vancouver.*

climate correlations, the results are within 10% for typical heating loads. Figure 4 shows how the predicted values, C, compare with the DOE-2.1E-generated cooling loads. The predictions are within 10% of the simulated values. It was possible to generate climate correlations for the coefficients for the cooling equations. For most regions in Canada, cooling loads can be calculated within 10% of the DOE-2.1E results. Figure 5 shows the agreement between the cooling loads calculated using the climate correlations for Vancouver and the DOE-2.1E simulations.

SUMMARY

A methodology was developed for predicting the effect of envelope thermal characteristics on energy use in commercial buildings. Part of the methodology consists of methods for conducting a parametric study of the perimeter zones of a model building for the climates of interest (Crawley 1992). The result of the parametric studies can be used to generate coefficients for simplified models predicting energy use. If several parametric studies are done, then climate correlations can be developed

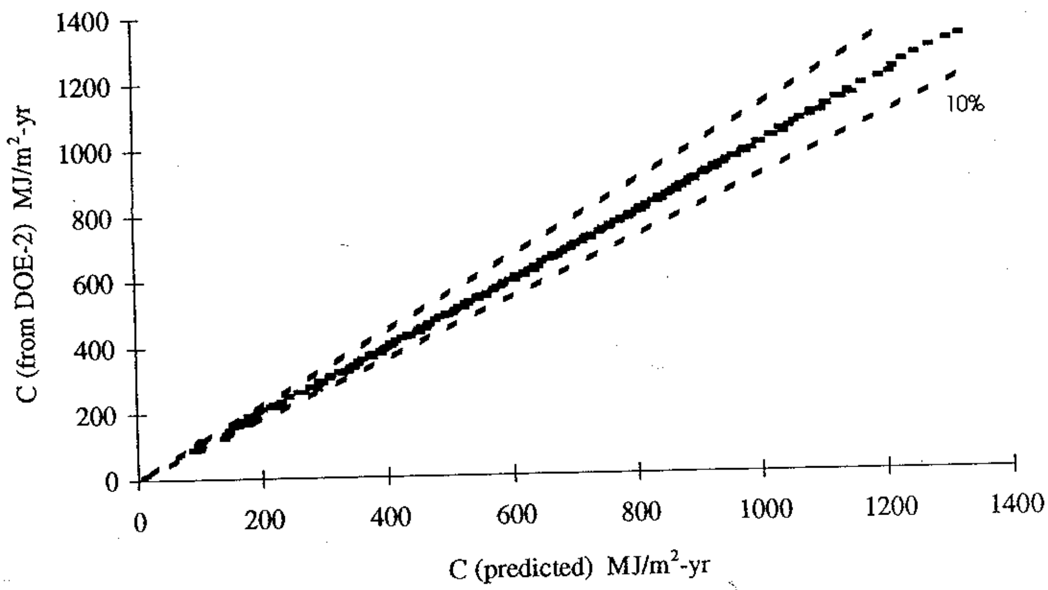

Figure 4 *Comparison of annual cooling system loads, C, calculated using cooling equations with loads predicted by DOE-2.1E.*

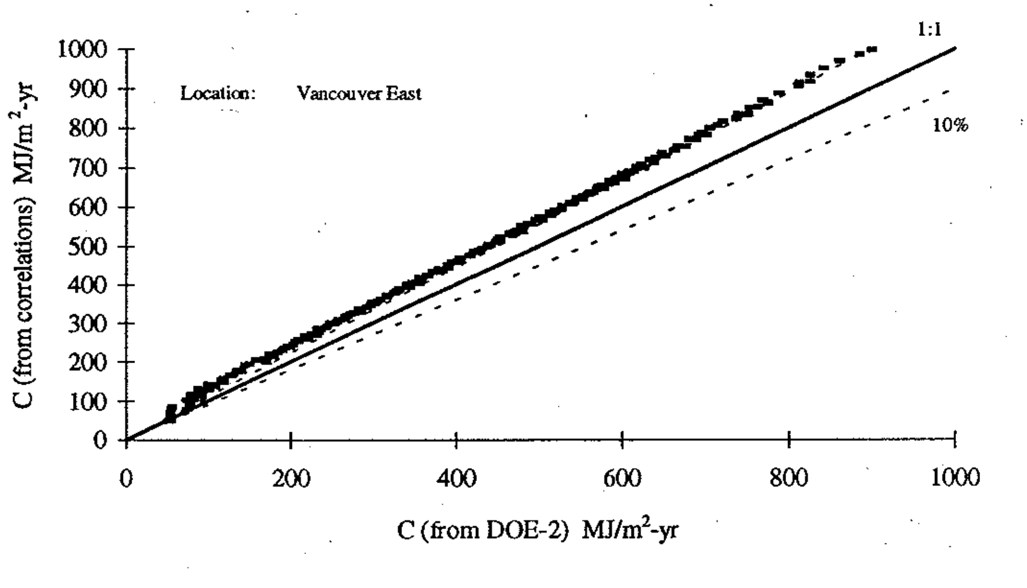

Figure 5 *Comparison of annual cooling system loads, C, calculated using climate correlations with loads predicted by DOE-2.1E for Vancouver East orientation.*

to extend the models to locations not simulated. The models consist of straightforward methods for calculating the heating and cooling system loads. The system loads are calculated using the three decoupled envelope parameters, U (thermal transmittance), V (solar gain), and W (internal gains). The heating system loads are calculated by progressively modifying the annual heat loss to account for solar gain, internal gain, and solar and internal gain interaction. The annual heat loss was shown to be a linear function of U, the slope and intercept being dependent on climate. The slope and intercept also were shown to vary linearly with heating degree-days. Climate correlations were developed for the solar gain reduction factor, SGRF, by shifting the curves of the location in question to a specific location. A similar method was developed to account for internal gains; however, the internal gain reduction factor, IGRF, was found to be independent of orientation. A similar method was derived for cooling. It was found that cooling loads could be calculated as the sum of a base cooling load and a correction term for transmission. The base cooling was found to vary linearly with the solar gain and internal gain parameters. A minimum cooling load, a result of the HVAC system modeled and the minimum ventilation requirement, also was found to occur. The models are robust and predict energy use well in moderate to extreme Canadian climates, unlike other correlation models that were generated for predominantly cool climates. The methodology has been extended to include hot climates and it appears to be independent of climate, HVAC system, and operational assumptions (Thomas and Prasad 1995).

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