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Predicting the Effects of Changes in Thermal Envelope
Characteristics in Energy Consumption: Application and Verification
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by

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PREDICTING THE EFFECTS OF CHANGES IN THERMAL ENVELOPE CHARACTERISTICS ON ENERGY CONSUMPTION: APPLICATION AND VERIFICATION OF A SIMPLE MODEL FOR AUSTRALIAN AND CANADIAN CLIMATES

S. M. Cornick¹, P.C. Thomas² and D.K. Prasad³

ABSTRACT: A simple energy model was used for determining thermal envelope characteristics and building envelope trade-off procedures for the new Canadian and Australian energy efficiency codes for new buildings. The model relates heating and cooling system loads to envelope thermal characteristics. It was developed from thousands of DOE2.1E simulation runs. Two separate databases, one containing 25 Canadian locations and the other containing 9 Australian locations were created. The heating and cooling models were developed from these databases. The model is shown to give consistent results although there are significant differences in climate, construction of the building envelope, building operational schedules and HVAC system configurations. This paper briefly describes the DOE2.1E models used for the study in each country, highlighting similarities and differences. The consistency of results predicted by the model is discussed for typical climatic locations in both countries. The methods for predicting heating and cooling system loads are shown to produce good results over a wide range of climates and for different system configurations. The paper also discusses the development of climate correlations to extend the range of the models to include locations not in the original databases.

INTRODUCTION

Canada and Australia are in the process of developing national energy efficiency codes for buildings as part of continuing government initiatives to reduce energy consumption and the resulting rate of increase of greenhouse gas emissions. This paper outlines a simple model used to predict energy consumption in perimeter zones (Cornick and Sander, 1995). The performance of the model is compared for various building constructions, operation schedules, HVAC system configurations, and climates. Specifically, a comparison is made between heating climates (Canada) and cooling climates (Australia). In Canada the developed model forms an integral part of the prescriptive and trade-off compliance paths of the National Energy Code for Buildings. In Australia, the model is being reviewed by Standards Australia for use as a systems

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performance compliance method for building envelopes.

The Canadian Code

In Canada, two separate energy codes were produced; a code for houses and a code for buildings. Part 3 of the code for buildings specifies the thermal characteristics of the building envelope (National Energy Code for Buildings). The envelope portion of the Canadian code has three compliance paths: a prescriptive path, a trade-off path, and a full performance path. The trade-off and full performance procedures use the prescriptive requirements to calculate the energy budget of a reference building against which the proposed design is compared.

The prescriptive requirements generated for the Canadian code were based on economic criteria. The optimal economic envelope characteristics were determined by minimizing the sum of incremental construction costs and the present value of the energy costs over the life cycle of the envelope (Sander *et al.*, 1995). A simple model predicting changes in heating and cooling system loads were required for the life cycle costing procedure. This model was also specified as the energy calculation method for the trade-off compliance path for the Canadian Code (Sander and Cornick, 1994).

The Australian Code

Separate research efforts are being carried out which will culminate in energy efficiency standards for both residential and commercial buildings in Australia. The Nationwide Home Energy Rating Scheme (NatHERS) is a simulation based approach for domestic houses, which will lead to star rating of homes based on energy performance. Two studies have been carried out for commercial buildings. The Commercial Building Energy Code project phase-I (CBEC) study determined cost effective levels of energy efficiency for various components of four building systems (SRCI, 1993). The National Solar Architecture Research Unit at the University of New South Wales (SOLARCH) developed the database and trade-off equations for the building envelope using the parameters and models described in this paper in a study sponsored jointly by the Energy Research and Development Corporation and Standards Australia, (Prasad, 1994). Further research is anticipated to combine and extend the findings of these two studies into a full fledged Commercial Building Energy Code.

For the Australian code, it is envisaged that compliance via the systems performance option could be a two step process. First, the allowable energy budget for the perimeter zones are computed using the prescriptive values (derived from least life cycle cost considerations under a specified economic scenario) applied to a proposed building design. Trade-offs to the envelope characteristics of the proposed design are then allowed as long as the energy budget is less than or equal to energy budget of the prescriptive case. A simple model was required to quickly calculate the allowable energy budget and energy use of the proposed design. This trade-off procedure is similar to the trade-off path in the proposed Canadian Code.

PARAMETERS

The most important part of the process in the development of the predictive energy models was the development of a method to characterize and study the effects of enve-

lope characteristics on energy consumption. A key element of this method was the decoupling of the relevant envelope characteristics in order to conduct parametric studies on the building envelope. The thermal properties of the building envelope were characterized by three parameters. Crawley (1992) provides a detailed explanation as to how these parameters were derived. The three parameters are; U , a transmission parameter which accounted for heat loss or gain through the envelope, V , a solar parameter which accounted for solar gains through the envelope, and W , an internal gain parameter which characterized internal loads in the perimeter zone, specifically lights, equipment and people. It was decided not to include a parameter for internal mass in the parametric analysis (Crawley, 1992; Crawley, Schliesing, and Boulin 1990). Internal mass can shift the timing and change the magnitude of peak cooling and heating loads. However for most buildings with typical values of U , V , and W and typical operating schedules the effect of mass on total energy use is small (10% or less). Although mass may effect the total annual energy consumption, the slopes representing the change in heating and cooling system loads for a corresponding change in the parameters U , V , and W do not change significantly with mass (Cornick and Sander, 1995). The ranges of these envelope parameters were chosen to suit local practices and climates thus allowing envelope studies to be conducted for a wide range of climates and construction types. The parameters were defined as:

$$U = (U_{\text{glass}} * A_{\text{glass}} + U_{\text{wall}} * A_{\text{wall}}) / A_{\text{total}} \quad \text{W/m}^2 \cdot ^\circ\text{K}$$

$$V = A_{\text{glass}} * SC_{\text{glass}} / A_{\text{total}} \quad \text{Dimensionless}$$

$$W = I * A_{\text{floor}} / A_{\text{total}} \quad \text{W/m}^2$$

where:

A_{wall} = opaque wall area, m^2

A_{glass} = window wall area including frame, m^2

A_{total} = gross wall area, $(A_{\text{w}} + A_{\text{g}})$, m^2

A_{floor} = floor area associated with envelope, typically 4.5 m deep
(5m for the Australian study), m^2

U_{wall} = opaque wall U-value, $\text{W/m}^2 \cdot ^\circ\text{K}$

U_{glass} = window U-value, including frame, $\text{W/m}^2 \cdot ^\circ\text{K}$

SC_{glass} = window shading coefficient

I = design heat gain from lights, people, and equipment, W/m^2 floor area.

ASSUMPTIONS

Simple buildings were simulated in order to isolate the three thermal parameters, U , V , and W from the effect of ground and roof interaction. The building model is a modification of a five zone model used to develop the first set of regression equations for

ASHRAE Special Project 41 (Pacific Northwest Laboratory 1983) in order to update ASHRAE 90.1. Similar models and methods were used to revise the regression equations in 90.1 (Berkeley Solar Group, 1986; Wilcox, 1991). The California Energy Commission (CEC) used a similar model in setting the requirements for its third generation nonresidential energy standards (CEC 1990). DOE2 was the energy simulation tool used for all of these studies. A recent comparison of DOE2 with other simulation tools as part of the BESTEST program shows that DOE2 gives results comparable to other simulation tools (Judkoff and Neymark, 1995). For the marginal differences used for code calculation purposes the results produced from DOE2 and the perimeter zone model were deemed acceptable. Several building specific and operational assumptions were made to reflect the typical construction practices in both countries. The differences stem mainly from the fact that the Australian climate is cooling dominated while the climate in Canada is heating dominated. For example the maximum value of U for Australia is 3.38 (single glazing) whereas in Canada the maximum practical value of U is 2.839 (double glazing). Operational assumptions also reflect the climate differences. In Australia for example, it is common practice to shut off all HVAC equipment after hours. In Canada however buildings cannot be operated in this mode; heating, usually with thermostat setback, must be available at night.

Canadian NRCC Model

The model simulated for the National Research Council of Canada (NRCC) parametric study was a four zone building. Each zone represented a strip of exterior wall located at mid height of a typical building and facing one of the cardinal orientations. The central core zone was not modelled. Adiabatic interior walls and floor/ceiling bound each of the perimeter zones. A medium weight floor (340 kg/m^2) was chosen to simulate the effect of internal mass. Windows are assumed to be a strip of double glazed window running the entire length of the zone. The exterior wall of a perimeter zone was a five layer wall comprising, an outside finish (2 mm steel siding), 10 mm of plywood sheathing, a layer of insulation (305 mm), a layer of foil (0.2 mm), and an interior finish (13 mm of gypsum). The exterior wall, shown in Figure 1a, had little mass, about (137 kg/m^2). Crawley (1992) provides a detailed specification of the DOE2.1E model used for Canadian Energy Code.

The fixed assumptions for each zone were:

- no interzone heat transfer
- fixed infiltration rate 0.25 l/s/m^2
- internal loads on a six day office schedule
- heating setback to 15°C and cooling off when unoccupied
- medium weight floor construction, 200 mm heavy weight concrete slab
- light wall construction

System specific assumptions were:

- packaged VAV system with terminal reheat
- 13°C supply air

- free cooling (enthalpy controlled airside economizer)
- minimum ventilation 9.4 l/s person 9 ANSI/ASHRAE Standard 62-1989)

Figure 1. Exterior wall sections, (a) for Canadian parametric study and, (b) for Australian parametric study. Material codes are from the DOE2.1E manual.

Australian Model

Initially it was planned to use the simulated results of the 12 perimeter zones of a three floor, 15 zone building based around the model used to set the stringency levels in the CBEC study. The basic model is similar to the Canadian model except for the HVAC system and the increased wall mass. The wall section, shown in Figure 1b, was a four layer wall consisting of an exterior finish layer, an insulation layer of varying thickness, a single heavy weight concrete block, and an interior finish. The wall mass was about twice the mass of the Canadian model ranging from 225 to 235 kg/m². The floor weights for both models were similar. Initial runs showed differences in the energy use for the top and ground floors due to roof and floor interactions. Reviewing the project objectives, it was felt that a simple but effective trade-off procedure for the vertical envelope could be developed by using the energy performance of the middle floor perimeter zones only. Therefore only the energy performance for the middle floor were used in deriving the envelope trade-off equations. The final simulation model had the following major differences from that used in the NRCC study.

- a five and half day office schedule
- cooling and heating were not available after office hours (no setback)
- fixed infiltration rate 0.25 air changes/hr (0.35 l/s/m²)
- a Packaged Single Zone (PSZ) HVAC system fitted with a gas furnace for heating served each individual zone
- minimum outside air was fixed at 10 l/s/person as per AS 1668 ventilation Standard; enthalpy control economy cycles were modelled for each zone
- medium mass envelope

DATABASES

Both the Australian and Canadian Energy Codes are designed to be regionally sensitive with respect to climate, energy cost, and construction cost. To account for this regional sensitivity it was decided to construct databases for both countries containing parametric studies of their respective model buildings located in representative climates. In this way accurate predictions for changing energy consumption could be made for important climatic regions. The database could also be used to generate climate correlations in order to predict energy consumption for locations not represented in the current databases.

Twenty five Canadian locations were chosen in order to develop a database of DOE2.1E envelope studies. The twenty five locations cover most of the Canadian climate types ranging from relatively warm climates such as Toronto and Windsor to extreme climates such as Resolute (approximately 75° N latitude). The locations chosen also represent most of the larger urban centers accounting for the majority of con-

struction activity. Three Canadian cities, Toronto, Winnipeg, and Vancouver, were selected for the Canadian-Australian comparison. These cities are representative of the majority of populated centers across Canada and typify Canadian climates. Table 1 shows the HDD and CDD of the sample cities.

Table 1. Selected Australian and Canadian locations.

Location	HDD18 ⁴	CDD18 ⁵	VSS/VS ⁶
Canberra, Australia	2160	241	12.0
Darwin, Australia	0	3450	10.4
Sydney, Australia	743	556	11.4
Toronto, Canada	4218	224	8.3
Vancouver, Canada	3112	30	8.2
Winnipeg, Canada	5965	169	10.9

In developing the Canadian envelope database a parametric study was done for each of the twenty five locations chosen. Six values of U , V , and W were chosen to cover the typical range of buildings constructed in Canada. Crawley (1992) describes how the values of the parameters were chosen. A study examining the effect of mass on energy consumption and a compliance survey by Cornick (Cornick and Sander, 1995) show that the ranges encompass most of the practical Canadian constructions. The values for the parameters are shown in Table 2. For each location in the Canadian database all possible combinations of the parameters were simulated, totalling 216 DOE2.1E runs per location.

Table 2. Values for the parameters U , V , and W used in the Canadian and Australian parametric studies. The ranges are typical of construction techniques in both countries.

Parameter

Canadian						
U ($W/m^2 \cdot ^\circ K$)	0.23	0.57	1.14	1.70	2.27	2.84
W ($W/m^2 \cdot ^\circ K$)	0.0	13.5	26.9	53.8	80.7	107.6
V	0.0	0.2	0.4	0.6	0.8	1.0
Australian						
U ($W/m^2 \cdot ^\circ K$)	0.39	1.06	1.69	2.29	2.85	3.38
W (W/m^2)	0.0	41	71	100	N/A	N/A
V	0.0	0.2	0.4	0.6	0.8	1.0

⁴HDD18 = Heating Degree Days 18°C.

⁵CDD18 = Cooling Degree Days 18°C.

⁶Average Daily Vertical Solar. For Canada use the Southern orientation VSS, for Australian locations use the Northern orientation VSN, MJ/day-m².

Nine locations in Australia were modelled to develop the Australian envelope database. The locations include all the state and territory capitals accounting for most commercial building activity. Together these locations cover all the major climate types in Australia, except for the few Snowy Mountain locations for which complete weather data is not yet available. Darwin is a hot location, Alice Springs represents a desert climate with both hot and cold periods, Sydney, Perth and Brisbane represent warm temperature climates, while Hobart and Canberra are the cooler locations in the country. Table 1 shows the range of climates that were considered for the three Australian locations selected for comparison with the Canadian locations.

To develop the Australian database, 144 simulation runs were carried out for each of the 9 locations, with parameter values given in Table 2. The parameter ranges for facade U-value, take into account the higher values in common building practice for Australian temperate to warm climates.

HEATING

A simple heating model was developed to predict the change in annual heating load for the simulated buildings given a change in one of the thermal envelope parameters. The model consists of progressively adjusting the Seasonal Heat Loss, L , using solar and internal gain reduction factors. L is a measure of the heating required in a perimeter zone having no solar and no internal gains. The Seasonal Heat Loss, L , for the perimeter zones can be calculated using the transmission characteristics of the building envelope, specifically U . The relationship between Seasonal Heat Loss and the envelope transmission parameters, U , is linear (Equation 1) and is shown in Figure 2. The slope of the lines give a general indication of climate. Winnipeg is a heating dominated climate whereas Sydney appears to require little heating. L can be written as:

$$L = b_{0j} + b_{1j} * U \quad W/m^2 \quad (1)^7$$

where:

U = U value parameter, $W/m^2 \cdot ^\circ K$

b_{0j} and b_{1j} are climate dependent coefficients

j = {East, West, North, South}

Solar gains in buildings tend to reduce the annual heating system loads. The Solar Gain Reduction Factor, **SGRF**, was defined as the ratio of the annual heating system load including solar gains (but not including internal gains), L_s , and the Seasonal Heat Loss, L . **SGRF** represents the amount of solar gain in the perimeter zones and is a function of the solar parameter, V , and the Seasonal Heat Loss. Figure 3 shows the relationship between **SGRF** and the V parameter for Winnipeg and Sydney. The curves describing **SGRF** are shifted for each orientation. A single curve was fitted to predict **SGRF** for all the locations in the Canadian database (Cornick and Sander 1994). For each location in the database four sets of coefficients, one for each orien-

⁷This represents the heating system load per m^2 of wall along a perimeter zone having an orientation j .

Figure 2. Seasonal Heat Loss, L, versus U parameter for Winnipeg and Sydney.

tation, were generated. The same form of the equation was used to predict SGRF for locations in the Australian database, only the coefficients changed. The equation predicting SGRF is:

$$\text{SGRF} = L_v/L = f(V, L) = 1/(1 + \alpha_{1j} * x + \alpha_{2j} * x^2 + \alpha_{3j} * x^3) \quad (2)$$

where:

$$x = V/L$$

α_{1j} , α_{2j} , α_{3j} are location dependent coefficients

$j = \{\text{East, West, North, South}\}$

Figure 3(a). Solar gain reduction factor versus solar parameter, V, for North and South orientations of Winnipeg.

Relationship of SGRF to Solar Parameter V

Figure 3(b). Solar gain reduction factor versus solar parameter, V , for North and South orientations of Sydney.

Similarly, internal gains in buildings also contribute to the reduction of annual heating loads. The internal gain reduction factor, **IGRF**, was defined as the ratio of the annual heating load including internal gains (but not including solar gains), L_w , to the Seasonal Heat Loss, L . This factor represented the amount of internal gain in the perimeter zones and is a function of the internal parameter W and the Seasonal Heat Loss. Figure 4 shows the relationship between **IGRF** and the W parameter for Winnipeg and Sydney. Internal gains are the same for the cardinal orientations therefore the curve describing **IGRF** is independent of orientation. A single curve was fitted to predict **IGRF** for the Canadian database locations (Cornick and Sander 1994). Again the same form of the equation was used to predict **IGRF** for locations in the Australian database. New coefficients were generated for the Australian locations. The equation predicting **IGRF** is:

$$\text{IGRF} = L_w/L = f(W, L) = \exp(\beta_1 * y + \beta_2 * y^2 + \beta_3 * y^3) \quad (3)$$

where:

$$y = W/L$$

$\beta_1, \beta_2, \beta_3$ are location dependent coefficients

The annual heating system load, Q , for a perimeter zone can be calculated as the product of the seasonal heat loss, L , and the solar gain and internal gain reduction factors, **SGRF** and **IGRF** (Equation 4).

$$Q = L * SGRF * IGRF^8 \quad W/m^2 \quad (4)$$

Relationship of IGRF to Internal Load Parameter, W

Figure 4(a). Internal gain reduction factor versus internal gain parameter, W, for North and South orientations of Winnipeg.

Relationship of IGRF to Internal Load Parameter, W

Figure 4(b). Internal gain reduction factor versus internal gain parameter, W, for North and South orientations of Sydney.

⁸The model used in the Canadian energy code contained a Gain Interaction Factor, GIF, to account for the interaction of internal and solar gains (Cornick and Sander, 1994). The model described here however was adequate for predicting heating system loads for the colder Australian climates since the heating system loads for Australia were relatively small. The Gain Interaction Factor was not used as part of the Australian model. Consequently GIF was not used for the comparative study described in this paper.

Figure 5 compares heating loads calculated using the model and those obtained from the DOE2.1E simulations. The model predicts the annual heating system loads to within 10% for typical heating loads.

Calculated Annual Heating Vs. DOE-2, MJ/m²

Figure 5(a). Comparison of predicted heating loads versus DOE2.1E simulations for Winnipeg.

Calculated Annual Heating Vs. DOE-2, MJ/m²

Figure 5(b). Comparison of predicted heating loads versus DOE2.1E simulations for Sydney.

Of critical importance was how well the model predicted changes in annual heating loads due to changes in the envelope parameters. One reason for this was that in the Canadian code the prescriptive levels were selected by minimizing the sum of incremental construction costs and the present value energy cost for different con-

struction options (Sander *et al.*, 1995). Another reason was that the model forms the basis for the trade-off calculations for the Canadian code and is being reviewed for use in the Australian code. The trade-off path allows the designer to adjust the V and U parameters to satisfy an energy budget therefore the model must accurately predict the effect of a change in U and V . Figures 6, 7, and 8 show how the model predicts changes in heating due to changes in envelope parameters, U , V , and W . The figures compare derivatives dQ/dX ($X = \{U, V, W\}$) calculated from the simulations with those derived from the model. The slopes calculated from the model compare well with those calculated from the DOE2.1E simulations.

Figure 6(a). Comparison of change in heating for change in U , dQ/dU for Winnipeg.

Figure 6(b). Comparison of change in heating for change in U , dQ/dU for Sydney.

Figure 7(b). Comparison of change in heating for change in V , dQ/dV for Sydney.

COOLING

A two part model was developed to predict the change in cooling system loads due to a change in U , V , or W . The first part of the model calculates the Base Cooling Load, C_0 . The Base Cooling Load was defined as the cooling system load for a perimeter zone having no transmission losses or gains (i.e. $U = 0$). In the absence of transmission gains or losses any loads introduced to the interior must be removed when cooling is required. Consequently the base cooling load is linearly proportional to the V and W parameters (Equation 5). This is shown in Figure 9.

$$C_0 = a_{0j} + a_{1j} * V + a_{2j} * W \quad \text{W/m}^2 \quad (5)$$

Figure 8(a). Comparison of change in heating for change in W , dQ/dW for Winnipeg.

Figure 8(b). Comparison of change in heating for change in W , dQ/dW for Sydney.

This simple linear model was an adequate predictor of the cooling system loads when the system loads became large. This was because, unlike heating, cooling system loads are primarily the result of solar and internal gains and the effect of U on cooling is small. In Canada, however, the cooling system loads were found to be small. Some of the cooling loads were small enough that the loads were primarily the result of the minimum ventilation requirements and the choice of HVAC system. The calcu-

Cooling Load at various values of V and W for
 $U = 0.23 \text{ w/m}^2\text{-}^\circ\text{K}$

Figure 9(a). Cooling load at $U = 0.23$ for varying values of V and W for Winnipeg, South.

Cooling Load at various values of V and W for
 $U = 0.39 \text{ w/m}^2\text{-}^\circ\text{K}$

Figure 9(b). Cooling load at $U = 0.39$ for varying values of V and W for Sydney, North.

lation of C_0 was slightly modified to reflect this minimum condition⁹. A similar minimum cooling load was predicted for Australia and was observed to occur in the cooler locations such as Canberra. The revised equation for the base cooling load is shown below (Equation 6).

$$C_0 = \max(C_{\min}, a_{0j} + a_{1j} * V + a_{2j} * W) \quad \text{W/m}^2 \quad (6)$$

where:

$C_{\min}$ is the minimum cooling load for a particular climate location.

a_{0j} , a_{1j} and a_{2j} are climate and orientation dependent coefficients.

$j = \{\text{East, West, North, South}\}$

The second part of the cooling model accounts for transmission gains or losses across the envelope. An Envelope Correction Term, ΔC , was defined. The correction term either decreases or increases the cooling system load and is climate dependent. Figures 10(a) and (b) show the change in cooling due to a change in U for mild and cold climates. An increase in the value of U produced a decrease in the cooling system load. The U value effect increases with increased cooling loads until it becomes almost linear. In cold climates, such as those in Canada, the effect of transmission losses on heating differs by an order of magnitude from the effect of transmissions loss on cooling. The advantage of free cooling are more than offset by increased heating system loads.

Figure 10(a). Effect of envelope transmission on cooling loads for Winnipeg, South.

⁹Note that the HVAC system selected and the minimum ventilation requirement would also result in a minimum heating load, however in Canadian climates this minimum was never reached.

Figure 10(b). Effect of envelope transmission on cooling loads for Sydney, North.

Figure 10(c). Effect of envelope transmission on cooling loads for Darwin, North.

Figure 10(c) shows the envelope effect in a hot climate, such as Darwin. In Darwin the ambient temperatures are mostly above the cooling setpoint. Decreasing the value of U decreases the amount of heat transferred into the building thus lowering the cooling system load. Like cold climates however the effect of envelope gains is small. Unlike cold climates the effect of reducing the amount of insulation in the envelope decreases as cooling loads become larger. Reducing cooling system loads by increasing the amount of insulation in the envelope has a marginal payback in hot climates. In fact in mild climates, where ambient temperatures are never very far from comfort,

decreasing the value of U can actually have a marginal adverse effect on energy consumption (Thomas and Prasad, 1995). In these climates with small heating needs, the energy reduction for heating due to increased insulation can be less than the increase in cooling energy due to loss of free cooling.

A general form for the envelope correction term was defined as:

$$\Delta C = a_{3j} * U + a_{4j} * U/C_0 \quad \text{W/m}^2 \quad (7)$$

where:

a_{3j} and a_{4j} are climate and orientation dependent coefficients.

C_0 is the base cooling load for orientation

$j = \{\text{East, West, North, South}\}$

This general form worked well for both hot and cold climates. A simplification of the envelope correction term can be made for locations having net loss through the envelope i.e. having a graph similar to that in Figures 10(a) and (b). In this case the cooling curves are cut off at $C_{\min}$, the minimum cooling system load for that location. The $C_{\min}$ cut off was a boundary condition used to eliminate one of the coefficients from the general form (Equation 7). The simplified Envelope Correction Term is shown below (Equation 8).

$$\Delta C = a_{3j} * U * (1 - C_{\min}/C_0)^{10} \quad \text{W/m}^2 \quad (8)$$

Since all Canadian locations exhibited the same $\Delta C/\Delta U$ profile as that in Figure 10(a) the simplified correction term (Equation 8) was used to calculate the envelope correction term for Canadian National Energy Code for Buildings. Australian locations span the range from hot climates, where net transmission gains occur across the envelope, to cooler climates, such as Canberra where net losses occur across the envelope. Since ΔC could not be simplified for hot climates such as Darwin the Australian Energy Code trade-off calculations used the more general form for the envelope correction term (Equation 7).

Cooling system loads for a perimeter zone are calculated as the sum of the Base Cooling Load, C_0 , and the Envelope Correction Term, ΔC . Where a minimum cooling load exists the cooling system load is greater of $C_{\min}$ and the sum of C_0 and ΔC (Equation 9).

$$C = \max(C_{\min}, C_0 + \Delta C) \quad \text{W/m}^2 \quad (9)$$

¹⁰When the coefficients for the general equation were solved for numerically the coefficients for locations having a minimum cooling load were such that $a_4 = -a_3 * C_{\min}$. This can also be shown algebraically by assuming that if $C = C_{\min}$ at $V = 0$, $W = 0$, and $U = u$, then $C_0 = C_{\min}$ by definition. Consequently ΔC must be 0. Solving for this boundary condition coefficient the a_4 coefficient becomes $-a_3 * C_{\min}$. In locations such as Darwin $C_{\min}$ occurs when $U = V = W = 0$. The correction term cannot be simplified for these locations.

Figure 11 compares cooling loads calculated using the model and those obtained from the DOE2.1E simulations. Of critical importance was how well the model predicted changes in annual cooling loads due to changes in the envelope parameters. Figures 12, 13, and 14 show how the model predicts changes in heating due to changes in envelope parameters, U , V , and W . The figures compare the derivatives dC/dX ($X = \{U, V, W\}$), calculated from the DOE2.1E simulations with those derived from the model.

Figure 11(a). Comparison of cooling loads calculated using model and DOE2.1E results for Winnipeg.

Figure 11(b). Comparison of cooling loads calculated using model and DOE2.1E results for Sydney.

Figure 12(a) shows the predicted slopes dC/dU plotted against the slopes calculated from DOE2.1E for Winnipeg. For moderate values of C_0 the model predicts the slope well, however, as C_0 increases the effect of U becomes progressively linear and tends to diverge from the trend predicted by DOE2.1E. Summertime transmission gains (or losses) however tend to be insignificant when compared to solar and internal gains. For the purposes of the Canadian Energy Code this error was tolerable since for Canadian climates solar and internal gains are the predominant factors in determining cooling system loads. Figure 12(b) shows dC/dU for Sydney. The cooling model predicts that envelope losses have a linear effect on cooling system loads. In this case the model doesn't predict the trend for U very well. For Sydney however the effect of envelope losses on cooling system loads is negligible compared to the effect of solar aperture and internal loads. To get a quantitative feel for how much the parameters U , V , and W change the cooling system loads for a building an equivalency was calculated. This equivalency calculated how much change in U or V was required to effect a change equal to a 1 W/m^2 change in the internal load parameter, W . Typical values for U , V , and W were assumed to be $2.3 \text{ W/m}^2\text{-K}^\circ$, 0.4 , and 30 W/m^2 respectively¹¹. For the Australian model, a change of 1 W/m^2 in W (a 3% change in W) is equivalent to a 1% percent change in North facing window area or tint (2% for the South side). In Sydney adding a layer of insulation of $R_{si} 7$ would produce an increase in the cooling system load equivalent to 1 W/m^2 . Even in a hot climate, such as Darwin, the effect of envelope on cooling is small. In Darwin a layer of $R_{si} 5$ would have to be added to the envelope to get an equivalent decrease in the cooling system loads. For the purpose of the Australian Energy Code the insensitivity shown in Figure 12(b) was tolerable given the overwhelming dominance of solar aperture (Thomas and Prasad, 1995). Controlling solar gains and internal load is more cost effective approach to reducing cooling system loads.

Figure 12(a). Comparison of change in cooling for change in U , dC/dU for Winnipeg.

¹¹These values assume a window to wall ratio of 50%, a shading coefficient of 0.8, $U_{\text{glass}} = 4.04$ (double glazed), and $U_{\text{wall}} = 0.56$.

Figure 12(b). Comparison of change in cooling for change in U, dC/dU for Sydney.

The slope predicting the change cooling system loads for a change in solar aperture is well predicted by the model for Winnipeg (Figure 13a). For Sydney (Figure 13b) however the slope dC/dV appears to be insensitive to solar aperture. For large cooling system loads the cooling model becomes linear with U, V, and W. The error in the solar term is due to the error introduced in correcting for envelope transmission, however the slopes are predicted to within 10% of the slopes obtained from DOE2.1E. All 144 combinations of U, V, and W are shown in Figure 13(b) and these combinations cover the complete range of constructable buildings. The same phenomenon is apparent in the predictions of the change in cooling due to change in internal load dC/dW for Sydney. Again for large cooling loads the model becomes linear with U, V, and W and an error is introduced in correcting for the envelope transmission. The cooling model still predicts dC/dW within 10% over the complete range of building constructions.

CLIMATE CORRELATIONS

The new Canadian Energy Code was designed to be regionally sensitive. In order to permit the calculation of prescriptive requirements for locations not in the original database the heating and cooling models were extended to include climate correlations¹². All the climate correlation equations were based on available weather data,

¹²The Canadian Energy Code is divided into several administrative regions each with different envelope requirements. The regions represent distinct climatic and economic regions and account for sensitivity in fuel prices and construction costs as well as climate. The provinces and territories were responsible for selecting the appropriate zones and the weather they wished to use. 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 which subsequently appeared in the Life Cycle Costing Analysis procedure and Tradeoff specification (Sander and Cornick, 1994).

Figure 13(a). Comparison of change in cooling for change in V, dC/dV for Winnipeg.

Figure 13(b). Comparison of change in cooling for change in V, dC/dV for Sydney.

specifically, cooling degree days, heating degree days, vertical solar radiation (VS_j^{13}), and latitude. Correlating the cooling coefficients to climate was straightforward since the cooling coefficients C_{min} , a_0 , a_1 , a_2 and a_3 had some physical significance. Figure 15 shows the comparison between cooling system loads calculated using the cooling equations with coefficients generated using the climate correlations and the results from DOE2.1E simulations for Vancouver. The difference between the predicted and simulated cooling system loads is 10%.

¹³_j = {North, South, East, West}

Figure 14(a). Comparison of change in cooling for change in W, dC/dW for Winnipeg.

Figure 14(b). Comparison of change in cooling for change in W, dC/dW for Sydney.

Compared to the cooling equations, correlating the heating equation coefficients to climate was more complex. The seasonal heat loss, L , was simple to correlate since the coefficients b_{0j} and b_{1j} have some physical significance. The coefficient b_{0j} represents the characteristics of the selected HVAC system as well as the infiltration and ventilation losses for a specific location while b_{1j} is a measure of the temperature of a given location. Both these coefficients varied linearly with heating degree days. The curves predicting **SGRF** and **IGRF** were best fit curves and could not be directly correlated to climate. Since the curves for the reduction factors were similar for each city a climate dependent parameter was derived that would shift curves for a particular

location to specific reference curve. It was then possible to correlate the parameters that shifted the **SGRF** and **IGRF** curves to weather data.

Cooling Loads from Climate Correlations Vs. DOE-2 Cooling Loads

Figure 15. Comparison of cooling load calculated using climate correlations with loads predicted by DOE2.1E for Vancouver East orientation.

In order to calculate the reduction factors for a location not in the original database the curve shift parameters are generated from the climate data for the location in question. The shift parameters are used to modify the x and y variables of Equations 2 and 3 respectively. The reference curves for **SGRF** and **IGRF** are then used to calculate the location specific values of **SGRF** and **IGRF**. Figure 16 shows the comparison between heating system loads calculated using the heating equations with climate correlated coefficients and the results of DOE2.1E simulations for Vancouver. Most of the predicted values for the heating system loads are within 10% of the system loads predicted by DOE2.1E. A detailed description of the climate correlations for heating is given in Cornick and Sander (1994).

The current study is one of the steps towards developing and implementing building energy efficiency standards for Australia. The results of this and other studies are being reviewed and further research is anticipated. Such research could extend the present study by developing correlations for locations for which comprehensive weather data is not available.

Heating Loads from Climate Correlations Vs. DOE-2 Heating Loads

Figure 16. Comparison of annual heating load calculated using climate correlations with loads predicted by DOE2.1E.

SUMMARY AND CONCLUSIONS

This paper described a simplified method of predicting the effect of envelope thermal characteristics on heating and cooling system loads. The method relied on deriving decoupled envelope parameters to describe the transmission, solar, and internal gain characteristics of the perimeter zones of simple model building. The method consisted of the following steps:

1. Describe the geometry of the exterior zones of the building to be modelled. The geometry consists of the dimensions, the window to wall ratio, the wall and floor cross sections;
2. Describe the HVAC system and operational assumptions;
3. Select the ranges of the parameters U , V , and W based on local practice and climate considerations;
4. Conduct a parametric study for all combinations of U , V , and W for all the major climatic locations of interest;
5. Generate the coefficients, for each for location, for the heating and cooling equa-

tions described here;

6. If the database of parametric studies is large enough generate climate correlations to generate coefficients for locations not in the database;
7. Use the heating and cooling models described in this paper to predict heating and cooling system loads given values of U , V , and W .

This paper demonstrated that the methods outlined in this paper are robust. It can be used for a variety of climates, different HVAC systems, different geometry's and different operational assumptions. The method can be used to construct databases of parametric studies, climate correlations, or site specific models.

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