NRC Publications Archive
Archives des publications du CNRC

A correlation equation to determine residential cooling energy consumption in Canada

Newsham, G. R.; Sander, Daniel M (Dan); Moreau, A.

For the publisher’s version, please access the DOI link below./ Pour consulter la version de l’éditeur, utilisez le lien DOI ci-dessous.

Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/23000786
Paper (National Research Council of Canada. Institute for Research in Construction); no. IRC-P-3119, 1993-07

NRC Publications Archive Record / Notice des Archives des publications du CNRC :
https://nrc-publications.canada.ca/eng/view/object/?id=50e630a5-161c-489d-970b-7d28ff81dcc1
https://publications-cnrc.canada.ca/fra/voir/objet/?id=50e630a5-161c-489d-970b-7d28ff81dcc1

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at
https://nrc-publications.canada.ca/eng/copyright
READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L’accès à ce site Web et l’utilisation de son contenu sont assujettis aux conditions présentées dans le site
https://publications-cnrc.canada.ca/fra/droits
LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D’UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at
PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n’arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

National Research Council Canada
Conseil national de recherches Canada

National Research Council Canada
Conseil national de recherches Canada

Institute for Research in Construction
Institut de recherche en construction

NRC·CNRC

A Correlation Equation to Determine Residential Cooling Energy in Canada

by Guy R. Newsham, Dan M. Sander and Alain Moreau

Reprinted from:
Building Research Journal
Vol. 2, No. 1, 1993, p. 39-52
1 East St. Mary's Road, Champaign, IL 61820, USA
(IRC Paper No. 3119)

NRCC 35486

A Correlation Equation to Determine Residential Cooling Energy Consumption in Canada

Guy R. Newsham, Dan M. Sander, and Alain Moreau

ABSTRACT

We have developed a simple correlation equation for predicting residential cooling energy consumption in Canada. Inputs to the equation are: internal gains, envelope U-values, glazing area, shading coefficient and climate parameters. Separate equations, of the same form, have been developed for both manually vented and non-vented buildings. This paper describes the development of the seasonal cooling energy correlation equation, and compares its predictions with those of an hourly simulation model.

INTRODUCTION

The number of Canadian homes with air conditioners has increased rapidly in recent years. For example, between 1988 and 1990 the number of households in Ontario with central air conditioning rose from 6 percent to 32 percent; 49 percent of homes built since 1988 incorporated central air conditioners (Ontario Hydro 1990).

This increase in residential cooling is of particular concern to those utilities seeking to reduce network electricity use. Indeed, many utilities have initiated aggressive Demand Side Management (DSM) programs, with the aim of reducing residential electricity demand. These DSM programs often include cash rebates for the adoption of energy efficient appliances. However, the impact on residential energy consumption of replacing an existing appliance with a more energy efficient one is complex. For example, while a more efficient appliance will consume less electrical energy, it will also produce less heat. This reduction in internal heat gain will increase heating system loads in the heating season, and reduce cooling system loads in the cooling season. Depending on the building and the climate, the net saving in energy consumption may be significantly different from the simple reduction in electrical energy consumption of the appliance. As part of a larger effort to address the impact of energy efficient appliances on network energy consumption, we were charged with developing a simplified method to predict residential cooling energy consumption in Canada. The calculation of peak cooling loads were beyond the scope of the study.

Guy R. Newsham is *a Research Associate, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario. Dan M. Sander* is *a Senior Research Officer, Institute for Research in Construction, National Research Council of Canada, Ottawa, Ontario. Alain Moreau* is *a Research Engineer, LTEE, Hydro-Québec, Shawinisan, Québec.*

The interactions between internal gains and building loads make it difficult for utilities to predict future load growth and the impact of DSM programs. Hourly simulation models of building heat transfer can calculate the interactions well, but are typically difficult to use. For policy analysis applications, a better solution would be an appropriate simplified method for calculating building energy consumption. There would be some loss of accuracy at the level of an individual building. However, if one is trying to predict the impact over tens of thousands of households, this loss of accuracy is offset by the gain in simplicity. A simplified method could be easily incorporated into a spreadsheet, whereby a change in internal gain or other building parameters would produce a corresponding change in building energy consumption almost immediately.

A number of simplified methods have been developed that are capable of predicting building heating and/or cooling energy consumption to within typically 15 percent of the value predicted by an hourly model. These methods fall into two categories: degree-day and bin methods (Kusuda, Sud, and Alereza 1981, Guntermann 1981, Alereza 1985), and correlation equations (Peterson, Jones, and Hunn 1989, Sullivan et al. 1986, Sullivan et al. 1985, Parken and Kelly 1981, Barakat and Sander 1986).

To calculate cooling coil energy, the degree-day method utilizes an equation of the following form:

$$C = HL \times CDD \times 24/1000 \qquad (1)$$

where

C = Seasonal cooling coil energy, kWh;

HL = Building heat loss coefficient in summer, Wt°C; and

CDD = Annual cooling degree days.

$$CDD = (T_o - T_b) \times N_d \qquad (1a)$$

where

T_0 = Design summer outdoor temperature ($T_0 > Tb$), °C;

Tb = Base temperature (in the simplest case equal to the design indoor temperature, Ti °C; and

Nd = Number of days in cooling season.

Therefore, the basic degree-day method does not account for internal or solar gains, a serious drawback. To include internal and solar gains, variable-base degree-day methods have been developed in which the cooling degree days are calculated to a base temperature derived from the following equation (ASHRAE 1989):

$$T_b = T_i - \left(\frac{Q_{is}}{HL}\right) \qquad (2)$$

where

Qis = Mean sum of internal and solar gains, W.

The bin method adds further sophistication. This method recognizes that using a single, mean design outdoor temperature may be inadequate. A more accurate energy prediction is achieved by calculating cooling energy at several values of outdoor temperature. The seasonal cooling requirement for the building is then found from:

$$C = (Y TI \; x \; nn + y \; ri \; x \; nri + y \; T.J \; x \; nT3 \; \ldots) \qquad (3)$$

where

''(I'j = Cooling coil load at outdoor temperature Tj, kW;

nTi = Number of hours outdoor temperature is at Tj; and

∫nTj = Total number of hours in cooling season.

This method requires bin temperature data (giving n'IJ) for the location.

Correlation methods use statistical techniques to consistently relate building parameters (independent variables) to resultant energy consumption (dependent variable). For a particular location:

$$C = function \; (building \; parameters) \qquad (4)$$

Consistency can be achieved across geographical locations only if the coefficients of the correlation can themselves be reliably correlated to climate parameters:

$$C = \textit{function (building parameters, climate)} \qquad (5)$$

The main problem is the definition of suitable building parameters as independent variables.

At the onset of this project we were undecided as to which of the simplified methods to pursue. Of the references listed, only Kusuda, Sud, and Alereza (1981), Sullivan et al. (1986), and Parken and Kelly (1981) dealt with residential cooling. There was no method that was clearly superior when compared to an hourly model, and none of the methods had investigated parametric variations in internal gain to the extent that we intended. In the end, we decided to pursue a correlation method, principally due to our experience in developing these methods in the past (Barakat and Sander 1986).

METHODS AND PROCEDURES

Hourly Simulation Runs

The EASI hourly simulation model was chosen to calculate the cooling energy consumption from which the correlation was derived. EASI employs the ASHRAE transfer function method, and was originally developed by Public Works Canada. EASI was the model used by Barakat and Sander (1986) to develop a correlation method for predicting the utilization of internal heat gains in off-setting heating load.

For this project, a modification to EASI was made which attempted to account for the window opening behavior of occupants. In a residence, the occupants may choose to open windows to cool the building through increased ventilation, before resorting to mechanical cooling. We modelled this response in the following way: if the cooling load could be met by increased ventilation, then the ventilation rate was increased above the minimum infiltration rate to the ventilation rate that would satisfy the cooling set-point (up to a given maximum air flow rate); if the maximum ventilation rate did not meet the cooling load, then the ventilation rate remained at the minimum infiltration rate (the windows were closed) and mechanical cooling took over. These assumptions are consistent with the ventilative cooling assumptions made by ASHRAE (1989). They represent an occupant gaining the maximum possible benefit from increased ventilation by window opening and thus form a lower boundary to the cooling energy requirements.

The Modelled House

The house modelled in these studies was derived from the base case house used in the ongoing development of the new Canadian Energy Code (Swinton and Sander 1992). The following parameters remained constant for all simulations:

- Floor Area, A_f: 160 m², square plan;
- Wall Area, A_w: 184 m²;
- Volume: 604 m³;
- Thermal Mass: 60 kJ/°Cm² floor area (interior);
- Thermostat: Heating, winter (Oct. - Apr. only) 22°C: Cooling, summer (May - Sep. only) 24°C;
- Max. ventilation: 0.2 m³/s (windows open).

The following parameters were varied between runs, over the given range of values, but remained constant for all hours of any particular run:

- Internal Gains (incl. occupants), I: 0 - 12.5 W/m², in 1.25 W/m² increments;
- Glazing (fraction of wall area glazed x shading coefficient): 0 - 0.5, in steps of 0.1, glazing equal on all walls;
- HLF = mean U-value (incl. infiltration) $\times A_w/A_f$: 0, 0.29, 0.58, 1.15, 1.73, 2.30, 2.89 W/°Cm².

The calculation of transmission losses and gains did not include the attic space above the ceiling. Although solar radiation falling on the roof does raise the temperature in the attic space, Canadian practice dictates that the attic be well ventilated and the ceiling highly insulated ($U < 0.2$ W/°Cm^2). Therefore, heat gain through the ceiling was not considered a significant component to the cooling load. Similarly, we did not consider solar gains through opaque wall elements, which have been shown, using DOE 2.1E, to be very small in Canadian climates (Cornick 1993).

The range of parameters studied was far wider than that likely to be found in any sample of Canadian homes. Therefore, any correlation which is accurate over this range of parameters is likely to be stable for any sample of residences to which it is applied.

To calculate infiltration in terme of a U-value:

$$U_{inf} = C_p \rho F \quad (6)$$

where

U_{inf} = U-value due to infiltration, W/°C;

C_p = Specific heat of air, J/kg°C;

ρ = Density of air, kg/m^3; and

F = Flow rate of infiltration air, m^{3}s^{-1}.

Sensible cooling energy consumption was calculated for all combinations of internal gain, glazing area and U-value, giving a total of 462 runs for each geographical location. Runs were performed for the following locations: Fredericton, Montreal, Ottawa, Toronto, Windsor, Winnipeg, Edmonton, and Vancouver (...**Figure 1**). This selection adequately covers the Canadian climatic range in the most populated areas. Two separate sets of runs were performed: first, assuming a house where the windows were not opened to exploit passive cooling (non-vented case); and second, for a house with the window opening behavior described above (vented case).

It was assumed that the seasonal cooling energy consumption could be reasonably calculated from the sum of hourly cooling energy consumptions for the period May to September. For some combinations of parameters and climate, the hourly model may yield a cooling load at other times of the year, it is reasonable to assume that, in Canada, mechanical cooling would not be employed in residences during October to April.

Figure 1. The eight Canadian cities for which the correlation was derived.

RESULTS

The Cooling Correlation

The instantaneous (hourly) sensible heat balance during the cooling season is given by:

$$g_{tot} = g_i + g_s - l_t \quad (7)$$

where

g_{tot} = Total instantaneous heat gain, kWh/m^2

g_i = Instantaneous internal gain, kWh/m^2

g_s = Instantaneous solar gain, kWh/m^2

l_t = Instantaneous transmission loss, kWh/m^2

All gains are expressed in terme of floor area.

If the room air temperature is below the cooling set-point g_{tot} will result in a rise in room air temperature; if the room air temperature is above the cooling set-point then g_{tot} becomes the instantaneous cooling load.

Therefore, over the whole of the cooling season:

$$C_f = \mathbf{function}\ (G_i, G_s, L_t) \quad (8)$$

where

Cr= Seasonal sensible cooling energy consumption, kWh/m^2;

Gi = Seasonal total of intemal gains, kWh/m^2;

G.= Seasonal total of solar gains, kWh/m^2; and

L_1= Seasonal transmission losses, kWh/m^2 (seasonal transmission gains for Canadian climates are insignificant, less than 100 kWh in most cases; see also Jones and Howell (1986)).

Note that Cr is the cooling coil energy consumption. To obtain the system (or billing) energy consumption, one should use the following equation:

$$\mathrm{Cay.-}\ \frac{.2!}{COP} \qquad (9)$$

where

Cay, = System (or billing) energy consumption, kWh/m^2; and

COP •Coefficient of performance of system.

Gt depends on the occupancy schedule and the internal gains and is described in the following equation:

$$G_i = \frac{(H_c \times I)}{1000} \qquad (10)$$

where

He = oocùpied hours in 5 cooling months; in this case, all hours May - Sept. = 3672.

a.and Lt are climate dependent parameters. G,is described by the following equation:

$$G,= \frac{(SIIC \times SC \times Wg)}{Ar} \qquad (11)$$

where

Suc= Total solar gain on all vertical surfaces during the cooling season (May - Sept.), kWh;

SC = Shading coefficient; and

W_f=Fraction of wall area glazed.

Lt is described by the following equation:

$$L, = kt \times HLF \qquad (12)$$

kt is a climate-dependent heat loss parameter, normalized to tloor area. It is the value that the term CC.CU, G, Gt> - Ci(0, G, Gt> / HLF] tends to, calculated by the hourly model, as G.and Gt tend to their upper limits. This is illustrated **in Figure 2** for Toronto. After trying many parameter combinations, $k_1$was found to be accurately correlated to climatic parameters in the following way:

$$k_1 = a_0 + a_1 \cdot HDD2 + \quad \cdot VS + as \cdot VSS + a_4 \cdot CDD1 + a_5 \cdot CDD2 + a_6 \cdot DRNG \qquad (13)$$

where

HDD2 ..Annual heating degree days (base 18.3 oc);

VSS ..Mean daily solar radiation on south vertical, MJ/m^2;

CDDI = Annual cooling degree days (base 10°0);

CDD2 ..Annual cooling degree days (base 18.3 oc)

DRNG •Mean daily temperature range for July (oC);

VS •VSS + VSN + VSW;

VSN •Mean daily solar radiation on north vertical, MJ/m2;

VSW = Mean daily solar radiation on west vertical, MJ/m^2; arid

a_0==-65.8451, a_1= 0.007881, a_2= 15.4141,
a_3 = -25.8951, a4 = 0.02770, a5 = -0.1427,
ae = 0.3416.

Figure 3 compares kt derived from the hourly model and *kt* derived from the climate correlation of Equation 13, for all eight locations.

We reasoned first tbat the ratio of mechanical cooling to total gain, CIGtot (Gt.ot = Gt + GJ, would be a good dependent parameter, since it would always lie between 0 and 1 for both the vented and non-vented cases, and that having such simple limits for both cases would facilitate finding a correlation appropriate to both.

After trying many independent parameter combinations, guided by those parameters used by Barakat and Sander (1986), we found that C/Gtot was a function of the inverse of the total gain (1/Gtot), the gain-to-loss ratio (Gtot/Lt), and the ratio of total gains to solar gains (Gtot/G). Linear regression on combinations of these three parameters to C/Gtot yields an equation of the following form:

$$
\begin{aligned}
\frac{C}{G_{tot}} = e_1 &+ f_1 \cdot \left[\frac{G_{tot}}{G_s}\right] + e_2 \cdot \left[\ln\left(\frac{1}{G_{tot}}\right)\right] \\
&+ f_2 \cdot \left[\frac{G_{tot}}{G_s}\right] \cdot \left[\ln\left(\frac{1}{G_{tot}}\right)\right] \\
&+ e_3 \cdot \left[\ln\left(\frac{G_{tot}}{L_t}\right)\right] \\
&+ f_3 \cdot \left[\frac{G_{tot}}{G_s}\right] \cdot \left[\ln\left(\frac{G_{tot}}{L_t}\right)\right] \\
&+ e_4 \cdot \left[\ln\left(\frac{1}{G_{tot}}\right)\right] \cdot \left[\ln\left(\frac{G_{tot}}{L_t}\right)\right] \\
&+ f_4 \cdot \left[\frac{G_{tot}}{G_s}\right] \cdot \left[\ln\left(\frac{1}{G_{tot}}\right)\right] \cdot \left[\ln\left(\frac{G_{tot}}{L_t}\right)\right]
\end{aligned}
\qquad (14)
$$

where

and f_i are climate-dependent coefficients.

Once the coefficients e_i and f_i had been generated for all eight locations we found that Equation 14 could be simplified since: e_2, e_3, and e_4 were linearly related to e_1; f_2 was linearly related to f_1; and f_4 was linearly related to f_3:

Non-vented:

$$e_2 = -0.1655 + 0.1719 \cdot e_1 \qquad (15a)$$

$$e_3 = 0.2347 - 0.4522 \cdot e_1 \qquad (15b)$$

$$e_4 = 0.03783 - 0.08003 \cdot e_1 \qquad (15c)$$

$$f_2 = 0.03170 + 0.2259 \cdot f_1 \qquad (15d)$$

$$f_4 = -0.01594 + 0.2249 \cdot f_3 \qquad (15e)$$

Vented:

$$e_2 = -0.1601 + 0.1541 \cdot e_1 \qquad (16a)$$

$$e_3 = 0.2286 - 0.7045 \cdot e_1 \qquad (16b)$$

$$e_4 = 0.03045 - 0.1191 \cdot e_1 \qquad (16c)$$

$$f_2 = 0.02954 + 0.2061 \cdot f_1 \qquad (16d)$$

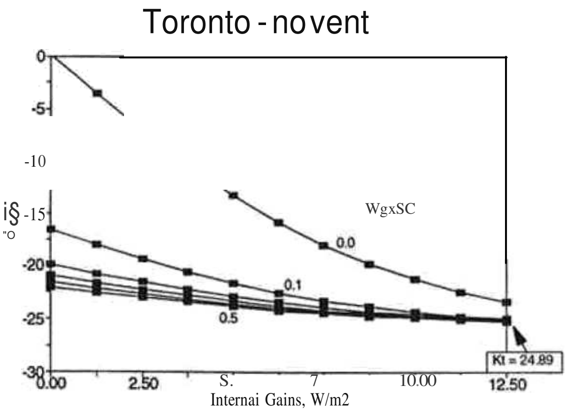


Figure 2. Derivation of the heat loss parameter kt, curves for a single value of HLF (1.15), are shown.

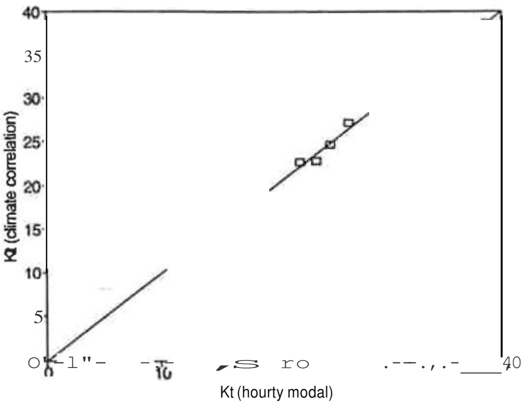


Figure 3. kt derived from climate correlation vs. kt derived from hourly modal, for all eight locations.

$$f_{,} = 0.000278 + 0.2072\ .fa \tag{16e}$$

These relationships are illustrated in **Figures 4 (a) ·(•).** Therefore, for consistency across geographical locations, climate dependence for only 3 coefficients (ei. fi. and f_3) need be derived. Mer trying many parameter combinations, we found that ei. f_1, and f_3 were correlated to climate parameters by the following set of equations:

Non-vented:

$$e1 = ao + a_1 \cdot VS + a_2 \cdot VSS + a_3 \cdot CDD1 + a_4 \cdot CDD2 + a_5 \cdot CDHl + as \cdot DRNG \tag{17}$$

where

CDHl = Annual Cooling Degree Hours (base 26.7 °C); and

$ao = 26.0884$, $a_1 = -0.9139$, $a_2 = 0.7031$, $aa = -0.01372$, $a_4 = 0.02067$, $a_6 = 0.006446$, $aa = -0.6308$.

$$f1 = ao + ai \cdot VS + a_2 \cdot VSS + a_3 \cdot CDD1 + a_4 \cdot CDD2 + a_6 \cdot CDHl + as \cdot DRNG \tag{18}$$

where

$ao = -6.06729$, $a_1 = 0.2349$, $a_2 = -0.1976$, $o_3 = 0.002864$, $o_4 = -0.004017$, $o_6 = -0.001767$, $oa = 0.1767$.

$$fa = ao + ai \cdot VS + a_2 \cdot VSS + aa \cdot CDD1 + a4 \cdot CDD2 + a_6 \cdot CDHl + aa \cdot DRNG \tag{19}$$

where

$oo = -0.6555$, $o_1 = 0.02538$, $o_2 = -0.01831$, $oa = 0.0006844$, $o_4 = -0.001820$, $a5 = 0.0001315$, $a_6 = -0.001379$.

Vented:

$$e_1 = a_0 + ai \cdot VS + a2 \cdot VSS + aa \cdot CDD1 + a_4 \cdot CDD2 + a_6 \cdot CDHl + as \cdot DRNG \tag{20}$$

where

$o_0 = 23.0141$, $o_1 = -0.8474$, $a_2 = 0.6758$, $a3 = -0.01187$, $04 = 0.01825$, $a5 = 0.005293$, $aa = -0.5414$.

$$f1 = ao + ai \cdot VS + a_2 \cdot VSS + aa \cdot CDD1 + a_4 \cdot CDD2 + a_6 \cdot CDHl + as \cdot DRNG \tag{21}$$

where

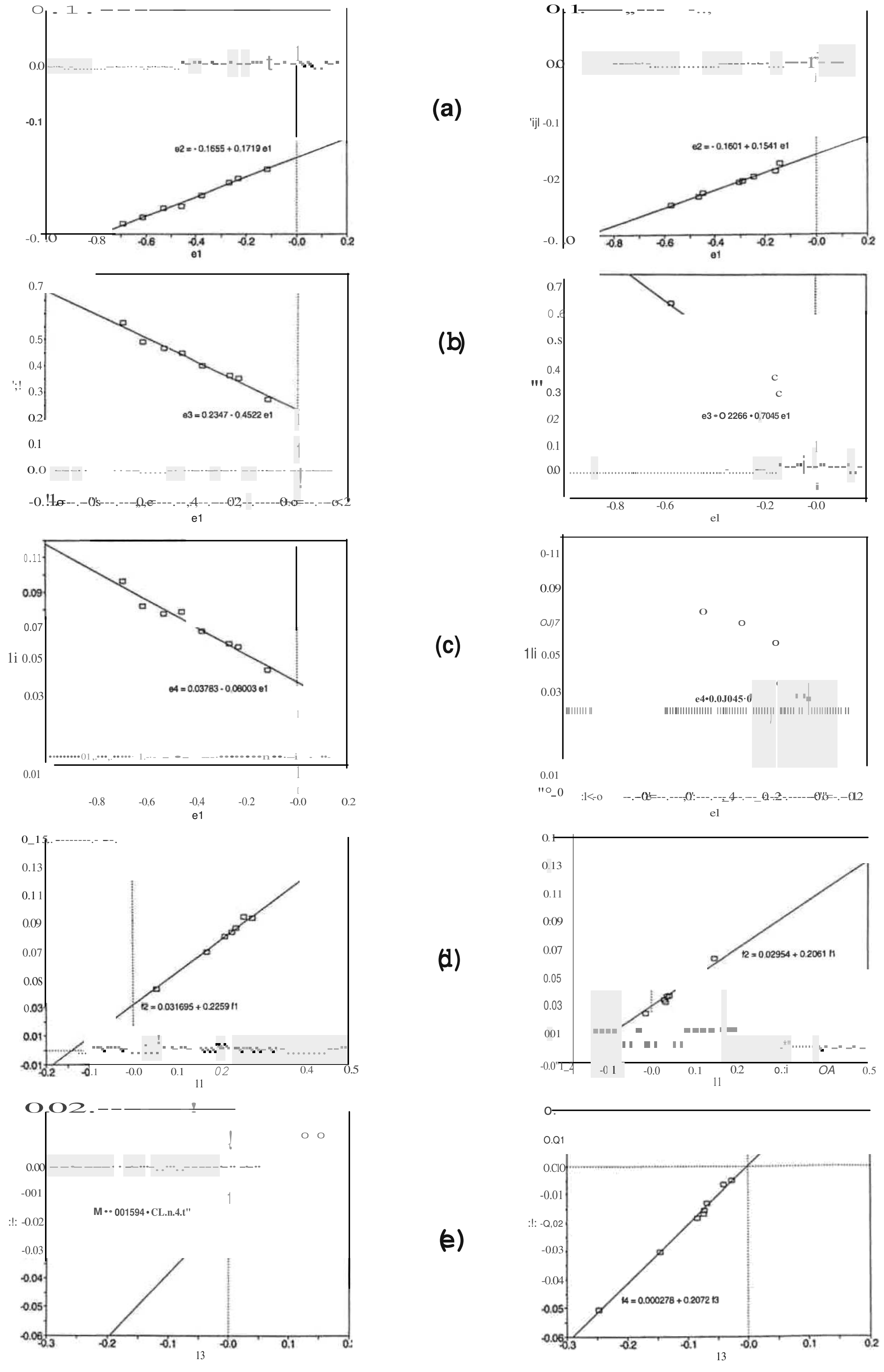
$ao = -0.5568$, $a_1 = 0.04818$, $a2 = -0.05074$, $a_3 = -0.0003145$, $a_4 = 0.001088$, $a5 = -0.0001684$, $a_6 = 0.03147$.

$$fa = a_0 + ai \cdot VS + a_2 \cdot VSS + aa \cdot CDD1 + a_4 \cdot CDD2 + a_6 \cdot CDHl + as \cdot DRNG \tag{22}$$

where

$a_0 = 5.07264$, $o_1 = -0.2343$, $o_2 = 0.2090$, $aa = -0.002028$, $a4 = 0.002298$, $a5 = 0.001342$, $ae = -0.1264$.

The climate parameters VS, VSS, HDD2, CDDl, CDD2, CDHl and DRNG can be found in data-sets published by ASlffiAE/IES (ASHRAFJIES 1989) and Environment Canada (Tsi-Cbih 1991). **Table 1** liste these climate parameters for the eight Canadian locations specifically addressed in this paper. **Figures 5 (a) •** (c) illustrate the relationship between elt flt fa derived from the individual regressions for each location, and the elt f_{11} fa derived from the climate correlations of Equations 17 to 22.



Non-vented

Vented

Figure 4. The linear relationships between correlation coefficients for both the non-vented and vented cases.

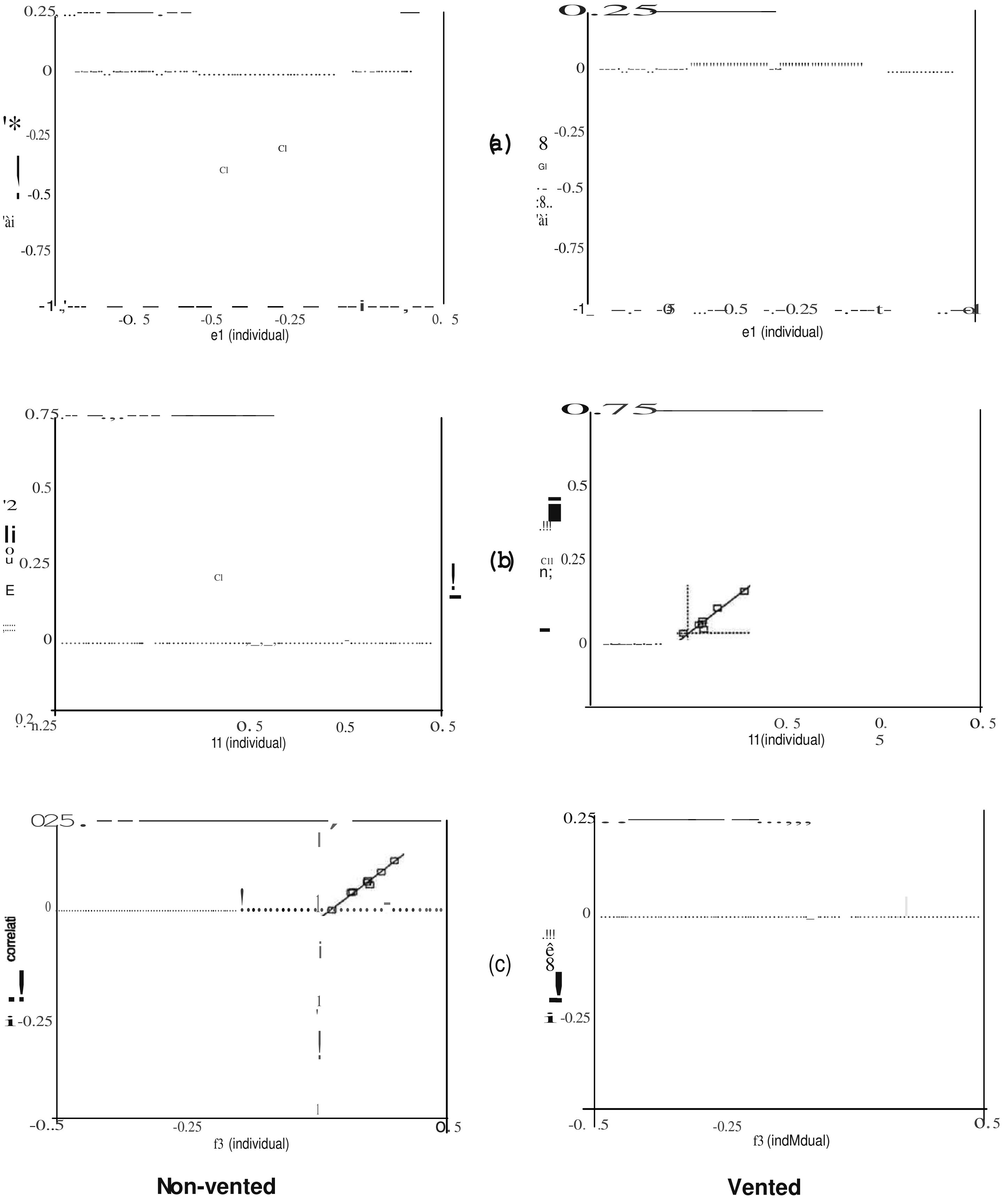


Figura 5. Correlation ccefficlenls darivad Fran the dimala correlation vs. oorralation coefficients of the Individuel regressions, b- all eight loc:ations.

DISCUSSION

Accuracy of fit

Figures 6 (a) • (c) show the annual cooling energy consumption calculated using the correlation vs. EASI annual cooling energy consumption, for the base case house under both vented and non-vented conditions for Toronto, Winnipeg and Vancouver; results for all combinations of internal gain, U-value and glazing are shown. In the vast majority of cases, the differences are less than 10 percent. The absolute differences are, again in the vast majority of cases, less than 1000 kWh/year; with a COP of 3 and an electricity rate of 7.5 /kWh, this amounts to an error of $25/year.

Tables 2 and 3 show the mean absolute and percentage differences for all eight cities for both the vented and non-vented cases. The mean percentage differences are less than 7 percent in all cases, and in most cases less than 5 percent. Mean absolute differences are less than 1000 kWh in all cases. Although, as might be expected, cooling energy consumption for the vented cases is lower than for corresponding non-vented cases, the mean percentage differences in the vented cases are generally higher. This is due to the extra degree of freedom introduced by the window opening option.

Limitations

The correlations have been derived for a house of a single form and thermal mass. Therefore, although the correlation can be applied to any size house, it should only strictly be applied to houses with equal glazing on all facades, and to houses of thermal mass 60 kJt'Cm^2• However, a large fraction of Canadian wood-frame houses do fit into this mass category. Another limitation is that many of the assumptions made for the base case house, particularly those referring to the heat transfer at opaque surfaces, are specific to Canadian construction and climate.

The correlations are very sensitive to the input climate data. For reliable results, it is extremely important to use only the input climate data supplied in this paper (the data used to derive the correlations are ten year averages), the data from which the correlations were derived. While this limits the applicability of the correlations to those cities specifically listed in the report, these cities are representative of the most populated areas of Canada. The same limitation exists for the correlations of the ASHRAFJIES 90.1 envelope compliance procedure (ASHRAE/IES 1989).

Internal Gain Schedule

The correlation was developed for a constant, 24 hour internal gain schedule. However, runs for a subset of climates using a more typical residential internal gain schedule (Barakat and Sander 1986) **(Figure 7),** with the same total internal gain as the constant schedule, showed that the correlation did not change significantly.

Human Behavior with Respect to Air Conditioner Use

Recent studies (Kempton, Feuermann, and McGarity 1992, Lutzenhiser 1992) indicate that the interaction between residential occupants and their air conditioning systems is far more complicated than that modeled here. Here we model a "thermostatic" control strategy, in which the system cycles on and off automatically to attain a pre-set room temperature; in the vented case, the initiation of this thermostatic control is delayed by opening windows. While "thermostatic" control may be the control strategy anticipated by manufacturers, the above studies found that, in the case of room air conditioners, a majority of users adopted a "manual" control strategy. The "manual" control strategy involved the user cycling the machine on and off as desired; when on, the thermostat was usually set to provide continuous operation. In most cases, the "manual" strategy resulted in a lower energy consumption than the "thermostatic" strategy. However, the parameters which stimulate users to adopt the "manual" strategy, and to decide when to cycle the air conditioner, have yet to be determined. Therefore, at present it would be impossible to model this kind of control in a study of this kind.

Latent Cooling

The above correlation predicts only sensible cooling energy consumption. We also investigated methods of calculating latent cooling energy consumption, for example CHBA (1991). However, the extra complication incurred in generating an accurate latent cooling energy

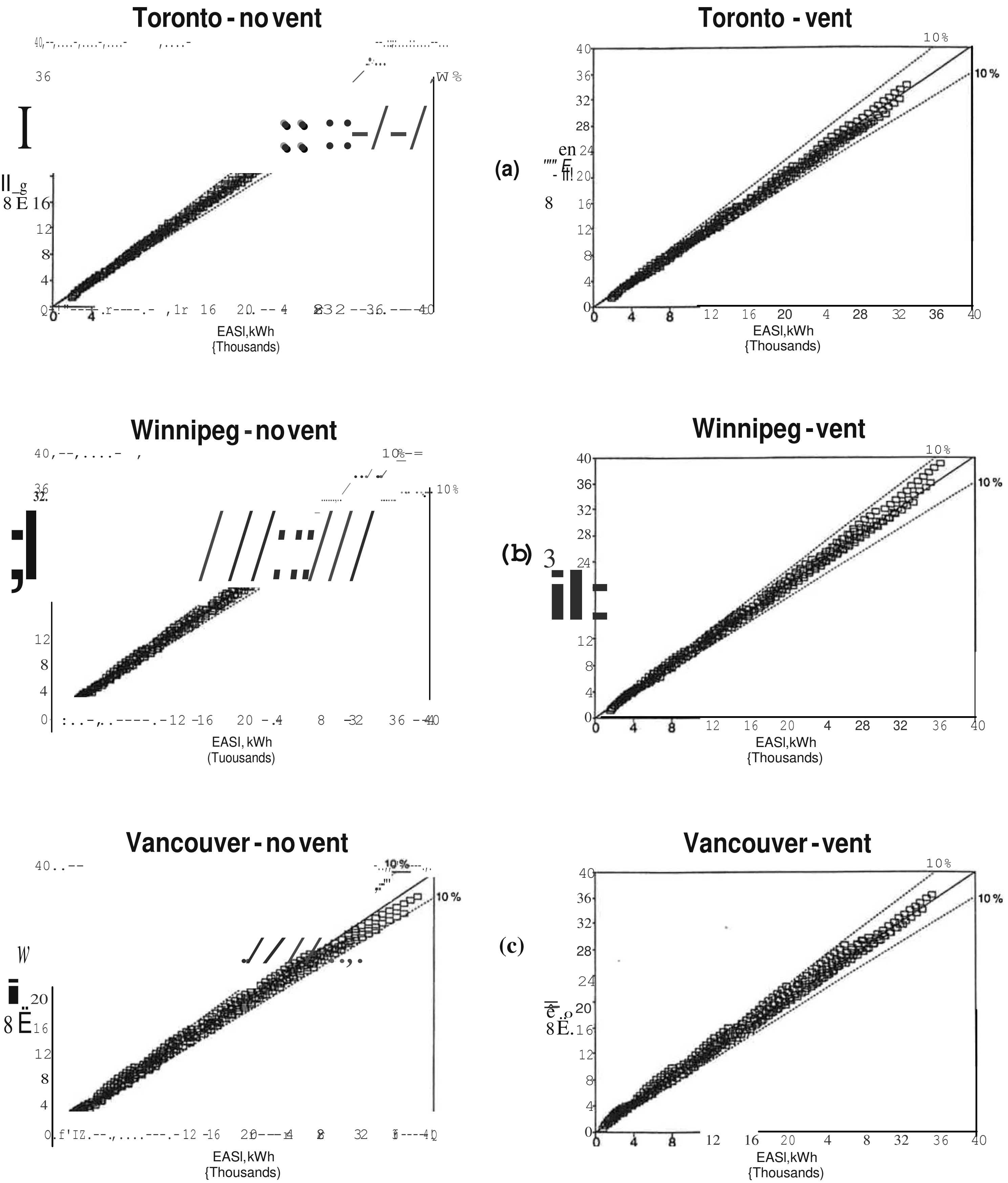


Figure 6. Cooling energy consumption calculated using the correlation vs. EASI cooling energy consumption, for all building parameter variations, for both the vented and non-vented cases, in Toronto, Winnipeg, and Vancouver. 10% difference levels are indicated.

Table 1. Climate parameters for 8 Canadian cities.

City	HDD2	VS	VSS	CDD1	CDD2	cnm	DRNG
Fredericton	4840	18.21	9.20	928	124	319	12.7
Montreal	4615	17.65	8.67	1201	226	315	10.6
Ottawa	4758	18.27	9.13	1164	212	407	11.4
Toronto	4218	17.37	8.34	1201	224	510	12.5
Windsor	3687	18.82	8.86	1535	371	781	10.9
Winnipeg	5965	21.11	10.99	1000	169	479	12.5
Edmonton	5938	21.06	10.97	592	27	88	18.1
Vancouver	3112	17.12	8.25	859	80	8	9.1

Table 2. Mean percentage and absolute differences between the annual cooling energy consumption calculated by an hourly model and that calculated using the correlation, for all building parameter variations for a non-vented house.

City	Mean Differences %	Mean Differences absolute, kWh/year
Fredericton	2.7	325
Montreal	3.0	474
Ottawa	3.2	393
Toronto	2.8	391
Windsor	3.3	569
Winnipeg	3.4	521
Edmonton	4.7	728
Vancouver	5.7	781

Table 3. Mean percentage and absolute differences between the annual cooling energy consumption calculated by an hourly model and that calculated using the correlation, for all building parameter variations, for a vented house.

City	Mean Differences %	Mean Differences absolute, kWh/year
Fredericton	2.9	344
Montreal	3.7	522
Ottawa	4.3	490
Toronto	4.0	506
Windsor	6.8	971
Winnipeg	3.4	480
Edmonton	6.9	897
Vancouver	6.5	641

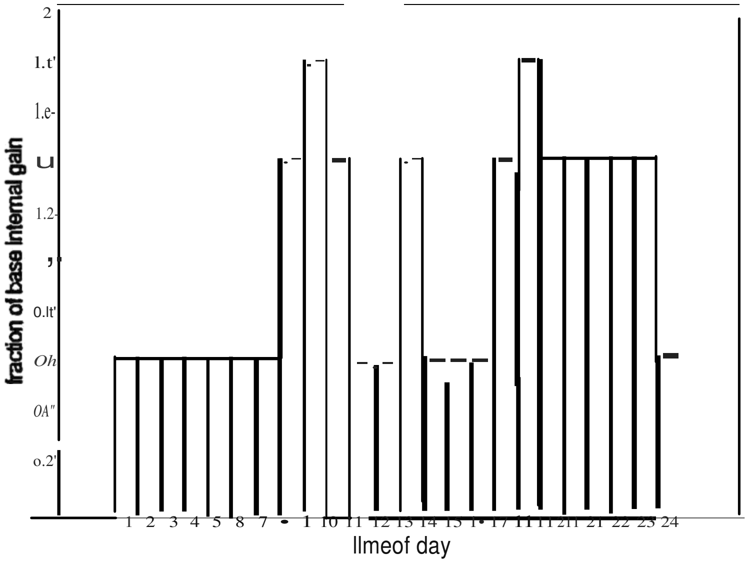


Figure 7. Typical residential internal gain schedule.

consumption does not seem justified given the nature of the correlation we are trying to derive. In addition, the vast majority of domestic air conditioners do not respond to latent loads. Therefore, if one wishes to calculate latent cooling energy consumption, it is probably adequate to use the simplified procedure given in the ASHRAE Handbook (ASHRAE 1989), which expresses the latent energy consumption as a function of the sensible energy consumption.

Future Work

This work is continuing with the aim of enhancing the method's flexibility, accuracy and applicability. First, the influence of thermal mass on cooling energy consumption will be investigated. Secondly, monthly correlations will be derived. There are two potential benefits to using a monthly correlation:

- the correlation can then be applied to residences with a shorter cooling season than May to September; and
- the sum of the monthly differences between the correlation and the hourly model is likely to be smaller than the differences exhibited by the seasonal correlation. Preliminary results indicate that in both cases (varying mass and monthly correlations) the form of the correlation is robust and will not change.

CONCLUSIONS

A simple correlation equation to determine seasonal residential cooling energy consumption in Canada has been developed. It allows the quick determination of the change in residential cooling energy consumption corresponding to changes in internal gain, envelope U-value, glazing area, and shading coefficient. Considering its simplicity, the correlation is relatively accurate. The mean percentage difference compared to the output of an hourly model, over a wide range of building parameters and climates, was 3.6 % in a non-vented house, and 4.8 % in a house where the windows were opened to provide ventilative cooling. Absolute differences are less than 1000 kWh in the vast majority of cases; with a COP of 3 and an electricity rate of 7.5 ¢/kWh this amounts to a difference of $25/year.

As the correlation was developed for a Canadian house with equal glazing on all facades and a thermal mass of 60 kJ/°Cm^2, the correlation should strictly only be applied to houses of this construction and form. However, a large fraction of Canadian residences do fit into this mass category. In the future, the thermal mass dependence of the seasonal correlation will be investigated, and monthly correlations will be developed with the aim of further enhancing the method's flexibility, accuracy and applicability. Preliminary results indicate that in both cases (varying mass and monthly correlations) the form of the correlation is robust.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Mr. Darren Wooff for his help in the development of the correlation; and Mr. Bill Jones (Ontario Hydro), and Dr. Sherif Barakat (National Research Council Canada) for their helpful comments on this paper. This study was funded by Hydro Quebec (HQ) as a part of their project "Assessment of the Impact of Internal Heat Gains on the Thermal Loads in the Residential Sector." This HQ project was funded in equal parts by the Canadian Electrical Association (CEA) under CEA contract number 9102 U 849, and by Hydro Quebec.

REFERENCES

Alereza, T. 1985. Application of variable-base degree-hours in commercial buildings. *ASHRAE Transactions*, 91 (2B), 893-906.

ASHRAE. 1989. *ASHRAE handbook of fundamentals*. Atlanta, ASHRAE.

ASHRAE/IES. 1989. *Standard 90.1: Energy efficient design of new buildings*. Atlanta, ASHRAE.

Barakat, S.A., and D.M. Sander. 1986. The utilization of internal heat gains. *ASHRAE Transactions*, 92 (1A), 103-115.

CHBA. 1991. *HOT-2000 technical manual*, Chapter 10. Ottawa, Canada, Canadian Home Builders Association.

Cornick, S.M. 1993. National Research Council Canada. Private communication.

Guntermann, A. 1981. A simplified degree-day method for commercial and industrial buildings. *ASHRAE Transactions*, 87 (1), 461-472.

Jones, W.R., and B.T. Howell. 1985. Comparison of heating load calculation methods with measured data. *Ontario Hydro Research Division report no. 85-299-K.* Toronto, Canada, Ontario Hydro.

Kempton, W., D. Feuermann, and A.E. McGarity. 1992. "I always turn it on super": user decisions about when an how to operate room air conditioners. *Energy and Buildings*, 18, 177-191.

Kusuda, K., I. Sud, and T. Alereza. 1981. Comparison of DOE-2 generated residential design energy budgets with those calculated by degree-day and bin methods. *ASHRAE Transactions*, 87 (1), 491-506.

Lutzenhiser, L. 1992. A question of control: alternative patterns of room air-conditioners use. *Energy and Buildings*, 18, 193-200.

Ontario Hydro. 1990. Residential appliance survey: report no. MR 91-61. Toronto, Canada, Ontario Hydro.

Parken, W.A., and G.E. Kelly. 1981. Estimating residential seasonal cooling requirements. *ASHRAE Transactions*, 87 (1), 473-490.

Peterson, J.L., J.W. Jones, and B.D. Hunn. 1989. The correlation of annual commercial building coil energy with envelope, internal load, and climate parameters. *ASHRAE Transactions*, 95 (1), 206-214.

Sullivan, R., et al. 1985. Commercial building energy performance analysis using multiple regression. *ASHRAE Transactions*, 91 (2A), 337-353.

Sullivan, R., et al. 1986. Thermal analysis of buildings-configuration perturbations and observed climate interface. *ASHRAE Transactions*, 92 (1), 137-151.

Swinton, M.C., and D.M. Sander. 1992. Economic levels of thermal resistance for house envelopes: consideration for a national energy code. *Proceedings of 18th annual conference of the Solar Energy Society of Canada*, Edmonton. Ottawa, Canada, SESCI.

Tse-Chih, A. 1991. Project to prepare climatic design information for ASHRAE standard 90.1-1989 and ASHRAE handbook. Downsview, Canada, Environment Canada.