Solar Energy Vol. 36, No. 6, pp. 499–507, 1986
Printed in the U.S.A.

0038–092X/85 $3.00 + .00

A SIMPLIFICATION OF WEATHER DATA TO EVALUATE DAILY AND MONTHLY ENERGY NEEDS OF RESIDENTIAL BUILDINGS†

MEHDI N. BAHADORI
College of Architecture and Environmental Design, Arizona State University, Tempe, AZ 85287

and

MARK J. CHAMBERLAIN
ISTEC Ltd., Hamilton, Ontario, Canada

(*Received* 16 *January* 1985; *accepted* 21 *May* 1985)

Abstract—Hourly, daily, monthly and annual heating and cooling requirements of a residential building located in Ottawa, Ontario, Canada were estimated, employing ENERPASS as the energy simulation tool, and performing hour-by-hour energy analysis. The following weather data were employed:

(i) Ten years (1967–1976) of weather data. The ten-year average of the results is identified as TYA.
(ii) A typical meteorological year (TMY) generated using the same ten years of data.
(iii) Two different hourly ambient air temperature distributions ($T1$ and $T2$) for a typical day in each month. The solar radiation on each surface was estimated using the mean monthly clearness index.

The house use patterns, including heat generation and the thermostat setting, were taken the same when using TYA, TMY, $T1$ or $T2$. The analysis was carried out for the house as it is (well insulated and airtight), and for two modifications: one with larger infiltration rate and lower wall thermal resistance, and the other with larger south-facing window area and using super-windows. The results of this study show that the long-range hourly, daily, monthly and annual heating and cooling requirements of a residential building located in a cold climate can be predicted by employing mean daily maximum and minimum temperatures and the mean monthly clearness index for each month. This amounts to substantial savings in computational costs, in either using many years of weather data or generating a TMY for the site. For locations lacking detailed hourly weather data, the use of data and the procedure outlined in this study may be employed to predict the long-range thermal performance of simple residential buildings.

1. INTRODUCTION

Currently there exist many computer programs for the energy analysis of buildings. Most of these programs require hourly weather data of the site as part of their input. The programs employ different levels of sophistication in analysing various components of the energy exchange in the system and can eventually estimate the hourly, daily or monthly energy requirements for heating and cooling of the building. They may also predict the size and the energy consumption of equipment such as fans, pumps, etc. Some of these programs have been written specifically to analyse certain passive solar heating features such as direct gain, mass walls, sunspace, etc. No attempt is being made here to list these programs or to cite their strengths or limitations. Several comparisons of some of these programs are available in the literature[1–6].

The use of hourly data (for 8760 hours per year) can be expensive. Furthermore, the year selected for energy analysis may not represent an average or a typical meteorological year of the location. To determine the energy performance of the building for a typical year, one can perform the energy analysis for many years (which adds to the computational costs) and take some kind of averaging of the results, or create, from many years of available past weather data, a datum to represent a typical meteorological year (TMY)[7–9]. There have been several attempts to reduce the need for hourly energy analysis by manipulating the hourly weather data so that daily and monthly energy requirements can be predicted at lower costs of computation or handling of data[10, 11].

In addition to high costs involved in using hourly weather data for energy simulations, there exists another major disadvantage for this process: such data may not be available for the location of interest. There are many cities, particularly in the developing countries, for which the detailed hourly data such as temperature, solar radiation, wind velocity and direction, etc., required for hourly en-

† The research was carried out when M. N. Bahadori was a visiting professor (on leave of absence from Shiraz University, Shiraz, Iran) in the Department of Mechanical Engineering, and M. J. Chamberlain a research engineer with the Building Engineering Group, University of Waterloo, Waterloo, Ontario, Canada.

ergy analysis, are not recorded. In these cities, one may find records on daily maximum and daily minimum temperatures, the duration of sunshine or cloud cover, etc., for many years. It is highly desirable to estimate the energy requirements of buildings for heating and cooling using the available data.

The purpose of this investigation was to show that the hourly, daily and monthly energy needs of simple buildings can be estimated using only a limited available weather data for the location. The data needed are the mean daily maximum and mean daily minimum temperatures and the average clearness index for each month. In this research, a residential building located in Ottawa, Ontario, Canada was considered for analysis.

2. DESCRIPTION OF THE BUILDING

The building considered for energy analysis is a two-storey residential building with a full basement used as a living space[12]. The building has a total floor area of about 300 m^2. The building is well insulated and is airtight. It has the following thermal resistances: windows, 0.41 m^{2}C/W (double glazed); exposed walls, 6.32 m^{2}C/W; ceiling-roof, 10.50 m^{2}C/W. It also has a large south-facing window of 19.55 m^2 (as compared to a total window area of 31.11 m^2). The infiltration through the house was estimated to be equivalent of $\dot{n}$ = 0.5 air changes per hour.

Two modifications of the above (reference) house were also considered in this study. They are the following:

Modification 1. Wall thermal resistance of 3.5 m^{2}C/W and the infiltration rate of $\dot{n}_1$ = 1.0 ac/h. This is the case of a house not so well insulated nor airtight.

Modification 2. South-facing window area of 29.33 m^2 with a thermal resistance of 1.03 m^{2}C/W. This is the case of using oversized south-facing super-windows for more effective direct gain passive solar heating.

In both modifications, the remaining dimensions, parameters or physical properties, remained the same as in the reference house. That includes the house use pattern (by a family of four), the night-time thermostat setback of 16°C (from 20°C during the day), no natural ventilation in summer, etc.[12].

3. WEATHER DATA EMPLOYED FOR THE ANALYSES

The following weather data were employed to estimate the heating and cooling requirements of the building:

(a) Ten years (1967–1976) of hourly weather data for Ottawa. The data include the temperature, total and diffuse solar radiation intensities on a horizontal surface, relative humidity and wind velocity.

(b) Hourly weather data representing a typical meteorological year (TMY) for Ottawa. These data were produced using the same ten years of weather data as mentioned above[9].

(c) Two temperature distributions, one given by [13]:

$$T - \bar{T}' = A_t'[0.4632 \cos(t' - 3.805) + 0.0984 \cos(2t' - 0.360) + 0.0168 \cos(3t' - 0.822) + 0.0138 \cos(4t' - 3.513)], \quad (1)$$

where

$$t' = \frac{2\pi}{24}(t - 1) \quad (2)$$

and

$$A_t' = 25.8\,\bar{K}_T - 5.21; \quad (3)$$

and the other equation given by

$$T - \bar{T} = \frac{1}{2} A_t \cos \dot{\omega}(t - 15). \quad (4)$$

In these equations, T is the hourly temperature (in °C), $\bar{T}'$ the mean monthly temperature, t the time (12 at solar noon), $\bar{K}_T$ the mean monthly clearness index[14], $\dot{\omega} = 2\pi/24$ or 15°/hr and $\bar{T}$ and A_t are given by:

$$\bar{T} = \frac{1}{2}(T_x + T_n), \quad (5)$$

$$A_t = (T_x - T_n), \quad (6)$$

where T_x and T_n are the mean daily maximum and the mean daily minimum temperatures of the air for the month of interest.

It is clear that with these temperature distributions, we need only to specify $\bar{T}$, $\bar{K}_T$, T_x and T_n for each month. The values of $\bar{T}'$ and $\bar{T}$ are generally very close to each other and one can use $\bar{T}$ given by eqn (5) in place of $\bar{T}'$ without much error. Table 1 gives the Ottawa weather data employed for this analysis[14–17].

(d) *Solar radiation data.* With a knowledge of mean monthly clearness index $\bar{K}_T$ given for Ottawa[14], the solar radiation intensity on each wall facing direction j (north, east, south or west), was determined as follows:

$$I_j = R_{bj} I_{bh} + \frac{1}{2} I_{dh} + \frac{1}{2} \rho_{gr} I_h, \quad (7)$$

where subscripts b and d refer to the beam and diffuse components of the solar radiation and h to horizontal surface. The term R_{bj} was determined from a knowledge of the sun angles[14] and ρ_{gr} is the reflectivity of the ground surrounding the wall j. For

Table 1. Ottawa weather data employed with the analyses $T1$ and $T2$

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Daily Max.Temp., T_x	-6.4	-4.7	1.3	10.9	18.3	24.0	26.4	25.1	20.1	13.8	5.1	-3.7
Mean Daily Min.Temp., T_n	-15.6	-14.4	-7.5	0.3	6.5	12.3	14.8	13.5	9.1	3.6	-2.4	-11.6
Mean Daily Temp., $\overline{T}'$	-10.9	- 9.5	-3.1	5.6	12.4	18.2	20.7	19.3	14.6	8.7	1.4	-7.7
$\overline{T} = \frac{1}{2}(T_x + T_n)$	-11.0	- 9.6	-3.1	5.6	12.5	18.2	20.6	19.3	14.6	8.7	1.4	-7.7
$\overline{K}_T$ [14]	0.51	0.56	0.57	0.52	0.54	0.57	0.57	0.56	0.54	0.48	0.40	0.44
$\overline{K}_T^*$	0.50	0.55	0.55	0.51	0.51	0.52	0.54	0.53	0.50	0.47	0.37	0.44
$A_t = (T_x - T_n)$	9.2	9.7	8.8	10.6	11.8	11.7	11.6	11.6	11.0	10.2	7.5	7.9
$A_t' = 25.8\overline{K}_t - 5.21$	7.95	9.24	9.5	8.21	8.72	9.5	9.5	9.24	8.72	7.17	5.11	6.14
Wind Velocity, m/s	4.5	4.7	4.74	4.65	4.38	3.89	3.44	3.44	3.75	4.07	4.42	4.42

NOTES: All temperatures and the amplitudes are in °C. $\overline{K}_T^*$ is estimated from the solar radiation data [17] and are given here only for comparison with those given by Reference 14.

other terms, we have[14]:

$$I_h = k_T I_{oh}, \tag{8}$$

$$I_{dh} = I_h - I_{bh}, \tag{9}$$

$$I_{oh} = I_{sc}\left[1 + 0.033\cos\left(\frac{360N}{365}\right)\right]\cos\theta_z, \tag{10}$$

$$k_T = [a + b\cos\dot{\omega}(t - 12)]\overline{K}_T, \tag{11}$$

$$a = 0.409 + 0.5016\sin(\omega_s - 60), \tag{12}$$

$$b = 0.6607 - 0.4767\sin(\omega_s - 60). \tag{13}$$

In these equations k_T is the hourly clearness index, I_{oh} the extraterrestrial solar radiation intensity on a horizontal surface, I_{sc} the solar constant (1353 W/m^2), N the day number (N = 1 for 1 January), θ_z the zenith angle and ω_s is the horizontal sunset hour angle. The ratio of diffuse to total radiation in a horizontal surface was selected from[18]:

$$I_{dh}/I_h = 1 - 0.249k_T \text{ for } k_T < 0.35, \tag{14a}$$

$$I_{dh}/I_h = 1.557 - 1.84k_T \text{ for } 0.35 < k_T < 0.75, \tag{14b}$$

$$I_{dh}/I_h = 0.177 \text{ for } k_T > 0.75. \tag{14c}$$

The following day numbers were selected in this analysis[14] to represent the months of January through December: N = 17 (17 January), 47 (16 February), 75 (16 March), 105 (15 April), 135 (15 May), 162 (11 June), 198 (17 July), 228 (16 August), 258 (15 September), 288 (15 October), 318 (14 November), and 344 (10 December). With a latitude of 45.45 for Ottawa, cos θ_z, R_{bj} and ω_s were calculated for these days[14] and I_j's were determined for all the walls.

4. SELECTION OF A COMPUTER PROGRAM FOR ENERGY ANALYSIS

A computer program called ENERPASS[19] was chosen for the energy analysis. In a previous study[12], ENERPASS and another computer program called TARP (Thermal Analysis Research Program)[20] were selected for the energy analysis of the same building, using Ottawa weather data for 1981.

ENERPASS is a medium level, hour-by-hour energy simulation program, requiring about ⅓ of a megabyte of disk storage for the source and executable code. One weather data file requires about 132 kilobyte of disk storage. TARP, on the other hand, is a high level hour-by-hour energy simulation program, requiring about 2 megabytes of disk storage for the source and executable code. One weather data file requires about 500 kilobyte of disk storage. TARP must be run on a mainframe, while ENERPASS could be run on a mainframe or a microcomputer.

It was found that the results of energy analysis using TARP and ENERPASS were very close to each other[12]. Because of much lower costs of running ENERPASS, we decided to use this computer program for our energy analysis here.

5. ENERGY ANALYSES AND PRESENTATION OF THE RESULTS

Energy analyses were performed for the reference building and its modifications using one or more of the following data:

(i) Ten years of weather data and estimating the ten-year average (TYA) for each month.
(ii) The weather data specified as a typical meteorological year (TMY).
(iii) The hourly temperature distribution for each month given by eqn (1) and the solar radiation intensities calculated for the selected representative days (12 days to represent 12 months of the year), as was discussed in Section 3(d). This analysis is called *T*1.
(iv) The hourly temperature distribution for each month given by eqn (4) and the solar radiation intensities the same as in (iii) above. This analysis is called *T*2.

The effect of wind velocity in both analyses *T*1 and *T*2 is the same as we have selected the same infiltration rate and the convective heat transfer coefficients for both cases.

The following energy analyses were performed:

(I) For the reference house:

(a) Hour-by-hour energy analysis to determine monthly energy requirements for heating and cooling, using TYA, TMY, *T*1 and *T*2. Tables 2 and 3 and Fig. 1 show the results. When using *T*1 and *T*2, the monthly requirements were determined by multiplying the daily needs by the number of days in the month.

(b) Hour-by-hour energy analysis for every day of the months of January and July, using TMY, and hour-by-hour energy analysis for 17 January and 17 July, using *T*1 and *T*2. Table 4 and Fig. 2 compare the results. When using TMY data, the monthly averages are obtained by taking the average of 31 (days) values at each hour of interest.

(II) For the modified houses:
Hour-by-hour energy analysis to determine monthly energy requirements for heating and cooling, using TMY, *T*1 and *T*2. The energy simulations were carried out for both modifications 1 and 2. Table 5 compares the results for the modified houses. Figure 3 shows the monthly

Table 2. Monthly heating requirements of the reference house, GJ/mo

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL REQUIR. GJ/yr
1967	14.59	16.17	12.34	6.80	3.97	0.31	0.06	0.08	0.80	3.43	8.77	13.25	80.57
1968	19.29	15.11	10.55	4.20	2.54	0.78	0.08	0.13	0.15	2.30	9.04	14.81	78.98
1969	15.21	11.63	11.16	6.01	3.09	0.71	0.09	0.03	0.72	3.26	7.67	14.81	74.39
1970	18.82	14.35	11.18	6.02	2.66	0.48	0.10	0.08	0.57	2.19	6.87	16.19	79.51
1971	18.24	13.95	11.73	7.28	2.52	0.47	0.11	0.20	0.25	2.00	8.89	14.30	79.94
1972	15.31	15.11	13.65	8.11	2.09	0.84	0.13	0.11	0.39	4.10	8.67	14.92	83.43
1973	14.68	13.75	8.84	5.86	2.82	0.54	0.03	0.02	0.63	1.80	8.06	13.85	70.88
1974	15.78	13.85	11.73	5.89	3.76	0.40	0.06	0.03	0.81	3.18	7.49	11.99	74.97
1975	15.15	12.42	11.62	6.99	1.00	0.42	0.02	0.06	0.74	2.58	6.21	15.35	72.56
1976	18.84	12.46	12.00	4.96	3.39	0.25	0.10	0.11	0.71	3.88	8.14	16.40	81.24
TYA	16.59	13.88	11.48	6.21	2.78	0.52	0.08	0.09	0.58	2.87	7.98	14.59	77.65
TMY	15.14	13.82	11.31	5.81	2.36	0.38	0.12	0.07	0.68	2.55	6.19	14.78	73.21
T1	16.95	13.93	10.70	5.26	1.71	0.23	0.00	0.00	0.14	1.63	7.57	14.81	72.93
T2	16.94	13.93	10.70	5.28	1.77	0.23	0.00	0.00	0.13	1.65	7.56	14.81	73.00

Table 3. Monthly cooling requirements of the reference house, GJ/mo

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL REQUIR. GJ/yr
1967	0.00	0.00	0.00	0.00	0.04	0.68	0.96	0.86	0.63	0.09	0.00	0.00	3.26
1968	0.00	0.00	0.00	0.09	0.10	0.33	1.08	0.81	0.74	0.32	0.00	0.00	3.47
1969	0.00	0.01	0.00	0.03	0.10	0.52	1.00	1.29	0.41	0.16	0.00	0.00	3.52
1970	0.00	0.00	0.00	0.07	0.11	0.58	1.03	1.06	0.33	0.23	0.01	0.00	3.42
1971	0.00	0.00	0.00	0.00	0.20	0.64	0.79	0.79	0.52	0.15	0.00	0.00	3.09
1972	0.00	0.00	0.00	0.01	0.32	0.33	0.99	0.73	0.60	0.09	0.00	0.00	3.07
1973	0.00	0.01	0.02	0.08	0.05	0.69	1.32	1.40	0.58	0.22	0.00	0.00	4.37
1974	0.00	0.01	0.02	0.04	0.03	0.47	0.92	1.01	0.31	0.12	0.01	0.00	2.94
1975	0.00	0.01	0.00	0.00	0.60	0.81	1.26	1.13	0.19	0.18	0.08	0.00	4.26
1976	0.00	0.01	0.00	0.16	0.12	0.72	0.78	0.95	0.42	0.23	0.01	0.00	3.40
TYA	0.00	0.005	0.004	0.05	0.17	0.58	1.01	1.00	0.47	0.18	0.01	0.00	3.48
TMY	0.00	0.01	0.01	0.06	0.16	0.56	1.11	1.18	0.49	0.19	0.08	0.00	3.85
T1	0.00	0.00	0.00	0.00	0.08	0.75	1.32	1.20	0.40	0.00	0.00	0.00	3.75
T2	0.00	0.00	0.00	0.00	0.13	0.80	1.36	1.25	0.45	0.00	0.00	0.00	3.99

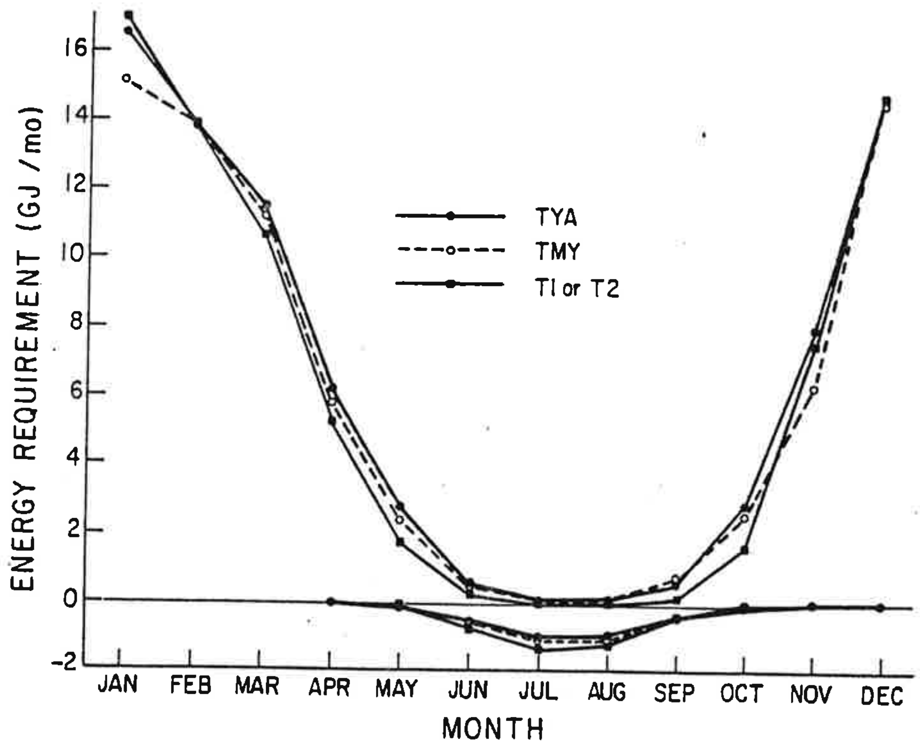

Fig. 1. The monthly heating and cooling requirements of the reference house, employing TYA, TMY, *T1* and *T2*.

Table 4. Heating and cooling loads of the reference house

HOUR	HEATING LOAD, kW				COOLING LOAD, kW			
	TMY		T1	T2	TMY		T1	T2
	JAN 17	MONTHLY AVERAGE	JAN 17 OR MONTHLY AVERAGE		JUL 17	MONTHLY AVERAGE	JUL 17 OR MONTHLY AVERAGE	
1	5.46	3.68	4.91	5.34	0.00	0.00	0.00	0.00
2	6.50	4.34	5.72	6.20	0.00	0.00	0.00	0.00
3	7.32	4.90	6.32	6.76	0.00	0.00	0.00	0.00
4	7.98	5.33	6.76	7.12	0.00	0.00	0.00	0.00
5	8.52	5.65	7.12	7.30	0.00	0.00	0.00	0.00
6	9.00	5.95	7.34	7.34	0.00	0.00	0.00	0.00
7	7.59	4.54	5.79	5.63	-0.18	-0.12	-0.09	-0.07
8	11.74	8.52	9.52	9.26	-0.25	-0.14	-0.11	-0.10
9	12.75	9.84	10.14	9.86	-0.06	-0.05	0.00	0.00
10	10.97	8.59	8.33	8.12	-0.32	-0.16	-0.14	-0.15
11	8.26	6.93	6.46	6.27	-0.77	-0.43	-0.53	-0.54
12	6.88	6.42	5.80	5.62	-0.90	-0.47	-0.67	-0.70
13	5.92	5.66	5.02	4.89	-1.19	-0.64	-0.96	-0.99
14	5.08	5.16	4.68	4.57	-1.46	-0.80	-1.20	-1.24
15	4.64	4.91	4.92	4.79	-1.52	-0.88	-1.28	-1.32
16	4.70	5.03	5.48	5.36	-1.48	-0.86	-1.22	-1.26
17	4.68	4.47	5.04	4.90	-1.66	-1.10	-1.39	-1.44
18	4.81	4.10	4.84	4.66	-1.76	-1.21	-1.41	-1.49
19	5.94	4.91	5.75	5.55	-1.45	-0.92	-1.02	-1.09
20	6.41	4.62	5.49	5.33	-1.47	-0.97	-1.00	-1.07
21	7.88	5.88	6.88	6.79	-0.93	-0.48	-0.46	-0.48
22	8.30	6.06	7.19	7.24	-0.63	-0.35	-0.30	-0.28
23	9.15	7.02	8.20	8.40	-0.27	-0.11	-0.05	0.00
24	4.88	3.14	4.20	4.53	-0.14	-0.07	0.00	0.00
	DAILY HEATING REQUIREMENTS, MJ/d				DAILY COOLING REQUIREMENTS, MJ/d			
	631.21	488.34	546.74	546.57	-59.22	-35.14	-42.54	-44.00

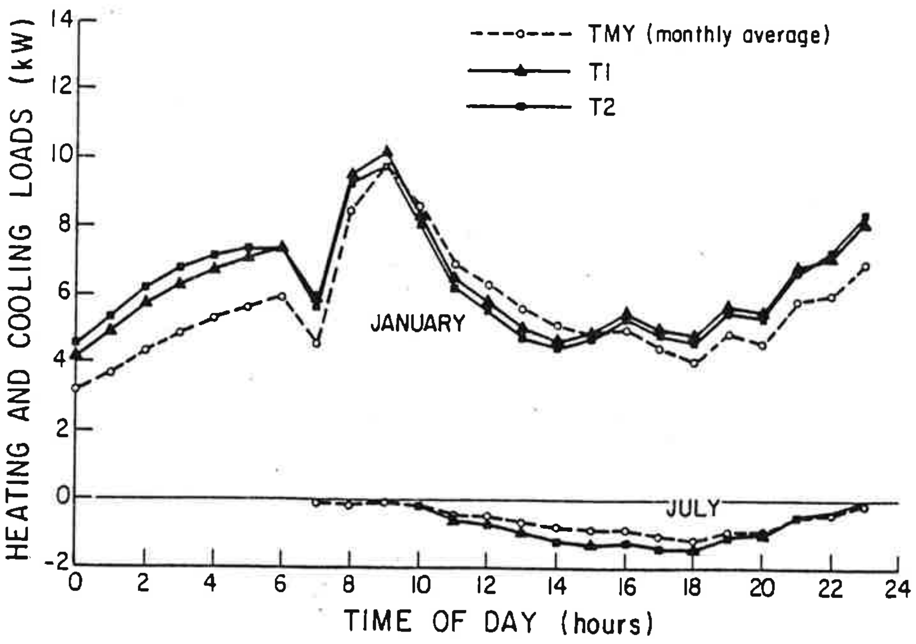

Fig. 2. The heating and cooling loads of the reference house, employing TMY, *T*1 and *T*2.

Table 5. Monthly heating and cooling requirements of the modified houses, GJ/mo

		DATA	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL REQUIR. GJ/yr
HEATING	MODIFICATION 1	TMY	26.85	25.12	20.69	10.85	4.7	0.83	0.30	0.26	2.17	6.31	12.08	26.40	136.56
		T1	30.01	24.84	19.91	10.31	3.61	0.41	0.05	0.07	0.60	5.27	14.79	26.41	136.28
		T2	30.0	24.84	19.92	10.36	3.62	0.48	0.05	0.06	0.65	5.36	14.78	26.42	136.54
	MODIFICATION 2	TMY	11.62	10.38	8.50	4.35	1.63	0.22	0.07	0.03	0.35	1.55	4.53	11.32	54.55
		T1	13.0	9.97	7.25	3.43	1.17	0.12	0.00	0.00	0.06	0.56	5.11	11.40	52.07
		T2	13.0	9.98	7.24	3.46	1.24	0.12	0.00	0.00	0.06	0.62	5.11	11.41	52.24
COOLING	MODIFICATION 1	TMY	0.00	0.00	0.00	-0.03	-0.06	-0.39	-1.00	-1.05	-0.32	-0.09	-0.03	0.00	-2.97
		T1	0.00	0.00	0.00	0.00	0.00	-0.48	-1.15	-0.92	-0.11	0.00	0.00	0.00	-2.66
		T2	0.00	0.00	0.00	0.00	0.00	-0.57	-1.23	-1.03	-0.15	0.00	0.00	0.00	-2.98
	MODIFICATION 2	TMY	-0.16	-0.38	-0.37	-0.40	-0.51	-0.96	-1.57	-1.70	-1.00	-0.59	-0.31	-0.09	-8.04
		T1	0.00	-0.05	-0.16	-0.09	-0.61	-1.29	-1.88	-1.85	-1.10	-0.27	0.00	0.00	-7.30
		T2	0.00	-0.05	-0.16	-0.12	-0.66	-1.33	-1.91	-1.89	-1.14	-0.31	0.00	0.00	-7.57

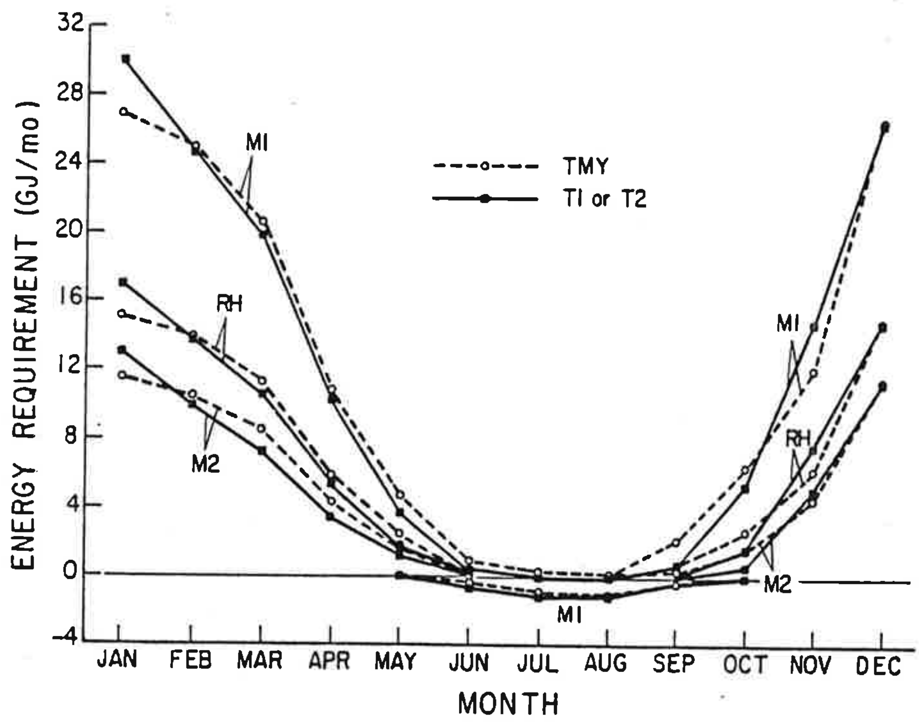

Fig. 3. The monthly heating and cooling requirements of the reference (RH) and modified houses ($M1$ and $M2$).

energy requirements for the reference as well as the modified houses.

In the above tables and figures, when heating and cooling needs are presented side by side, negative sign (−) is employed to show the cooling requirements.

6. DISCUSSION

With reference to Tables 2–5 and Figs. 1–3, we can make the following observations:

(a) The results of energy analyses using the ten-year (1967–76) average (TYA), the typical meteorological year (TMY), *T*1 and *T*2 are very close to each other. Although the hourly energy requirements may differ from each other, the difference in daily, monthly and annual energy requirements for heating and cooling predicted by TYA, TMY, *T*1 and *T*2 become very small. Some of the differences between TYA or TMY and *T*1 and *T*2 may be due to the fact that TYA and TMY are based on ten years of weather data while *T*1 and *T*2 are based on about 30 years of weather data[14–17]. Furthermore, such differences are often observed even when using two different energy simulation programs for the same weather data[12].

(b) In almost all cases, the results of *T*1 and *T*2 are the same, indicating that a simple sinusoidal temperature distribution for the ambient air is sufficient for energy analysis.

(c) The hourly energy requirements for 17 January and 17 July using TMY are quite different from those of the monthly average values using TMY, indicating that 17 January was perhaps a colder, and 17 July, a warmer day than the respective average days (see Table 4). The monthly average values were determined by estimating the hourly energy requirements for 31 days of the month and taking the arithmatic average of these values for each hour. In cases of *T*1 and *T*2, the values given for 17 January or 17 July and the monthly averages are the same.

(d) The drop in heating load at 7:00 a.m. in January (see Table 4 and Fig. 2) is due to the use pattern and the thermostat setting in the house[12].

(e) The cooling requirements estimated in all of the analyses are due to sensible heat gains. The latent load may be estimated by assuming a wet-bulb temperature distribution for the ambient air in each month and knowing the monthly average latent heat generation in the house.

7. CONCLUSIONS

From the energy analysis carried out for a residential building located in Ottawa, using:

(i) ten years (1967–76) of weather data;

(ii) the data generated from the same ten years of weather data to represent a typical meteorological year (TMY);

(iii) an hourly sinusoidal temperature distribution for a typical day in each month and the solar radiation intensities on each surface estimated from the mean monthly clearness index (called *T*2),

the following conclusions may be drawn.

(a) The ten-year average (TYA) monthly heating and cooling requirements are close to those estimated using TMY data. For the months of December and January, the differences between the predicted energy needs are about 1.4% and 3%, respectively. The annual heating requirement estimated by TYA and TMY differ only by about 6%. For the months of July and August, the differences are 10% and 18%, and the annual cooling needs differ by about 11%.

(b) The hourly, daily, monthly and annual heating and cooling energy requirements may be estimated by using an hourly sinusoidal temperature distribution and estimating the solar radiation intensity on each surface. All one needs are the mean daily maximum and minimum temperatures for each month and the mean monthly clearness index. These temperatures are often available at any weather station and the mean monthly clearness index can be estimated from a knowledge of cloud cover at the site.

(c) Although the close agreements between the energy requirements estimated using TMY and *T*2 (based on the mean monthly maximum and minimum temperatures and clearness index) are demonstrated for a residential building located in Ottawa, further investigation is needed (using different types of buildings and climatological conditions) to show the versatility of the procedure presented here for estimation of the energy requirements of buildings. In cities (particularly in the developing countries) for which detailed hourly weather data and TMYs are not available, one can use the *T*2 data and the procedure presented here to estimate the heating and cooling requirements of buildings.

Acknowledgements—The authors wish to thank Mrs. B. Neglia of the Building Engineering Group for typing the manuscript.

REFERENCES

1. S. J. Feldman and R. L. Merriam, Building energy analysis computer programs with solar heating and cooling capabilities. Arthur D. Little, Inc., Cambridge, Mass. Research Project 1269-1, August 1979.
2. W. O. Wray, A quantitative comparison of passive

solar simulation codes. *The Fifth National Passive Solar Conference*, AS/ISES pp. 121–125, Amherst, Massachusetts (1980).
3. T. Kusuda, Review of current calculation procedures for building energy analysis. U.S. National Bureau of Standards, Washington, D.C., NBSIR 80-2068, July 1980.
4. R. Judkoff, D. Wortman and B. O'Doherty, A comparative study of four building energy simulations: Phase II, DOE-2.1, BLAST-3.0, SUNCAT-2.4, and DEROB-4. *The Sixth National Passive Solar Conference*, AS/ISES pp. 367–371, Portland, Oregon (1981).
5. J. G. F. Littler, Comparison of design tools: carried out by member countries of the EEC. *The Eighth Annual Passive Solar Conference*, ASES pp. 895–898, Sante Fe, New Mexico (1983).
6. P. R. Rittelmann, S. F. Ahmed and J. E. Davy, Survey of design tools for passive and hybrid low energy buildings, *The Eighth Annual Passive Solar Conference*, ASES, pp. 93–98, Santa Fe, New Mexico (1983).
7. I. J. Hall, R. R. Prairie, H. E. Anderson and E. C. Boes, Generation of a typical meteorological year. *Proc. of the 1978 Annual Meeting of the American Section of the International Solar Energy Society*, pp. 669–671, Denver, Colorado (1978).
8. I. J. Hall, R. R. Prairie, H. E. Anderson and E. C. Boes, Generation of a typical meteorological year for 26 SOLMET stations. Sandia Laboratories *Report SAND* 78-1601, Albuquerque, New Mexico (1978).
9. D. L. Siurna, L. J. D'Andrea and K. G. T. Hollands, A Canadian representative meteorological year for solar system simulation. *Proc. Tenth Annual National Meeting of Solar Energy Society of Canada*, pp. 85–88, Calgary, Alberta (1984).
10. C. D. Barley, Passive solar modelling with daily weather data. *Proc. of the Fourth National Passive Solar Conference, American Section of the International Solar Energy Society*, pp. 278–281, Kansas City, Missouri (1979).
11. E. Arens, L. Flynn and D. Nall, A method to abbreviate hourly climate data for *computer simulation of annual energy* use in buildings. *Proc. of the Fourth National Passive Solar Conference*, pp. 282–286, American Section of the International Solar Energy Society, Kansas City, Missouri (1979).
12. M. N. Bahadori, M. J. Chamberlain and R. I. Nafziger, Analysis of passive cooling options for low-energy housing. Solar Energy Program, National Research Council Canada, Ottawa, Ontario (1984).
13. D. G. Erbs, S. A. Klein and W. A. Beckman, Estimation of degree-days and ambient temperature bin data from monthly average temperatures. *ASHRAE J.*, pp. 60–65, June 1983.
14. J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes*. John Wiley and Sons, New York (1980).
15. ——, *Canadian Normals, Temperature, 1941–1970*. Environment Canada, Downsview, Ontario (1975).
16. ——, *Canadian Normals, Wind, 1955–1972*. Environment Canada, Downsview, Ontario (1975).
17. J. E. Hay, An analysis of solar radiation data for selected locations in Canada. Fisheries and Environment Canada, Climatological Studies No. 32, October 1977.
18. J. F. Orgill and K. G. T. Hollands, Correlation equation for hourly diffuse radiation on a horizontal surface. *Solar Energy* **19**, 357 (1977).
19. S. C. Carpenter, Development of a General Computer Program for Simulation of Passive Solar Heating Systems: ENERPASS. *Proc. Energex '82, Solar Energy Society of Canada* pp. 760–765, Regina, Saskatchewan, Canada (1982).
20. G. N. Walton, *Thermal Analysis Research Program Reference Manual*. U.S. National Bureau of Standards, *NBSIR* 83-2655, March 1983.