Energy Vol. 17, No. 3, pp. 235–246, 1992
0360-5442

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A NEW METHOD FOR EVALUATING THE NORMALIZED ENERGY CONSUMPTION IN OFFICE BUILDINGS

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(Received 13 February 1991; received for publication 10 July 1991)

Abstract—Information derived from utility bills for commercial buildings can be directly used to define indices such as energy budget (kWh/m^2/yr), energy cost (\$/m^2/yr) or load factor. An analysis of these data reveals patterns of energy use in buildings and serves to disaggregate the total energy use among major end-uses. For example, weather-normalization permits comparison of the energy consumption of a building in two different years by eliminating the effect of different climatic conditions. In this paper, a new method is presented for weather-normalization and is used to evaluate the normalized energy consumption in several office buildings in Montréal. Finally, the results derived from our new method are compared with those obtained from the well-known PRISM method, using utility bills from 24 gas-heated buildings and 14 electrically-cooled buildings.

1. INTRODUCTION

The utility bills are the main source of information for evaluating the energy performance of commercial buildings. They usually, indicate: (i) the interval between readings (e.g., from 88/03/20 to 88/04/17) and the corresponding number of days, (ii) the total energy consumption (in kWh for electricity, liters for oil, m^3 for gas), (iii) the total cost (in dollars), (iv) the maximum electrical demand measured during that interval, and (v) the penalties for exceeding the subscribed electrical demand.

By using this information, the researcher can define indices such as energy budget expressed in equivalent kWh/m^2 floor area/yr, energy cost in \$/m^2 floor area/yr or load factor, or through a supplementary analysis of these data he can discover some patterns of the energy use in buildings. For example, a certain amount of energy used depends entirely on the climatic conditions, and this amount varies from building to building. The comparison of energy consumption in a building in two successive years can be meaningless if the effect of different weather conditions is not eliminated.

The weather-normalization techniques are usually based on the assumption that the energy consumption in a building is composed of a non-weather-dependent component, which is due to lighting, office equipment, appliances, hot water, and is almost constant throughout the year, and a weather-dependent component, which varies linearly with the climatic conditions, expressed as heating/cooling degree-days or outdoor temperature. The weather-dependent term is calculated for reference or long-term annual average conditions, giving the normalized annual energy consumption

$$\text{NAC} = a + bf(\text{climatic conditions}).$$

The PRInceton Scorekeeping Method (PRISM)[1] is a weather-normalization method, which was initially created for calculating changes in energy consumption in a group of heated houses without cooling, and subsequently was developed for evaluating changes in electrical consumption in houses with cooling systems and using another fuel for heating. These options correspond to the heating-only and cooling-only models in the PRISM program.[2] Later, analysis of the reliability of estimates from the PRISM program was extended to individual houses.[3] Presently, the heating and cooling model is under development for houses using electricity as the single source of energy.[4]

The PRISM method assumes a linear relationship between energy consumption and the heating or cooling degree-days, i.e.,

$$E_i = a + bH_i(T_{\mathrm{REF}}), \qquad [\mathrm{kWh}/(\mathrm{m}^2\,\mathrm{day})], \tag{1}$$

where E_i is the daily average energy consumption for the interval i, calculated by dividing the total amount indicated on the utility bill by the total floor area and by the number of days of that interval; a is the base level or non-weather-dependent daily energy consumption; b is the slope of the weather-dependent energy consumption and corresponds to the ratio between the heat-loss rate and the efficiency of the HVAC system; $H_i(T_{\mathrm{REF}})$ is the number of degree-days computed for the reference temperature T_{REF} within the interval i.

The user has to input the starting and ending day of each meter reading period, along with the energy consumption. For each location, three different weather data files must be available and contain the following information: (i) daily average temperature, calculated as the average of the maximum and minimum values, which are provided by the meterological stations; (ii) long-term average heating degree-days for several reference temperatures, and (iii) long-term average cooling degree-days for several reference temperatures.

Least-squares linear regression is then used to estimate the parameters a and b for a guessed value of the reference temperature T_{REF}. In the second step, an interactive procedure based on Newton's method is used to estimate T_{REF} for which the linear relationship between E_i and $H_i(T_{\mathrm{REF}})$ leads to the highest correlation coefficient R^2. Finally, the normalized annual energy consumption (NAC) is obtained by using the parameters a and b, together with the long-term annual average of heating or cooling degree-days $H_0(T_{\mathrm{REF}})$

$$\mathrm{NAC} = 365a + bH_0(T_{\mathrm{REF}}) \quad (\mathrm{kWh}/\mathrm{m}^2). \tag{2}$$

The PRISM has been used by several utility companies, research centres and private contractors to evaluate the efficiency of energy-conservation programs applied to houses.[1]

Reynolds and Fels[3] have defined the reliability criteria for estimates from the heating-only model applied to houses. The estimate of the normalized annual consumption (NAC) is reliable if (i) the correlation coefficient R^2 is ≥ 0.7, (ii) the coefficient of variation CV(NAC) is ≤ 0.06, and (iii) the standard error of the reference temperature does not have a very large or infinite value. The estimate of the heating part $bH_0(T_{\mathrm{REF}})$ is reliable if the coefficient of variation $\mathrm{CV}[bH_0(T_{\mathrm{REF}})]$ is equal to or less than 0.16.

Rufo and Brambley[5] used the cooling-only PRISM model to analyze the electrical consumption of houses in a hot and humid summer climate (St. Louis, MO) and the heating-only model for gas consumption in a mild heating climate (San Diego, CA). The normalized annual consumptions are well-determined, the values of R^2 being ≥ 0.8. However, the estimates of the heating or cooling slope b are less accurate in these climates, the standard error taking values between 0.19 and 0.30 for heating and 0.33 and 0.45 for cooling.

Reynolds et al[4] used the PRISM model to analyze the energy consumption in 52 small commercial buildings, and they suggested that the following reliability criteria for estimates of electrical use should be less restrictive than those for houses:

$$R^2 \geq 0.6 \text{ and CV (NAC)} \leq 0.08.$$

In addition, the criterion regarding the standard error of the reference temperature should be neglected.

Haberl and Vajda[6] applied the PRISM model to obtain daily components of steam consumption for two large office buildings in Washington, DC. Then, the daily metered data were used together with the PRISM estimates to evaluate the occupancy adjustments for each weekday, for both heating and non-heating seasons. In addition, the 3-D hourly profiles were used to identify the operational and maintenance problems.

Haberl and Komor[7] used the PRISM model to determine statistically the primary functions for which electricity is used in a shopping center. For instance, 80% of total electrical consumption of the general merchandise store was used as base level, and only 20% for cooling. The coefficient of correlation R^2 was equal to 0.954, and the coefficient of variance CV was equal to 0.019.

Haberl et al[8] developed the Building Energy Analysis Consultant (BEACON) system, that is capable of continuously monitoring and diagnosing the operation and maintenance problems. The system was composed of two major components: (i) regression-based predictors of "normal" energy consumption, and (ii) an expert system, containing facts and heuristics about the operational characteristics and the causes of "abnormal" energy consumption.

Another weather-normalization approach was suggested by Kusuda,[9] developed by Zmeureanu[10] and uses the energy signature of a building, which is defined as a relation between the daily average energy consumption and the daily average outdoor temperature, along with the frequency of occurrence of several temperature bins, in order to calculate the normalized annual energy consumption.

In this paper, the method previously introduced by the author is modified to use long-term average temperature data, calculated over a 15-yr period (1974–1988), and is then used to evaluate the normalized annual energy consumption for a sample of office buildings in Montréal. Finally, the results from the new method are compared with those given by the PRISM method.

2. THE NEW METHOD

Our new method may be used for all building types, using either electricity as a unique energy source or any combination of electricity, gas, oil, and steam. In this paper, the method is only applied to office buildings using gas for heating and electricity for cooling, lighting and equipment. The domestic hot water is heated either by gas or electricity.

This method can be used by a researcher/designer to analyze the utility bills collected from a commercial building, along with weather data from the closest meteorological station. A small micro-computer program has to be developed, and then linked to a commercially available statistical analysis package to perform the analysis. This approach is used to analyze quickly the energy performance of several office buildings and to compare the new method with the PRISM method. However, the most interesting use of this method is within the application software of the Energy Management and Control Systems (EMCS) installed in large commercial buildings. These systems record data such as outdoor temperature, number of hours of operation, starting and stopping time of HVAC systems, and energy used by the entire building or used for the major end-uses.

Implementation of this method is an easy task for the developer of the application software. It enables the building manager or the operating team to evaluate the normalized energy use and the base load during different periods of operation (e.g., on weekdays vs weekends, days vs nights, summer vs winter). The base-load energy consumption can be used along with other data provided by EMCS to disaggregate the total energy use into the major end-uses and to define daily, monthly and seasonal patterns of energy use. The actual normalized energy consumption can be continuously compared with some target values, assessed by the building manager. Any excesses will generate an appropriate warning.

Our method involves the following two steps, which correspond to (i) development of the building energy signature and (ii) calculation of the normalized annual energy consumption.

Step 1

The building energy signature is defined as a linear relation between the daily average energy consumption E_i expressed in equivalent kWh/(m^{2}yr) and the daily average outdoor temperature T_i in °C, for each meter reading interval i, i.e.,

$$E_i = \alpha + \beta T_i. \quad (3)$$

The hourly dry-bulb temperatures at Dorval airport in Montréal over a period of 15 yr (1974–1988) are available in a weather-data file from Environment Canada, Atmospheric Environment Service. Since there is a large difference, in large commercial buildings, in the pattern of energy consumption between occupied and unoccupied hours, it seems appropriate to calculate the average daily temperature for each meter reading interval, using only values corresponding to the operating hours of the HVAC system. For example, the average daily temperature for the interval 21 December 1987–22 January 1988, with the HVAC system on between 7:00 and 20:00, is −7.00°C, while it is −7.29°C for 24-h operation.

If this method is implemented within an Energy Management and Control System, then the operating hours are continuously monitored. If this method is used by an individual researcher, then the information about the operating hours is provided by the building manager along with the utility bills or other data such as total rentable area.

The Statgraphics statistical package[11] is used to plot and visualize the distribution of monitored data $(E, T)_i$, and to eliminate the obvious outliers. A simple procedure is then used to define the base load or non-weather-dependent energy consumption: (i) select the lowest energy consumption E_i, which usually occurs in the summer for gas-heated buildings and in the winter for electrically-cooled buildings. However, in some office buildings, the minimum electrical consumption is noticed in April/May or September/October. (ii) In the case of electrically-cooled buildings, which have the larger variation of energy consumption, we accept a maximum variation of the monitored base load of about 10% around the average value. Therefore, all monitored energy consumption with values between E_{min} and $1.2E_{min}$ is considered to be independent of the outdoor temperature. If the energy consumption for at least two more meter reading intervals falls within the given range, then the base-load electrical energy consumption B_L is calculated as the average of values within that range. In another case, the point corresponding to the previous minimum energy use is eliminated as being an outlier, a new minimum energy consumption is selected, and then the process is repeated. For gas-heated buildings, the minimum energy consumption indicates directly the base load energy use. (iii) The monitored data $(E, T)_i$, which are not included in the base-load, are then used to define the weather-dependent energy signature. By using the simple linear regression analysis provided by the statistical package, the coefficients α and β are obtained, along with some statistics such as the correlation coefficient R^2, standard error and t-statistics.

The coefficient β is expressed in kWh/(m^2 day °C), and indicates the rate of increase of the weather-dependent energy consumption. The building consumes energy above the base load only when the outdoor temperature drops below the reference temperature T_{REF} (heating) or increases above T_{REF} (cooling). Hence, the reference temperature at which the weather-dependent curve equals the base load $E = \alpha + \beta\ T_{REF} = B_L$ is calculated as follows:

$$T_{REF} = (B_L - \alpha)/\beta. \quad (4)$$

Therefore, the building energy signature is developed for the interval covered by the utility bills. However, as proved by Zmeureanu[10] based on computer simulation, this energy signature does not change in time, unless some renovations or modifications in operation take place in the building.

Step 2

The energy signature is now used, along with outdoor temperature data, to calculate the normalized annual energy consumption (NAC). Calculations are performed for the period covered by the utility bills. By comparing the results with the monitored energy consumption, a correction coefficient ε for the weather-dependent term is obtained:

$$\varepsilon = [(E_m - N_m B_L)/C_1] N_m N^2_{HVAC}/N_T, \quad (5)$$

where E_m = total energy consumption from the utility bills in kWh/(m^{2}yr), N_m = total number of days covered by the utility bills, B_L = base-load energy consumption in kWh/(m^2 day), N_T = total number of hours when $T_{DB} < T_{REF}$ for gas-heated or $T_{DB} > T_{REF}$ for electrically-cooled buildings, N_{HVAC} = number of daily operating hours of HVAC systems in hours/days. The weather-dependent energy consumption is

$$C_1 = \begin{cases} \sum_{i=1}^{n} (\alpha \mp \beta T_{DB,i} - B_L)\mathrm{BIN}(T_{DB,i}) & \text{if } T_{DB} < T_{REF}(\text{heating}), \\ & \text{or } T_{DB} > T_{REF}(\text{cooling}), \\ 0 & \text{if } T_{DB} \geq T_{REF}(\text{heating}), \\ & \text{or } T_{DB} \leq T_{REF}(\text{cooling}). \end{cases} \tag{6}$$

$\mathrm{BIN}(T_{DB,i})$ is the number of hours of occurrence of the dry-bulb temperature bin having T_{DB} as center during operation of the HVAC system. The minus sign (−) corresponds to the heating model and the plus sign (+) to the cooling model. The number of hours N_T and $\mathrm{BIN}(T_{DB,i})$ are calculated by using the weather-data file.

The normalized annual energy consumption is calculated by using the hourly data of the dry-bulb temperature over a 15-yr period, viz.

$$\mathrm{NAC} = 365B_L + \varepsilon C N_{T,15}/(365N_{HVAC}^2), \tag{7}$$

where $N_{T,15}$ is the number of hours when $T_{DB} < T_{REF}$ for gas-heated or $T_{DB} > T_{REF}$ for electrically-cooled buildings, calculated as an average over a 15-yr period. The weather-dependent energy consumption, calculated as an average over a 15-yr period, is

$$C = \begin{cases} \frac{1}{15}\sum_{j=1}^{15}\sum_{i=1}^{n} (\alpha \mp \beta T_{DB,i,j} - B_L)\mathrm{BIN}(T_{DB,i,j}) & \text{if } T_{DB} < T_{REF}(\text{heating}), \\ & \text{or } T_{DB} > T_{REF}(\text{cooling}), \\ 0 & \text{if } T_{DB} \geq T_{REF}(\text{heating}), \\ & \text{or } T_{DB} \leq T_{REF}(\text{cooling}). \end{cases} \tag{8}$$

By replacing the correction coefficient ε, one obtains the final formula for calculating the normalized annual energy consumption

$$\mathrm{NAC} = 365B_L + \begin{cases} (E_m - N_m B_L)\frac{C}{C_1}\frac{N_{T,15}}{N_T}\frac{N_m}{365} & \text{if } T_{DB} < T_{REF}(\text{heating}), \\ & \text{or } T_{DB} > T_{REF}(\text{cooling}), \\ 0 & \text{if } T_{DB} \geq T_{REF}(\text{heating}), \\ & \text{or } T_{DB} \leq T_{REF}(\text{cooling}). \end{cases} \tag{9}$$

3. NORMALIZED ANNUAL GAS ENERGY CONSUMPTION OF OFFICE BUILDINGS IN MONTREAL

In this section, the new method is used to calculate the normalized annual gas energy consumption for several office buildings in Montréal, and then the results are compared with those given by the PRISM method.

During a survey of the energy performance of office buildings in Montréal carried out by Zmeureanu et al,[12] and Zmeureanu and Fazio[13] the utility bills of 74 buildings with a total rentable area of about 2.5 million m^2 were collected. The comparison between the PRISM and

Table 1. Parameters in the normalized annual gas consumption resulting from use of the new method.

Building	NAC kWh/ m^2yr	Base Load kWh/ m^2day	Weather - dependent energy signature $G = \alpha - \beta . T_{DB}$							
			R^2	α kWh/ m^2 day	CV(α)	t(α)	β kWh/ m^2 day°C	CV(β)	t(β)	T_{ref} [°C]
2	22.63	0	0.849	0.114	0.14	7.12	0.013	0.154	5.3	8.77
6	206.91	0.04	0.681	0.887	0.121	8.3	0.038	0.211	4.8	22.29
11	202.78	0	0.808	1.515	0.107	9.4	0.078	0.167	5.8	19.42
15	505.61	0.36	0.98	1.859	0.02	45.2	0.068	0.044	22.3	22.04
19	267.80	0.07	0.985	0.962	0.023	43.3	0.04	0.025	25.2	22.30
20	75.19	0.004	0.876	0.356	0.087	11.6	0.019	0.105	8.0	18.53
21	261.98	0.14	0.926	0.992	0.049	20.4	0.041	0.088	11.2	20.78
22	265.15	0.027	0.769	1.140	0.118	8.5	0.056	0.179	5.5	19.88
24	189.19	0	0.852	0.644	0.098	10.2	0.032	0.156	6.8	20.13
30	255.20	0.003	0.93	0.936	0.041	24.4	0.049	0.065	15.4	19.04
31	52.69	0.008	0.828	0.208	0.087	11.7	0.009	0.144	6.9	22.22
33	279.37	0.037	0.973	1.084	0.035	28.7	0.053	0.058	16.9	19.76
36	243.78	0	0.615	0.935	0.129	7.8	0.047	0.321	3.1	19.89
39	266.75	0.03	0.894	1.159	0.071	14.2	0.053	0.115	8.7	21.30
40	257.28	0	0.981	1.194	0.029	33.8	0.071	0.056	18.7	16.82
42	176.03	0	0.888	0.856	0.075	13.4	0.041	0.112	8.9	20.88
43	488.73	0.04	0.882	2.88	0.071	14.1	0.129	0.116	8.7	22.02
47	380.93	0.35	0.878	1.295	0.06	16.3	0.049	0.112	8.9	19.30
50	573.42	0	0.723	2.811	0.105	9.5	0.141	0.255	3.9	19.94
51	236.00	0	0.685	1.076	0.139	7.15	0.06	0.25	3.9	17.93
59	116.42	0.007	0.415	0.287	0.237	4.2	0.016	0.356	2.8	17.50
60	172.90	0.02	0.833	0.453	0.093	10.8	0.021	0.143	6.7	20.62
61	463.95	0	0.822	1.383	0.074	13.5	0.072	0.153	6.4	19.21
63	181.73	0.003	0.901	0.737	0.065	10.4	0.0335	0.104	9.5	21.91
Average	256.08	0.047	0.833	-	0.086	16.0	0.051	0.146	9.35	19.84

Table 2. Parameters in the normalized annual gas consumption (NAC) resulting from use of the PRISM analysis using the daily average outdoor temperature over 24 h [$NAC = 365\ \alpha - \beta H_0(T_{REF})$].

Building	NAC [kWh/ m²yr]	R²	CV(NAC)	α [kWh/ m² day]	CV(α)	β [kWh/ m² day°F]	CV(β)	T_ref [°C]
2	23.07	0.915	0.122	0.0039	2.86	0.009	0.374	3.5
6	203.50	0.943	0.071	0.0692	1.03	0.0326	0.149	12.6
11	202.06	0.858	0.136	0.0365	3.87	0.0363	0.25	11.9
15	494.50	0.983	0.025	0.3072	0.37	0.0424	0.062	19.9
19	262.55	0.905	0.078	0.0231	7.73	0.0286	0.15	19.7
20	79.59	0.95	0.083	0.0109	2.88	0.0168	0.136	10.1
21	253.02	0.967	0.04	0.1807	0.34	0.0291	0.111	14.8
22	264.38	0.804	0.154	-0.0224	13.60	0.0377	0.291	16.5
24	182.23	0.901	0.104	0.0134	7.78	0.0285	0.203	14.3
30	271.24	0.957	0.043	-0.0373	2.21	0.0393	0.075	16.6
31	51.41	0.831	0.116	-0.0181	5.29	0.0054	0.201	22.8
33	283.72	0.986	0.039	-0.0609	2.01	0.0372	0.073	18.5
36	242.98	0.821	0.132	-0.0672	4.25	0.0328	0.24	18.3
39	266.08	0.902	0.097	-0.0255	8.34	0.0323	0.18	19.0
40	258.55	0.993	0.026	-0.0375	1.19	0.0408	0.049	15.3
42	175.84	0.912	0.088	0.0178	5.54	0.0253	0.18	15.4
43	476.26	0.884	0.091	-0.1048	4.01	0.0554	0.167	20.4
47	374.29	0.904	0.058	0.3297	0.542	0.0323	0.161	17.8
50	562.75	0.869	0.113	-0.1734	3.21	0.076	0.197	18.5
51	236.46	0.868	0.13	0.0316	4.95	0.0439	0.249	11.7
59	106.66	0.481	0.30	-0.0092	22.66	0.0176	0.558	14.4
60	168.48	0.831	0.117	-0.0552	4.92	0.0181	0.214	22.3
61	500.58	0.944	0.076	-0.1783	1.94	0.0608	0.131	20.4
63	176.71	0.912	0.082	-0.0201	6.43	0.0208	0.149	19.6
Average	254.84	0.89	0.097	-	4.91	0.033	0.189	16.43

the new method is then performed using those data from the survey which correspond to buildings using different energy sources for heating and cooling, such as gas for heating and electricity for cooling. Table 1 presents the parameters of the normalized annual gas consumption resulting from the new method, along with some statistics, and Table 2 presents results given by the PRISM method.

The maximum difference of the normalized annual gas consumption between these two methods is 9.2%, with an average of 0.5% for the entire sample (Table 3). The maximum difference in estimating the part of heating in the total gas consumption is 8.9% with an average of 0.6% for the entire sample.

Additional comments concerning the results given by the PRISM method are of interest. Since the energy consumption in office buildings is influenced by a large number of parameters related to operation of the building and HVAC systems, the reliability criteria for estimates, as defined by Reynolds and Fels[3] and presented in Sec. 1 seem to be too severe for this type of building. Although the correlation coefficient R^2 is >0.8, which satisfies the specified criteria, the coefficient of variation CV(NAC) exceeds the recommended value of 0.06 (Fig. 1). It appears that for office buildings an upper limit of 0.14 is more appropriate to account for the large number of factors affecting energy use.

4. NORMALIZED ANNUAL ELECTRICAL CONSUMPTION OF OFFICE BUILDINGS IN MONTREAL

Among 24 office buildings used in the previous section for analysis of gas consumption, only 14 show a clear pattern of electrical energy consumption. For example, Fig. 2 shows variations

Table 3. Normalized annual gas consumption calculated by PRISM and new methods.

		Interval of Consumption yy/mm/dd		Normalized Annual Gas Consumption (NAC) [kWh/m²yr]			Heating Consumption NAC		
Building	Gas Consumption [kWh/m²/yr]	From	To	PRISM	New	Difference [%]	PRISM	NEW	Difference [%]
2	22.37	87/12/21	88/12/23	23.07	22.63	-1.9	0.938	1.0	6.6
6	199.29	87/12/29	88/12/28	203.50	206.91	1.7	0.876	0.93	6.2
11	197.15	87/12/29	88/12/28	202.06	202.78	0.4	0.934	1.0	7.1
15	489.23	88/01/01	88/12/31	494.50	505.61	2.2	0.773	0.74	-4.3
19	258.72	87/12/23	88/12/23	262.55	267.80	2.0	0.968	0.905	-6.5
20	60.52	87/12/23	88/11/23	79.59	75.19	-5.5	0.95	0.981	3.3
21	223.98	87/12/18	88/11/23	253.02	261.98	3.5	0.739	0.805	8.9
22	259.18	87/12/23	88/12/23	264.38	265.15	0.3	1.0	0.963	-3.7
24	152.74	87/12/22	88/11/22	182.23	189.19	3.8	0.973	1.0	2.8
30	247.81	87/07/07	88/06/29	271.24	255.20	-5.9	1.0	0.996	-0.4
31	50.45	88/01/01	88/12/31	51.41	52.69	4.0	1.0	0.945	-5.6
33	271.30	87/12/23	88/12/22	283.72	279.37	-1.5	1.0	0.952	-4.8
36	236.37	87/11/20	88/11/23	242.98	243.78	0.3	1.0	1.0	0
39	255.94	87/12/29	88/12/28	266.08	266.75	0.3	1.0	0.959	-4.1
40	254.79	87/12/23	88/12/22	258.55	257.28	-0.5	1.0	1.0	0
42	168.92	87/08/24	88/08/26	175.84	176.03	0.1	0.963	1.0	3.8
43	474.81	87/11/11	88/11/17	476.26	488.73	2.6	1.0	0.985	-1.5
47	369.50	87/11/23	88/11/25	374.29	380.93	1.8	0.678	0.664	-2.1
50	557.82	87/12/23	88/12/22	562.75	573.42	1.9	1.0	1.0	0
51	247.33	87/12/11	88/12/20	236.46	236.00	-0.2	0.951	1.0	5.2
59	114.05	87/12/23	88/12/22	106.66	116.42	9.2	1.0	0.978	-2.2
60	133.06	88/02/02	88/12/28	168.48	172.90	2.6	1.0	0.958	-4.2
61	406.63	88/01/07	88/12/22	500.58	463.95	-7.3	1.0	1.0	0
63	174.07	87/12/23	88/12/22	176.71	181.73	2.8	1.0	0.994	-0.6
Average	245.50	-	-	254.84	256.08	0.5	0.95	0.956	0.6

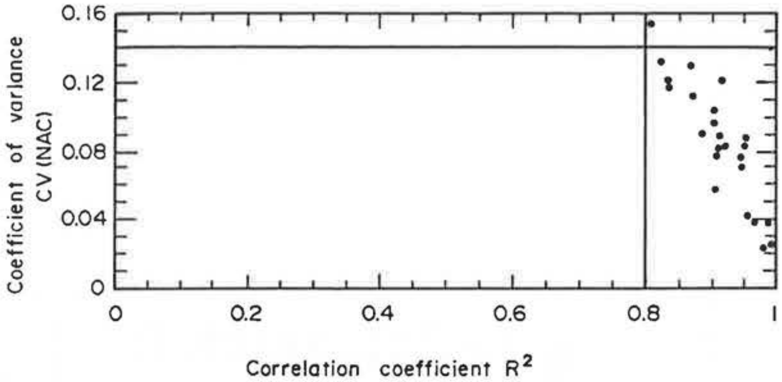

Fig. 1. Coefficient of variance CV(NAC) vs the correlation coefficient R^2 for gas-heated office buildings, as given by the PRISM method.

of the daily energy consumption in two buildings and suggests that other factors such as modification of the thermal control or renovation of the building envelope or mechanical systems played a major role. Hence, the weather-normalization techniques can be applied only to 14 buildings from the previously mentioned sample. Table 4 presents the parameters of the normalized annual electrical consumption resulting from the new method, along with some statistics, and Table 5 presents results given by the PRISM method. The maximum difference of the normalized annual electrical consumption between these two methods is 17.2%, with an average of 3.4% for the entire sample (Table 6). We note that the part of the cooling-energy consumption due to the climatic conditions is about 10% of the total energy use, and the rest is mainly used for lighting, office equipment and evacuation of the internal heat gains. Referring

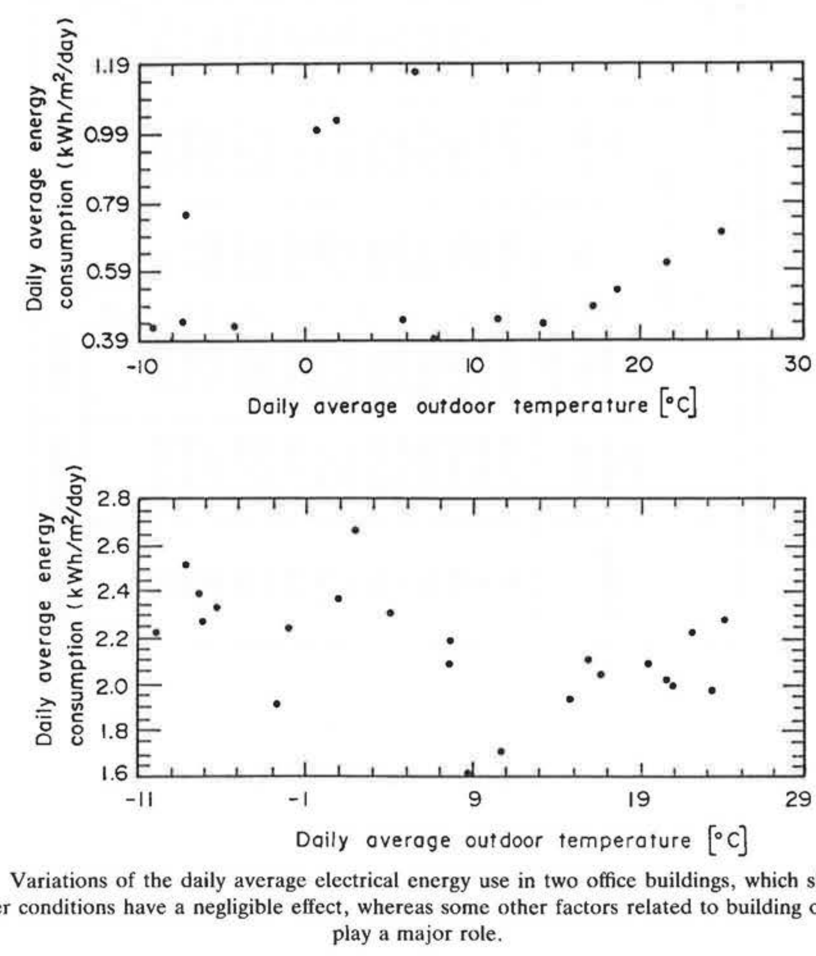

Fig. 2. Variations of the daily average electrical energy use in two office buildings, which show that weather conditions have a negligible effect, whereas some other factors related to building operation play a major role.

Table 4. Parameters of the normalized annual electrical consumption resulting from use of the new method.

Building	NAC [kWh/ m^2yr]	Base Load [kWh/ m^2day]	Weather - dependent energy signature $E = \alpha + \beta.T_{DB}$							T_{ref} [°C]
			R^2	α [kWh/ m^2day]	CV(α)	t(α)	β [kWh/ m^2day°C]	CV(β)	t(β)	
2	235.42	0.645	0.10	0.753	0.02	49.9	-0.0012	0.917	1.1	90.0
6	206.59	0.566	0.57	0.654	0.044	22.7	0.0089	0.292	3.45	-9.9
19	258.65	0.613	0.75	0.624	0.039	25.8	0.0098	0.184	5.5	-1.12
20	324.86	0.818	0.31	0.815	0.026	38.4	0.0033	0.485	2.1	0.91
21	135.74	0.328	0.54	0.333	0.063	16.1	0.0052	0.288	3.4	-0.96
23	207.51	0.471	0.56	0.46	0.03	32.4	0.0042	0.262	3.75	2.62
24	315.14	0.787	0.86	0.637	0.028	35.9	0.0097	0.134	7.6	15.46
30	84.82	0.222	0.89	0.181	0.021	48.0	0.0018	0.139	7.5	22.8
31	238.38	0.65	0.061	0.721	0.053	18.8	-0.0023	1.24	0.8	30.8
33	109.52	0.224	0.83	0.104	0.385	2.6	0.0136	0.184	5.4	8.8
39	217.25	0.563	0.64	0.555	0.042	23.8	0.0074	0.23	4.2	1.08
40	83.47	0.173	0.89	0.180	0.039	25.3	0.004	0.125	8.1	1.75
43	240.40	0.517	0.79	0.545	0.073	13.7	0.0226	0.146	6.9	-1.24
47	421.39	0.933	0.54	0.914	0.047	21.2	0.0112	0.295	3.5	1.70
Average	219.99	0.536	0.595	-	0.065	26.76	0.007	0.351	4.52	-

Table 5. Parameters of the normalized annual electrical consumption resulting from use of the PRISM analysis [$NAC = 365\ \alpha + \beta H_0(T_{REF})$].

Building	NAC [kWh/m²yr]	R^2	CV(NAC)	β [kWh/m²day]	CV(α)	β [kWh/m²day °F]	CV(β)	T_{ref} [°C]
2	237.54	0.01	0.019	0.6501	0.02	0.2874	3.17	27.8
6	210.59	0.69	0.035	0.5306	0.049	0.0149	0.69	14.1
19	254.82	0.94	0.014	0.6168	0.022	0.0175	0.192	12.1
20	300.83	0.58	0.018	0.8167	0.019	0.0775	4.43	23.3
21	137.96	0.43	0.059	0.3388	0.09	0.0077	0.89	11.1
23	187.54	0.61	0.03	0.4696	0.051	0.0088	0.60	11.4
24	318.20	0.94	0.014	0.7777	0.022	0.0145	0.226	9.35
30	87.62	0.77	0.023	0.2218	0.038	0.0031	0.47	10.0
31	247.68	0.08	0.041	0.6746	0.043	0.0585	22.3	23.9
33	106.64	0.95	0.029	0.2278	0.05	0.018	0.19	13.3
39	214.49	0.84	0.023	0.5353	0.032	0.0173	0.415	14.2
40	73.23	0.91	0.027	0.1588	0.061	0.0033	0.227	2.9
43	205.14	0.95	0.018	0.5150	0.023	0.0356	0.283	17.7
47	396.48	0.59	0.033	0.9841	0.048	0.0151	0.66	9.03
Average	212.77	0.66	0.027	-	0.041	0.041	2.48	-

to the reliability criteria for the results given by the PRISM method, we observe (Fig. 3) that the lowest correlation coefficient R^2 is about 0.5, while the coefficient of variation CV(NAC) is below 0.04, with only one exception of 0.06.

5. CONCLUSIONS

The new method is an alternative offered to building managers, owners, designers, and researchers to evaluate the normalized annual energy consumption and the base load, and shows results which are comparable with those provided by the PRISM method.

Table 6. Normalized annual electrical consumption calculated by use of the PRISM and new methods.

		Interval of Consumption		Normalized Annual Electrical Consumption NAC [kWh/m²yr]			Cooling Consumption / NAC	
Building	Electrical Consumption [kWh/m²yr]	From	To	PRISM	Proposed	Difference [%]	PRISM	Proposed
2	239.13	87/12/21	88/12/23	237.54	235.42	-0.9	0	0
6	200.89	87/12/22	88/12/23	210.59	206.59	-1.9	0.08	0
19	259.90	88/01/04	88/12/31	254.82	258.65	1.5	0.116	0.135
20	331.44	87/11/20	88/11/24	300.83	324.86	8.0	0.008	0.081
21	137.36	87/12/23	88/12/23	137.96	135.74	-1.6	0.103	0.118
23	212.58	87/12/02	88/12/06	187.54	207.51	10.6	0.085	0.172
24	321.41	87/11/23	88/11/25	318.20	315.14	-1.0	0.107	0.088
30	88.39	87/11/04	88/11/03	87.62	84.82	-3.2	0.076	0.045
31	257.54	88/01/01	88/12/31	247.68	238.38	-3.8	0.005	0.005
33	107.32	88/12/22	88/11/28	106.64	109.52	2.7	0.22	0.253
39	219.66	87/12/22	88/12/23	214.49	217.25	1.3	0.088	0.054
40	79.75	87/11/30	88/11/01	73.23	83.47	14.0	0.208	0.244
43	244.39	87/11/10	88/11/10	205.14	240.40	17.2	0.083	0.215
47	430.36	87/11/02	88/11/05	396.48	421.39	6.3	0.093	0.192
Average	242.02	-	-	212.77	219.99	3.4	0.091	0.114

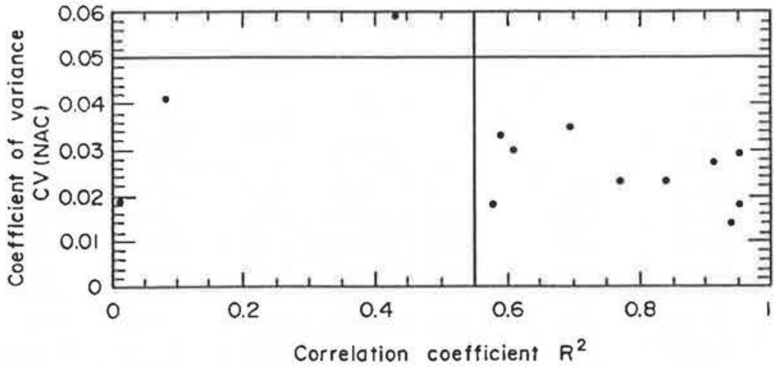

Fig. 3. Coefficient of variance CV(NAC) vs the correlation coefficient R^2 for electrically-cooled office buildings, as given by the PRISM method.

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