PREDICTING ENERGY USE - INFLUENCE OF THE RECORDING INTERVAL*

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ABSTRACT

The recording interval used to record energy use data for evaluating the performance of residential buildings often differs considerably when comparing energy use evaluation studies. Utility data are typically recorded on an approximate monthly basis, which is in contrast to an evaluation of solar heat gain effects which may require hourly or more frequent data. A variety of recording intervals between these two is also commonly used.

This paper discusses a study that showed that the recording interval has considerable influence on the heating energy use rate (slope) and the base temperature resulting from a regression model used to model heating energy use. Fifteen-minute space heating energy use data recorded for four electrically-heated homes in the Minneapolis, Minnesota, area between Jan. 1 and April 30, 1982 were used in the study. The data were aggregated to create the data sets needed to examine the effects of changes in the recording interval on model parameters. An increase in the recording interval increased the slope of the regression model and decreased the predicted base temperature of the building. In predicting annual space heating energy use in a typical meteorological year (TMY), the compensatory changes that occurred in the slope and base temperature were not sufficient to prevent significant differences. The variation was 1-7% for the 4 houses studied.

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INTRODUCTION

Utilities typically record residential energy consumption on an approximate monthly basis. Thus, one year of data yields only 12 points for characterizing the annual fuel use of a residence. In the case of heating energy, eight points or less may apply. As a result, the researcher seeking to evaluate the energy related performance of a residential building will often record data on a more frequent basis. The selection of the data recording interval is often made with little regard for its effects on regression models used in many energy use analysis methods. A look at the effects of using different recording intervals on a selected energy use model is the subject of this paper. This information may be both informative and valuable to the researcher making decisions about data recording intervals.

Capabilities of available data acquisition systems are such that restrictions due to equipment capabilities and personnel time limitations are becoming smaller factors in influencing the recording interval selection. These systems allow energy consumption to be measured at frequent intervals and have sufficient internal storage to free the researcher from continuous involvement in the measurement process. Thus, data recording intervals as small as 15 minutes are commonly being used in an attempt to better understand the energy use of a building.

Several things happen when using small recording intervals that do not occur when using a larger interval. If the interval is small enough, the heating system may be on, off, or both in the course of the interval for a given outdoor temperature. This is due to thermostat dead bands, internal loads, internal heat capacities, and other characteristics. Measurements of zero energy use for outdoor temperatures well below the base temperature of the building result. Also, for the same outdoor temperature, the heating system may be on for as little as one minute of a 15-minute period or on for the entire period. This phenomenon is responsible for the high scatter common in data recorded in short time intervals.

This study was performed to examine the effects of the recording interval on regression model parameters and resulting predictions of energy use. Thus, some direction to the researcher involved in energy use performance monitoring may be provided.

METHODOLOGY

A data set of 15-minute space heating energy use data recorded for four electrically-heated residences in the Minneapolis, Minnesota, area was used to examine recording interval effects. The data covered a 16 week period (10,752 15-minute temperature and energy use rate averages recorded between Jan. 1 and April 30, 1982) for each home. Five recording intervals were constructed by aggregating (averaging) individual data points: 15 minutes, hourly, daily, weekly, and biweekly.

The influence of the recording interval was studied by performing linear regressions of heating energy use rate on outdoor temperature using a model of the form:

$$EC' = \hat{A}_0 + \hat{A}_1 * T_i \qquad (1)$$

where the hat (ˆ) symbol indicates estimated values and

- EC' = rate of heating energy use, watts,
- $\hat{A}_0$ = intercept of the regression line with the heating energy use rate axis, watts,
- $\hat{A}_1$ = slope, rate of heating energy use per unit of temperature difference, watts/^oF,
- T_i = average outdoor temperature for the ith interval, ^oF.

The base temperature of each house, T_b, was that temperature which corresponded to the intersection of the regression line with the temperature axis, i.e., the temperature at which the heating energy use rate was zero. To determine T_b, one can set EC'=0 and solve Equation 1 to obtain

$$T_b = - \hat{A}_0 / \hat{A}_1. \qquad (2)$$

Slope and intercept regression parameters from Equation 1 were used to predict energy use via the relation:

$$EC^* = k * SUM_{i=1}^{n} \{ \hat{A}_0 + \hat{A}_1 * T_i \}, \qquad (3)$$

where "SUM" indicates a summation and

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*For this study, all zero values in the data sets were used in the calculation of EC of the measurement period since few values were recorded when outdoor temperatures exceeded the estimated T_b. For predicting energy use using TMY data, temperatures above T_b were considered not to contribute to the values calculated from Equations 3 and 4.

EC = heating energy use, watt-hours,

k = length of recording interval, hours,

n = number of intervals in the consumption period, and

T_i = average temperature in the ith interval of the consumption period, ^oF.

Standard errors for the predicted heating energy use (SE_{EC}) were estimated from the relationship:

$$(SE_{EC})^2 = k^2 * \{ [n^2 * Var \hat{A}_0] + [(SUM\ T_i)^2 * Var \hat{A}_1] + [2 * n * (SUM\ T_i) * Cov (\hat{A}_0,\hat{A}_1)] \} \quad (4)$$

where

$Var \hat{A}_0$ = variance of the intercept estimate, $watts^2$,

$Var \hat{A}_1$ = variance of the slope estimate, $watts^2/^oF^2$, and

$Cov (\hat{A}_0,\hat{A}_1)$ = covariance of the slope and intercept estimates, $watts^2/^oF$.

It should be noted that the standard errors calculated from Equation 4 may give conservative values since they do not include any variance associated with the estimate of T_b.

RESULTS

Zero energy use was recorded for several intervals in each 15-minute data set. When aggregated to generate longer interval data sets, several zero energy use values also resulted for hourly data. No zero values occurred in the daily, weekly, or biweekly data. The frequency of zero values in the 15-minute data sets ranged from less than 1% to approximately 9%. A summary of the zero data points in each data set is presented in Table I.

The inclusion and deletion of zero energy use values can have significant effects on the base temperature resulting from heating energy models. When analyzing data that includes significant periods of non-heating, care must be exercised in the treatment of non-heating periods.[1,2] The zero values and their corresponding temperatures for the 15-minute and hourly data sets of House 21 can be seen in Figures 1 and 2. Since zero energy use values recorded at temperatures above estimated base temperatures comprised only a small percentage of recorded data (see Figure 1), zero energy use values were not deleted from any data set in these analyses.

To examine the magnitude of errors associated with the prediction of energy use, standard errors were calculated for the space heating energy use of the measurement period predicted from measured temperature data.* Standard errors of predicted heating energy use for the measurement period ranged from less than 0.5% for the 1/4-hour recording interval (10,752 data points) to 4.0% for the biweekly interval (8 data points). Standard errors from linear regression models are strongly influenced both by the number of data points and by the scatter within the data set. The severity of scatter for these models is indicated by the square of the correlation coefficient, R^2. An R^2 of 1 indicates perfect correlation such that all data points lie on the regression line. Values of R^2 from the 15-minute data sets averaged 0.59, reflecting the high scatter in 15-minute data. Average R^2 values for the hourly to biweekly data sets ranged from 0.74 to 0.97. R^2 values, standard errors of predicted heating energy use, and regression model parameters for the four houses are summarized in Tables II and III. Typical scatter in 15-minute to weekly data sets can be seen in Figures 1 through 4.

In general, the slope of the regression model increased considerably as the recording interval became longer (see Tables II and III). Between the shortest (1/4-hour) and longest (biweekly) intervals, the slope of the regression model increased approximately 15% for Houses 23, 24, and 25. An increase of only 2% occurred for House 21. In conjunction with the slope increase, the base temperature decreased in response to longer recording intervals. Between the two extreme recording intervals, the base temperature decreased between 5.3 and 6.5 ^{o}F for Houses 23, 24, and 25. A 1 ^{o}F decrease occurred for House 21.

Since the regression models must all pass through the point of average use and average temperature (which is the same for all intervals), any change in the slope of the regression line will be associated with a change in the base temperature in the opposite direction. As a result, the predicted heating energy use for the <u>measurement period</u> is unaffected by recording interval changes. When the slope and base temperature were used to calculate the energy use for a time period corresponding to the dates of the measurement period but using outdoor temperature data for a typical meteorological year (TMY), predicted energy use was approximately equivalent for all recording intervals (within 1.6% in all cases). Results differed when TMY outdoor temperature data were used to predict annual energy use. Differences in predicted annual energy use between the 1/4-hour and biweekly recording intervals ranged from 5 to 7.2% for Houses 23,24, and 25, and only about 1% for House 21. On average, the smallest change in predicted annual energy use occurred between the 1/4-hour and hourly data sets (~0) and the weekly and

*The measurement period is the 16 weeks over which data was collected. In using the measured temperature data on which the model was based, the least-squares method results in predicted energy use = measured energy use for the measurement period.

biweekly data sets (0.6%). The ratio of the number of data points used in the regression model changed the least in going between these intervals (4 to 1 and 2 to 1). The predicted annual energy consumption using TMY outdoor temperatures and the slope and base temperature values for each recording interval are summarized in Table IV.

The change in base temperature from the 1/4-hour to biweekly recording interval for House 21 was 0.9 F and corresponded to a 1% change in the predicted annual energy use. For Houses 23 and 25, the change in base temperature from the 1/4-hour to biweekly recording interval was 5.3 ^{o}F and 5.4 ^{o}F, respectively, and corresponded to 5 and 5.9% changes in predicted annual energy use. For House 24, the change in base temperature was 6.5 ^{o}F and yielded a change in predicted annual energy use of 7.2%. Thus, a 1 ^{o}F decrease in base temperature corresponded to an approximate 1% decrease in predicted annual space heating energy use.

CONCLUSIONS

The heating requirements and heating system of a residence may be such that energy use data recorded on a short time interval can result in considerable data where zero energy use is measured for very low outdoor temperatures. This primarily occurs in recording intervals of an hour or shorter and can occur frequently in 15-minute data.

Base temperatures estimated with data recorded using different recording intervals will likely yield two considerably different values. The same result occurs in the estimation of the slope of the regression model, i.e., the rate of heating energy use with respect to outdoor temperature). A greater difference between recording intervals will increase the differences of these estimates. If data are used to look for a change in these parameters* to compare the building performance before and after a retrofit or the performance of different buildings, data should be recorded using common intervals.

In general, using a longer recording interval increases the slope of the regression model. This, in turn, results in a decrease in the estimate of the base temperature. For a similar recording period (Jan. 1 - Apr. 30), energy use predictions for a time period corresponding to the measurement period and using TMY outdoor temperatures will likely be in close agreement for different recording intervals. However, in using results from a shorter time period to predict annual heating energy use using TMY outdoor temperatures, significant differences can occur. The predicted annual energy use decreased at an approximate rate of 1% per 1 ^{o}F decrease in the base temper-

*A change in the base temperature and/or the slope of the model (the rate of energy use in the building) can indicate a change in thermostat setting, a change in use pattern, installation of a retrofit, or other change causing a variation in energy requirements.

ature resulting from a longer recording interval.

The inherent scatter in recorded data does not by itself provide an indication of the standard error that can be expected in predicting heating energy use. The standard errors of these predictions are strongly dependent on both the scatter and number of data points used in the regression model. As a result, although the scatter may be large for a short recording interval, the short interval can allow a large number of data points to be collected such that much smaller errors can be obtained as opposed to weekly or larger recording intervals. In the selection of a recording interval, consideration should be given to both the number and expected scatter of data points such that the standard errors of energy use predictions can be maintained at an acceptable level. Consider, for example, the evaluation of a retrofit for space heating energy use which is expected to yield 15% savings. Both pre- and post-retrofit data are to be collected over the heating season assumed to last 8 months. Thus, approximately 17 weeks each are available for collecting pre- and post-retrofit data. If recorded as weekly averages, 17 values would result. Results from this study indicate that standard errors of predicted space heating energy use could be expected to be around 2.5%. For 95% confidence, errors would be +/- 5%. This represents one-third of the expected savings of the retrofit and will likely be unacceptable. Thus, a daily or hourly recording interval is needed to reduce the standard error of the estimates. If the retrofit savings were larger or more time was available for data collection, weekly measurements could possibly be used.

In summary, regression model parameters and resulting estimates of space heating energy use can be strongly influenced by the data recording interval. Factors that should be considered in the selection of a recording interval are:

1. the amount of time available to collect data,

2. the number of data points one can expect to obtain as defined by time and a selected recording interval,

3. the scatter that is typical for data collected at the selected recording interval, and,

4. the magnitude of the standard errors of predicted energy use that can be expected and the acceptable limits for these errors.

If a change in the base temperature or the heating energy use rate with respect to outdoor temperature (regression model slope) is to be used as an indicator of a change in the performance of a building or the difference in performance between buildings, care should be taken to assure data collection at the same recording interval. In addition, like recording intervals should be used where energy use estimates generated from two different data sets are to be compared.

REFERENCES

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Table I. Number of zero values in each data set.*

Data set	Total points	House Number			
		21	23	24	25
1/4-hour	10752	550(5.1%)	950(8.8%)	11(0.1%)	65(0.6%)
Hour	2688	63(2.3%)	91(3.4%)	0	5(0.2%)
Day	112	0	0	0	0
Week	16	0	0	0	0
Biweek	8	0	0	0	0

*Recording periods: House 21, 24, 25 - Jan. 1 to Apr. 22; House 23 - Jan. 9 to Apr. 30; 1982.

Table II. Regression model results for Houses 21 and 23.*

Recording interval	Number of data points	House 21 A_1 (watts/°F)	T_b** (°F)	R^2	SE_{EC}† (%)
1/4-hour	10752	64.9	62.7	.566	0.4
hour	2688	64.9	62.7	.664	0.6
day	112	65.9	62.0	.859	1.6
week	16	67.2	61.2	.922	3.0
biweekly	8	66.3	61.8	.935	4.0

Recording interval	Number of data points	House 23 A_1 (watts/°F)	T_b** (°F)	R^2	SE_{EC}† (%)
1/4-hour	10752	87.0	62.8	.528	0.5
hour	2688	87.0	62.7	.796	0.5
day	112	91.0	61.0	.913	1.5
week	16	96.3	58.8	.963	2.5
biweekly	8	99.9	57.5	.982	2.5

*Measured space heating energy use: House 21 - 7778 kWh, House 23 - 9549 kWh.

**T_b is estimated outdoor temperature where EC′ = 0, i.e., $T_b = -A_0/A_1$.

† For discussion, standard errors were calculated for the predicted energy use of the measurement period (predicted from measured temperature data using Equation 3). For this case, the least-squares method results in predicted energy use = measured energy use.

Table III. Regression model results for Houses 24 and 25.*

Recording interval	Number of data points	House 24 A_1 (watts/°F)	T_b** (°F)	R^2	SE_{EC}† (%)
1/4-hour	10752	80.2	68.4	.574	0.3
hour	2688	80.2	68.4	.722	0.5
day	112	83.2	66.6	.825	1.7
week	16	92.4	61.8	.943	2.5
biweekly	8	92.2	61.9	.963	3.0

Recording interval	Number of data points	House 25 A_1 (watts/°F)	T_b** (°F)	R^2	SE_{EC}† (%)
1/4-hour	10752	107.5	62.3	.703	0.3
hour	2688	107.5	62.3	.788	0.5
day	112	114.8	59.6	.914	1.4
week	16	122.8	57.0	.967	2.2
biweekly	8	122.9	56.9	.982	2.5

*Measured space heating energy use: House 24 - 10,845 kWh, House 25 - 12,408 kWh.

**T_b is estimated outdoor temperature where EC′ = 0, i.e., $T_b = -A_0/A_1$.

† For discussion, standard errors were calculated for the predicted energy use of the measurement period (predicted from measured temperature data using Equation 3). For this case, the least-squares method results in predicted energy use = measured energy use.

Table IV. Recording interval effects on predicted annual energy use using TMY outdoor temperature data for Minneapolis, Minnesota.

House number	Recording interval	A_1 (watts/°F)	T_b* (°F)	Predicted annual energy use (kWh)
21	1/4-hour	64.9	62.7	11,785
	Hour	64.9	62.7	11,785
	Day	65.9	62.0	11,679
	Week	67.2	61.2	11,578
	Biweek	66.3	61.8	11,668
23	1/4-hour	87.0	62.8	15,852
	Hour	87.0	62.7	15,798
	Day	91.0	61.0	15,568
	Week	96.3	58.8	15,226
	Biweek	99.9	57.7	15,062
24	1/4-hour	80.2	68.4	17,548
	Hour	80.2	68.4	17,548
	Day	83.2	66.6	17,230
	Week	92.4	61.8	16,262
	Biweek	92.2	61.9	16,282
25	1/4-hour	107.5	62.3	19,252
	Hour	107.5	62.3	19,252
	Day	114.8	59.6	18,686
	Week	122.8	57.0	18,169
	Biweek	122.9	56.9	18,116

*T_b is estimated outdoor temperature where EC′ = 0, i.e., $T_b = -A_0/A_1$.

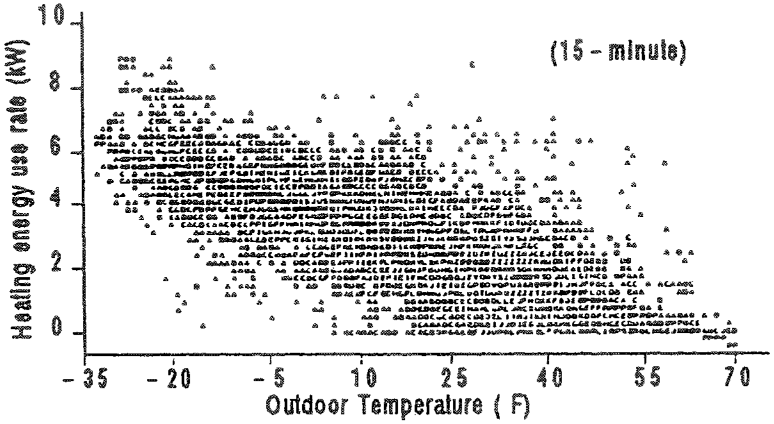

Fig. 1. Space heating energy use rate vs. average outdoor temperature for 15-min. recording interval: House 21. A=1, --, Z=24, P=predicted.

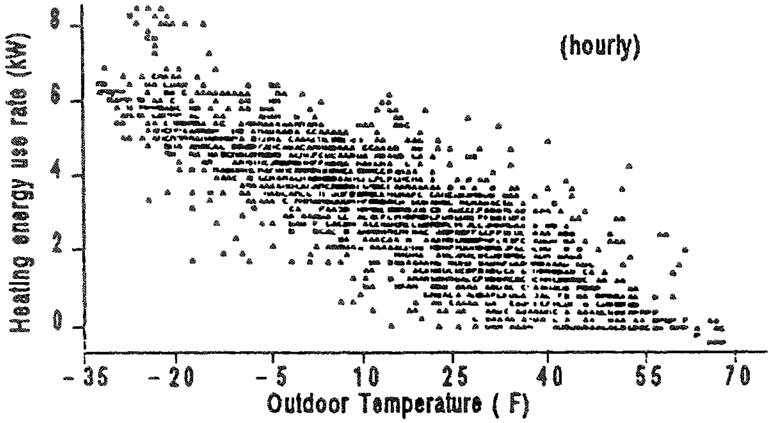

Fig. 2. Space heating energy use rate vs. average outdoor temperature for hourly recording interval: House 21. A=1, --, Z=24, P=predicted.

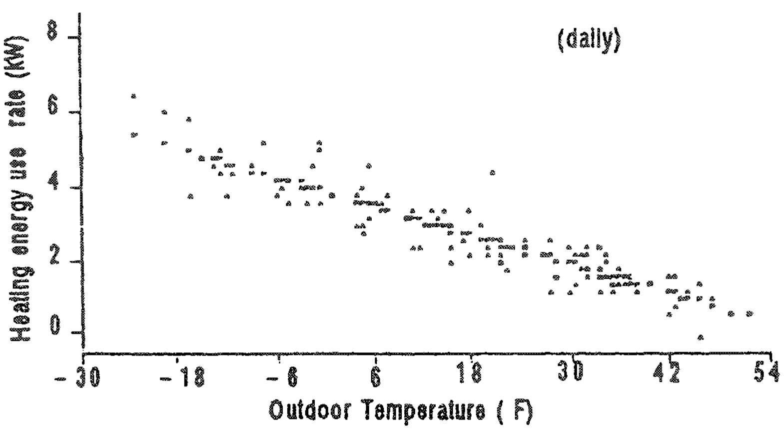

Fig. 3. Space heating energy use rate vs. average outdoor temperature for daily recording interval: House 21. A=1, --, Z=24, P=predicted.

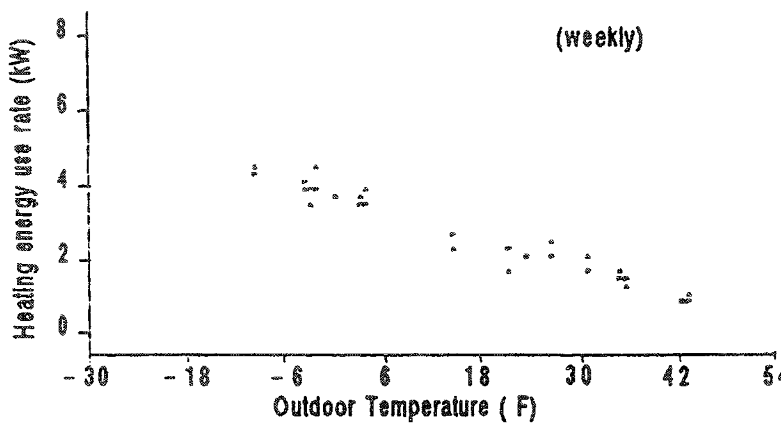

Fig. 4. Space heating energy use rate vs. average outdoor temperature for weekly recording interval: House 21. A=1, --, Z=24, P=predicted.