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ABSTRACT

Based upon an engineering and statistical analysis of energy use on community and two-year college campuses, a simple model for describing energy use is introduced and applied to data from 80 campuses to determine average values for the parameters of the model. These values indicate that the use of energy does not depend on the type of heating fuel or combination of fuels used, but rather on the physical construction of the campus buildings and the way they are utilized. Since the model automatically separates out differences in size and climate between campuses, it provides an individual campus with an objective means of comparing its energy use with that of its peers. (Author/DC)

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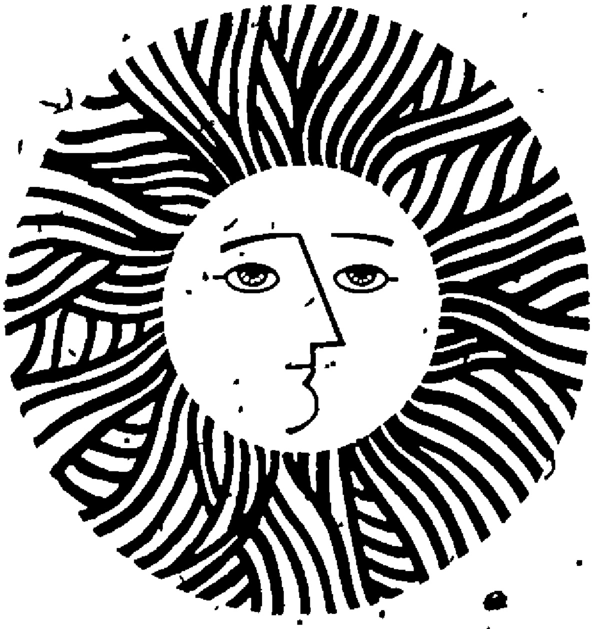
Carl M. York

March 1980



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ABSTRACT

This paper provides an analysis of energy use on community college campuses which justifies the introduction of a simple model for describing that energy use. The model is then applied to the data from 80 campuses to determine average values for the parameters of the model. The model can be used to measure the energy savings of conservation programs as well as the cost avoidance associated with those savings. Because the model explicitly takes into account variations in weather, it provides an essential tool for evaluating energy conservation programs.

An Analysis of Energy Use on Community College Campuses

by

Carl M. York
Lawrence Berkeley Laboratory

I. Introduction

In 1977 a collaborative program of energy conservation on five community college campuses in northern California was begun by the Lawrence Berkeley Laboratory and the Pacific Gas and Electric Company. The program adapted a strategy that had been used by PG & E with elementary and high schools in the Fresno area for use in the community colleges. After one year of this pilot program, it was estimated that the five campuses had saved a total of 90×10^9 BTU's with a corresponding cost avoidance of $310,000. The U.S. Department of Energy, which sponsored LBL's participation in this program urged that the program be expanded to all community colleges in the United States. This was done and a national program was launched in January of 1979 by LBL in collaboration with the League for Innovation in the Community Colleges, a national organization based in Los Angeles. Meanwhile the efforts of PG & E were directed toward establishing an on-going energy management program for the 120 colleges and universities in their service area. An informal collaboration between LBL and PG & E continued and focused on the need to resolve several problems that had arisen in the determination of energy savings and cost avoidance.

The most important question that had to be resolved was how to correct the observed energy savings for the fact that the weather might be colder in one year than in the next. In fact the observed savings might have been due to warmer weather rather than the conservation program. This problem was very similar to the question which was posed by the national program where the energy use of campuses in Florida would have to be compared with those in Minnesota, if possible. No simple solution could be found to this dilemma in the literature on the subject, so a model for energy use on a campus was devised. This paper describes the physical basis for that model, the statistical basis for believing its relevance to the data from eighty of the colleges in the national program, and finally a discussion of the model itself.

An earlier paper[1] describes the model and explains how college administrators can use it to determine the energy savings and cost avoidance of programs on their campuses. That paper deliberately avoided the technical arguments which are presented here to justify the model and its use.

II. Energy Use in Buildings--An Engineering Analysis

Shrader[2] has written down an equation to describe the use of heating energy to maintain a constant temperature in a building. The equation can be simplified to serve as a basis for a model which gives the fuel usage in terms of heating degree days and two constants which are characteristics of the building. The building is considered to be a thermodynamic system which has both heat losses and heat gains. When the inside air temperature is maintained at a constant level, then these gains and losses are just equal to each other. So the problem is to write down expressions for the heat gains and losses and then set them equal to each other.

The heat loss from a building is due to transmission through the building's shell and to infiltration of cold air from the outside through cracks and other openings. The transmission losses, H_t, can be written

$$H_t = A'U\,(T_i - T_o)$$

where:

- H_t is the heat transmitted through the shell (in BTU/sq.ft. hr.);
- A' is the total area of exposed shell surface (in sq.ft.);
- U is the composite coefficient of thermal transmission of the shell (in BTU/sq.ft. °F hr.);
- T_i is the indoor temperature (in °F); and
- T_o is the outdoor temperature (in °F)

A given building will have a thermal transmission coefficient which depends on its design, construction, and building materials. Hence U can be thought of as a constant which is characteristic of an individual building.

The infiltration heat loss includes the heat required to warm the outdoor air to room temperature, as well as the heat required to evaporate water to maintain the humidity inside the building. The heat loss by infiltration, H_i, can be written:

$$H_i = Q\rho C_p (T_i - T_o) + Q\rho h (W_i - W_o)$$

where: Q is the volume of outdoor air entering the building (in cu.ft./hr.);

ρ is the density of air (in lb./cu.ft.);

C_p is the heat capacity of the air (in BTU/lb. °F);

h is the latent heat of vaporization (in BTU/lb. of water);

W_i is the relative humidity of indoor air (in lb. of water/lb. of dry air); and

W_o is the relative humidity of outdoor air.

The heat loss of the building will be the sum of these expressions, $H_t + H_i$.

The heat gained by the building can be identified with four sources. They are: the heat from sunlight warming the outside walls and entering the windows, S; the heat generated by people's bodies, P; the heat given off by lights and appliances, E; and finally the heat provided by the furnace, F, to maintain the inside air temperature. These heat gains can be added and then set equal to the heat losses to obtain the heat balance. That is,

$$S + P + E + F = H_t + H_i .$$

If the fuel used in the furnace is gas, and the efficiency of the furnace, e, is the fraction of the heat energy which goes into the building, then

$$F = eG'$$

where G' is the amount of gas (in BTU/hr.) which is burned. Because we want to express our final answer in terms of the total fuel used per month on a campus, let g be the amount of gas used in stoves, water heaters and other gas consuming appliances. Then the total gas used and recorded on the utility meters will be

$$G = g + G'$$

and

$$F = e(G - g) .$$

If this expression is substituted into the heat balance equation and the various terms are rearranged, we can write:

$$G = \frac{1}{e} [(A'U + Q\rho C_p)(T_i - T_o) + Q\rho h(W_i - W_o) - (S + P + E) + eg]$$

$$= a + b(T_i - T_o) .$$

where $a = \frac{1}{e} [Q\rho h(W_i - W_o) - (S + P + E) + eg]$

and $b = \frac{1}{e} (A'U + Q\rho C_p)$

The resulting simple equation

$$G = a + b(T_i - T_o)$$

is valid at a given time. In order to use the equation to understand fuel use compared to outside temperatures, we will sum over all of the quantities for a one month period. Then G would be the total fuel use in one month, and $(T_o - T_i)$ is the total temperature difference in that same month. The constants, a and b, would be summed over that month. That is, a would depend on the total humidity difference, $(W_i - W_o)$ during the month, the total solar heat absorbed during the month, the number of people in the building during the month (the "occupancy" factor), and the amount of heat contributed by lights and appliances during the month.

In a community college the number of people per month in a given building is not the same from one month to the next. Nor is the energy used for lighting the same in December as in June. However, for this analysis the constants, a and b, have been taken to have the same values from month to month and from year to year. This assumption will be justified below for the colleges in our study.

The value of the total temperature difference, $T_i - T_o$, can be set equal to the number of heating degree days (HDD) in the month. The heating degree day is based on the observation that when the temperature goes below 65° F, the heaters in most buildings are switched on to maintain a comfortable inside temperature. Above 65° F, the heaters will not be used. When the average temperature for a given day (obtained by adding the high and low temperatures for a twenty-four hour period and dividing by two) is one degree below 65°, it counts as one heating degree day. The "degree day" concept assumes that the same amount of heating fuel is needed for any combination of cold and duration that can be added to give the same number of heating degree days. For example, ten days at 64°, five days at 63°, two days an 60°, and one day at 55°, all count as ten heating degree days. It is assumed that each combination will require the same amount of fuel. Over the years this assumption has proved to be useful in estimating customers' fuel needs during periods of cold weather, so we shall replace the average value of the temperature difference with HDD, the number of heating degree days in the month.

The equation for fuel use,

$$G = a + b \text{ HDD},$$

for a single building has an interesting property, when a collection of buildings is to be heated. If we indicate the i^{th} building by a subscript i to distinguish it from all of the others, then we can write

$$G_i = a_i + b_i \text{ HDD}$$

for the i^{th} building. If now we add up the gas used by all of the N buildings on a campus, we can write

$$G_{TOT} = \sum_{i=1}^{N} G_i = \left(\sum_{i=1}^{N} a_i\right) + \left(\sum_{i=1}^{N} b_i\right) \text{ HDD}$$

or

$$G_{TOT} = A + B \text{ HDD}$$

That is, the total campus usage is equal to a constant, $A = \Sigma a_i$, plus B HDD, where $B = \Sigma b_i$. Data on the total fuel use can be used to determine the constants A, called the "base use" and B, the "aggregated thermal performance index". Woteki and Fels[3] have used this approach to predict the demand for gas by all of the residences served by a utility district in terms of the number of heating degree days predicted for that district by the U.S. Weather Service.

This analysis indicates that there is a linear relationship between the heating fuel usage in a building and the number of heating degree days. Furthermore, this relation holds for a collection of buildings on a campus, even if they have quite different structural characteristics and utilization patterns. This implies that it should be possible to calibrate a campus in terms of its energy usage and then measure the effects of a conservation program. Such a conservation effort would produce a change in the characteristic constants of the building or campus, and hence in the fuel usage.

III. Energy Use on a Campus--A Statistical Analysis

All of the 1230 Community and Junior Colleges in the United States were invited to join a program of energy conservation sponsored by the Department of Energy and implemented by the League for Innovation in the Community Colleges and the Lawrence Berkeley Laboratory. In March of 1979, 304 colleges volunteered to participate in the program and of these, 80 submitted data on their campuses and their utility bills. The data that were collected included electricity use per month, fuel use per month (broken out by natural gas, oil, coal, or other), and the energy costs per month for a twelve month period in 1978-79. Additional information was requested on the floor space of the campus buildings (in gross square feet), the enrollment of full time equivalent students (FTE) in the fall of 1978, and the number of heating degree days (HDD) in each month corresponding to the fuel used in that month.

In earlier studies several indicators of campus energy use have been used. The values of these indices for the present sample of campuses are included here to provide an indication of the variation in time of their values. The first indicator is the "Energy Use Index" which is defined by the ratio:

$$EUI = \frac{\text{Total Energy Used Per Year}}{\text{Total Gross Square Feet}}$$

The EUI has been used as a measure of the energy efficiency of buildings, just as the efficiency of an automobile is measured in miles per gallon. Unfortunately, it assumes that the energy use of a building in Florida is comparable to that of a building in Minnesota. The average value of EUI for this sample is listed in Table I together with earlier values.

Another indicator which is of interest to every campus administrator is the cost of energy per square foot per year. Again the average value is entered in Table I for comparison with earlier work. Finally, there are two other indicators which have been used in the past and they are also included in the table. They are the Annual Energy Use per Full Time Equivalent Student (FTE), and the Annual Cost of Energy per Full Time Equivalent Student. These two indices are useful if you know the growth trends in the student body of a given campus, or if you need to know how to structure tuition fees to allow for energy cost increases. However, our analysis in this paper focuses more directly on conservation measures applied to the phycisal plant, so we will not pursue the discussion of these student body related indices. Their average values for the schools in our sample are included in Table I.

The trends of the four indices in Table I are marked. The total energy used both per square foot and per FTE has dropped sharply since 1972-73. In spite of these decreases, the costs, both per square foot and per FTE, have increased. The explanation of the first trend lies in the efforts of colleges to cut back on their energy use, while the cost increases are clearly connected to the rising [illegible] of energy. The first trend should be emphasized because it is clear that conservation efforts <u>are working</u> on the Community College campuses.

In Reference 4, an attempt was made to take into account the variation of climate with the geographic location of the campus in constructing the total statistical sample for their study. How well this worked for the subset of two year colleges in their total sample cannot be determined. The averages for the present study which are reported in Table I are not corrected in any way for climate variation. An objective method for doing this will be developed below.

In a study of 1343 school plants for grades K-12, the Educational Facilities Laboratories[5] found a linear relationship between fuel use and the number of heating degree days for several classes of school plant construction. The engineering basis for such a relationship has been derived in the previous section and we will now seek to establish a similar relationship on the basis of our statistical sample of community colleges.

a. The Dependence of Energy Use on Climate

The Energy Use Index, introduced above, provides a measure of the energy use on a campus which is independent of the size of the campus. To determine whether or not the EUI's of the campuses in our sample depended upon their goegraphic location, a "scatter diagram" of EUI vs. Heating Degree Days per year was plotted. This is shown in Figure 1. It is striking to note that there is such a wide variation in the EUI values for a given number of heating degree days. However this indicates that conservation measures can reduce energy use of most of the campuses in our sample. From this plot there is a clear indication that the trend is for those campuses in colder climates, i.e., with more heating degree days, to have higher energy use indices. The straght line shown in the figure has been drawn by performing a least squares fit to the data plotted in Figure 1. Its characteristic constants are an intercept at

$$\text{EUI} = 86.6 \times 10^3 \text{ BTU/sq.ft.yr.}$$

and a slope of

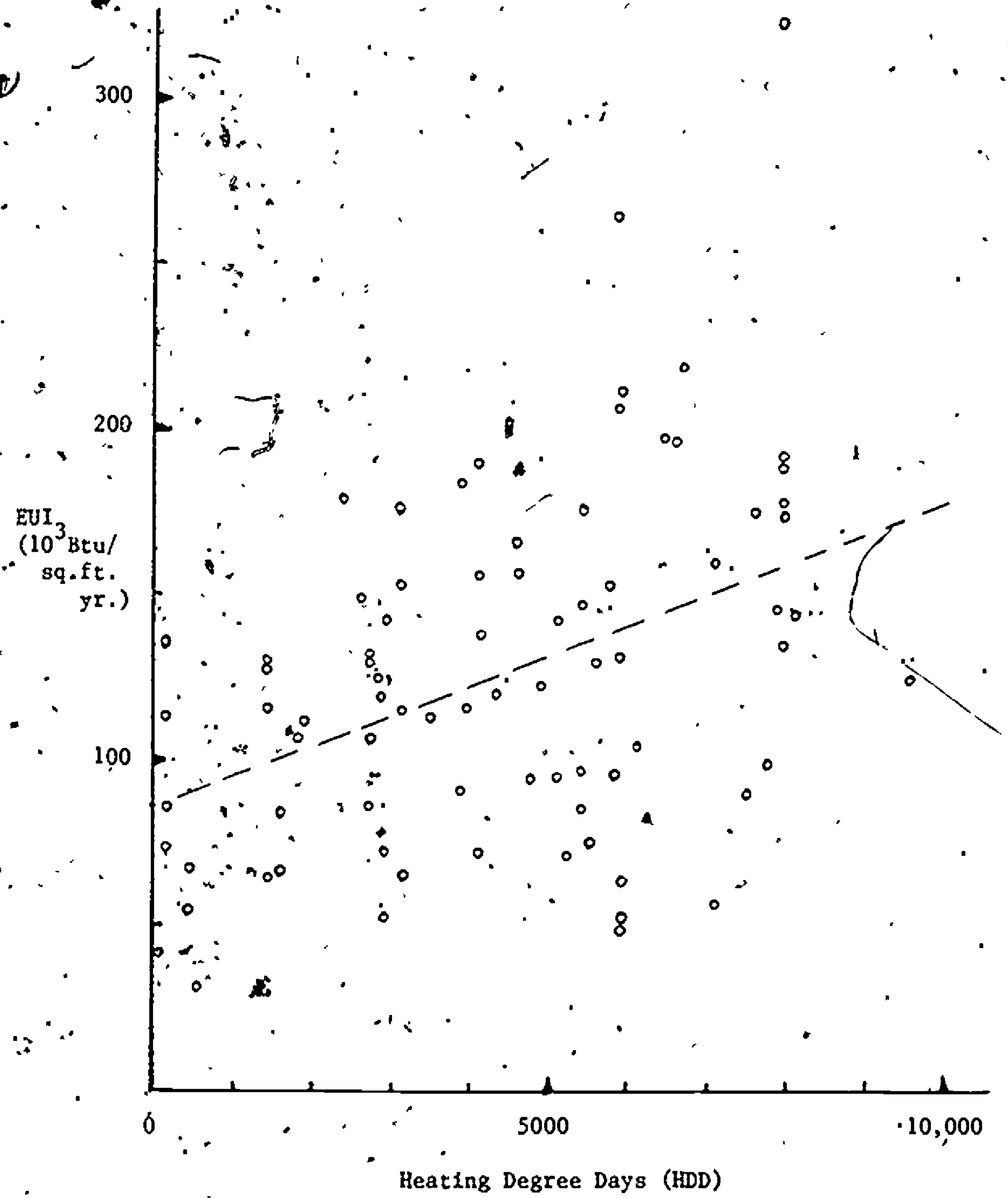
$$1.9 \text{ BTU/sq.ft. HDD}$$

The correlation coefficient is $r = 0.40$ indicating a rather poor fit. It

FIGURE 1.

Scatter Diagram of Energy Use Index,EUI

vs. Heating Degree Days,HDD



is not surprising that the correlation coefficient is relatively low, because in any given range of HDD values there is a wide variation in the EUI values, as noted above. These data on energy use are consistent with a linear dependence on heating degree days as suggested by the engineering equation derived in the preceding section. In this sample of data no attempt has been made to distinguish between total energy use and fuel use on a campus. Nor has a distinction been made between the various types of fuel, e.g., gas, oil, coal, or electricity. These distinctions will be examined below.

b. The Dependence of Energy Use on Campus Size

To determine whether or not the Energy Use Index depends on the size of the campus, the data on EUI were plotted against the gross square feet of floor space on the campus, as shown in the scatter diagram of Figure 2. These data were fitted to a straight line by the method of least squares and the line is plotted on the diagram. The intercept is at

$$EUI = 1.21.5 \text{ MBTU/sq.ft. yr.}$$

the very small slope is

$$0.01 \text{ MBTU}/10^3 \text{ sq.ft.}$$

and the correlation coefficient is $r = 0.05$. From this it can be concluded that no significant dependence of EUI on campus size exists.

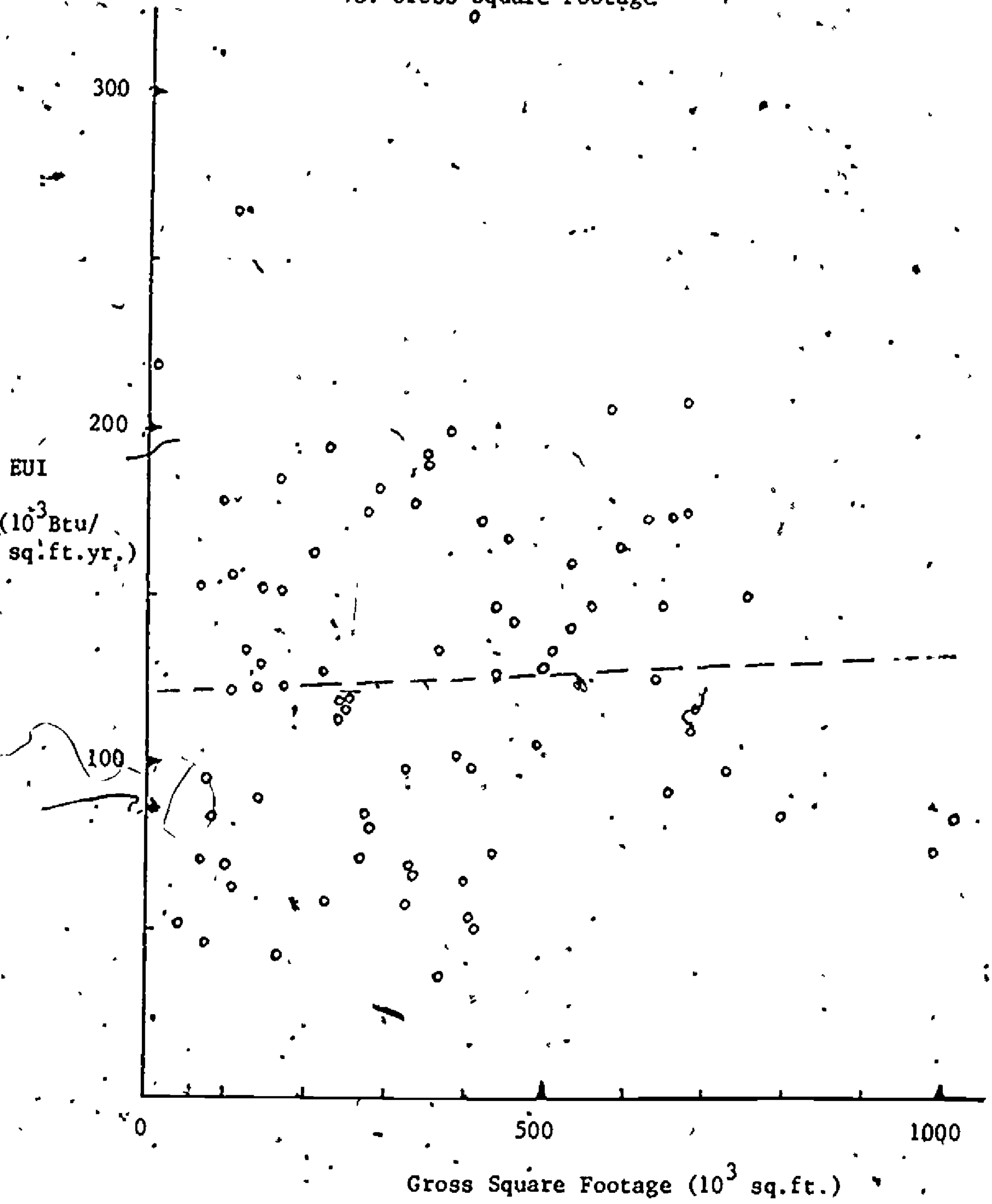
c. The Dependence of Energy Use on Occupancy.

The occupancy of the buildings on a campus requires a measure of the number of people inside the buildings at each time during a day. In terms of Shrader's equation, the number of persons, P, contributes to the heating of a building, while the volume of outside air, Q, that enters the building

FIGURE 2.

Scatter Diagram of Energy Use Index (EUI)

vs. Gross Square Footage



will partially depend on the number of students entering and leaving the building through its doors. When monthly sums were taken over these quantities, both of these variables were reduced to constants. The question now arises as to whether energy use depends on the number of students. One measure of the average occupancy of a campus is the number of full time equivalent students (FTE) on the campus. This number was included in the data collected for each campus and was used in this part of the analysis.

The data for EUI's were plotted against the corresponding number of FTE's for each campus as shown in Figure 3. When a straignt line was fitted to the data, as indicated, it gave an intercept of

$$\text{EUI} = 121.9\ \text{MBTU/sq.ft.yr.}$$

and the slope is

$$1.0\ \text{MBTU}/10^3\text{sq.ft.yr. FTE}$$

The correlation coefficient of 0.08 again indicates no significant correlation. From this result we can conclude that the intensity of energy use on a campus does not depend significantly on the size of the student body as measured in FTE.

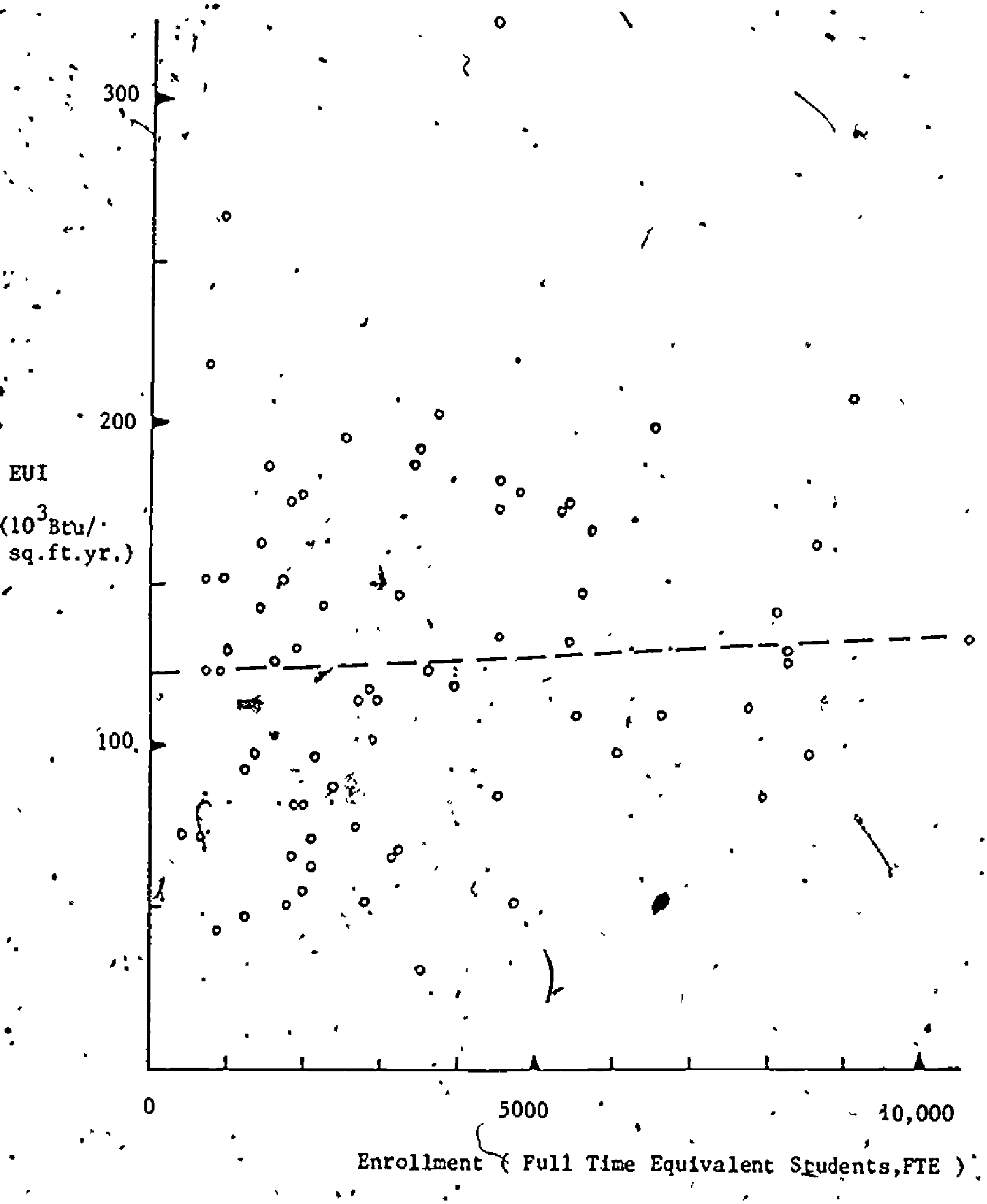
d. Some Consistency Checks on the Data

Because the various college districts have regulations which provide for a proportionality between the enrollments and the amount of building floor space, some relationship is expected to exist in our sample between these two parameters. Our data for 80 campuses included both the number of full time equivalent students, FTE, and the gross square footage of the buildings on the campus. If a straight line is fitted to the data, the slope of the line is 1 FTE per 86.8 gross square feet. This is a reasonable

FIGURE 3.

Scatter Diagram of Energy Use Index (EUI)

vs. Student Enrollment (FTE)



guideline for construction of facilities and indicates that our sample of colleges does not have any significant biases in terms of space utilization. The correlation coefficient for this fit of the straight line to the data is $r = 0.54$. In view of this degree of correlation between FTE and campus floor space, it is not surprising that the correlations of EUI with both of these quantities were found to be small in the preceding paragraphs.

Consider next the indices in Table I. Here the value for the average Energy Use Index was given as:

$$128 \times 10^3 \text{ BTU/sq.ft.}$$

and the energy use per full time equivalent student was

$$13.1 \times 10^6 \text{ BTU/FTE}$$

The ratio of these two quantities gives the FTE per gross square foot and should be comparable to the slope of the line above (1 FTE per 86.8 gross square feet) by regression analysis. The ratio here is one FTE per 98 gross square feet, which is within 10% of that value.

The variation of EUI with heating degree days can provide another check. The average number of heating degree days per year in the sample was 4382 HDD/yr. Using this value in the equation of EUI gives

$$\begin{aligned} EUI &= 88.5 \times 10^3 + 9.1 \text{ HDD} \\ &= 128 \times 10^3 \text{ BTU/sq.ft.yr.} \end{aligned}$$

This value can be compared with the average EUI value in Table I of 128×10^3 BTU/sq.ft.yr. The two values agree to within 1%.

Consistency checks of this type serve to verify that our sample of campuses does not have any serious biases which might affect the conclusions drawn from the analysis. The relatively small sample of data and the wide spread of values of the several variables led to the conclusion that the application of more sophisticated statistical techniques was not warranted. It should be noted that the use of r, rather than r^2, as the correlation coefficient is not standard practise. However, the advantage of using r in the present analysis will become clear in a later discussion of the correlation between energy use and cooling degree days.

IV. The Linear Model of Heating Fuel Use

From the preceding sections one can conclude that a linear relationship should exist between fuel use and the number of heating degree days on a campus. It has also been shown that in the data from our sample of community colleges that definite correlations exist between the Energy Use Index and heating degree days per year, as well as between the size of the campuses and their enrollments. No clear correlation was found between the Energy Use Index and the size of the campus, or the size of the student body. Because the average administrator of a community college does not have the technical background, or interest in pursuing an analysis of the type presented above, a simplified model which embodied these conclusions was developed.[1]

This model separates the use of electricity and the use of fuel for heating. Then each campus' utility bills for one year are analyzed to determine three parameters: the average monthly electricity use, $\bar{E}$; the base fuel use, a; and the thermal performance index, b. The fuel bills are combined with heating degree day data to determine the constants, a and b, by performing a least squares fit to the linear equation

$$G = a + b\ HDD$$

Here G is the heating fuel and HDD is the number of heating degree days in a given month.

These constants can be used to determine the energy savings that result from the application of conservation measures. If the data that have been used to determine the constants a and b are taken from a year designated as a "base year", then the gas that you would expect to use in any subsequent month would be just a + b HDD. Here HDD would be number of heating degree days for the month in question. The expected electricity use in that month would be $\overline{E}_B$, where the subscript, B, indicates the value for the base year. The differences between these expected uses and the actual usage in a month give the energy savings.

We can write

$$\Delta G = a + b\ HDD - G_A$$

for the gas, and

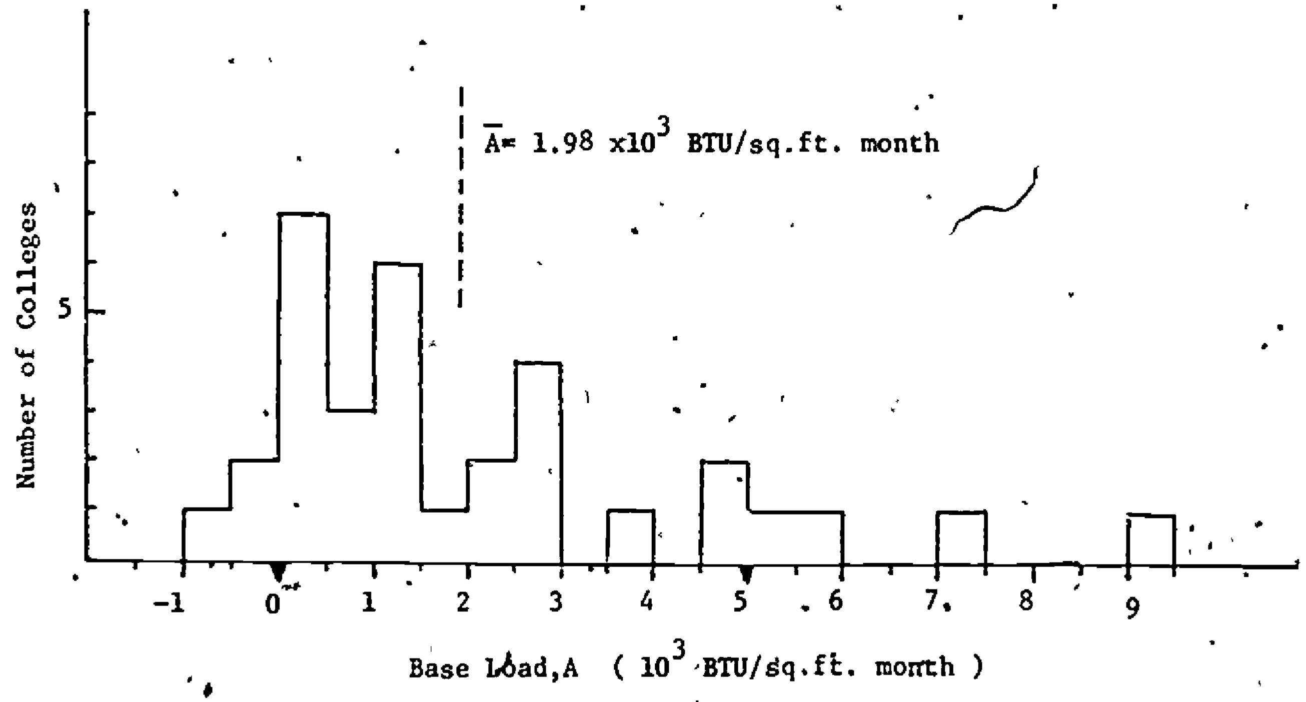
$$\Delta E = \overline{E}_B - E_A$$

for the electricity savings in the given month. Here G_A and E_A are the actual amounts of gas and electricity used in the month. If ΔG and ΔE are positive, there have been energy savings as a result of the conservation measures. These energy savings can be converted to dollar values, called the "cost avoidance" for the month, if they are multiplied by the current billing rates for gas and electricity.

As developed in Reference 1, this model requires a modification to the constants, a and b, to convert them to "intensities". This is done by dividing the constants by the number of gross square feet on the campus and converting their units to BTU. In terms of the new calibration intensities, A, B, and $\overline{E}$, several new directions were explored. First the sample of 80 campuses were separated into categories depending on heating fuel type. All campuses use some electricity for lighting, ventilation and so on, but there were four classes of heating fuels, gas, gas plus oil, oil, and electricity. This last case is referred to as an "all electric" campus. Histograms of the constants, A, B, and $\overline{E}$, were plotted and the average values were calculated as shown in Figure 4.a, b, and c. Table II summarizes

FIGURE 4.

a. Distribution of Values of Base Load,A



b. Distribution of Values of Thermal Performance,B

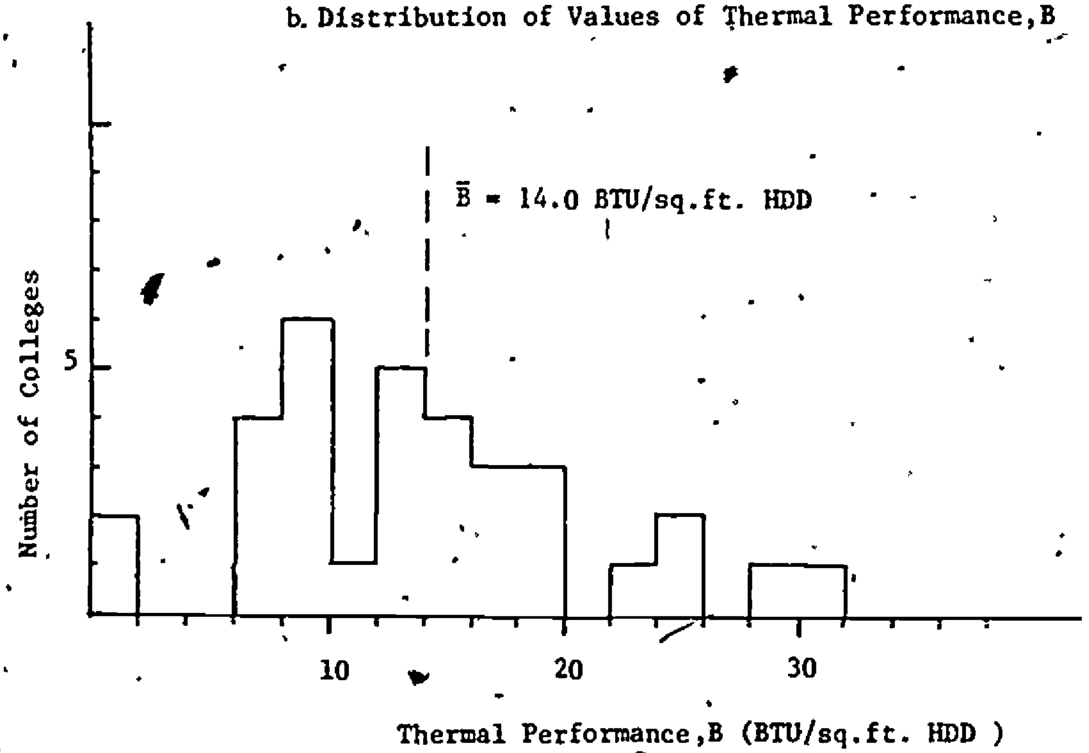
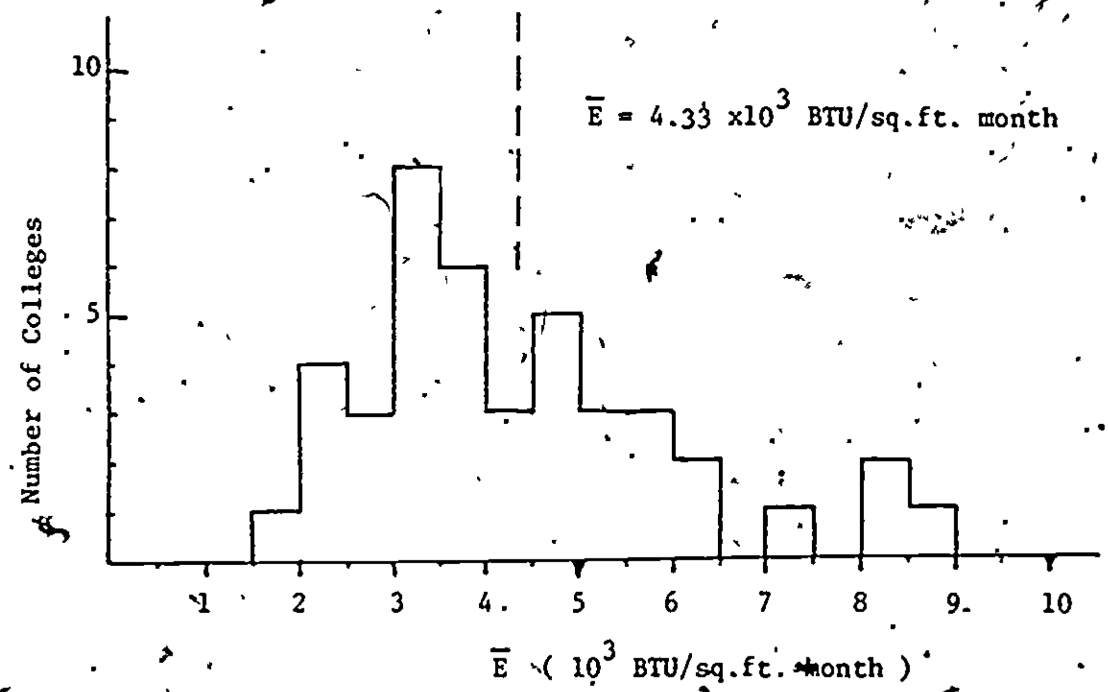


FIGURE 4. (Cont'd.)

c. Distribution of Values of Average Electrical Use



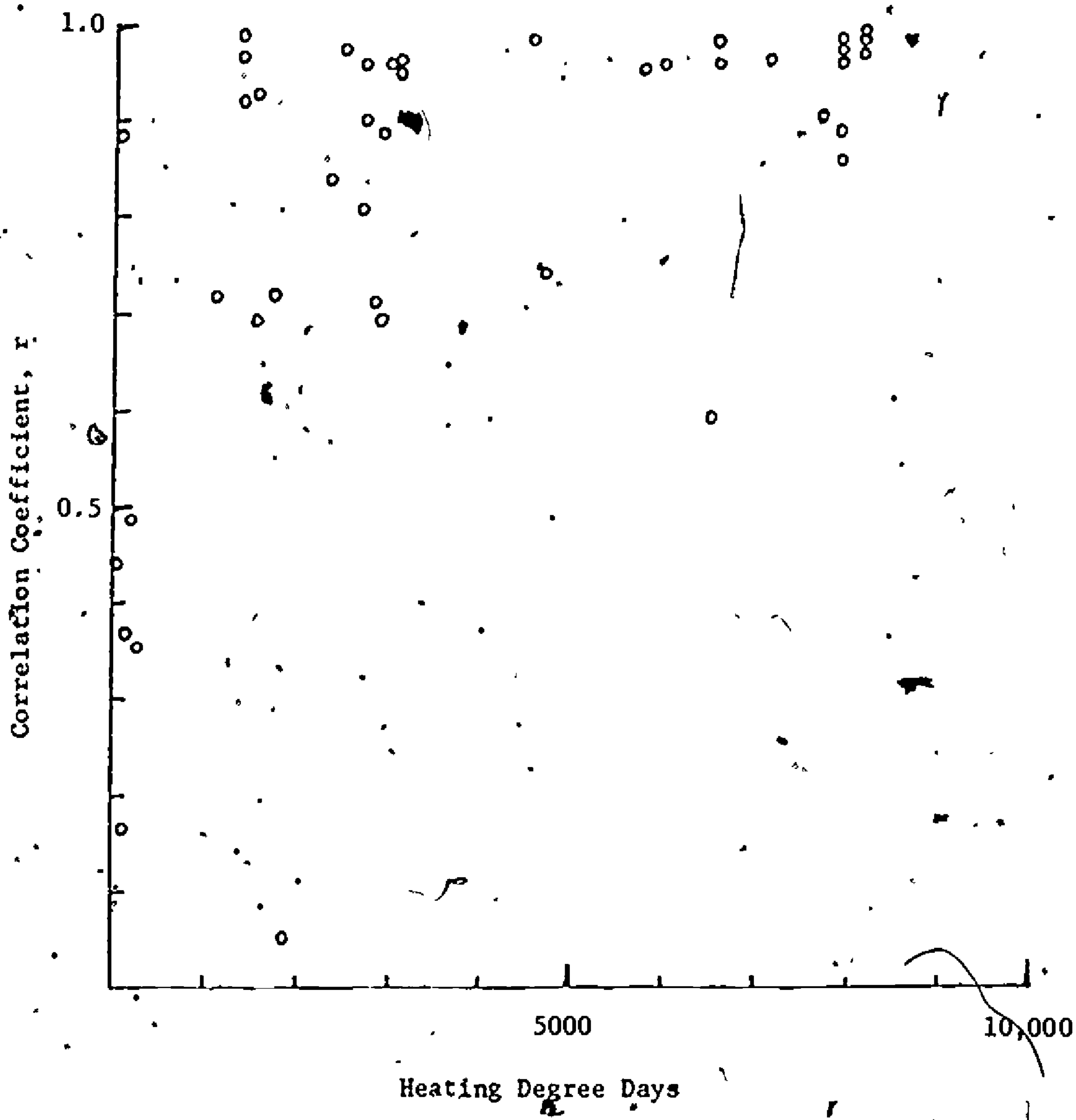
the results of a similar calculation for the four fuel types and shows that with the exception of the all electric campus, the values of $\bar{E}$, M, and B are roughly independent of the fuel type.

The detailed study of the gas-fueled campuses led to several insights about the limitations of this method of modeling the energy use on a campus. The first and most important was revealed by a study of the correlation coefficient for a goodness of fit of the fuel use to heating degree days. The correlation coefficient, r, plotted against the total number of heating degree days in a year, is shown in Figure 5. With only one exception the campuses with fewer than 1000 heating degree days per year had very low correlation coefficients. It was decided on this basis to exclude them from further analysis. Those few additional cases in which the correlation coefficient was found to be less than 0.5 were also omitted. Presumably the poor correlation in warm climates has to do with the fact that the gas used for heating is not large compared to the base uses, such as hot water, stoves, swimming pool heaters, and so on. As a result, no clear correlation between the total gas bills and the number of heating degree days emerges. In at least one case of poor correlation it was found that the utility company used an averaging method of billing based on the previous year's fuel use. This method produced roughly equal monthly payments, but wiped out any correlation between the utility bill and the seasonal variation of heating degree days.

In the early stages of this study it had been hoped that a model for electricity use could be deduced which would enable air conditioning to be related to cooling degree days in an analogous way to that used above for heating fuel. It was assumed that the "cooling use" would be propor-

FIGURE 5.

Scatter Diagram of the Correlation Coefficient, r, for a Linear Fit to Fuel Use Against Heating Degree Days



tional to the number of cooling degree days, CDD, and that the monthly electrical use, E, could be written as the sum of a base use and the cooling use. That is,

$$E = d + e\ CDD$$

In the sample of gas-fueled campuses used above, there were no consistent results for the values of d and e. In fact 15 of the 42 cases analysed in this way had negative slopes for a straight line, i.e., $e < 0$. To summarize this situation, the values of the correlation coefficient were plotted in a scatter diagram against their corresponding number of annual cooling degree days, and this plot is shown in Figure 6. As a result of this incoherent result, the idea of using a linear equation to relate electrical use and cooling degree days was abandoned and the simple monthly average of the electricity use in the base year was adopted.

The failure of cooling degree days to relate in a simple way to energy use is a well known problem.[6] However, a clear exception to this observation was found in the case of the 9 all electric campuses in our sample To analyze the data from these campuses, a linear relationship of the form

$$E = d + e\ CDD + f\ HDD$$

was assumed. The utility bill data were used to fit the constants d, e, and f. In each case the correlation coefficient was greater than 0.83 and the mean values for the constants were

$$\bar{d} = 4.2 \times 10^3 \text{ BTU/sq.ft.mon.}$$

$$\bar{e} = 3.1 \text{ BTU/sq.ft. CDD}$$

$$\bar{f} = 6.80 \text{ BTU/sq.ft. HDD}$$

Because the base use, d, depends primarily on the lighting used on a campus, it is not surprising that it comes out to be very nearly equal to

FIGURE 6 .

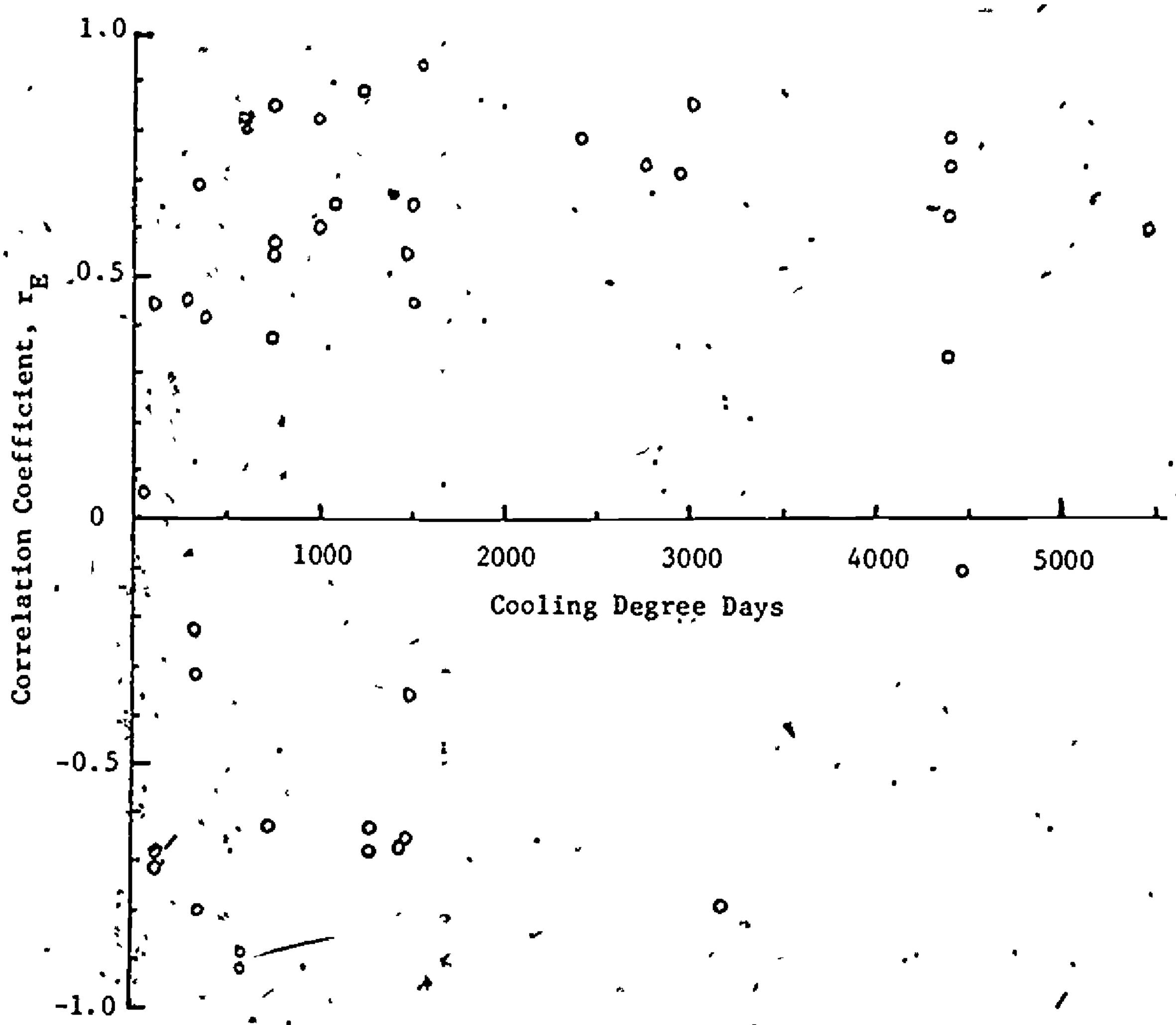
Scatter Diagram of Correlation Coefficient, r_E,

for a Linear Fit to Electric Use

against Cooling Degree Days

(Negative Values of r_E Correspond to a Negative

Slope of the Fitted Straight Line)



the values of $\overline{E}$ found in Table II for those campuses that are lighted with electricity, but heated with other fuels. The thermal performance index for the all electric campus is $\overline{f}$, and is seen to be approximately one half the values found for campuses heated with fossil fueld. An explanation for this difference can be found if one notes that the formula for the thermal performance index, b, is inversely proportional to the furnace efficiency, e. Because gas and oil furnaces must be vented up a chimney to discharge their waste products, the efficiency by which they convert fuel to useful space heat is only about 60%. However, nearly 100% of the electric energy entering an electric boiler is converted to space heating. Hence, the observed ratio of almost a factor of two in the thermal performance index can be attributed to the differences in thermal efficiency between electric and fossil fuel fired boilers.

In a few of the cases that were analyzed, the value of the base use constant, a, was found to be negative. This could be explained by the fact that the buildings on the campus did not turn on their heaters when the outside air temperature reached 65° but at some lower temperature. If one analyzed the heat flow into, and out of a building, as done in Reference 2, it can be shown that each building has its own reference temperature, which is the outside air temperature at which the heating system actually switches on. There is no reason why this should be 65° F, because it depends on the wall and roof insulation, window area, room ventilation, lighting intensity, average occupancy, and other details of the building's construction and use. In our equations above a term can be introduced to correct for this offset of the effective value of HDD. We could write for the heating use

$$b\ (HDD - T)$$

where T is the number of degree days that is required to correct the reference temperature of a given campus building from 65° to its true value. Then the total gas consumption would be

$$G = B_G + b\ (HDD + T) + P_G$$

and this could be rewritten as

$$G = a' + b\ HDD$$

where

$$a' = B_G + bT + P_G$$

This implies that our analysis cannot distinguish between the base use, or an offset in the reference temperature for the number of degree days, unless there is some other information.

There are several potential problems that should be borne in mind when utility bills are used for this type of analysis. First, the billing periods in one year can vary from those in another by as many as six days out of 30, or 20 percent. Meters are read on the five normal working days of the week, except when holidays or clusters of holidays interrupt the process. Hence the possible variation. A meter may not be read as scheduled, because the meter-reader could have had an accident along his route or have been prevented in some other way from doing his job. There is also the possibility of the meter being misread or of the reading being incorrectly recorded. In this case, a bill for a very small amount of energy may be received and then followed the next month with a bill for both the energy used during the first period, plus that used in the second period. To correct for such an error some appropriate average must be taken over the two month period.

One problem that is almost certain to arise is the fact that the billing period will not coincide with the beginning and ending of a month. On the other hand, the weather service gives the number of heating degree days in a given calendar month. Clearly the number of heating degree days should correspond to the period during which the heating fuel was used and the Pacific Gas and Electric Company has a computer program to make this adjustment.[7] A similar correction was used in the work of Woteki and Fels.[3] In the present analysis, it had to be assumed that the billing period coincided with the number of heating degree days that were reported, because no provision was made to collect information on billing periods with the other data. There is no direct way to verify whether the fuel bills and degree days used in this study are synchronous. However, the high values of the correlation coefficients displayed in Figure 5 could be interpreted as an indication that any lack of synchronism does not seriously affect the general validity of the linear model of fuel use.

V. Conclusions

From the preceding analysis we have concluded that a collection of buildings in one location, such as a community college campus, can be represented by a linear relationship between its heating fuel use and the number of heating degree days. In addition an average electricity use is needed to complete the description of energy use on the campus. This representation, or model, depends on three parameters, the base fuel use, the thermal performance index of the buildings and the average electricity use. These parameters can be expressed as indices of intensity of fuel use when converted to common units of BTU's per gross square foot and then used to compare the energy use on different campuses. The average values of these indices for campuses using different fuel mixtures are very nearly constant with the exception of all electric campuses. This indicates that the use of energy does not depend on the heating fuel or combination of fuels, but rather on the physical construction of the campus buildings and the way they are utilized. This model automatically separates out differences in size and climate between campuses and provides an individual campus with an objective means of comparing its energy use with that of its peers. By adopting a base year of performance, this model also permits the energy savings and cost avoidance of conservation measures to be determined in an objective way. Such a determination is essential for measuring the progress of those campuses that have adopted conservation or energy management programs.

The model does not produce satisfactory results if it is applied to campuses with less than 1000 heating degree days per year. However, the results are not sensitive to other small errors such as missed meter readings, or variations in billing periods.

The model provides a tool for college administrators to use in evaluating the management of energy use on their campuses.

VI. Acknowledgements

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4. Atelsek, F.J. and Goldberg, I.L., HEP Report No. 31, pl. 9, April 1977. (sample of 73 2-year colleges).

5. "Energy Conservation in Schools: A Report on the Development of a Public School Energy Conservation Service", Educational Facilities Laboratories Contrac FEA No. C-04-50047-00, October 1975.

6. The use of cooling degree days, CDD, to estimate the energy needed for cooling a building, does not give satisfactory results. Other measures, such as "equivalent" full-load hours of operating cooling equipment give equally poor results. A full discussion of this problem is given in ASHRAE-76: "Systems Handbook", Chapter 43, American Society of Heating, Refrigerating and Air Conditioning Engineers, New York, 1976.

7. Private Communication from James McClure of the School Plant Program of the Pacific Gas and Electric Company, September 1979.

TABLE I SUMMARY OF ANNUAL ENERGY USE AND COST

	1972-3[a]	1974-5[a]	1978-9[b]
Annual BTU/Gross Square Feet	183,000	135,000	128,000
Annual BTU/Student (FTE)	29.2×10^6	20.6×10^6	13.1×10^6
Annual Cost/Gross Square Foot	30.9¢	41.0¢	75.0¢
Annual Cost/Student (FTE)	$ 49	$ 63	$ 75

[a] Atelsek, F.J. and Gomberg, I.L., HEP Report No. 31, p.9, April 1977

[b] Results from LBL Sample (80 Community Colleges)

TABLE II

The Average Values of $\overline{E}$, A and B for 80 Campuses

Fuel Mix	No. of Colleges	$\overline{E}$ X 10^3 BTU/Sq.ft. mon.	A X 10^3 BTU/sq.ft. mon	B BTU/sq.ft. HDD
Electricity & Gas	49	4.33	1.98	13.3
All Electricity	10	6.48	-	-
Electricity + Oil	6	4.13	2.14	10.4
Electricity + Gas + Oil	15	4.30	3.51	12.5
Overall Averages	80	4.52	2.58	12.8

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