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ABSTRACT

An energy analysis model is provided for college administrators in which information from their utility bills is used to measure the amount of energy saved and to determine the fuel costs avoided when they undertake an energy conservation program. Because the model explicitly takes into account variations in weather, it provides an essential tool for evaluating energy conservation programs. An example, using actual data from a two-year college in California, is worked through in detail. A simple, graphical method of solution is presented to avoid the use of any sophisticated mathematics. The results of applying this analysis to 70 two-year colleges is used to establish the average performance characteristics of these institutions. An individual campus can then analyze its own data and compare its energy usage with that of its peers. Finally, a discussion of how these calculated results can be used to map a strategy for implementing a campus conservation program is presented. (Author/DC)

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Walter Deckel, Blake Heitzman, Joseph Koford,
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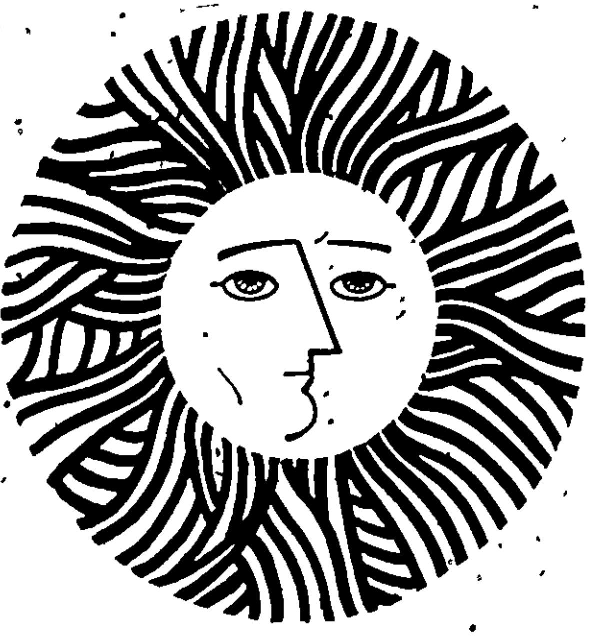

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Measuring Energy Conservation with Utility Bills

Walter Deckel
Blake Heitzman
Pacific Gas and Electric Company

and

Joseph Koford
Betsy Krieg*
Carl York
Lawrence Berkeley Laboratory
Berkeley, California 94720

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* Now employed by the Pacific Gas and Electric Company

Abstract

The purpose of this paper is to show college administrators how to use their utility bills to measure the amount of energy saved and to determine the fuel costs avoided, when they undertake an energy conservation program. An example, using actual data from a 2-year college in California, is worked through in detail. A simple, graphical method of solution is presented to avoid the use of any sophisticated mathematics.

The results of applying this analysis to 70 two-year colleges is used to establish the average performance characteristics of these institutions. An individual campus can then analyze its own data and compare its energy usage with that of its peers.

Finally, a discussion of how these calculated results can be used to map a strategy for implementing a campus conservation program is presented.

MEASURING ENERGY CONSERVATION WITH UTILITY BILLS

BY

Walter Deckel and Blake Heitzman, PG & E

and

Joseph Koford, Betsy Krieg, and Carl York, LBL

I. INTRODUCTION

In recent years rising fuel costs have forced many colleges and universities to examine their use of energy and to introduce programs of energy conservation on their campuses. We have found in our work with these institutions that there is a great need for a simple, technically correct method for documenting the amount of energy saved by these conservation efforts. The objective of this paper is to explain how to use the information in a utility bill to measure the saved energy and to determine the avoided costs, when conservation measures are applied.

This paper will describe the information on a utility bill, a "common sense" model to calculate energy use on a campus, and a calculation of energy savings for a 2-year college in California. Seventy similar colleges in the United States have been analyzed to determine the average values and distributions of values of the constants used in this energy model. The result enables a college to analyze its own utility bills and determine where its use of energy falls relative to the national picture. Finally, we indicate a way to use the results of the analysis to map a strategy for improving the efficiency of energy use on the campus.

II. UTILITY BILLS

Although the exact format of a utility bill varies, all contain the following information:

The name and address of the customer;

An account number;

The number of days in the billing period;

The previous meter reading;

The present meter reading

The amount of energy used (in therms and kWh), during the billing period;

The unit cost of the given form of energy for the billing period is either given, or can be calculated; and

The total cost of the energy used during the billing period ("Pay this amount!").

In natural gas and electricity bills, additional information is sometimes included, such as the average daily energy use, or the comparable daily energy use in the previous year. Bills for coal, oil and liquid petroleum products, however, are quite different. Since a coal, oil or propane furnace requires a place to store the fuel until it is needed, the bill will state how many gallons or tons were left in the storage place, the unit cost of each, and the total charge for the amount delivered. This might differ from the amount of fuel actually used during the billing period. In this case, some means for measuring fuel use, other than the bills from fuel deliveries must be found. Most of the college campuses that use oil, coal or LPG do monitor fuel use. Our discussion will be limited to electricity and gas, but the analysis can be applied to other fuels.

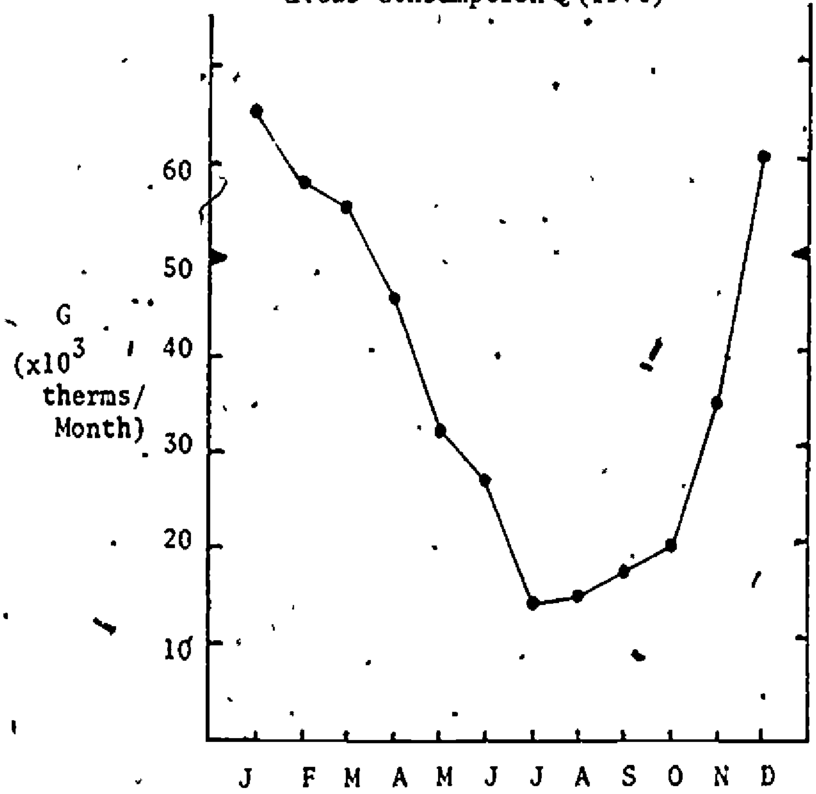
The data in Table I are taken from the utility bills of a two year college in California and these data are plotted in Figure 1. They will be used in the analysis to be carried out below.

III. ENERGY USE ON A COLLEGE CAMPUS

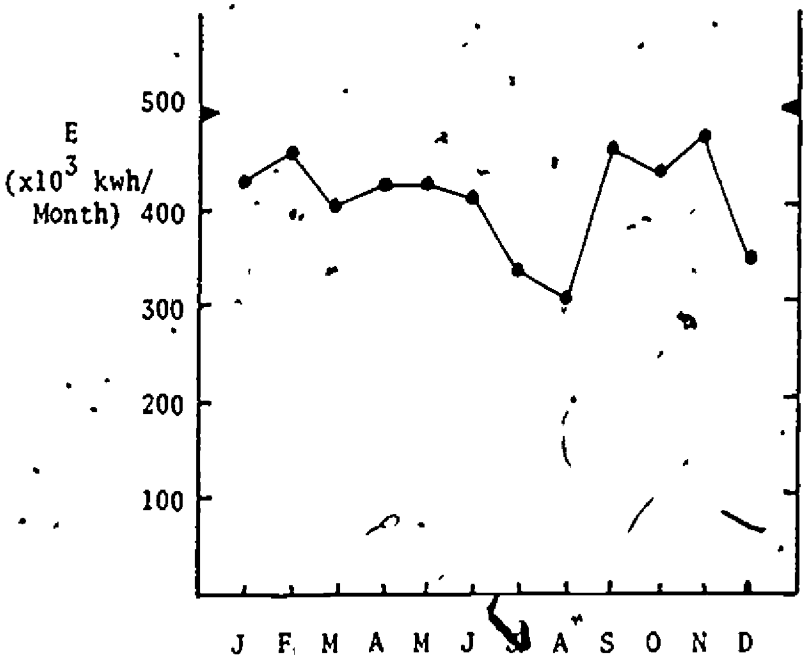
The energy used on a campus can be broken down into three classes of uses. A certain amount of energy is required to maintain a campus, independent of the weather and utilization of campus buildings. Some security lights, thermostated rooms, refrigerators, hot water heaters, and other appliances will be in operation at all times of the year. This kind of energy use is identified as the "base use". If the weather gets cold, then the buildings will require heat, and conversely if it gets hot, air conditioning may be required. The energy used for this heating and cooling will be called the "heating use" and will depend primarily on the outside air temperature.

FIGURE 1

a. Gas Consumption (1976)



b. Electricity Consumption (1976)



Finally there is energy that is consumed because it is needed to carry out the academic program. This "program use" will result from the use of gas kilns in a ceramic class, arc welders in the shops, bunsen burners in the chemistry laboratories, or lights in classrooms. The program use will depend primarily on the number of students and their academic programs. These three uses are one way to classify the energy use on a campus, and provide an intuitive way to analyze the utility bills.

We can write an equation for the total gas used in any month as:

$$G = B_G + H_G + P_G$$

where G is the total gas used and is measured in "therms," B_G is the base use, H_G is the heating use for gas, the P_G is the program use.

The heating use is assumed to be proportional to the number of heating degree days in the month. A heating degree day, HDD, is based on the idea that when the temperature goes below 65° F, in most buildings the heaters will switch on to maintain a comfortable temperature. When it is above that temperature, the heaters will not be in use. When the average temperature for a given day (obtained by adding the high and low temperature for a 24-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, 10 days at 64°, 5 days at 63°, 2 days at 60°, and 1 day at 55° are all equal to 10 heating degree days. Over the years this assumption has proved to be useful in estimating customer's fuel needs during a period of cold weather. Hence, we shall assume that the heating use for a campus is proportional to the number of heating degree days, or:

$$H_G = b \text{ HDD}$$

where H_G is the heating use, b is a constant of proportionality and HDD is the number of heating degree days in a given billing period. The constant, b, can be determined from the billing data, as shown below. Each week the National Weather Service field offices provide degree day data, as do some utility companies.

The program use, P_G, during the academic year depends on the enrollment and the academic calendar. Although enrollments always suffer some attrition during a term and usually drop off from the fall term high to a summer term low, these trends will be assumed not to affect the energy loads for a campus. One reason for this assumption is that if the academic program consists primarily of a set of scheduled classes, then a 10 or 15 percent decrease in the number of people in those classes, will not change the need to heat and light the classrooms. For these calculations we will assume that the program use is a constant, i.e., P_G = constant.

The final equation can then be written:

$$G = B_G + bHDD + P_G$$

or:

$$G = a + bHDD$$

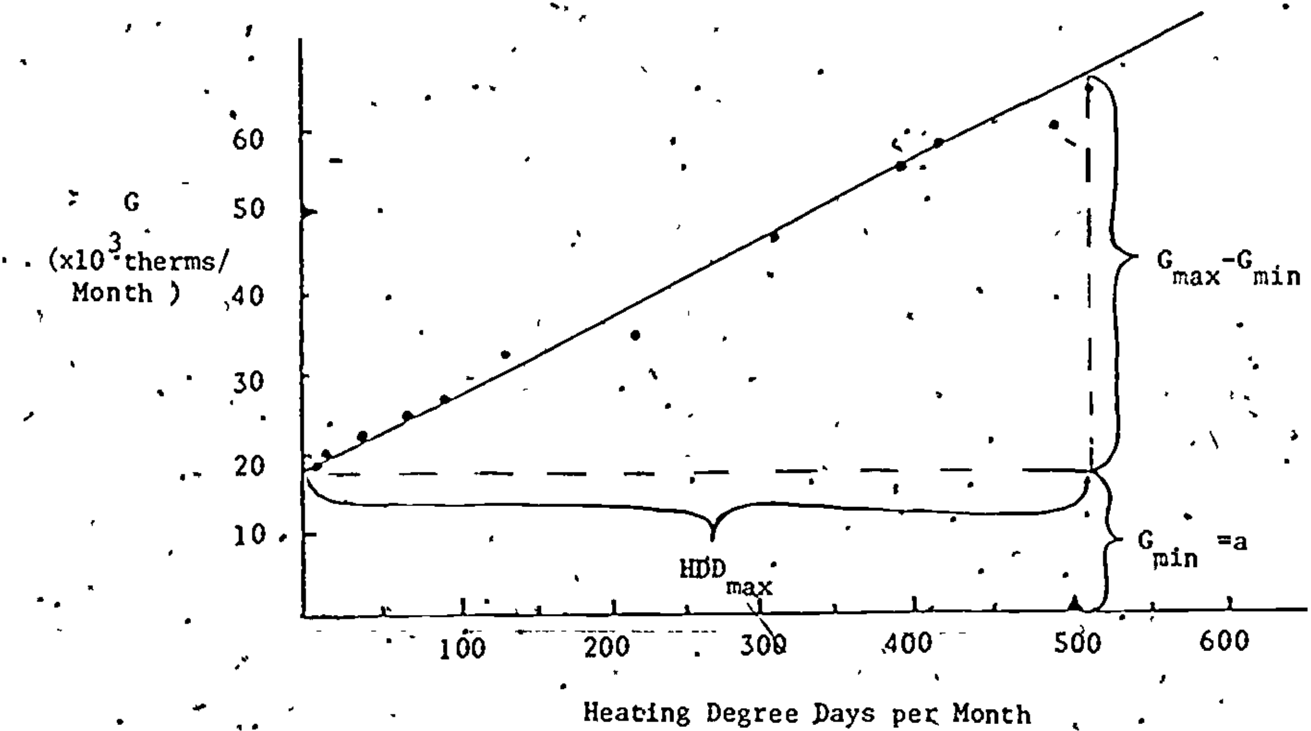
where $a = B_G + P_G$ = constant. There are standard mathematical methods for determining the constants, a and b, when twelve measurements of G are taken from the utility bills, and a corresponding set of values for HDD are available for a given year. We have chosen the method of "least squares" to fit the data and to determine the constants, because many of the programmable, hand-held computers now available are fitted with a program to do this kind of calculation. Other, more sophisticated regression analyses could be performed, but have not been done, because of the limited accuracy of the billing data. However, the most direct way to determine the constants is simply to plot the amount of gas used in a given month against the number of degree days in that month. This has been done in Figure 2 for the 1976 data which were given in Table I. A ruler was used to draw a straight line through the points and the base constant, a, is just the point of intersection of the line with the vertical axis. The value is about 19×10^3 therms per month. The constant, b, is just the slope of the line and is given by the ratio:

$$b = \frac{G_{max} - G_{min}}{HDD_{max}}$$

FIGURE 2

Gas Consumption per Month Plotted

Against Heating Degree Days per Month



In this case:

$$b = \frac{(65 - 19) \times 10^3}{508} = 91 \text{ therms/HDD}$$

The values are to be compared with those determined from the least squares fit which gave $a = 18.47 \times 10^3$ therms per month and $b = 90.4$ therms per HDD.

The assumption that a linear relationship exists between the amount of fuel used and the number of degree days has been verified for elementary and high schools by the Educational Facilities Laboratories.[1] In their studies they found that the performance characteristics of 1443 school buildings could be analyzed under this assumption. The engineering basis for this assumption has been developed by Shrader.[2] The constant, a, is called the "base use", while the constant, b, is called the "thermal performance index". The thermal performance index depends upon the physical characteristics of a building such as the insulation in the roof and walls, the area of windows, the efficiency of the heating system, and so on. The constants, a and b, which were introduced earlier apply to all of the buildings on a campus and are simply the sum of similar constants for each individual building on that campus. Hence, the base use and thermal performance index determined from the total utility bill are aggregates for the entire campus.

If the campus has a substantial number of unit air conditioners or several central chiller units which are powered by electricity, then the electric energy load could be written as:

$$E = B_E + C_E + P_E$$

where B_E is the constant base electric use , and again the program use, P_E, will be assumed to be constant. The heating use, which is really a cooling use, C_E, will be taken to be proportional to the number of "cooling degree days", CDD, in the month. A cooling degree day is analogous to a heating degree day, but is measured for outside temperatures in excess of 65°F, at which cooling systems are supposed to be switched on. Cooling degree days can be obtained from the local utility company or National Weather Service in the same way as heating degree days. Under these assumptions, the electricity use can be written as:

$$E = d + eCDD ,$$

where $d = B_E + P_E$ and e are constants. Again, the twelve-month data could be used to determine the constants. The electricity usage in a billing period, E, is measured in kilowatt hours, kwh.

After analyzing the data from 70 colleges, we have concluded that the use of this equation is not justified.[3] Instead the average monthly electricity, $\bar{E}$, is an adequate measure for most purposes.

The exception to this rule is the "all electric" campus. There are 9 such cases in our sample and they are analyzed in the Appendix below. In the remainder of our sample, we have found that the air-conditioning load, which goes up in the summer, seems to be offset by a drop in other electricity usage such as classroom lighting.

IV. CALCULATION OF SAVINGS

The energy savings on a campus can be calculated by choosing some "base year" prior to energy-conserving efforts. The energy usage in the current year can then be compared to that of the base year to see if the conservation program has been successful. To allow for changes in weather between the two years, the fuel usage in a given month should be compared with an "expected base year usage." The expected usage takes the values of a and b which were determined from our equations above for the base year and multiplies by the number of degree days actually observed in the current month to determine the amount of energy that could have been expected to be used. This "expected" value is compared to the actual usage to determine the amount of energy saved.

The monthly savings in gas and electricity can be written as the following equation:

$$\Delta G = (a + hHDD) - (G)_A$$

and

$$\Delta E = \overline{E}_B - (E)_A$$

Here, a, b, and $\overline{E}_B$ are the constants for a campus and are determined from monthly energy use data for the base year as shown earlier. HDD is the number of heating degree days in the current month and $(G)_A$ and $(E)_A$ are the "actual" amounts of gas and electricity used during the current month.

If ΔG and ΔE are positive numbers, then there has been an energy savings and the conservation efforts are paying off. The amount of payoff is called the "energy savings" for the current month and its dollar value is called the "cost avoidance." The cost avoidance is calculated by multiplying ΔG and ΔE by the current cost of gas and electricity. Several colleges have made budgetary arrangements to recover this fuel cost avoidance in order to provide for funding of their campus conservation program. If this can be arranged, it enhances the direct incentives to campus program participants.[4]

As an example, consider the 1976 data for the two-year college in California that was presented in Table I and Figure 1. The corresponding data for 1977 are shown in Table II. Two columns have been added to the table to give the "expected" gas usage each month, which is given by (a + bHDD). The gas savings, ΔG are also shown. Here the values of a and b are those calculated for the base year, 1976, while the values of HDD are those given in Table II for 1977. The difference between the "expected" and "actual" gas usage, ΔG, is given for each month in the last column. The total values for ΔG and ΔE are:

$$\Delta G = 472.7 \times 10^3 - 383.6 \times 10^3$$

$$= 89.1 \times 10^3 \text{ therms/year}$$

$$\Delta E = 4926 \times 10^3 - 4462 \times 10^3$$

$$= 464 \times 10^3 \text{ kWh/year}$$

Given that in 1977 the rates were \$0.25/therm for gas and that the rates for electricity were \$0.044/kWh, the cost avoidance can be calculated to be:

$$\text{Cost Avoidance} = (89.1 \times 10^3 \times \$0.25) + (464 \times 10^3 \times \$0.044)$$
$$= \$42,681 .$$

The above calculations are based on the assumption that no new buildings have been opened on the campus since the base year constants were determined. When buildings are erected or torn down, a simple correction can be made. If it is assumed that each gross square foot of the building on the campus has the same average energy use as every other gross square foot, then the "expected usage" in a given year can be adjusted by multiplying by the area of the buildings in that year divided by the area of the buildings in the base year. If these areas are denoted by S and S_B, then the equations for energy savings can be written

$$\Delta G = (a + bHDD)\ S/S_B - (G)_A$$

and

$$\Delta E = \overline{E}_B\ \ S/S_B - (E)_A .$$

This correction assumes that the new, or destroyed, buildings have the same thermal performance as the average building on the campus. The ratio, S/S_B, will be greater than one if new buildings have been added, or it will be less than one if some buildings have been torn down or taken out of operation.

V. COMPARISON BETWEEN CAMPUSES

It would not be reasonable to compare the energy use on a large campus with that on a small one. Nor would it be reasonable to compare the energy use of a campus in Florida with one in Minnesota. The method of analysis described above separates the effect of climate, as expressed by heating degree days, and allows a comparison of the constants, a, b, and E. To correct for the differences in size of the various campuses, these constants are divided by the gross square footage of the buildings on the campus to obtain the "intensities of energy use". These intensities can then be compared.

From our analysis of 70 college campuses, 42 used only gas and electricity as their energy source. Of these only 33 had utility bill data which gave results which were analogous to our example given above. The other nine campuses were in the "Sun Belt" and had so few heating degree days (less than 1000 per year) that the data would not give a satisfactory fit with a straight line.

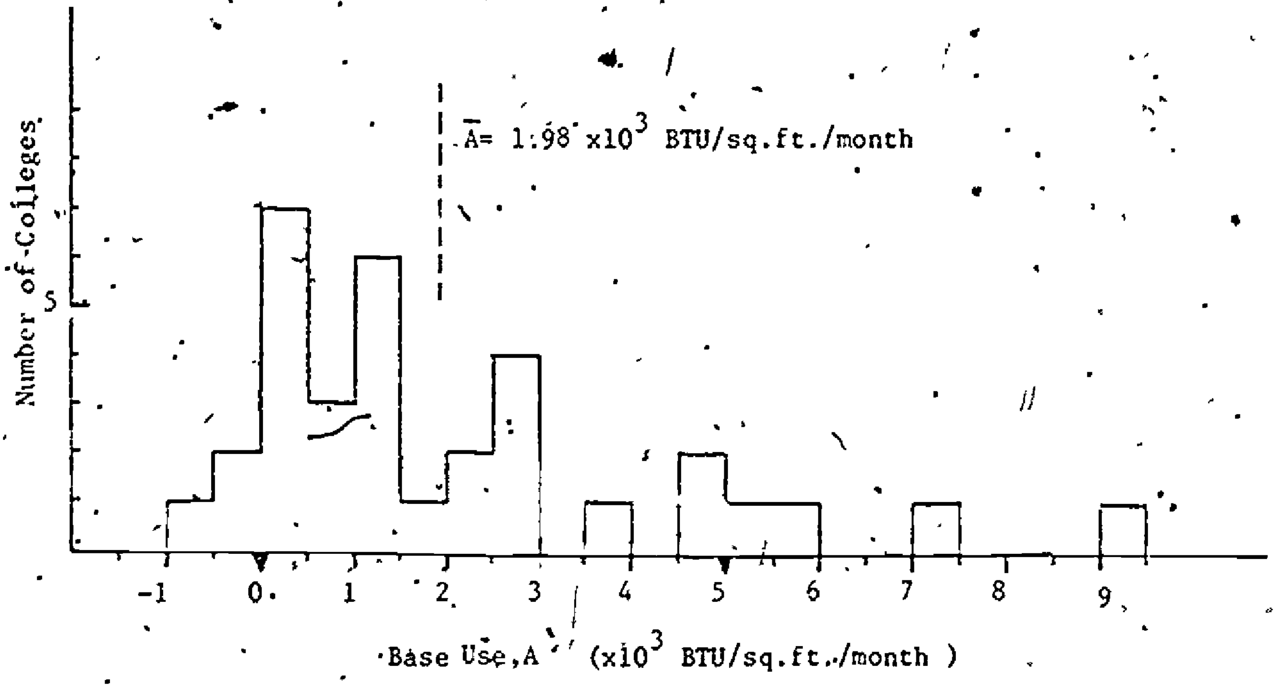
Frequency distributions of the energy use intensities have been plotted as histograms in Figure 3. In Figure 3a, the gas base use intensity, A, is shown, in Figure 3b, the gas thermal performance intensity, B, is shown; and in Figure 3c the average electrical intensity, $\bar{E}$, is shown. It should be noted that the values of the constants are expressed in British Thermal Units, BTU, for these comparisons. The conversions were made by noting that there are 100,000 BTU's in one therm and that there are 3413 BTU's in one kilowatt hour. It should be noted here that for every BTU of electrical energy delivered to the campus, three BTU's of fossil or nuclear fuel were consumed at the generating plant. Our calculations are limited to "on site" fuel use.

The most striking thing about the three distributions is the wide variation between individual campuses. In Figure 3a there are two values of base use which are slightly negative and the explanation of this possibility is given in detail in the Appendix below. The fact remains that some campuses use six or seven times as much energy as others to provide hot water and other gas heated services on a year around basis. It is not so surprising that the distribution of thermal performance in Figure 3b is widely varying, because the building standards for ceiling and wall insulation do vary appreciably across the country. In fact, the two campuses at the high end of the distribution are in California, where there are fewer heating degree days than in some other parts of the country and the past practices in building design have not emphasized thermal efficiency.

The average electrical use shown in Figure 3c again shows a broad variation. The heavy users of electricity could benefit from a de-lamping

FIGURE 3.

a. Distribution of Values of Base Use, A



b. Distribution of Values of Thermal Performance, B

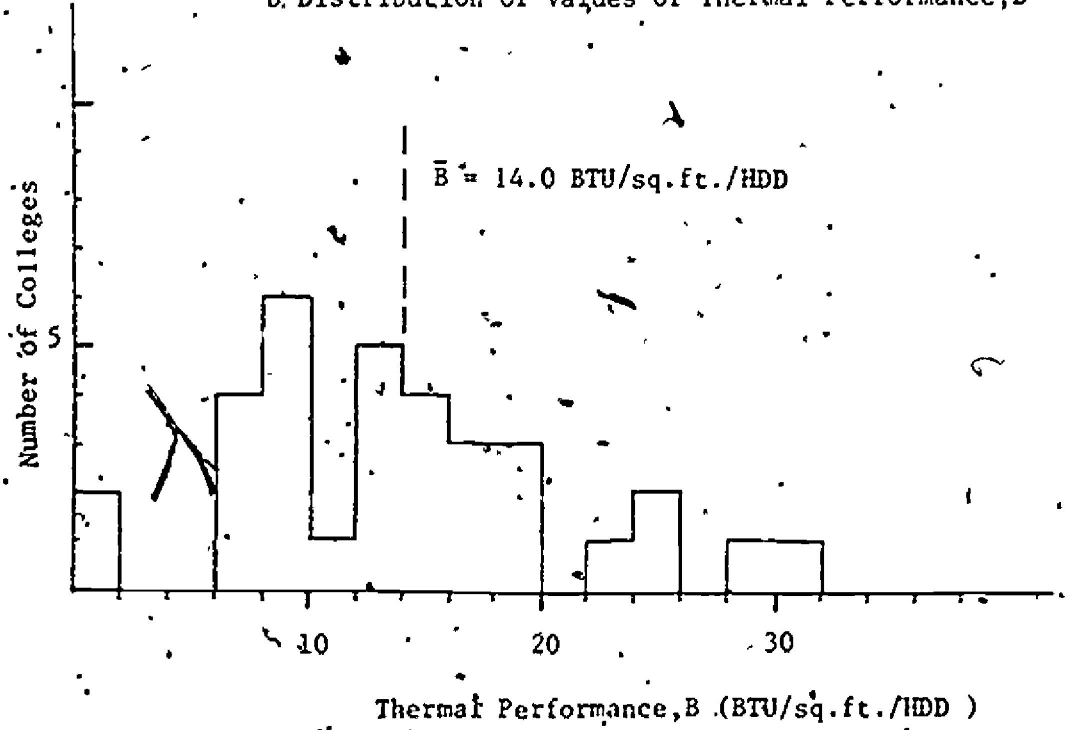
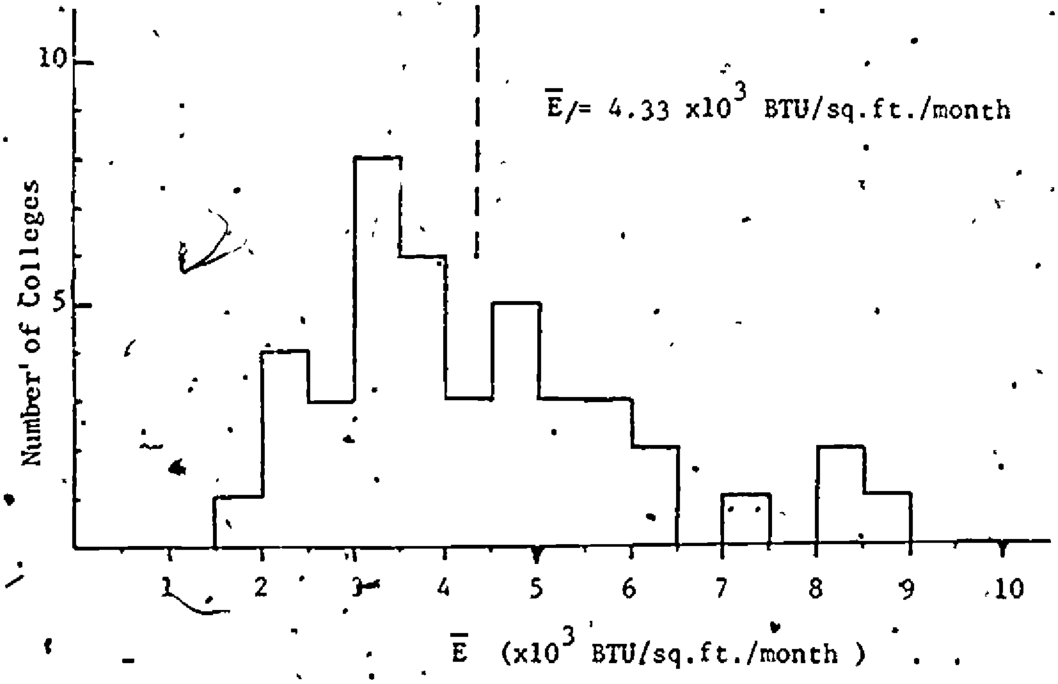


FIGURE 3 (Cont'd.)

c. Distribution of Values of Average Electrical Use



and re-lamping program. They should examine the light levels in their various buildings and consider the savings that are possible in replacing incandescent lamps with fluorescent lamps and substituting the new low wattage sodium lamps for the older mercury flood lamps used in parking lots and similar security lighting applications.

In earlier studies[5] several indicators of campus energy use have been used. The values of these indices for the present sample of campuses is included here to provide a sense of the variation in time of their values. The first indicator is the "Energy Use Index" which is defined by the ratio:

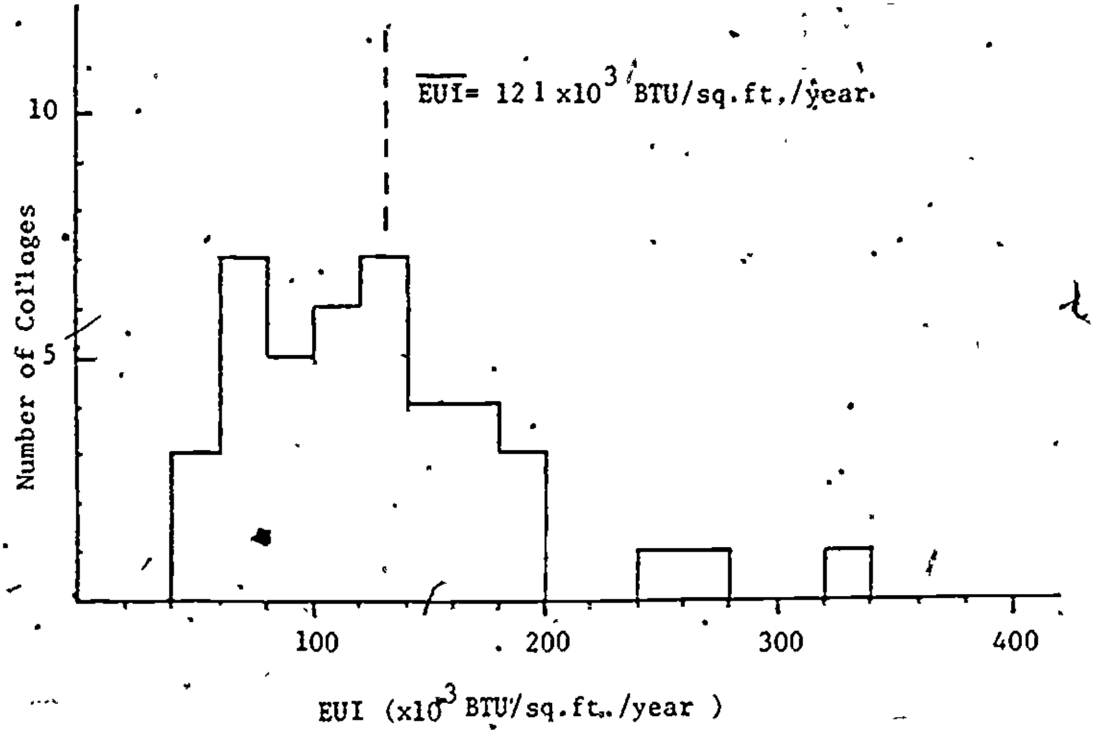
$$EUI = \frac{\text{Total Energy Used Per Year}}{\text{Total Gross Square Feet}}$$

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. Figure 4a shows the distribution of the set of 42 campuses studied here and again the average value is entered in Table III for comparison with earlier work, Finally, there are two other indicators which have been used in the past and are included in the table. They are the Energy Used per Full Time Equivalent Student (FTE) and the 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 has centered more directly on conservation measures applied to the physical plant, so we will ~~not~~ pursue the discussion of these student body related indices. Their average values for the 70 schools in our sample are included in Table III.

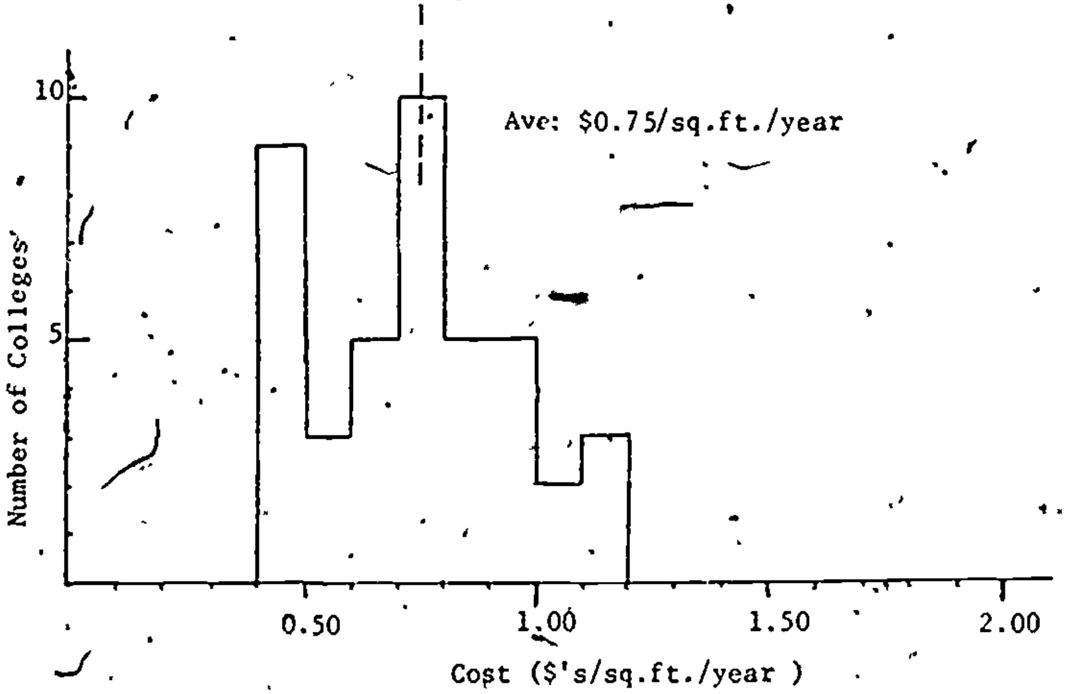
The trends of the four indices in Table III are marked. The total energy used both per square foot and per FTE has dropped markedly since 1972-3. In spite of these decreases, the costs, both per square foot and per FTE, have increased markedly. The explanation of the first trend lies

FIGURE 4

a.Distribution of Values of Energy Use Index



b.Distribution of Cost of Total Energy per Sqare Foot



in the efforts of colleges to cut back on their energy use, while the cost increases are clearly connected to the rising prices of energy. The first trend should be reemphasized, however, because it is clear that conservation efforts are working on the community college campuses.

VI. USING THE CONSTANTS TO MAP A CONSERVATION STRATEGY

Consider how the constants, A, B, and $\overline{E}$ could be used to plan a program of energy conservation. Our earlier example of a California campus can be used. Given that that particular campus had 420,000 gross square feet of building space, the indices become:

$$A = 4.5 \times 10^3 \text{ BTU/sq. ft./month,}$$

$$B = 21.7 \quad \text{BTU sq.. ft./HDD, and}$$

$$\overline{E} = 3.49 \times 10^3 \text{ BTU/sq. ft./month.}$$

It is seen that the base use and thermal performance index of this California school are higher than the average in Figure 3, while the electrical use is somewhat lower. The causes of the high base use should be carefully investigated. Pilot lights on hot water heaters and stoves might be replaced with intermittent ignition devices, leaks in the gas lines might be sought, the hot water heaters might be wrapped in fiberglass blankets, and the water temperatures might be lowered. The high value of B, the thermal performance index, could require more complex remedies, because the ceiling and wall insulation of buildings in California is quite often deficient. Infiltration of cold air around windows is another cause of heat loss, and might require a program of caulking and sealing window and door frames. The average electricity use is lower than average and could be studied after the other areas discussed above. For each of these three areas there are long, detailed lists of suggested ways to reduce energy consumption.[6,7] Such lists are valuable as a means of suggesting conservation measures that might otherwise be overlooked.

At some point no further energy savings can be achieved. It takes energy to operate campus services and academic programs. The objective of a campus conservation program is to reduce the energy use to a reasonable minimum and to determine whether increases in use are due to outside influences (such as weather or broken windows) or to wasteful practices in the campus community.

VII ACKNOWLEDGEMENTS

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Table I

1976 Data For A California 2 Yr. College

Month	Gas (x10³ therms)	Electric (x10³ kWh)	HDD	CDD
J	65.3	433	508	0
F	58.3	461	415	0
M	55.6	402	391	0
A	46.5	---[a]	309	0
M	32.8	849	129	29
J	27.1	417	88	173
J	18.9	333	7	136
A	19.8	303	14	127
S	22.4	462	35	78
O	24.7	441	65	41
N	34.6	477	216	7
D	60.3	348	486	0
TOTALS	465.8	4926	2662	591

[a] This is an example of "missed" meter reading, with a reading in May for usage in both April and May. In analyzing the data, the May reading was divided by 2 and inserted in the Table for April and May.

Table II

1977 Data and Calculated Values of Energy Saved
For A California 2-Yr. College

Month	Actual Gas Use (x 10^3 therms/ month)	Actual Electricity (x 10^3 kWh per month)	1977 HDD	1977 CDD	G expected (x 10^3 therm per month	ΔG (x 10^3 therms/ month)
J	64.9	403	564	0	70.0	5.1
F	47.2	366	355	0	51.0	2.8
M	45.5	415	413	0	56.0	10.5
A	28.8	387	188	8	35.0	6.2
M	28.9	384	245	10	41.0	12.1
J	22.3	313	55	110	24.0	1.7
J	13.6	292	5	144	19.5	5.9
A	13.4	340	3	151	19.3	5.9
S	14.9	383	37	58	22.3	7.4
O	21.0	407	117	19	29.7	8.7
N	36.3	416	321	0	47.9	11.6
D	46.8	356	422	0	57.0	10.2
TOTAL	383.6	4462	2725	500	472.7	88.1

Table III Summary of Annual Energy Use and Cost

	1972-3[a]	1974-5[a]	1978-9[b]
BTU/Gross Square Feet	183,000	135,000	121,000
BTU/Student (FTE)	29.2×10^6	20.6×10^6	$13.1 \text{ X } 10^6$
Cost/Gross Square Foot	30.9¢	41.0¢	75.0¢
Cost/Student (FTE)	$49	$63	$ 75

[a] Atelsek, F. J. and Gomberg, I.L., HEP Repor[illegible] No. 31, p. 9, April 1977 (73 Two Year Colleges)

[b] Results from LBL Sample (70 Community Colleges)

Appendix

LIMITATIONS OF THE ANALYSIS AND SOME SPECIAL CASES

A. Limitations in Using a Utility Bill

There are several potential problems that should be borne in mind. 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. An example of a missed reading is seen in the data of Table I. There is a blank, or zero, reading of the electric bill in April of 1976 and the value in May is clearly the sum of April and May. To correct this, we simply divided the value of the May reading by two and inserted that value as entries for April and May in the table before making the calculation.

B. The All-Electric Campus

There are a number of all-electric campuses around the country, and, as the name implies, they use electricity to provide heat, as well as air conditioning and light. In this case, the energy use equations become:

$$G = 0$$

and

$$E = d + eCDD + fHDD$$

That is, the electricity use just adds a new term for the electricity heating use which is proportional to the number of heating degree days. The new constant of proportionality is taken to be f.

The special opportunities and problems that the all-electric campus encounters have been described elsewhere.[8] We show the kind of energy use curves that can be obtained in Figure 5. Here the three coefficients, d, e and f have been computed by the least squares method, mentioned earlier. The actual data points are plotted near the top of the graph and the calculated points using the above equation are seen to interweave with the others as expected for a fitted curve. This result is analogous to the straight line that was drawn through the data points in Figure 2a, above. Below these two curves are plotted the three quantities which are added in the equation to give the calculated energy use in each month. The base use is a constant and shows as a straight, horizontal line on the graph. The cooling use is the coefficient, e, multiplied by the number of cooling degree days, CDD, in each month and reflects the variation in CDD throughout the year. Similarly, the heating use reflects the changes in the number of heating degree days in the year.

In our study, there were 9 all-electric campuses included. We have divided the constants, d, e, and f by the gross square footage of each campus and averaged the result to get some idea of the values to be expected. The average values are:

$\overline{d} = 4.00 \times 10^3$ BTU/sq. ft./month

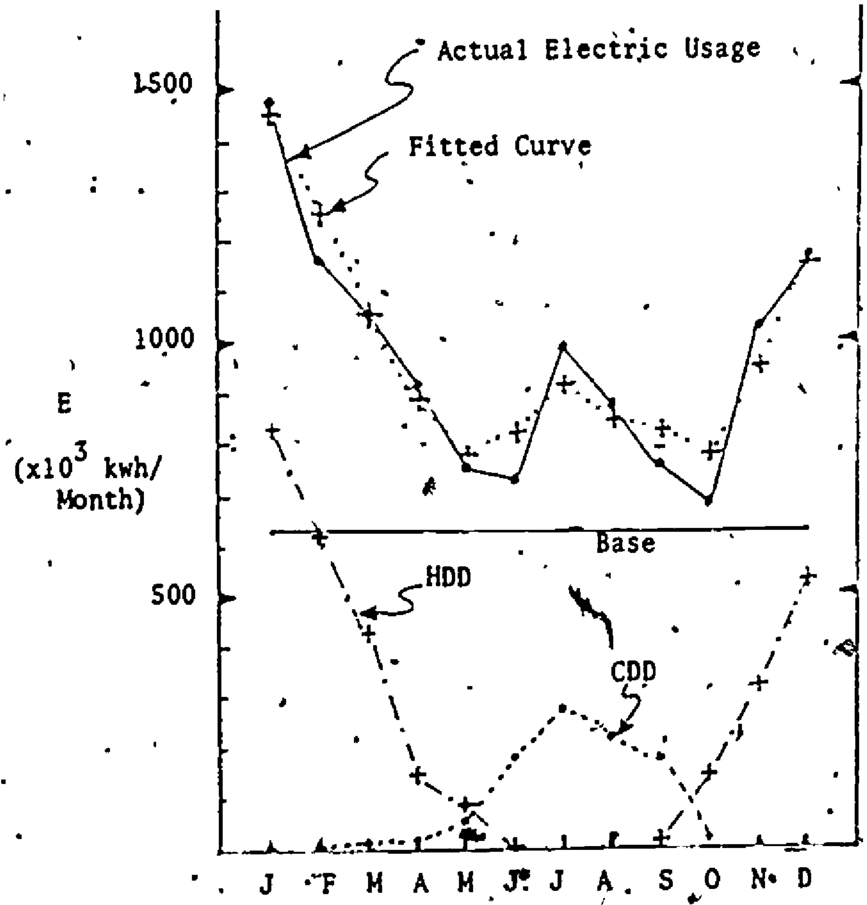
$\overline{e} = 3.11$ BTU/sq. ft./CDD

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

Because the base use $\overline{d}$, is primarily due to lighting on the campus, it is not an accident that it comes out to be very nearly equal to $\overline{E}$ for a campus that is lighted by electricity but heated with gas ($\overline{E} = 4.33 \times 10^3$ BTU/sq. ft./mon). In the all electric case the thermal performance is given by $\overline{f}$ and is seen to be approximately one-half the value for a gas heated campus ($\overline{B} = 14.0$ BTU/HDD). Presumably the higher cost of electricity per BTU, induced the architects and builders to make the buildings more thermally efficient on the all electric campus. This is a clear indication that the thermal performance of gas heated campuses can be improved substantially.

FIGURE 5

An All Electric Campus



C. The Gas Absorption Chiller

If a campus has an air conditioner which uses gas as the source of energy to drive it, such a cooling unit is called a "gas absorption chiller." Instead of the gas consumption going through a minimum in the summer, as it did in Figure 1a, the curve will show a bump that looks very much like that in Figure 5 for the all-electric campus. In this case, the equations for energy usage must be written:

$$G = a + bHDD + gCDD$$

and

$$E = d$$

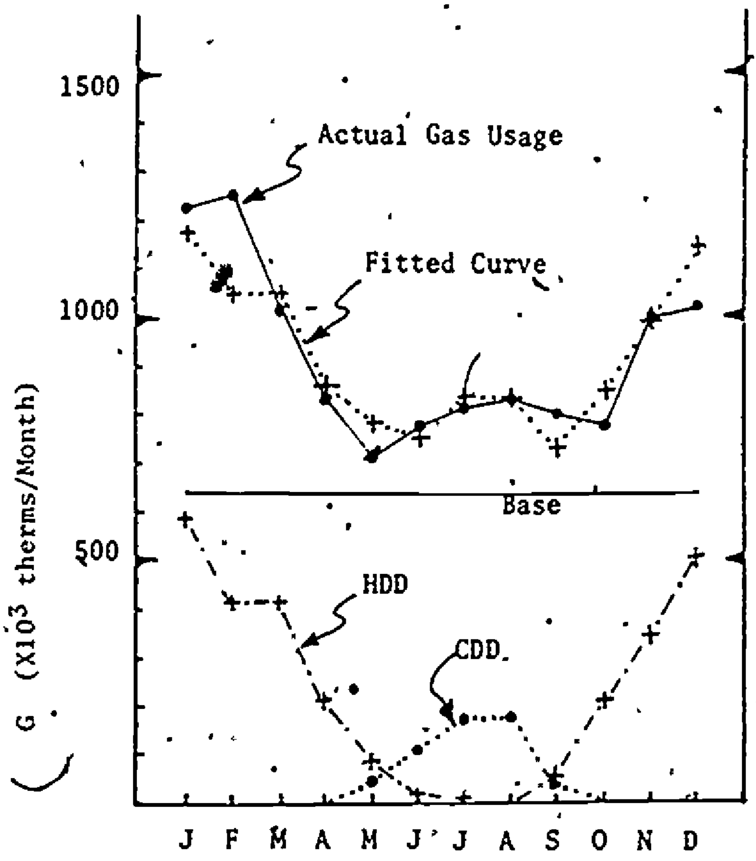
Here we have assumed that there are no electric air conditioners on the campus and that $C_E = 0$. The cooling use term, gCDD, has been added to the gas usage to reflect the impact of the gas absorption unit during warm weather. Figure 6 shows the variation of the gas consumption data interwoven with fitted curves whose coefficients were determined by the least squares fitting procedure. The base use term is shown as the horizontal line, while the heat use and cooling use are shown below. Unfortunately, when three constants are to be determined, there is no simple graphical scheme, such as that illustrated in Figure 2a, which can be used. Hence the regression analysis must be used.

D. Limits to the Analysis

When this type of analysis is applied to college campuses in parts of the country where the number of degree days in a year is small, we have concluded that it cannot be expected to work. If the number of degree days in a year is less than 1000, then the corresponding heating or cooling use term in the equations should be set equal to zero. This does not mean that heaters or air conditioners will not be needed for human comfort, but that the calculation method that we have developed is simply not sensitive enough to require that these terms be included.

FIGURE 6

A Gas Absorption Chiller



E. Negative Base Use

In a few of the cases we analyzed, a plot of the data like that in Figure 1a showed no gas usage during the summer months. When the gas usage was then plotted against the degree days, as in Figure 2a, the value of the constant, a, could fall below the HDD axis, and was negative. This negative base use was caused by the fact that the buildings on the campus do not turn on their heaters when the outside air temperature reaches 65°F, but at some lower temperature. If one analyzes 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 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. However, the 65° F heating degree day does work reasonably well for most situations and so we have adopted it.

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:

$$H_G = b\ (HDD + T)$$

Here T is the number of degree days that is required to correct the reference temperature of a given set of campus buildings. Then the total gas consumption would be:

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

and this could be rewritten as:

$$G = a' + bHDD$$

where

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

This says that our analysis cannot distiguish between the base use, or the program use or an offset in the reference temperature for the number of degree days, unless there is some other information. If, for example, it is known that in certain summer months that the gas usage is zero and the number of heating degree days is also zero, the intercept of the straight line in Figure 2a with the horizontal axis is a measure of how far the HDD scale has been displaced from zero. This is also related to how far the average reference temperature of the buildings on the campus is displaced from 65° F.

This displacement of the degree day reference and the inability to distinguish it from other constant energy uses is another limitation of this method of analysis. It is closely tied to the previous limitation that was discussed when too few degree days are encountered to make the heat load calculation meaningful. Although both of these limitations of our calculations can be corrected, it requires an entirely different approach[9] and will not be discussed here.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720