EVALUATING TEXAS STATE UNIVERSITY ENERGY CONSUMPTION ACCORDING TO PRODUCTIVITY

David Carnes
Mechanical Engineer-in-Training
Friberg Associates, Inc.
Fort Worth, Texas

Bruce D. Hunn, Ph.D.
Director of Technology
ASHRAE
Atlanta, Georgia

Jerold W. Jones, Ph.D., P.E.
Professor
Mechanical Engineering Department
The University of Texas at Austin
Austin, Texas

ABSTRACT

The Energy Utilization Index, energy consumption per square foot of floor area, is the most commonly used index of building energy consumption. However, a building or facility exists solely to support the activities of its occupants. Floor area alone is not a complete measure of the amount of service a facility provides. The energy consumption of a service institution, such as a university, could be evaluated according to its annual level of service. However, the variety of services delivered by an institution of higher education cannot be measured by a single, readily available number. Data Envelopment Analysis, a tool used primarily in management science, can find "benchmark" input consumption levels for productive entities with multiple inputs and outputs. It finds a consumption target for each form of energy consumed by an institution, based on the actual performance of comparable institutions. This

INTRODUCTION

State universities, technical colleges, and health science centers together account for most of the energy consumption and spending in facilities owned by the State of Texas (Hunn et al. 1995). In Fiscal Year 1993, these institutions spent $160.4 million on energy. Two public universities, Texas A&M University and the University of Texas at Austin, are the largest single consumers of energy among Texas state agencies. (The Texas Department of Criminal Justice, the prison system, is the third-largest energy user.) Because Texas public institutions of higher education consume so much energy, the State of Texas is naturally interested in keeping this consumption and cost under control. A detailed examination of energy consumption by this sector of state government would help indicate where resources for improving energy efficiency could best be utilized, by showing which institutions have the best energy-consumption practices and which need the most improvement. The most energy-efficient institutions demonstrate what the other institutions should be able to achieve.

Texas' State Agencies Natural Resource End-use Database, or SANRED, contains extensive data on energy consumption in state facilities. From 1987 to 1996 the Texas State Energy Conservation Office and its predecessor agencies tracked monthly use of natural resources by state agencies (Hunn et al. 1995). State agencies were required to submit semiannual reports of their use of various forms of energy. The agencies were to report only the energy that was purchased from an outside supplier. The SANRED energy data, obtained from utility bills, include electricity, natural gas, purchased steam or chilled water, and miscellaneous fuels such as propane and butane. Each agency's total energy consumption was reported as a weighted lump sum of all forms of energy.

traditional measure of facility energy consumption. It allows comparisons of energy consumption among facilities of different sizes. However, floor area alone is not a complete measure of the amount of service a facility provides the institution occupying it. A facility exists solely to help its occupants generate their products or services. The outputs generated by an institution indicate how much service its facility provides. This paper proposes a method of finding, for a facility, an energy use target based on that facility's output levels and the actual performance of other facilities.

Because, as will be shown, a university's output cannot be measured by a single quantity, the analysis method must handle multiple outputs. The proposed method, Data Envelopment Analysis, can handle multiple outputs and multiple inputs. This means that a facility's energy inputs do not need to be aggregated into a lump sum, and a consumption target can be found for each type of energy. A university's actual energy consumption can be evaluated against this custom-made standard. The application of this method to Texas state institutions of higher education will be demonstrated.

MEASURING THE SERVICE A UNIVERSITY CAMPUS PROVIDES

A facility with a low Energy Utilization Index is said to be energy-efficient. Thus, a facility's energy efficiency is defined according to its ability to provide a comfortable environment and "process" energy (used by computers and laboratory equipment, for example). The EUI uses floor area to represent the level of these services. The EUI is, in a sense, the energy required to support a generic square foot of building area. Direct comparison of the EUIs of two institutions assumes that an average square foot of building area provides both institutions with the same level of service, i.e., that an average square foot is used for the same number of hours and has the same occupant and equipment loads in both institutions. However, intensity of use can vary considerably even among institutions of the same type (Spielvogel 1980). If an institution has a large amount of underutilized space with low energy consumption, it will have a relatively low EUI and appear relatively energy-efficient.

The analyst could correct a facility's energy consumption for hours of utilization. For example, one of the energy intensity measures used with the Commercial Buildings Energy Consumption Survey is energy consumed per hour of operation (EIA 1992). This normalizing factor is defined as "total square footage of a building multiplied by total weekly hours of operation multiplied by 52 weeks per year." However, a square foot of laboratory space has more equipment than a square foot of classroom space. An hour of laboratory utilization intrinsically requires more energy than an hour of classroom utilization, but this normalizing factor does not account for the difference.

A university is not in the business of keeping buildings lit and cooled. The activities of a university dictate its need for conditioned floor area. Floor area is merely one of the tools a university uses in conducting its work. The quantity of that work is the measure of how much service the university campus provides. Kempski (1995) noted the following regarding universities:

> [they] might find a better measure of energy consumption than Btu per square foot. Close reviews of the records of major universities often reveal that energy use correlates more closely to student enrollment levels or the level of research-grant funding. (Kempski 1995)

The energy efficiency of an institution of higher education should be evaluated based on its energy consumption in delivering its true product: education. The first step in applying this principle to Texas state institutions of higher education is finding appropriate measures of their outputs.

The University's Outputs

Economists have used many output measures in examining managerial efficiency in postsecondary education (Ahn 1987). Tae Sik Ahn evaluated the overall productivity of Texas institutions of higher education, and defined three broad categories for the services of a university: community service, the creation of new knowledge (research), and the transmission of knowledge (teaching).

However, community service, because it takes a wide variety of forms, is practically impossible to quantify (Ahn 1987). A university's community service could include football games, continuing education, and faculty and student volunteer work. Economists acknowledge the existence of this type of output, but, because it is so hard to quantify, they usually ignore it in studies of university productivity. Ahn's analysis used research and teaching as the measures of a university's productivity, and this paper will also use those measures.

The simplest measure of a university's research activity is the amount of money is spends on research. Although research funding is actually an input consumed by a university, it does indicate the level of research activity at a university. Therefore, annual research expenditures will be used as an output in this analysis. Research spending data for Texas public institutions of higher education are available from annual reports published by the Texas Higher Education Coordinating Board (THECB).

The transmission of knowledge (teaching) is measured by semester credit hour enrollment. Ahn used undergraduate and graduate enrollment as separate output measures. This is because typically a professor devotes much more time to a graduate student than to an undergraduate, and because many graduate semester credit hours are devoted to non-classroom activities such as research and thesis and dissertation writing. These enrollment data are also readily available from THECB.

The University's Energy Inputs

As will be shown, the analysis method which is capable of handling the required multiple outputs can also handle multiple inputs. This means that the analysis can avoid the problem of aggregating the consumption of diverse forms of energy into a single number. Under a site energy accounting scheme, the reported consumption of each form of energy (kWh of electricity, MCF of natural gas, ton-hours of chilled water, etc.) is converted to the Btu of energy provided to the end user. Each form of energy has a unique set of uses. Reporting each form of energy in common units neglects the fact that they do not all provide the same kind of service to the consumer. For each Texas state university the total energy consumption can include three distinct categories of energy inputs: electricity, whose voltage is transferred to electrical devices; fuel, whose potential energy is released through chemical reactions; and purchased thermal energy, which represents heat transferred to chilled water or from steam or hot water.

A UNIVERSITY ENERGY CONSUMPTION MODEL

The EUI considers a building's provision of space as a process where a lump sum of energy is used to support a given amount of space:

$$\text{total energy} \rightarrow \text{floor area},$$

where floor area is fixed, and the energy manager seeks to minimize total energy consumption.

Simply replacing floor area with one of the output measures mentioned above would yield a ratio such as Btu per undergraduate semester credit hour. This kind of ratio would be misleading because it would neglect the university's other services.

Therefore, the proposed model of university energy consumption is:

$$\text{(electricity, fuel, thermal energy)} \rightarrow \text{(undergraduate semester credit hours, graduate semester credit hours, total research expenditures)},$$

where undergraduate semester credit hours, graduate semester credit hours, and total research expenditures are fixed. Here the energy manager seeks to minimize the consumption of electricity, fuel, and thermal energy.

The EUI evaluates the energy efficiency of a facility without regard for the facility's intensity of use. In contrast, the proposed model disregards the facility's size and considers only the ultimate outputs delivered at the facility. This approach reflects both the energy efficiency of the physical systems and how efficiently the facility is used.

It is necessary to aggregate the three outputs in order to find a ratio of energy to output. A weight for each of the outputs is required. *A priori* weights would presumably depend on the relative importance of each output, which is impossible to quantify objectively. Assigning a weight (i.e., energy value) to each type of energy input is also problematic, as we have seen.

The energy efficiency evaluation approach that will be discussed in this paper was derived from a paper (Baxter et al. 1986) that presented an analysis of the energy consumption of households. That analysis, instead of normalizing energy consumption by floor area, considered the number of people in the household and the number of rooms in the dwelling as the household's "outputs." Further, it avoided the problem of aggregating disparate sources of energy--in this case, electricity and fuel--by considering each a separate "input," without pre-assigning a weight to any of them. The analysts did so using a management-science technique, Data Envelopment Analysis.

DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) provides a measure of the relative efficiency of each entity, or decision-making unit (DMU), in a group. A DMU is any entity that takes in measurable inputs to produce measurable outputs. Past studies have considered power plants, courts of law, bank branches, and many other types of entities as DMUs (Golany et al. 1994; Lewin et al. 1982; Oral and Yolalan 1990). The method finds the "technical efficiency" of each DMU, where technical efficiency is the ratio of that entity's minimum possible input, given a fixed output level, to the actual input it used. Because it is often impossible to determine the ideal performance of an organization, Data Envelopment Analysis finds the technical efficiency of a DMU with reference not to a theoretical function, but to the best-performing DMUs in the group. Farrell (1957) introduced this concept, on which Data Envelopment Analysis is based.

Figure 1 illustrates the case of DMUs with one output and two inputs (Farrell 1957). Let the output be denoted by Z and the two inputs be denoted by E and F, and let

$$a_1 = \frac{E}{Z}\text{, and}$$

$$a_2 = \frac{F}{Z}.$$

Hence each point is described by the coordinates (a_1, a_2). The ratio a_1 could be considered the intensity of a DMU's consumption of Input E, and the ratio a_2 could be considered the intensity of its consumption of Input F. The curve CC' describes the "efficient frontier" for the DMU's in this group. The DMUs on the frontier are the best performers because they consume the smallest amounts of inputs E and F per unit of Z produced.

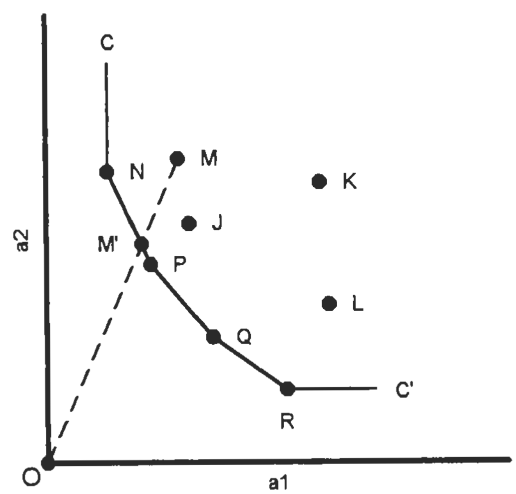

Figure 1. Efficiency of an entity relative to a best practice frontier (redrawn from Farrell 1957).

Any point on a frontier line segment P_iP_j is given by $(\lambda_i a_{i1} + \lambda_j a_{j1}, \lambda_i a_{i2} + \lambda_j a_{j2})$ (Farrell 1957). It is, in other words, a linear combination of the points that make up the segment. If a point lies on the line segment connecting P_i and P_j, the corresponding λ_i, $\lambda_j \geq 0$, and the λ's for all the other points are zero.

Consider, then, the case illustrated in Figure 1 (Farrell 1957). A technically efficient unit using inputs in the same relative proportions as M would be given by M'; M' is the "hypothetical comparison unit" of M. The technical efficiency of the actual unit M is therefore

$$\frac{OM'}{OM},$$

which is less than one. For a DMU on the frontier, meanwhile, such as Q, the technical efficiency would be equal to unity (OQ/OQ).

Note that the hypothetical unit M' is a linear combination of two adjacent DMU's, N and P. These two DMUs comprise the "reference group" of unit M. They are the two efficient DMUs which unit M most closely resembles. For unit M, the λ weights on units N and P are nonzero. They are, however, zero for all the other DMUs that do not contribute to unit M's hypothetical comparison unit.

The original Data Envelopment Analysis method is named the CCR method after Charnes, Cooper, and Rhodes, who extended Farrell's concept to DMUs that use multiple inputs and produce multiple outputs (Charnes et al. 1978). Suppose DMU j_0 has multiple inputs x_{ij0} and multiple outputs y_{rj0}. One can define the "efficiency score" for unit j_0 as

$$\frac{u_1 y_{1j_0} + u_2 y_{2j_0} + \ldots}{v_1 x_{1j_0} + v_2 x_{2j_0} + \ldots},$$

where u_1 is the weight given to output 1, y_{1j0} is the amount of output 1 from unit j_0, v_1 is the weight given to input 1, and x_{1j0} is the amount of input 1 to unit j_0 (El-Mahgary and Lahdelma 1995). Thus the score is a ratio of a weighted sum of outputs (a "virtual output") to a weighted sum of inputs (a "virtual input"). (The EUI is the reciprocal of this kind of score, where the "inputs" are the reported energy consumption levels, the weights are the assumed energy value of each form of energy, and conditioned floor area is the single "output.")

Now suppose that the weight applied to each input and output may be chosen to maximize this score, subject to two constraints: 1) if this same set of weights is applied to any DMU, including j_0, the efficiency score may not exceed one, and 2) no weight may equal zero, so that DMU j_0 may not neglect an input or output which makes it look bad.

The Data Envelopment Analysis method evaluates each DMU individually. In this application, each university receives input and output weights which maximize its relative efficiency score. This optimal set of weights will give at least one university a perfect efficiency score when the weights are applied to all of the universities. For each university, the corresponding set of perfect-scoring universities comprises its efficient reference group. These perfect-scoring universities make up the efficient frontier.

In mathematical terms, the goal is to maximize, for each DMU j_0, the efficiency score

$$h_0 = \frac{\sum_{r=1}^{s} u_r y_{rj_0}}{\sum_{i=1}^{m} v_i x_{ij_0}},$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \text{ for all } j,$$

and

$$u_r, v_i \geq \varepsilon > 0,$$

where s is the number of outputs and m is the number of inputs; $r = 1, \ldots, s$, and $i = 1, \ldots, m$; x_{ij} and y_{rj} are the input and output for DMU j, respectively; u_r and v_i are the weights which are chosen to find the maximum of h_0; and ε is a very small constant, meaning that all inputs and outputs must have a non-zero weight (El-Mahgary and Lahdelma 1995).

The evaluation of DMU j_0 produces two sets of weights. One set comprises the u and v weights, which maximize that DMU's efficiency score h_0 given by the formula above. Multiplying the inputs of DMU j_0 by h_0 should yield input levels approaching those of the hypothetical comparison unit. The other set comprises the λ weights applied to the other DMUs. The λ weights are applied to the inputs and outputs of the efficient DMUs, and the resulting weighted sums are the inputs and outputs of the hypothetical comparison unit for DMU j_0.

Data Envelopment Analysis provides a target performance level for each DMU. An efficient DMU in an inefficient DMU's reference group is a real-world example of what the inefficient DMU should be able to achieve (Boussofiane et al. 1991).

DEA APPLIED TO UNIVERSITY ENERGY CONSUMPTION

A demonstration of this method will show what kind of results this method gives, and how those results may be used. This demonstration used energy consumption data from SANRED and enrollment and research spending data from the Texas Higher Education Coordinating Board for Fiscal Year 1994 (THECB 1995). The analysis was performed using an early DEA computer program, CCR1, which was developed by the Center for Cybernetic Studies at the University of Texas at Austin (Dieck Assad 1986).

This relatively simple software was adequate for illustrating the DEA method, but the limitations of the program mean that the results of this analysis should not be considered prescriptive. The institutions will therefore be identified by letters, not by their names. Table 1 lists the institutions included in the analysis (identification letters were not assigned in the order of the table). Health science centers are excluded because their outputs differ from those of the other institutions.

Although a total of six inputs and outputs have been identified, CCR1 can only handle a total of five inputs and outputs (Dieck Assad 1986). Because all universities use electricity and all but one use fuel, but only a handful use purchased thermal energy, thermal energy will be dropped from the set of inputs. The thermal energy users will therefore be eliminated from the sample. Dropping these institutions will not affect the efficiency ratings of the ones remaining, because an institution using no thermal energy would never have a thermal energy user in its reference group. Therefore, the analysis assumes this model of university energy consumption:

(electricity, fuel) → (undergraduate semester credit hours, graduate semester credit hours, total research expenditures).

THE RESULTS OF DEA

Table 2 shows the results for this analysis. Each inefficient institution listed in the far left column has a corresponding efficient hypothetical comparison unit. The demonstration yields seven "efficient" universities with efficiency scores of one: P, R, U, W, X, Y, and EE.

Table 1. Institutions included in DEA sample.

Angelo State University
Lamar University
Lamar-Orange
Lamar-Port Arthur
Midwestern State University
Prairie View A&M University
Sam Houston State University
Southwest Texas State University
Stephen F. Austin State University
Sul Ross State University
Tarleton State University
Texas A&M University at Galveston
Texas A&M University-Corpus Christi
Texas A&M University-Kingsville
Texas A&M University
Texas A&M University-Commerce
Texas A&M University-Texarkana
Texas Southern University
TSTC-Amarillo
TSTC-Harlingen
TSTC-Sweetwater
TSTC-Waco
University of Houston-Clear Lake
University of Houston-Downtown
University of Texas at Arlington
University of Texas at Austin
University of Texas at Dallas
University of Texas at Tyler
University of Texas-Pan American
University of North Texas
West Texas A&M University

For a given inefficient institution, the inputs and outputs of the hypothetical comparison unit are a linear combination of the inputs and outputs of the efficient institutions in its reference group. The inputs and outputs of each efficient institution are multiplied by the weights in the table and summed to yield the inputs and outputs of the given inefficient institution's hypothetical comparison unit. Not all of the efficient institutions are necessarily part of a given reference group; for example, University DD has only one institution, University EE, in its reference group, and all the other efficient institutions have weights of zero. (An efficient institution will naturally have only one institution--itself--in its reference group.)

Consider the results for University T. The members of University T's reference group are Universities P and R. The inputs and outputs of each of these efficient institutions are multiplied by that institution's weight. These weighted inputs and outputs are summed to find the input and output values of University T's hypothetical comparison unit. University T's efficiency score of 0.9757 suggests that this institution should, based on the performances of its reference group, be able to reduce its energy consumption by (1 - 0.9757), or approximately 2.2%.

Figure 2, a direct comparison of University T with Universities P and R, shows which forms of energy University T consumes the most efficiently (El-Mahgary and Lahdelma 1995). The inputs and outputs are normalized so that no output value is greater than 100 and no input value has a negative smaller than -100. The fuel consumption of University T is only slightly greater than that of its nearest counterpart, University P. However, University T's electricity consumption is much greater than that of University P. Therefore, that is the area in which University T needs the most improvement.

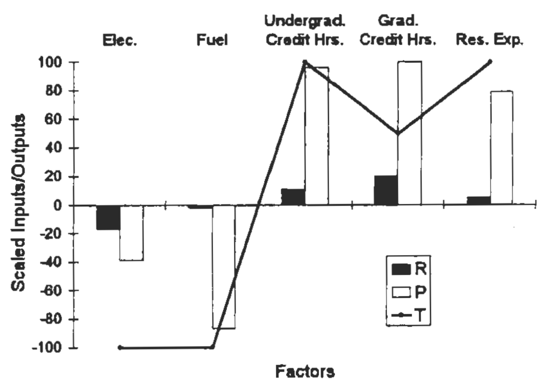

Figure 2. Factors for University T with respect to its reference units.

The same kind of graph can also show why one institution is considered more energy-efficient than another. Figure 3 shows a comparison of University AA with its only reference unit, University X. University AA consumes much less electricity and slightly less fuel than University X. However, it has much lower undergraduate enrollment than University X, and it has no research expenditures at all. University X consumes more energy than University AA, but it also delivers much more output. University X is therefore more energy-efficient.

									OUTPUTS			INPUTS			
												Electricity (GBTU)		Fuels (GBTU)	
	Efficiency	Weights of Efficient Institutions							Undergraduate	Graduate	Research Exp.				
UNIVERSITY	Score	UNIV. P	UNIV. R	UNIV. U	UNIV. W	UNIV. X	UNIV. Y	UNIV. EE	Sem. Cred. Hrs.	Sem. Cred. Hrs.	($1M)	Actual	Target	Actual	Target
A	0.3936	0.003	0.000	0.000	0.000	0.000	1.553	4.063	154956	8353	0.4	78.3	30.8	74.6	29.4
B	0.3715	0.005	0.000	0.000	0.000	0.000	6.836	1.141	160663	34130	0.3	94.7	35.2	83.7	31.1
C	0.3622	0.011	0.000	0.000	0.291	1.191	0.000	0.000	226100	11764	4.9	168.6	61.1	156.7	56.8
D	0.6566	0.004	0.000	0.000	0.000	0.000	1.185	3.514	131989	6687	0.1	39.9	26.2	44.2	29
E	0.5863	0.023	0.000	0.000	1.071	1.870	7.358	0.000	541657	90572	13.1	277.4	162.6	208.4	122.2
F	0.8082	0.004	0.000	0.000	0.000	1.260	2.451	2.526	326483	12702	1.4	85.9	69.5	39.1	31.6
G	0.4479	0.009	0.000	0.000	0.000	1.064	3.960	2.347	320595	21210	2.4	153.1	68.6	117.5	52.6
H	0.4429	0.053	0.000	0.000	0.000	0.000	4.619	11.902	495569	36315	6.6	224.9	99.6	632.3	280
I	0.3177	0.009	0.000	0.000	0.080	1.701	2.730	0.000	337004	19252	3.4	242.4	77	163.9	52.1
J	0.3411	0.004	0.000	0.000	0.000	0.000	2.123	0.324	51119	11209	0.2	32.9	11.2	58.2	19.9
K	0.4307	0.015	0.000	0.000	0.725	0.433	0.000	0.000	144331	15534	8.3	141.5	60.9	171.2	73.7
L	0.7067	0.005	0.000	0.000	0.123	0.858	0.822	0.000	167643	10998	2.4	58.9	41.6	41.4	29.2
M	0.5537	0.002	0.000	0.000	0.539	0.700	0.000	0.000	159730	19855	4.3	102.3	56.6	30.1	16.7
N	0.4456	0.004	0.000	0.000	0.220	0.795	4.790	0.000	234234	34002	2.6	136.1	60.7	52.9	23.6
O	0.5118	0.025	0.000	0.000	1.046	1.609	4.615	0.000	450907	76799	13.2	276.4	141.5	249.1	127.5
P	1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	948560	270229	234.7	212.5	212.5	4553.2	4553.2
Q	0.3233	0.010	0.000	0.000	0.000	0.000	2.330	3.182	147885	13821	0.3	93.2	30.1	174.5	56.4
R	1	0.000	1.000	0.000	0.000	0.000	0.000	0.000	108145	54618	15.2	91.6	91.6	104.7	104.7
S	0.8707	0.001	0.186	0.000	0.209	0.000	0.000	0.000	38207	0	4.3	33.9	29.5	26.6	23.2
T	0.9757	1.047	3.420	0.000	0.000	0.000	0.000	0.000	986823	135383	297.9	549.1	535.8	5251.9	5124.5
U	1	0.000	0.000	1.000	0.000	0.000	0.000	0.000	70526	21751	2.3	46.4	46.4	1.8	1.8
V	0.555	0.001	0.000	0.000	0.041	0.102	2.432	0.000	63697	13764	0.5	28.6	15.9	11.2	6.2
W	1	0.000	0.000	0.000	1.000	0.000	0.000	0.000	83718	45943	6.4	58.9	58.9	5.4	5.4
X	1	0.000	0.000	0.000	0.000	1.000	0.000	0.000	160656	0	0.4	34.9	34.9	4.6	4.6
Y	1	0.000	0.000	0.000	0.000	0.000	1.000	0.000	17636	4776	0.0	4	4	0.4	0.4
Z	0.3843	0.000	0.000	0.000	0.000	0.000	0.000	4.104	125540	0	0.0	62.8	24.1	67.3	13.2
AA	0.8759	0.000	0.000	0.000	0.000	0.463	0.000	0.395	86473	0	0.0	21.1	18.5	3.9	3.4
BB	0.866	0.000	0.000	0.000	0.000	0.000	0.000	1.046	32003	0	0.0	7.1	6.1	9.8	3.4
CC	0.2675	0.000	0.000	0.000	0.000	0.000	0.000	0.511	15636	0	0.0	11.2	3	73.3	1.6
DD	0.9887	0.000	0.000	0.000	0.000	0.000	0.000	1.604	49068	0	0.0	9.5	9.4	6.8	5.1
EE	1	0.000	0.000	0.000	0.000	0.000	0.000	1.000	30589	0	0.0	5.9	5.9	3.2	3.2

Table 2. Results of Data Envelopment Analysis Demonstration for Texas State Universities.

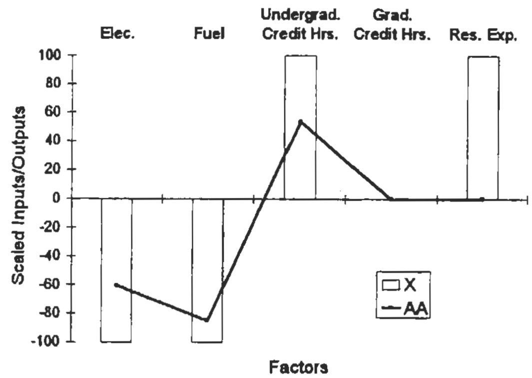

Figure 3. Factors for University AA with respect to its reference unit.

The analyst can see the overall effect of an input or output on the institutions' efficiency scores with a graph like Figure 4 (El-Mahgary and Lahdelma 1995). There does not appear to be a correlation between a university's size, as represented by its undergraduate enrollment, and its efficiency score. Most of the efficient institutions are relatively small ones, but the two largest institutions are also highly efficient.

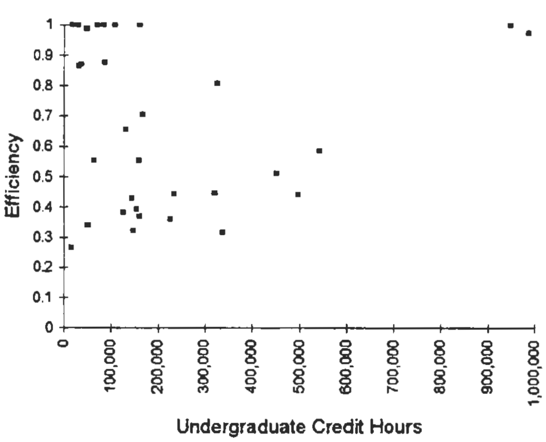

Figure 4. Efficiency vs. Undergraduate Credit Hours.

CONCLUSIONS

Data Envelopment Analysis has been found to be an appropriate method for evaluating university energy consumption according to productivity. This method bypasses the uncertainties intrinsic to using floor area to measure the amount of service provided by a facility. It obviates the assignment of values to disparate sources of energy. Each institution receives target energy consumption levels based on the actual energy consumption of other institutions with comparable output levels. Various data visualization techniques show how various factors affect institutions' efficiency scores.

FUTURE WORK

The university data should be analyzed using all three energy inputs. Current research involving DEA uses the standard optimizing code GAMS (General Algebraic Modeling System), which allows easy modification of the DEA model (Olesen and Petersen 1996). This is significant because the model proposed in this paper might not contain all of the important inputs and outputs.

The effects of external factors which might influence energy efficiency should be examined. LoanSTAR spending, average weekly classroom and laboratory utilization, and the degree of classroom technology use all might set an institution apart from its apparent peers. Entirely uncontrollable factors such as weather may also be significant. The influence of these factors on efficiency scores could be evaluated using regression analysis.

External, uncontrollable factors affecting energy efficiency can be included in the model as fixed inputs and outputs. For example, LoanSTAR spending, which would improve the energy efficiency of a campus, could be included as a fixed input (Claridge et al. 1994). This would prevent the unfair comparison of an institution with low LoanSTAR spending against one that has received many energy-efficiency improvements.

The DEA method ultimately will prove its worth if it helps reveal practices by energy-efficient universities which the less efficient universities can use. DEA could help university energy managers identify which universities have the best energy consumption practices.

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