ENERGY INDICATORS:
AN APPLICATION TO SCHOOL BUILDINGS

F. Conti **S. Hammarsten, Ph.D.** **S. Mahajan, Ph.D.** **A. Schieroni** **S. Zabot**

ABSTRACT

The knowledge of building energy indicators provides quick information about the energy performance in buildings. Building owners, managers and administrators can use this information to make their properties more energy efficient. By comparing the indicator(s) of a specific building with reference/target values, the energy-saving potential can be estimated and it can be decided whether or not it is worthwhile to take further action, such as a detailed audit followed by the implementation of energy-saving measures. Therefore, the energy indicators play a key role in rating of buildings for an audit.

In this paper we critique some of the most commonly used energy indicators and apply them to the selection of school buildings for energy audit in the region of Lombardy, Italy. It is found that the most suitable indicator is energy^2/floor area. For indicators of this type, the choice of geometric variable in the denominator seems to have little influence on the rank ordering.

INTRODUCTION

An energy indicator (EI) should be easy to calculate and highly correlated with some important aspect(s) of the energy performance of a building or a set of buildings. It is not necessary that the indicator be a direct measure of some physical parameter important for the energy balance of a building. It can derive its meaning through a correlation with an intermediate parameter, which in turn is correlated with some other important parameter. The need for energy indicators has been recognized for some time. Fairly extensive efforts (Masy 1983 and references therein) at the theoretical level have provided a number of acceptable and possibly useful energy indicators.

Although there are some studies of energy indicators (Norlén and Holgersson 1981; Hirst et al. 1985) for houses, such studies are missing for public/commercial buildings. Local governments, managers, administrators, etc., increasingly are facing the problem of choosing buildings for energy retrofit measures. Therefore, the need for a proper choice of energy indicators for energy retrofit measures in public/commercial buildings is particularly urgent. Often very little information, besides the energy consumption and a few physical parameters, is available or can be obtained. In this paper we critique some of the most commonly used energy indicators. The performance of these energy indicators is analyzed using field data from 250 schools in the Lombardy region.

Flavio Conti is a senior researcher at the Joint Research Centre, 21020 Ispra (Va), Italy; Stig Hammarsten is a visiting scientist at the Joint Research Centre, 21020 Ispra (Va), Italy, on leave from the Swedish Institute for Building Research; Sukhbir Mahajan is a visiting scientist at the Joint Research Centre, 21020 Ispra (Va), Italy, on leave from the Physics Department, California State University, Sacramento; Adelio Schieroni is a research assistant at Lombardia Resorse, Milan; and Sergio Zabot is a research officer at the Education Department of Regione Lombardia, Milan, Italy.

ENERGY INDICATORS

The energy indicators considered in this study are shown in Table 1. The most commonly used energy indicator is energy/floor area; we will call this indicator EI1. This indicator is easy to calculate and normally well correlated with the overall energy performance of a building (Hammarsten 1982). It is, however, not a direct measure of the thermal integrity of the building envelope. A simplified static energy balance equation for a building where space heating is dominating is

$$Q = \left(\sum U_i \cdot A_i + n \cdot \rho \cdot c_p \cdot V\right) \frac{DD}{\eta} \tag{1}$$

where
Q = total energy consumption
U_i = U-value of building element i
A_i = area of building element i
V = heated volume
DD = degree-days
n = air changes per hour
ρ = density of air
c_p = specific heat capacity of air
η = global seasonal efficiency of heating system

The usefulness of EI1 comes from the high correlation among A_{fl} (floor area), $\sum_i A_i = A_{env}$ (envelope surface area), and the volume, V. Indicators (i.e., $EI2 = Q/V$ and $EI3 = Q/A_{env}$) that are more directly related to the energy balance equation (1) have also been used. These indicators may be useful if buildings of different shape and size are compared. However, these indicators may be somewhat more complicated to calculate than EI1 and are, therefore, not necessary if the building stock is reasonably homogeneous. An alternative, in this case, would be to compute a shape factor, $F_{sh} = A_{env}/V$, and give the reference values for EI1 as a function of F_{sh}. The indicator, EI1, can be considered as a user index, i.e., it measures the amount of energy necessary to service a certain amount of conditioned floor area.

Another easily calculated user-oriented index is the energy consumption per occupant, i.e., $EI4 = Q/N_o$. For administrative controls of, say, schools, this can be an adequate indicator. For some types of buildings, there may be a substantial amount of user-dependent energy consumption. Energy consumption for hot water, or lighting, or electric appliances is an example of this type. In such situations, there is also a physical rationale behind EI4.

The cost curves for the most frequent energy retrofits may also influence the choice of indicator. Consider the two extreme types of cost curves as shown in Figure 1. Outdoor thermostats are an example of type A retrofits (cost independent of size). Retrofit insulation of walls, in which case cost normally scales with building size, will be closer to type B. The assumption behind the indicators discussed so far is that most energy-conservation measures have a cost-size relation similar to type B in Figure 1. However, if type A is dominating, the correct rule would be to simply rank buildings by the total energy consumption, EI5. A compromise would be to multiply the indicators EI1-EI4 with a weighting factor that is a function of building size, (e.g., energy consumption) resulting in the indicators EI6-EI9. This will then correspond to a cost-size relation of squared root type. The indicator EI6 = energy^2/floor area looks very promising, as it is easy to calculate and is based on a realistic cost assumption.

The decision to continue with more extensive data collection should be based on a comparison between the calculated energy indicator and a target value. The choice of target value is a function of the situation at hand. When energy indicators are used to measure the general performance of a building, it may be appropriate to give the target values as a function of shape factor, degree-days, age, type of building, and type of heating system used.

If the purpose is to rank buildings for energy auditing only, a single reference value should be used. It is not possible to modify the shape of the building, its age, or locality through energy retrofits. When planning an audit campaign for retrofits in a region with a variety of climates, retrofits will be more cost-effective in colder climates. It is, therefore, not correct to use indicators that have been normalized for weather severity. Energy indicators that normalize for the heating degree-days are, therefore, not considered in this study.

The heating system may, however, be modified or replaced as part of a retrofit action.

A simple way to compare buildings with different heating systems is to calculate the energy consumption in net energy terms using a table of standard efficiencies (e.g., $\eta = 1$ for electricity, $\eta = 0.7$ for oil burners, $\eta = 0.95$ for district heating). Alternatively, one could use delivered energy, but then the target values should be given as a function of the heating system. The efficiencies should be calculated for the conversion within the building boundaries, as the audit is normally limited to improvements within the building. If more extensive retrofits are considered, e.g., district heating for a whole area, other system boundaries may be appropriate.

EMPIRICAL RESULTS

An empirical evaluation of the effectiveness of different energy indicators would require an extensive monitoring of a statistically significant sample of buildings before and after retrofit. The dependent variable considered here is cost-effective energy savings. Therefore, the ideal approach would be to study the correlation between different energy indicators, calculated before retrofits, and actual savings achieved per unit of investment. A faster and cheaper approach is to use computer calculations of energy savings and costs. However, earlier research shows very weak correlations between calculated and measured savings. The Swedish study (Norlén and Holgersson 1981) on 341 retrofitted single-family houses showed large differences between empirical and theoretical estimates of the savings effect. The correlation coefficient was only 0.26, while the correlation coefficient between energy consumed before retrofit and the empirical saving was 0.56. Another study on residential retrofits in the U.S. Pacific Northwest (Hirst et al. 1985) gave similar results. This study also showed that floor area was correlated reasonably well with the actual energy savings.

To gain some experience of how different energy indicators perform, data from a sample survey covering 250 schools in the region of Lombardy, Italy, were analyzed. The data were collected by postal questionnaires sent to the administrative staff of the schools. The original aim of the data collection was to distribute funds for energy conservation. The quality of the data was rather low and it had to be screened several times for a variety of errors. The most commonly encountered errors were:

- incorrect units
- incorrect calculations of heat loss coefficients
- missing data or pure guesswork, e.g., even numbers in all places
- incorrect calculations of volumes and areas and confusion between total and heated volumes

A special computer program including several checks for consistency of data was used and useful data were obtained for about 175 of the 250 schools. The correlation matrix between the nine energy indicators discussed earlier was computed and is shown in Table 2. All the indicators with energy squared in the numerator (EI6-EI9) are highly correlated with total energy consumption (EI5). This implies that if the results from the residential sector mentioned above were valid for schools, one should use one of these indicators. The poor correlations between EI3 and the other indicators is probably linked to errors in the calculation of surface areas. In many cases, the envelope refers to the total building envelope instead of the envelope of the heated volume.

The low correlation between overall energy consumption (EI5) and indicators EI1-EI4 reflects the varying size of the school buildings in the sample. To get a better feeling for how the different indicators behave, we have listed the 20 highest ranking schools for every indicator in Table 3. A close look at this table shows that the rank order of the schools does not change significantly with respect to the indicators EI5-EI9. (For school 4415, geometrical data are missing and, therefore, EI6-EI8 cannot be computed for this school.) This implies that the use of more than one indicator is not worthwhile. The highest ranking schools for EI1 are generally small, so when EI1 is multiplied with energy to get EI6, the effect is to move these schools to much lower priority. For example, schools 4459 and 4634 ranked first and second, respectively, according to EI1, but are moved to 64th position and 47th position, respectively, according to EI6. If the costs of retrofit are more or less independent of the building size (type A in Figure 1) and/or the audit cost is high compared to the total investment, then EI6 is an obvious choice for ranking. On the other hand, schools 4102 and 2259, which rank highest according to EI6, move to 40th position and 25th position, respectively, according to EI1. The high ranking for these schools according to EI6 is a direct consequence of their large size (EI5). If the auditing cost is relatively small and/or if the cost of the retrofit is dependent of size (type B in Figure 1), then EI1 is the most suitable indicator.

CONCLUSION

As floor area is the most readibly available geometric variable and also can be considered as a user index, we propose to use it in the denominator of an energy indicator. The choice of nominator should reflect the cost-size relation expected for the retrofits considered. In most cases it seems realistic to assume that a significant part of the total cost, including the cost for auditing, is independent of the building size. We, therefore, propose to use energy^2/floor area (EI6) as indicator for ranking of school buildings for energy audits. We think that this indicator may also be well suited for residential and commercial buildings. It is as simple to calculate as energy/floor area (EI1), which is the most commonly used indicator today. It is highly correlated with overall consumption, which has been shown to be the indicator best correlated with actual energy savings.

REFERENCES

Hammarsten, S. 1982. "Major programmes for Energy Conservation." Energy audit workshop 13-15 April 1982, Document D22: 1982, Swedish Council for Building Research.

Hirst, E.; White, D.; Goelitz, R.; and McKinstry, M. 1985. "Actual electricity savings and audit predictions for residential retrofit in the Pacific North-west." Energy and Buildings, Vol.8, pp.83-91.

Masy, G. 1983. The use of energy indicators and target values in Belgium. Report, University of Liege.

Norlén, U.; and Holgersson, M. 1982. "Estimating effects of energy conservation measures: a Swedish study." New Energy Conservation Technologies, J.P. Milhone and E.M. Willies, eds., Springer Verlag.

ACKNOWLEDGMENTS

The authors are grateful to Mr. Giorgio Taccarelli for his contribution to the informatic aspects of the work.

TABLE 1
Energy Indicators Considered

EI1	(energy/heated floor area)
EI2	(energy/heated volume)
EI3	(energy/envelope area)
EI4	(energy/user)
EI5	(energy)
EI6	(energy^2/heated floor area)
EI7	(energy^2/heated volume)
EI8	(energy^2/envelope area)
EI9	(energy^2/user)

TABLE 2
Correlation Matrix of Different Energy Indicators for Schools in Lombardy

	EI1	EI2	EI3	EI4	EI5	EI6	EI7	EI8	EI9
EI1	1.000	0.797	0.388	0.563	0.112	0.398	0.307	0.221	0.243
EI2		1.000	0.397	0.607	0.089	0.307	0.385	0.211	0.241
EI3			1.000	0.247	0.279	0.341	0.319	0.541	0.308
EI4				1.000	0.080	0.193	0.200	0.155	0.372
EI5					1.000	0.921	0.896	0.908	0.893
EI6						1.000	0.940	0.915	0.836
EI7							1.000	0.895	0.887
EI8								1.000	0.895
EI9									1.000

TABLE 3

Rank Order of Schools in Lombardy According to Different Energy Indicators

Rank	EI1	EI2	EI3	EI4	EI5	EI6	EI7	EI8	EI9
1	4459	4459	3500	4459	4102	4102	4102	2259	2259
2	4634	4458	4358	4458	2259	2259	2259	4415	3444
3	4458	5819	4307	4174	3444	3444	3245	4102	4102
4	3489	3495	3497	2939	4415	2630	3444	3444	4415
5	4648	3699	4683	4456	2816	3245	3347	2630	4157
6	3699	3245	4415	3699	2630	3098	2816	2816	2816
7	3495	2963	2259	4457	4157	3347	3368	3347	2630
8	5691	2669	2630	2259	3245	2816	3247	3500	4162
9	3697	3368	3347	4189	3765	4157	3098	3765	3245
10	3098	4457	4459	4166	3347	3368	4157	3098	3347
11	5819	3198	3368	2432	2406	2406	2406	3245	2123
12	4456	2259	3765	4176	3098	3489	3105	3368	3098
13	2630	3347	2816	4173	4163	3247	2815	4157	3699
14	2963	4456	3489	3495	4161	4248	2630	2406	4181
15	3200	3489	3498	2669	4158	4162	3699	4307	2939
16	2650	4323	3699	3444	3247	2123	2123	3105	4174
17	3368	4703	4458	3382	4162	4648	3489	4358	2406
18	4621	3247	4457	4157	2123	3105	3765	2815	4248
19	2669	3244	5828	4178	4171	3699	3714	4828	4457
20	3245	3700	3105	4634	4159	4171	3486	2123	5702

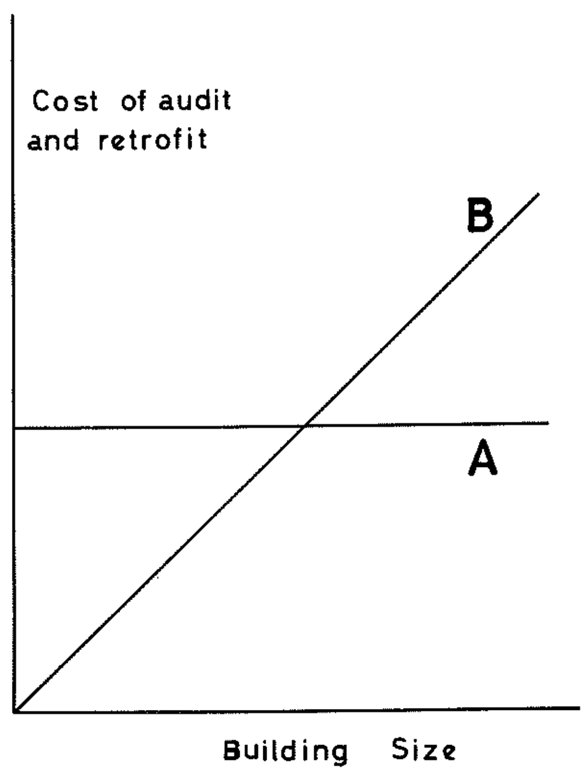

Figure 1. Relation between retrofit cost and building size