**Title**
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# APPLIED SCIENCE DIVISION

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## DISCLAIMER

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# ENERGY USE IN MINNESOTA SCHOOLS: AGGREGATE PERFORMANCE AND PERSPECTIVES ON ENERGY SAVINGS[†]

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# ABSTRACT

As part of an extensive and comprehensive evaluation of the U.S. Department of Energy's Institutional Conservation Program (ICP), we present an analysis of the energy performance of Minnesota schools during the 1970s and 1980s. We also estimate energy savings for individual schools and for the entire group of schools participating in the ICP. Finally, we compare estimated energy savings, based on technical audits, with monitored energy reductions.

We found that there was no significant discernible difference in the energy use intensities of ICP participants and nonparticipants in Minnesota as a result of the program. Accordingly, the unpenetrated stock of buildings represents a large audience for continued energy conservation efforts. We also found that year-to-year variation in energy use (which may be totally independent of energy conservation measures (ECMs)) for a particular institution can be quite large and may mask the energy savings of ECMs. Therefore, detailed information on the causes of "noise" in energy use is necessary for isolating the energy effects of ECMs.

The actual savings achieved in Minnesota schools, based on an analysis of pre-retrofit and post-retrofit energy usage, was about 5%, and they were primarily nonelectric savings. This amount was less than reported in other studies and less than the amount of "noise" in the consumption data. However, if one accepts that the ICP-supported ECMs do reduce energy requirements, then ICP (and, presumably, other energy conservation programs) are effectively saving energy use, preventing increases in energy use that would result were it not for the programs.

We found a systematic reduction in energy intensities from 1978 to 1981 and suggest that this might be due to a number of factors, including state regulations requiring the technical analysis of schools, increasing energy prices, and ICP-supported ECMs. Also, persistence of reductions in energy use is achievable. Whatever actions were taken by Minnesota schools to reduce energy use during this period were effective and continued to work for a number of years afterwards.

Based on our analysis of the Minnesota data and review of past studies, several conclusions were drawn regarding the methodology needed for estimating aggregate savings for the ICP. First, the data that states are required to collect from ICP participants are not detailed enough to allow attribution of energy savings to the specific measures that ICP supported. Second, independent of the attribution problem, the required data are not available from an adequate number of states to allow estimates of national aggregate

savings. And third, basing estimates of aggregate savings on monitored energy use data requires the adjustment of post-retrofit data to correct for external influences on energy use, as well as requiring a relatively large sample of buildings (e.g., several hundred for schools) to avoid biases in sample selection.

The analysis of the Minnesota data base has provided valuable insight about the energy performance of schools, particularly the amount of year-to-year variation in consumption that occurs in these institutions. The performance of these schools can also be used as a yardstick to measure energy performance in other institutions for assisting the targeting of energy conservation programs. Moreover, there is a need for more case studies with larger sample sizes and more detailed data that would allow a more precise determination of energy savings that could be generalized to schools at the national level. The case studies would also provide valuable data on how energy is actually used in school buildings, providing essential information for making informed decisions on future energy investments.

# INTRODUCTION

Since 1979, institutional buildings (colleges and universities, elementary and secondary schools, and hospitals) have been receiving financial assistance from the U.S. Department of Energy's (DOE) Institutional Conservation Program (ICP) to conserve energy. The ICP provides two types of financial assistance grants to promote energy conservation. One type of grant supports the technical analysis of the institution's facilities to identify appropriate energy conservation measures (ECMs) and is referred to as a TA grant. The second type of grant supports the design, purchase, and installation of ECMs and is referred to as an ECM grant. Grants are available only for buildings constructed prior to 1977. The program is implemented through state energy offices via DOE regional offices. The federal grant must be matched by funds from an institution, except in cases where hardship is demonstrated; in these cases, the federal grant can be up to 90% of the total cost of the technical analysis or ECM.

In 1985, DOE provided support to Lawrence Berkeley Laboratory and Argonne National Laboratory to carry out an evaluation of the ICP. The goal of the evaluation project was "to identify the most successful conservation measures (equipment and activities) available to the institutional buildings sector." One of the principal objectives of the evaluation project was to "determine the impact of the ICP grants program in fostering energy efficiency and saving energy." A separate paper estimating aggregate energy savings due to the ICP at the national level has been completed (Carroll *et al.*, 1987). In conjunction with the effort to estimate aggregate energy savings, energy use data for schools in Minnesota were analyzed, and the results of this analysis are the subject of this paper.

The primary purposes of this analysis are to provide an independent check of the aggregate energy savings estimates, and to substantiate the rationale for the method used in the aggregate estimate. Because the Minnesota data base includes institutions that have not participated in the ICP program, and because it also includes energy data for a number of years, we were able to conduct additional analyses that were important to the evaluation project but were not directly in support of the aggregation estimates. In particular, we compared the energy performance of ICP participants and nonparticipants and examined the long-term energy performance trends for individual institutions that represent a significant fraction of the total population of schools in the state.

## METHODOLOGICAL ISSUES

### Sample Selection

As part of their responsibility for implementation of the ICP, state energy offices are required to collect post-retrofit data for three years following installation of ECMs for all ECM grantees. During two time periods of the evaluation project, we attempted to contact all state energy offices to assess the status of their post-retrofit energy consumption data base for ICP participants. In the first contact (Fall 1985), ten offices indicated that they had computerized data sets. In more detailed discussions, it was found that only three states (Wisconsin, Ohio, and Minnesota[†]) had systematically collected the data, entered it into a computerized data base, analyzed it, and expressed confidence in its completeness and integrity. For three other states, computerized data were available in formats difficult to transfer to other types of computers. Some states maintained data bases that did not include consumption data, and others had partial records of consumption in hard copy. Ten additional states indicated that their data would be available on a computer within a year.

The second contact with state energy offices to assess monitored data availability (Winter and Spring 1987) indicated that one additional state, Illinois, had computerized its data, but that the data could not yet be made available for analysis. Several other states were in the process of computerizing the data, but most had no well-defined schedule for completion. In many cases, it was considered essentially impossible to assemble a meaningful data base. Since there had been no systematic attempt to gather the data from the grantees, the data were incomplete. In summary, there was a wide variation in the extent to which post-retrofit energy data have been collected, organized, and maintained, and only a few state data bases were available for detailed analysis.

We obtained post-retrofit consumption data from Wisconsin, Minnesota, and Ohio. The analysis reported in this paper is based on the Minnesota data base, the only data set that contained ICP participants as well as institutions not participating in the ICP.

### Minnesota's Data Base

Minnesota's data base includes approximately 1,300 public schools out of the 1,600 public and 400 private schools in the state, and it includes entries for both institutions

[†] Minnesota's data base includes consumption information for public schools and local government entities only. Hence, a private school that has received an ECM grant through ICP was not entered into the data base.

that have and have not participated in ICP.† The data base contains the following administrative information about each school:

- building's name and identification number;
- building type: elementary, secondary, area vocational technical institute, or other;
- reported floor area;
- county code;
- dollar value of ECM grants, by cycle; and
- whether the school participated in a state loan program for energy conservation measures.

The data base also includes the following energy consumption and cost information, for up to a possible nine years (the school years 1977-1986):‡

- fuel type, amount of fuel, and total cost of primary and secondary fuels;
- electricity cost and consumption;
- floor area and average student attendance for the year;
- kBtu/$ft^2$ for fuel, electricity, and total energy;
- \$/$ft^2$ for fuel, electricity, and total energy; and
- weather correction factor (normal heating degree days/actual heating degree days).

The energy consumption figures in the data base were collected from utility bills, and, therefore, represent site energy (the amount of energy used at the building site). These figures were converted to primary energy units (source energy) for all subsequent analyses to reflect the national perspective of the ICP evaluation project. The conversion factor used for changing electricity from site to source energy was 11,600 Btu/kWh (this includes a fuel efficiency adjustment and transmission/distribution losses).

The Minnesota data base does not include information about retrofits, so it was necessary to merge the Minnesota data base with information from the ICP Grant Tracking System (GTS) data base. The GTS data include technical information submitted as

† The data base also includes 350 other buildings that are not schools but that belong to school districts.

‡ The number of years of data present for each school varied, depending on whether the school reported information for that year. No school had data for the first year, 1977-1978.

part of the ICP grant application, and administrative data that track the progress of the grant from application through technical analysis and/or ECM installation, to close-out at the completion of the work for which the grant was provided. The following information was selected from GTS: name of school, type of school, ICP cycle of grant award, baseline energy use, estimated savings, number of ECMs funded in each of eight categories, ICP grant number, and building identification number within the grant.

The merging of the two data sets resulted in about 600 matches from the approximately 850 grant entries in the GTS list of Minnesota schools receiving ECM grants. The remaining 250 GTS entries included private schools not entered into Minnesota's data base, and, presumably, some public schools that had received ECM grants but did not submit post-retrofit energy use data to the state. In addition, there was a small number of schools that were not sufficiently identified in one of the two data bases (e.g., "Junior High School"); although they were potentially matchable, the effort required was not warranted. These 600 matches included multiple grants to individual schools, so the number of unique grantees (schools receiving one or more ECM grants) was closer to 500. To obtain the final data set, we eliminated the schools for which matching was difficult, and we narrowed the sample further by considering only those schools that had received exactly one ECM grant (i.e., we did not examine schools with multiple ECM grants). This selection process yielded a final sample of 381 schools: 216 elementary, 94 secondary, 51 combined, and 20 other (including vocational/technical schools).†

The average floor size in the final sample of ICP participants was about 85,000 $ft^2$. The mean enrollment for the 359 schools reporting data in the most recent year (1985-86) was 548 students. According to GTS information, the ICP-supported ECM distribution in the sample was comprised of the following: 22% installed envelope retrofits, 20% lighting, 18% controls, 21% heating, 15% ventilation, 3% miscellaneous, and less than 0.1% for cooling.‡ This distribution was very similar to the one obtained for the national sample of schools examined in our evaluation project. In the Minnesota sample, there was a slightly greater percentage of heating system retrofits and somewhat fewer envelope measures.

† In some analyses described in this paper, the sample may comprise fewer than 381 schools. For instance, a school may not have reported data to the Minnesota Energy Division for a specific year needed in the analysis. Also, schools receiving grants in Cycles 7 and 8 may not have had time to collect and report post-retrofit data. In some cases, we eliminated an institution from the sample if the square footage had changed during the course of reporting information.

‡ Percentages do not total to 100% because of rounding.

The sample of institutions that had not participated in ICP but for which energy data were available was 1149 schools: 415 elementary, 221 secondary, 187 combined, and 326 other. No merging of this subset was necessary, and no buildings were eliminated. This sample includes buildings other than classroom space. The average floor area in this sample was approximately 70,000 $ft^2$. When vocational and administrative buildings were excluded, the mean floor area increased to 80,000 $ft^2$. In 1985, the mean enrollment for nonparticipant schools was 500 students.

### Weather Correction

We used weather-corrected energy data in our analysis of energy use in Minnesota schools. The weather correction was supplied with the data received from Minnesota in the form of an annual normalization factor: the ratio of the long-term average for heating degree days to the heating degree days for a particular year. The correction factors for regions in Minnesota are presented in Table 1.

**Table 1. Weather-Correction Factors for Regions in Minnesota, 1977-1985**

| Region | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|---|---|---|---|---|
| NW | 0.959 | 0.882 | 1.042 | 1.101 | 0.982 | 1.067 | 1.025 | 1.021 | 0.975 |
| NC | 0.978 | 0.914 | 1.040 | 1.091 | 0.992 | 1.089 | 1.037 | 1.046 | 0.998 |
| NE | 0.991 | 0.950 | 1.031 | 1.035 | 0.982 | 1.050 | 1.014 | 1.028 | 0.990 |
| WC | 0.950 | 0.893 | 1.057 | 1.139 | 0.959 | 1.070 | 0.976 | 1.036 | 0.967 |
| C | 0.953 | 0.909 | 1.035 | 1.109 | 0.951 | 1.056 | 0.980 | 1.043 | 0.969 |
| EC | 0.971 | 0.905 | 1.025 | 1.070 | 0.949 | 1.055 | 0.993 | 1.019 | 0.971 |
| SW | 0.922 | 0.890 | 1.045 | 1.172 | 0.966 | 1.005 | 0.937 | 1.024 | 0.939 |
| SC | 0.917 | 0.901 | 1.025 | 1.115 | 0.942 | 1.040 | 0.946 | 1.051 | 0.955 |
| SE | 1.010 | 0.886 | 1.041 | 1.124 | 0.964 | 1.065 | 0.978 | 1.080 | 0.979 |

The weather correction was applied to nonelectric energy consumption only. It is important to note that this approach undercorrects the data since some components of electric energy use are coupled to weather (e.g., fans) but are not adjusted in this approach. Similarly, the approach overcorrects the data since all fuel use is adjusted, some of which might not be coupled to weather (e.g., water heating). In order to correct properly for weather variations, the distribution of energy end uses for each institution must be known, so that the proper fraction of total energy use (i.e., weather-sensitive end uses) can be normalized. However, in most schools in a severe climate, heating energy requirements dominate the end uses insensitive to climate, so the undercorrection used here should not introduce significant error.

## ENERGY ANALYSES

We conducted several analyses of energy use and energy savings in Minnesota schools. The first analysis examined the annual performance of individual buildings, focusing on the year-to-year variations in measured consumption; this analysis provides important background information needed to interpret measured energy savings. The second analysis compared the aggregate performance of ICP participants with that of nonparticipants. The third analysis examined the change in energy use before and after the grant award for ICP participants; this calculation was performed for individual institutions and for the entire group of institutions. And the fourth analysis compared estimated energy savings (based on TA estimates) with the savings calculated from Minnesota's measured data.

### Individual Building Performance

Energy consumption in buildings is known to fluctuate from year to year due to variations in weather conditions, services provided, and operating schedules and practices. Many of the factors causing these fluctuations are not precisely defined, and their individual impacts on energy use vary, depending on the physical, functional, and operating characteristics of the building. Since we were interested in calculating the savings attributable to ICP-funded ECMs, it was important for us to determine the amount of variation ("noise") in annual energy use. We were concerned that the amount of noise might overwhelm any changes in energy use that could be attributed to the installation of the ECMs. Consequently, the initial analysis of the Minnesota data examined the magnitude of these year-to-year variations in energy use for individual institutions. The measure of noise used in this analysis was the difference between the maximum and minimum annual energy consumption reported over the time period of interest, divided by the average annual consumption over that time period (i.e., the noise is expressed as a percentage of average consumption).

The noise analysis was performed for both ICP participants and nonparticipants. For participants, the analysis was performed for four time periods: (1) the years prior to the ICP retrofit, (2) the years after the ICP retrofit, (3) all years for which consumption data were available, and (4) all post-retrofit years after 1980. Results for only the fourth period are discussed in this paper. For nonparticipants, one time period was considered: all years after 1980. The rationale for the decision to use only data for the years after 1980 in the noise analysis is that very few retrofits took place in the post-1980 period, which eliminates one cause of fluctuations in energy use. Also, there appeared to be a systematic change in energy performance for many of the buildings in the data base between 1978 and 1981, which contributed to the apparent noise when data from both before and after the change were included.

Figure 1 shows the noise distribution for 255 ICP participants (part a) and 926 nonparticipants (part b). On the horizontal scale, "noise" is divided into 2% wide bins. The bin identifier indicates the center of the bin. For example, for ICP participants, the bin identified as "1" shows that 15 institutions have year-to-year variations in pre-retrofit annual energy consumption between 0% and 2% of their average annual consumption, and the bin identified as "3" includes 8 institutions whose pre-retrofit consumption varied between 2% and 4%. Outliers are not included in this figure.

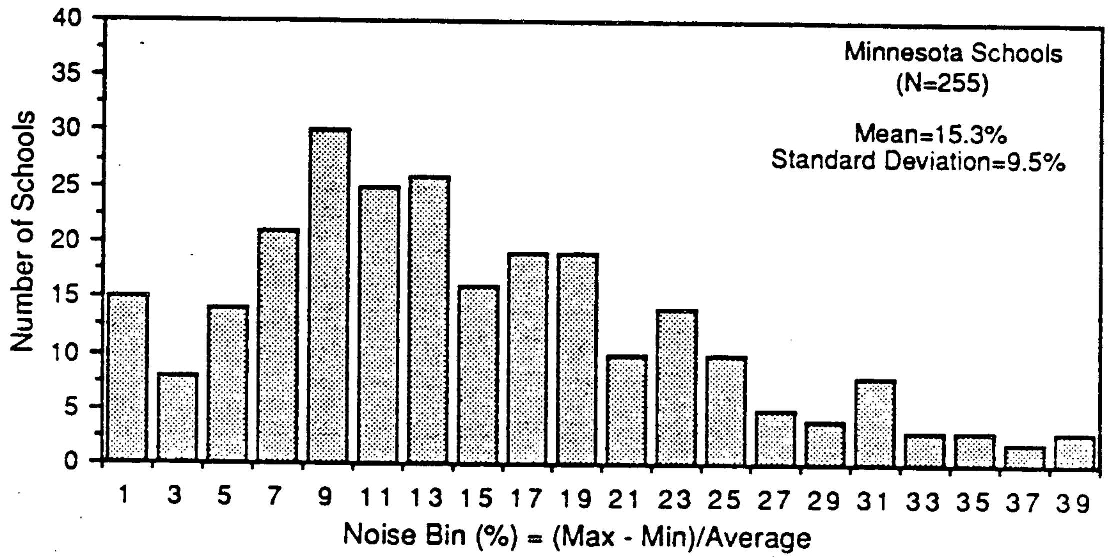
The figure indicates that the noise level is relatively large, and the level is similar for both participants and nonparticipants. For an individual building, the most probable range over which energy use varies from year to year is about 8-14%. The distributions are quite broad: about 68% of the institutions that participated in the ICP experienced year-to-year variations in energy use between 6% and 24%; for nonparticipants the range was between 6% and 28%. This measure of the width of the distribution is roughly similar to the one standard deviation limit for a normal distribution (i.e., we expect 66% of the sample to be within one standard deviation of the mean). Accordingly, ECM energy savings that are not of at least comparable magnitude (15% to 25%) may be masked by the noise. Also, the year-to-year fluctuations in energy use complicate attempts to attribute observed changes in energy use to any particular cause—such as the installation of a particular ECM. Moreover, the effect of an ECM may be combined with other effects, such as changes in connected electrical loads, that are often difficult to quantify.

### Aggregate Energy Performance of ICP Participants and Nonparticipants

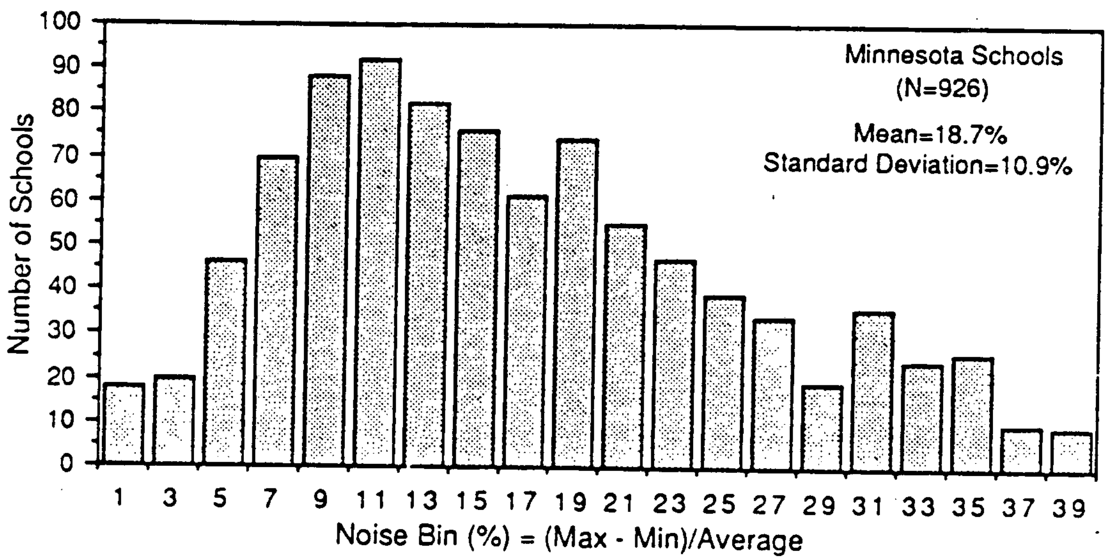
The overall energy use characteristics of schools in Minnesota were examined by aggregating energy use for the individual buildings on an annual basis. Annual energy use for each building was normalized by floor area to obtain an energy use index (EUI) with units of $kBtu/ft^2/yr$. The mean, standard deviation, and median of the EUI were calculated for all institutions reporting energy consumption data for that year. Because the

## Figure 1: "Noise" in Measured Annual Energy Consumption

**a. ICP Participants**




**b. Nonparticipants**



distribution of EUIs was positively skewed with a small fraction of the total square footage having very large EUIs, we also calculated the range for two-thirds of the cases closest to the peak of the distribution. We calculated half the width of this range ("half-width"), comparable to the standard deviation, and present half-widths with the other statistical indices in Table 2 (see below). This analysis was conducted separately for the subset of 381 institutions that received only one ICP-funded ECM grant and for the 1149 institutions that never received an ICP grant.

Figure 2 presents an example of this type of analysis by showing the distribution of EUI (in bins of 10 $kBtu/ft^2/year$) for the 336 ICP participants reporting energy data in 1983. Part a of the figure shows the relative frequency of EUIs by number of institutions; part b shows the relative frequency of EUIs by the total square footage ("floor-area-weighted EUIs") represented by the institutions having that particular EUI. There is essentially no visible difference in the shapes of the distributions, and the means of the two distributions are very similar (130 $kBtu/ft^2$ and 135 $kBtu/ft^2$). In conclusion, EUIs are not strongly associated with the size of the institution.

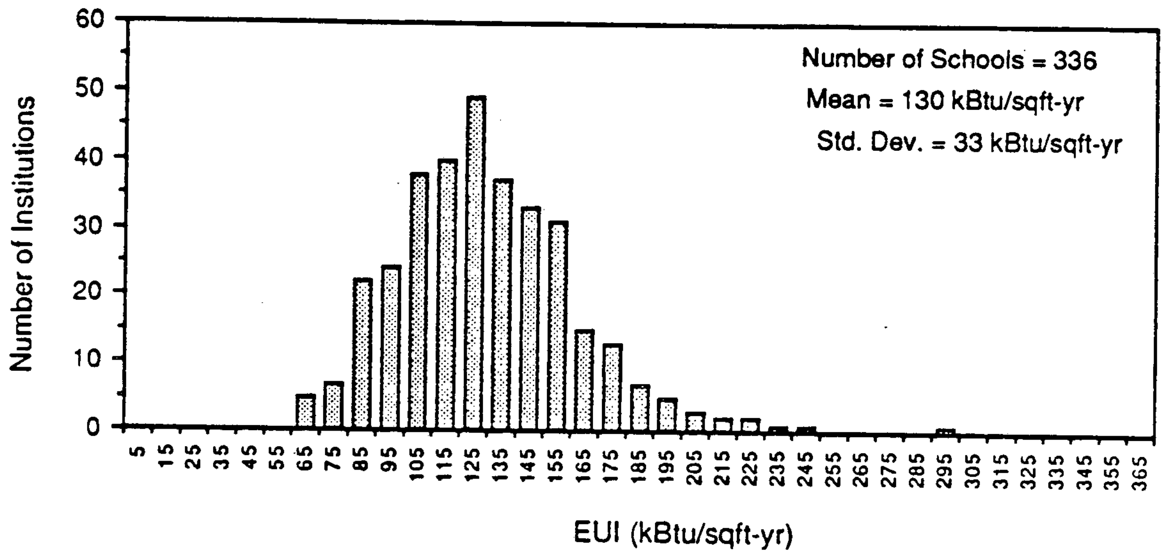
Figure 3 compares the floor-area-weighted EUIs in 1983 for the 336 schools that received a single ECM grant (part a), with 870 institutions that had not received grants (nonparticipants) (part b).† The shapes of the distributions differ for the two samples: the distribution of the ICP participants resembles a normal distribution while the distribution of the nonparticipants is more positively skewed with a small fraction of the total square footage having large EUIs. However, as seen in Table 2, the statistical indices of the distributions again are very similar, implying that, from the perspective of energy use intensity, ICP participants and nonparticipants are alike.

Table 2 summarizes the statistical characterizations of the floor-area-weighted frequency distributions by year. A portion of these data is shown graphically in Fig. 4, which shows the results for the average area-weighted EUI for both ICP participants and nonparticipants for each year in the Minnesota data base. From 1978 to 1983, the differences in EUI between the two groups were small; for 1984 and 1985, the EUI differences between ICP participants and nonparticipants increased. In all years, the

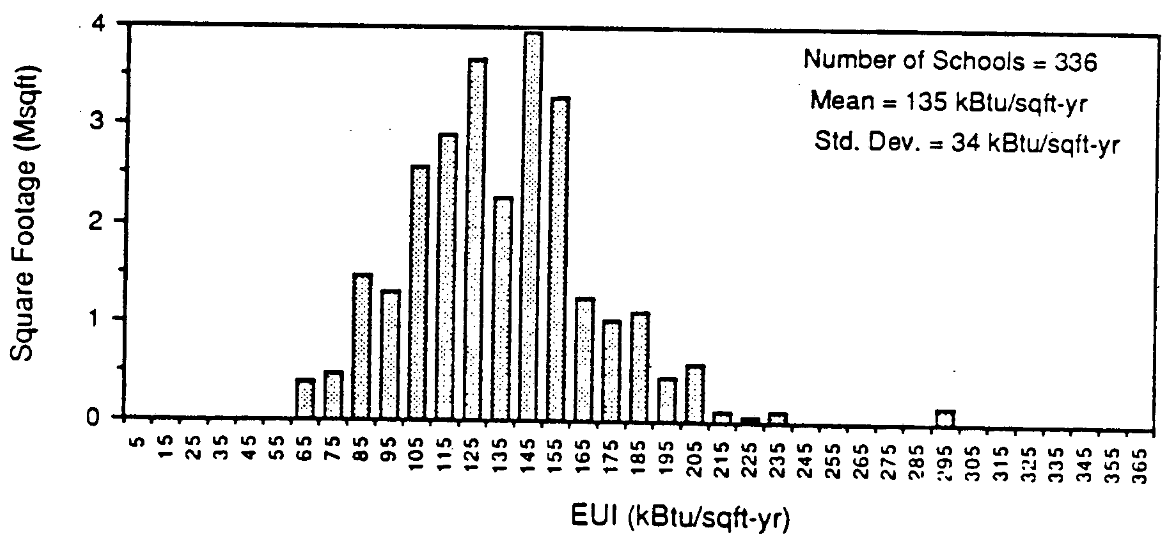
† In calculating statistical characteristics for nonparticipants, "outliers" with an EUI exceeding 370 $kBtu/ft^2/yr$ were not included, but they are shown in the overflow bin in the frequency distribution. There are 6 buildings in this bin out of 857 buildings in the sample (buildings reporting consumption data for the 1983-1984 school year), and they represent a small percentage of the total square footage. Their energy use ranged up to 850 $kBtu/ft^2/yr$, and the same buildings appeared in the overflow bin for most years for which data were available. The primary motivation for excluding them was that they were not typical "schools." Rather, they appeared to be special use buildings such as a nutrition center and an amphitheater.

## Figure 2: EUI Distribution for ICP Participants in 1983

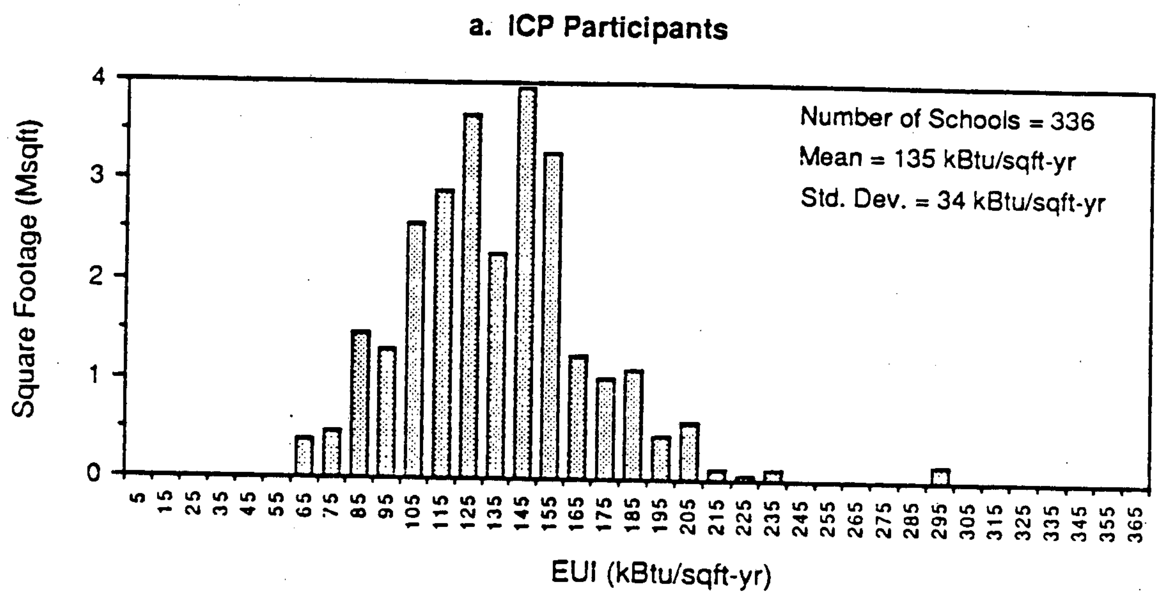
**a. By Number of Institutions**

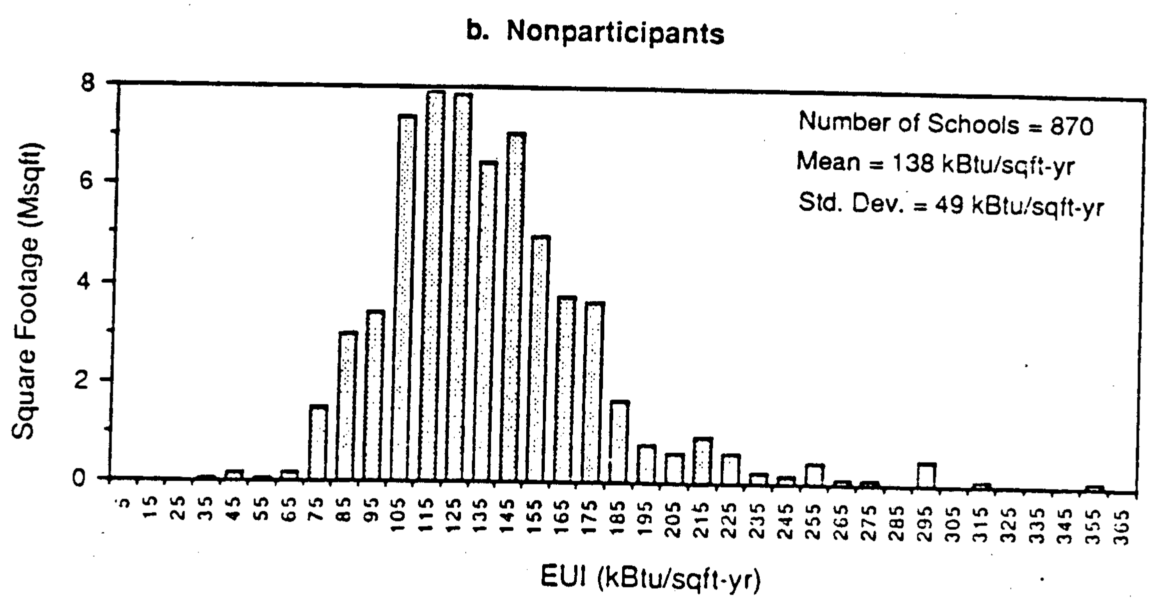



**b. By Square Footage**



# Figure 3: EUI Distribution in 1983



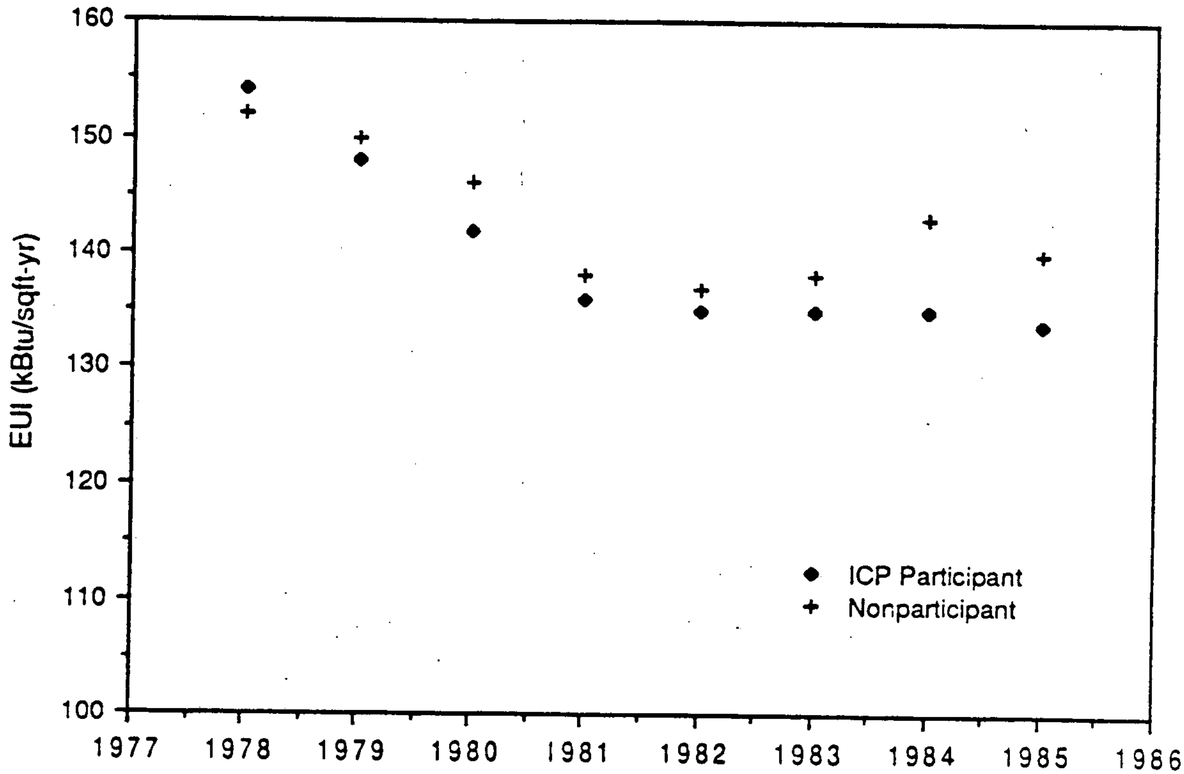
## Table 2. Statistical Summary of Floor-Area-Weighted EUIs, 1978-1985

| Participants | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Energy Use (kBtu/ft$^2$) | | | | Electricity (kBtu/ft$^2$) | | | | Nonelectric Fuel (kBtu/ft$^2$) | | | |
| Year | Sample Size | Mean | St. Dev. | Median | Half Width* | Mean | St. Dev. | Median | Half Width* | Mean | St. Dev. | Median | Half Width* |
| 1978 | 292 | 154 | 42 | 149 | 41 | 59 | 34 | 51 | 31 | 96 | 25 | 95 | 24 |
| 1979 | 318 | 148 | 39 | 143 | 32 | 54 | 30 | 50 | 26 | 94 | 24 | 94 | 24 |
| 1980 | 299 | 142 | 40 | 139 | 37 | 52 | 29 | 45 | 25 | 90 | 27 | 87 | 24 |
| 1981 | 326 | 136 | 35 | 131 | 30 | 52 | 28 | 46 | 25 | 84 | 25 | 84 | 22 |
| 1982 | 336 | 135 | 36 | 133 | 37 | 50 | 25 | 46 | 23 | 85 | 25 | 82 | 24 |
| 1983 | 336 | 135 | 34 | 134 | 33 | 52 | 25 | 46 | 23 | 83 | 24 | 82 | 24 |
| 1984 | 359 | 135 | 36 | 134 | 34 | 52 | 26 | 46 | 24 | 83 | 25 | 80 | 25 |
| 1985 | 359 | 134 | 38 | 131 | 38 | 55 | 27 | 47 | 25 | 79 | 25 | 76 | 25 |

| Nonparticipants | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Total Energy Use (kBtu/ft$^2$) | | | | Electricity (kBtu/ft$^2$) | | | | Nonelectric Fuel (kBtu/ft$^2$) | | | |
| Year | Sample Size | Mean | St. Dev. | Median | Half Width* | Mean | St. Dev. | Median | Half Width* | Mean | St. Dev. | Median | Half Width* |
| 1978 | 672 | 152 | 49 | 142 | 40 | 59 | 36 | 48 | 30 | 93 | 29 | 91 | 26 |
| 1979 | 817 | 150 | 45 | 141 | 38 | 57 | 32 | 48 | 28 | 93 | 31 | 88 | 28 |
| 1980 | 739 | 146 | 47 | 140 | 37 | 56 | 36 | 47 | 28 | 90 | 29 | 87 | 28 |
| 1981 | 817 | 138 | 42 | 129 | 34 | 55 | 32 | 47 | 25 | 83 | 25 | 79 | 25 |
| 1982 | 820 | 137 | 46 | 129 | 38 | 54 | 33 | 46 | 25 | 83 | 28 | 81 | 27 |
| 1983 | 870 | 138 | 46 | 131 | 35 | 57 | 36 | 49 | 27 | 82 | 26 | 80 | 25 |
| 1984 | 941 | 143 | 50 | 136 | 38 | 60 | 38 | 50 | 30 | 84 | 28 | 81 | 26 |
| 1985 | 978 | 140 | 47 | 132 | 40 | 60 | 36 | 51 | 29 | 81 | 28 | 79 | 26 |

*See text for definition.

## Figure 4: Area-Weighted Mean EUI for Participants and Nonparticipants



differences between the two groups are small relative to the widths of the EUI distributions. More importantly, the data show that there was substantial improvement in energy performance between 1978 and 1981, amounting to almost a 12% reduction during this period. Since this trend is present for both ECM grantees and for nonparticipants, it cannot be directly attributed to ICP retrofits. Two possible causes that might have resulted in reduced energy consumption during this period have been identified:

- In 1979, Minnesota required that all schools receive a technical analysis; this may have prompted widespread action in operations and maintenance measures and/or installation of ECMs.
- During the later 1970s and early 1980s, there was a trend towards increased energy prices in Minnesota. For example, for all Minnesota schools, average fuel prices increased from \$2.70/MBtu in the 1978 school year to \$5.16/MBtu in 1982, and average electricity prices increased from \$3.86/MBtu in 1978 to \$5.30/MBtu in 1982 (all prices are not adjusted for inflation). Thus, depending on the price sensitivity of schools, energy costs might have encouraged the reduction of existing energy use. However, if energy costs were a determining factor, we would have expected further reductions in energy intensity over time. On the other hand, "easy solutions" and behavioral changes (e.g., lower thermostat settings) might have been implemented at the onset of the rise in energy prices; as prices leveled off, the more difficult solutions may have been avoided and energy-related behavior may have reverted.

The available data do not permit us to state definitively whether one or both of these two factors, or some other circumstance, caused the reduction in energy intensities. The existence of this systematic change in energy use, as well as the timing of retrofit installations, is the reason that the time period for which the noise analysis was performed was limited to the post-1980 years.

The 12% performance improvement in energy use intensity persisted for five years. Translated to primary energy, this performance represents an aggregate annual energy savings of 1.6 trillion Btus, and an annual cost savings of about \$6 million at current energy costs.

Figure 4 shows no strong evidence of systematic improvement in energy performance since 1981, for either ICP participants or nonparticipants. The energy savings associated with ECMs supported by ICP since 1981 were not discernible in this analysis. This is consistent with survey results of hospitals, colleges, and universities carried out as part of the ICP evaluation (Collins *et al.*, 1987; Vine *et al.*, 1987). Survey respondents reported substantial levels of energy conservation activity during the 1980s, but about an equal number reported increases in energy consumption as reported decreases. The primary reasons for increased consumption were increases in floor area, expansion of services, and/or changes in operation, all of which can offset the performance improvements of ECMs. Consequently, the ECMs installed in Minnesota schools may be improving energy efficiency, but, because of changes in the schools' operating environments, actual energy use has been relatively constant. Thus, the ECMs may be containing increases in energy use that would otherwise occur.

Figure 4 also shows that there was little difference between the aggregate energy performance of ICP participants and nonparticipants; there was no evidence that ICP grantees were high energy users for whom energy savings were easier to achieve. Accordingly, the unpenetrated stock of buildings appears to be an equally viable audience for energy conservation attention. This too is qualitatively consistent with the results of the surveys of hospitals and of colleges and universities, where there were no apparent distinctions between ICP participants and nonparticipants in terms of level of energy conservation effort, experience, and ECMs installed.

Figure 4 does not show the level of "noise" indicated in the analysis of individual buildings, as discussed earlier. Since the year-to-year variations in energy use for any given institution are apt to be large, and many of the causes for the variations are not systematic, aggregation averages out a fraction of the noise. Accordingly, we analyze changes in energy use from both individual and aggregate perspectives.

### Individual Energy Savings

This analysis was initially performed by comparing the consumption for each institution in the last pre-retrofit year (the baseline year) with consumption for the first year following the grant, and, separately, for the second year following the ICP grant. Mean savings of 3% and 5% were obtained when one-year and two-year post-retrofit data were used, respectively. The uncertainty as to which "post-retrofit" year to use stems from uncertainty as to when the ECMs were actually installed. The Minnesota Energy Division indicated that in most grant cycles, perhaps only 33% of the grantees have installed all funded measures within one year of the award, and in some cases—especially in the earlier grant cycles—several years can pass before all measures are installed.†

† Personal communication from Jeremy de Fiebre, Grant and Loan Analyst, Minnesota Energy Division, Department of Public Service (Sept. 2, 1987).

Results of the initial analyses imply that the average ECM grantee achieved far smaller savings than would be expected based on past studies. We reviewed ten studies, cited in Table 3, that analyzed the actual energy savings after the installation of energy conservation retrofits in institutional buildings (especially schools and hospitals); not all buildings participated in the ICP program. The actual savings were based on comparisons of monitored energy data before and after the retrofit. Most of the evaluations of ICP institutions were conducted on buildings that had retrofits installed in the first few years of the program. Savings in schools participating in the ICP ranged from 18% to 30%. Thus, the Minnesota results appear to be surprisingly low.

Furthermore, Minnesota's measured savings are quite small in comparison with the noise in energy consumption from year to year. Therefore, we felt the data warranted further analysis. To this end, two additional calculations of savings were carried out. The first calculation used the difference between the average energy consumption for each institution for all pre-retrofit years and the average consumption for all post-retrofit years, excluding the questionable first year after grant award. This difference in energy consumption was then divided by the energy use in the baseline year, resulting in an average percentage of savings over the baseline year.

Results from this calculation of energy savings are summarized in Fig. 5, showing the number of institutions for which a given level of performance improvement was achieved. Relative energy savings are displayed in 5% bins. Using this method, the mean savings are slightly less than 9% with a standard deviation of nearly 15%. The spread in savings is large because the data include a broad range of measures applied to buildings with a broad range of pre-retrofit performance. It is important to note that the downward trend observed in Fig. 4 affects the relative energy savings. For most buildings in the data base, the average pre- and post-retrofit consumption were influenced by the systematic decrease in energy use between 1978 and 1981, so the "savings" calculated include those directly attributable to the ECM installed as well as the ICP-independent effect that produced the reduction. Consequently, the mean savings attributable to the ECM are smaller than the 9% savings mentioned above.

We also examined several other approaches in the calculation of individual energy savings. In the first approach, we weather-adjusted both electricity and nonelectric energy consumption and obtained very similar results to the ones achieved when only nonelectric energy consumption was weather-adjusted. Using a second method, we weather-adjusted nonelectric energy consumption and used site electricity (rather than source electricity), and we obtained slightly higher values for the mean (11%) and standard deviation (16%). In the third approach, we examined only source electricity savings

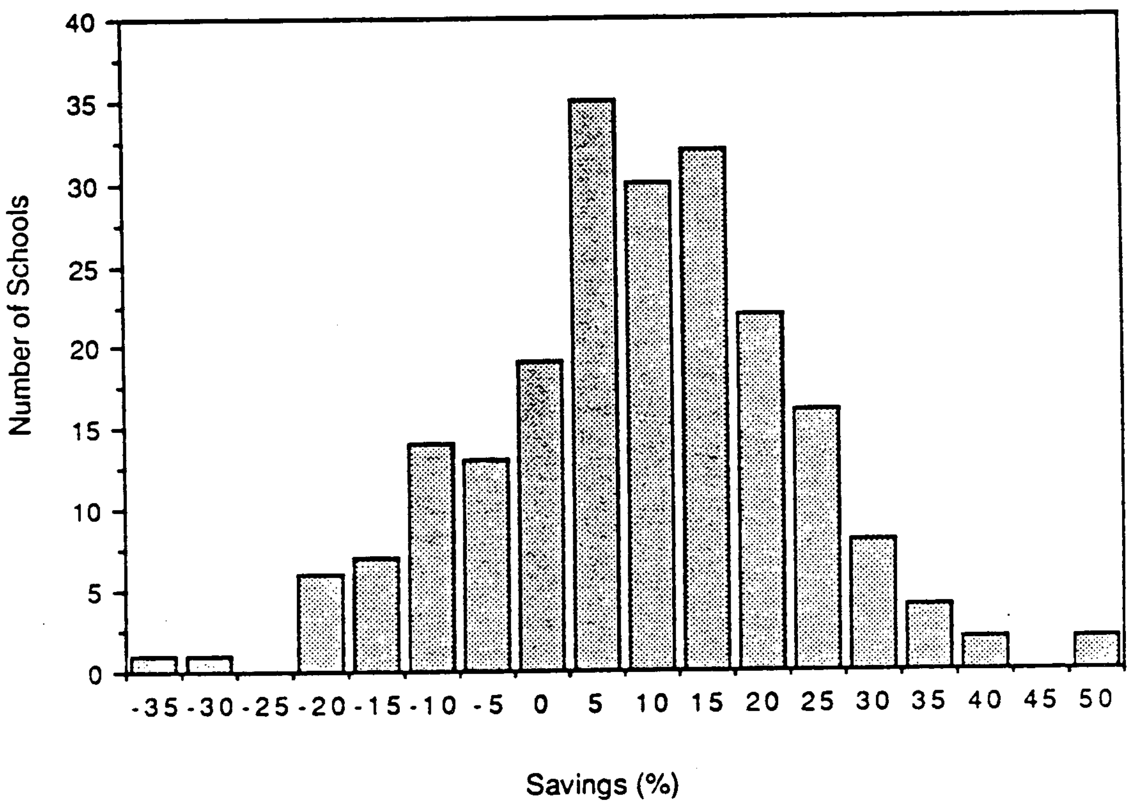
**Table 3. Studies on Energy Savings of Retrofits—Actual Savings**

| Study | Reference | Institutional Type | Energy Savings | Sample Size | Comments |
|---|---|---|---|---|---|
| BECA-CR | Gardiner (1984) | Elem. schools | 27% | 82 | Savings are for site energy; national sample; |
| | | Sec. schools | 27% | 28 | |
| | | Colleges | 41% | 13 | |
| | | Hospitals | 27% | 6 | |
| IBP (BPA) | Keating (1987) | All inst. | 13% | 51 | A mix of ICP and IBP buildings; Pacific Northwest sample; wthr-corrected |
| ICP (DOE) | TSG* (1983) | Cycle I and II | 13% | 136 | 24 had EA only; 112 had ECMs; sample is from ten states; no wthr correct. |
| | | Schools | 22% | | |
| | | Hospitals | 8% | | |
| Idaho | Idaho (n.d.) | ICP Cycles I and II | 14% | 41 | 31% savings in 11 Cycle II bldgs; weather corrected |
| Illinois | Beling (1981) | ICP I and II | | 37 | All completed EA; include local gov't |
| | | Electricity | 14% | | |
| | | Gas | 27% | | |
| | | Oil | 32% | | |
| Maine | Quintrell (1985) | Schools | 30% | 23 | ICP Cycles I to III; weather-corrected |
| | | Hospitals | 11% | 10 | |
| Minnesota | TSG* (1983) | ICP buildings | 11% | 173 | Savings occurred in 1979-82 |
| | | ECM grantees | 14% | | |
| PG&E | Griffin (1985) | K-12 schools | | 1220 | Bldgs. audited 1980-83; savings measured 18 mos. after; source elec. for schools; site elec. for others; non-ICP bldgs. |
| | | Electricity | 25% | | |
| | | Gas | 12% | | |
| | | C&U† | | 110 | |
| | | Electricity | 18% | | |
| | | Gas | 10% | | |
| | | Hospitals | | 428 | |
| | | Electricity | 11% | | |
| | | Gas | 8% | | |
| Schoolhouse Study | Rudy (1979) | Schools | | | Between 1976-77 and 1978-79 |
| | | Gas | 17% | 9 | |
| | | Electricity | 3% | 9 | |
| Wisconsin | Olle (1986) | ICP Schools | 24% | 235 | Not weather-corrected |
| | | | 18% | | Weather-corrected |
| | | ICP Hospitals | 13% | 29 | |

* The Synectics Group

† Colleges and universities

## Figure 5: Distribution of Relative Energy Savings



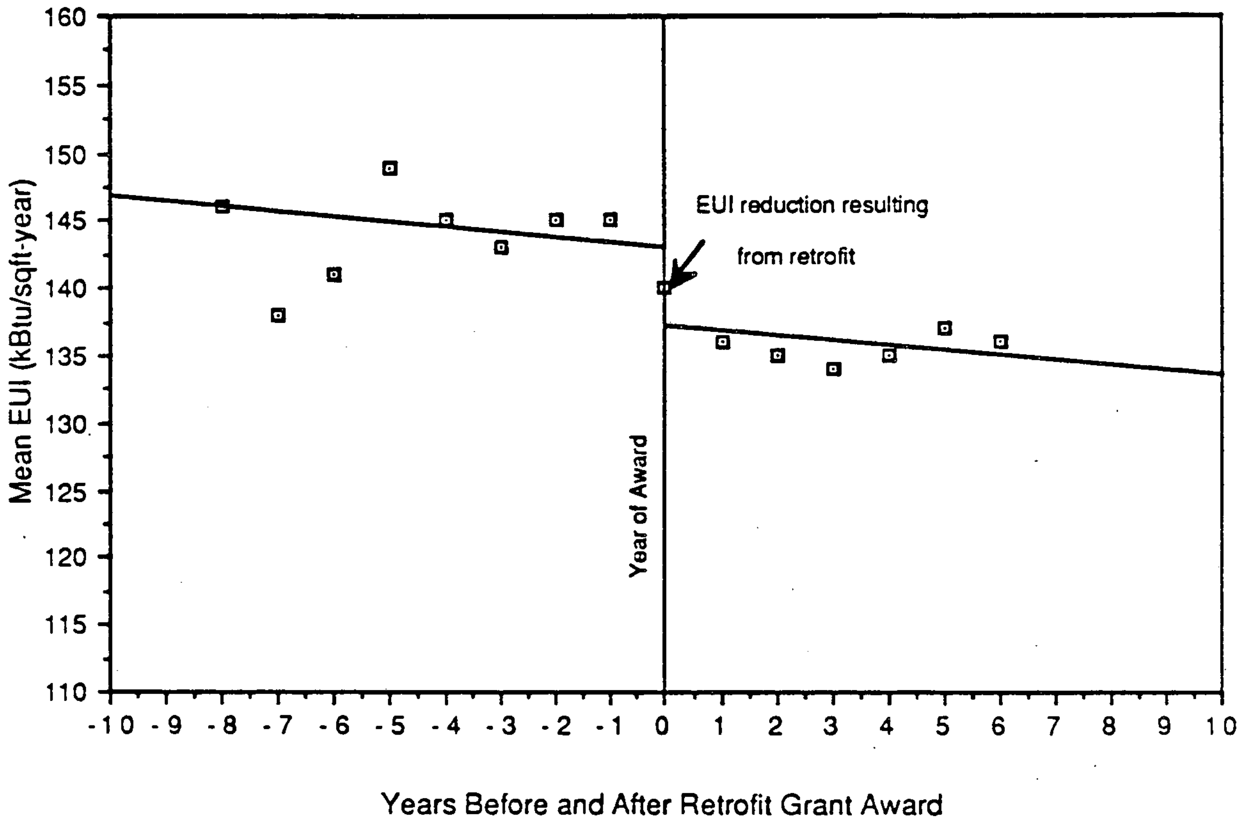
with no weather adjustment, and minimal savings were achieved (mean of 0.3%, and a standard deviation of 24%). And in the final method, we examined only nonelectric savings (weather adjusted) and obtained very similar results to our first strategy of comparing EUIs (page 11): a mean of 12% and a standard deviation of 17%. In sum, we conclude that energy savings that occurred in the Minnesota school sample were due to energy conservation measures that impacted fuels (rather than electricity). This is not too surprising because the emphasis of the ICP has been on the reduction of fossil fuel use, rather than electricity, and a number of Minnesota schools installed heating-related retrofits.

The final calculation of energy savings used aggregate data rather than the institution-specific data. As discussed earlier, the use of aggregate data averages out the noise inherent in the energy consumption data from the individual institutions, possibly leading to a more definitive estimate of savings. In this case, the weather-corrected energy consumption data were normalized in time so that the ECM grants for all ICP participants occurred at the same point in time; the results are shown in Fig. 6. For example, the aggregate energy use for the year preceding the grant (year -1 in Fig. 6) is 1978 for a 1979 grant recipient and 1984 for a 1985 grant recipient. Since the data are weather-corrected, the aggregation of data from different years is defensible, and since most sources of noise in the data are probably not systematic in time, aggregation should average out a portion of the noise. It is also important to note that the EUIs in this figure have been weighted by floor area (i.e., area-weighted EUIs) to provide a more representative and accurate description of the amount of energy used in these buildings.

One must be cautious in interpreting Fig. 6: the systematic decrease in EUI with time is not in conflict with Fig. 4, and it does not imply a systematic improvement in energy use over time. Since the data that were included for any particular "year" in Fig. 6 came from a variety of calendar years for the separate institutions, some of the data predated and some postdated the improvement in performance observed in Fig. 4 between 1978 and 1981. The overall trend towards a smaller EUI at later times (relative to the time when the grant was awarded) is due largely to that trend, which has no direct relationship to the ICP.

The significant feature of Fig. 6 is the discontinuity that occurs immediately after the grant award at "time zero." In the figure, lines have been drawn to guide the eye. During the years predating and postdating the award, the slope appears to be qualitatively constant, except during the first and second years following the award. This discontinuity is the energy use reduction in the year of the award. This implies an energy savings of about 5% associated with ECM grants.

**Figure 6: Distribution of Mean EUI Before and After Retrofit Grant Award**



The four types of energy savings calculations resulted in similar savings, about 5%. We believe that the calculation with aggregate consumptions rather than institution-specific consumptions may be more definitive. This method diminishes the importance of any single anomalous year; it averages out noise in the energy use for individual institutions; and it also gives a truer picture of energy use in the sector as a whole over time.

Finally, to put these results in perspective, it should be emphasized that repeated use of the word "savings" above may be misleading—more correctly we should refer to "energy use reductions." The change in energy use for all four calculations includes the savings effect of the ECMs in question. In addition, it includes the effects of other changes in function and operation, and effects of ECMs that may have been installed without ICP support. Without additional data, which is not available, it is not possible to identify which fraction of the calculated savings is attributable to ICP, or whether some of the savings have been offset by these other changes.

### Comparison of Predicted and Actual Savings

Identification of the ECMs to be installed in a building is usually based on some form of engineering analysis of the building. The ICP formalizes this procedure by requiring a fully documented technical analysis (TA) as part of the ECM grant application. This documentation must include the estimated energy savings for each ECM recommended. The results of this analysis are key elements in the application approval process, and they are entered into the GTS data base. The TA is often considered to be the technical underpinning of the ICP.

Past studies by Collins and Kammerud (1986) and Birdsall *et al.* (1987) have examined the accuracy of TA estimates: the former compared predicted with actual savings, and the latter compared TA estimates with results from the authors' own technical analysis of a subset of buildings used in the original analysis. In both cases, substantial discrepancies were observed, raising questions about the appropriateness of specific calculation techniques used in some analyses. Accordingly, as part of our examination of the Minnesota data, we compared estimated and actual savings.

Estimated savings were taken from the TA calculations recorded in the GTS data base. The actual savings—or more appropriately, the energy use reductions—for the Minnesota ICP participants were the differences between the average pre- and post-retrofit consumption as described in the previous section. The comparison is expressed as a percentage: the TA estimate was divided by the monitored energy use reduction.

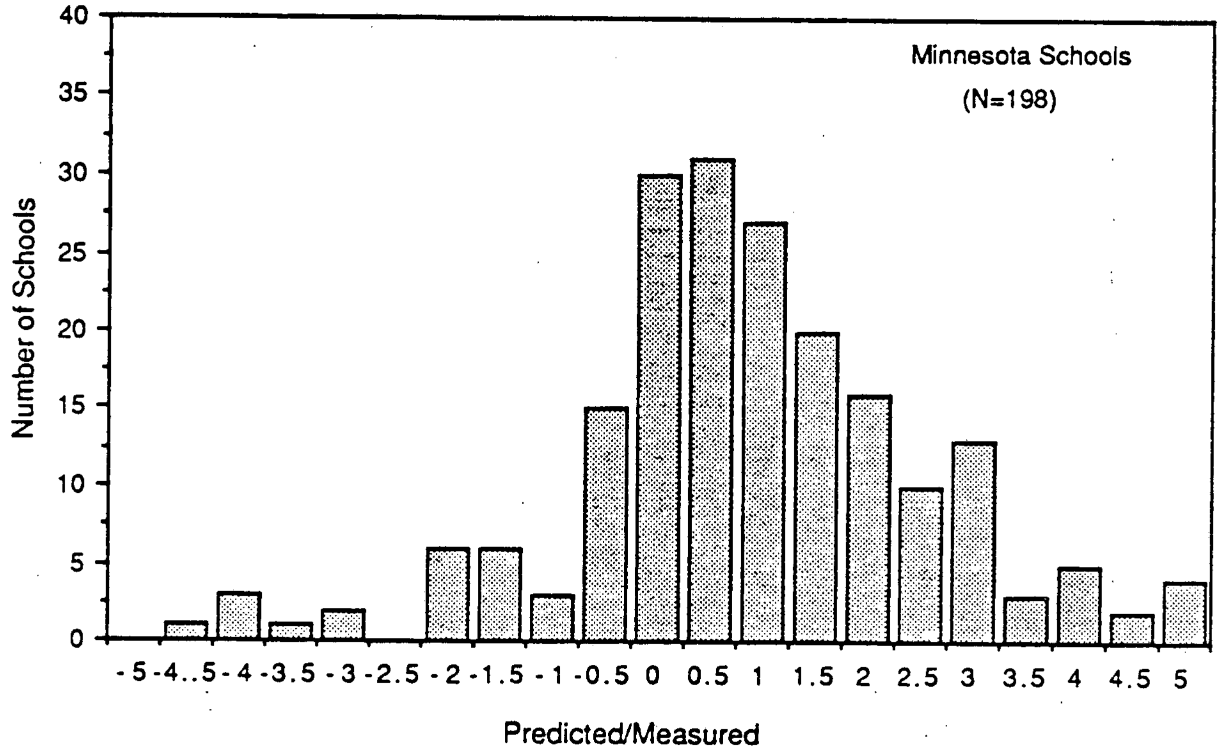
Figure 7 shows the ratio of TA estimates with measured savings and describes a broad distribution, ranging from −500% to +450%. The negative values reflect institutions where post-retrofit consumption is larger than pre-retrofit consumption; this may be due to the noise in the data discussed previously. The mean of the distribution is 72% and the standard deviation is 157%. The "outliers" (data points exceeding the range shown in the figure) have been removed from the calculation of the mean and standard deviation. The conclusion that the agreement between estimated energy savings and measured savings is poor is qualitatively consistent with our earlier findings for the Wisconsin data.

We constructed another histogram (not shown), similar to Fig. 7, using bins of 0.2 (instead of 0.5) in order to examine more closely those institutions with ratios between -0.5 and 2.5. We found a relatively flat distribution, indicating a large spread of institutions in this region with no discernible peak.

Because the distribution in Fig. 7 was not normal (and, therefore, descriptive statistics based on normal distributions are suspect) and because we wanted to remove some of the "noise" inherent in the individual calculations shown in Fig. 7, we constructed an "aggregate ratio" for the entire sample. This ratio was derived by dividing the sum of the predicted savings for all institutions by the sum of the measured savings for all institutions. The ratio was 0.95, indicating that, in aggregate, predicted savings were close to measured savings.

Somewhat surprisingly, because the mean of the distribution is less than 1, Fig. 7 implies that the typical TA estimate is smaller than the measured reductions. This is seemingly inconsistent with the TA study (Birdsall *et al.*, 1987) carried out as part of the ICP evaluation. However, as has been emphasized several times, the denominator in the ratio for which the distribution is shown cannot correctly be described as measured energy savings; rather, it is a total difference in the average consumption before and after retrofit and includes a variety of effects other than the ECMs for which the TA calculation is made. In particular, it includes an energy use reduction corresponding to the improvement in energy performance in the ICP-independent trend observed in Fig. 4. This reduction is comparable in size with the savings estimated in the previous section. On the other hand, the TA estimates are for ECM-derived savings only and do not include savings due to operations and maintenance (O&M) activities. Consequently, the results displayed in Fig. 7 should be adjusted to reflect the differences in assumptions. For example, the mean of the distribution is closer to 144% than 72%, and this adjusted result is more consistent with our expectations: we expected predicted savings to be greater than actual savings.

**Figure 7: Ratio of Predicted to Measured Energy Savings**



Because there is a lack of additional data that would allow attribution of the proper fraction of the measured change in energy use to the specific ECMs considered by the TA, one cannot reach quantitative conclusions regarding the accuracy of the TA estimate, or the quality of the design, specification, or installation of the ECMs. This was also true for the earlier study on ICP grantees in Wisconsin (Collins and Kammerud, 1986). Qualitatively, however, in the aggregate, the typical TA estimate of savings is not in substantial disagreement with monitored energy use data. Moreover, when the comparison in Fig. 4 is considered in light of the discussion of Fig. 1 (display of the noise level for each institution), the attribution of differences between esimated and actual savings to the TA calculation is questionable. In conclusion, the lack of a controlled experiment does not allow us to identify the true source of the differences between estimated energy savings and monitored energy use reductions.

## DISCUSSION AND CONCLUSIONS

Several broad conclusions can be reached based on the analysis of energy use data from schools in Minnesota:

- There was no significant discernible difference in the energy use intensities of ICP participants and nonparticipants in Minnesota as a result of the program. Accordingly, the unpenetrated stock of buildings represents a large audience for continued energy conservation efforts.
- Variation in annual energy use for a particular institution can be quite large and may mask the energy savings of ECMs. Therefore, detailed information on the causes of "noise" in energy use is necessary for isolating the energy effects of ECMs.
- The actual savings achieved in Minnesota schools, based on an analysis of pre-retrofit and post-retrofit energy usage, was about 5%, and they were primarily nonelectric savings. This amount was less than reported in other ICP-related studies and less than the amount of "noise" found in the consumption data.
- If one accepts that the ICP-supported ECMs do reduce energy requirements, then ICP (and, presumably, other energy conservation programs) are effectively containing energy use; that is, preventing increases in energy use that would result were it not for the programs.
- Persistence of reductions in energy use is achievable. Whatever actions were taken between 1978 and 1981 were effective and continued to work for a number of years afterwards.

We conclude from the aggregate data that existing energy conservation efforts, as they affect Minnesota schools, are producing incremental improvements in overall energy performance. This is not a criticism because the increments in aggregate energy use amount to substantial savings. Moreover, actual energy savings may be substantially larger than the 5% found in our analysis: a significant fraction of the savings may be offset by other physical or functional changes that often tend to increase energy use in the institution. Also, the attribution of year-to-year changes in energy use to specific causes (e.g., individual ECMs) is very difficult.

However, there is ample evidence from other studies cited earlier (see Table 3) that far more significant savings (20%) can be realized for individual buildings or groups of institutional buildings. One might question whether there are ways of replicating the experiences of these institutions in order to realize larger impacts on the subsector as a whole.

We believe that the difference between the savings estimated in this report for Minnesota schools and savings found in other studies can be primarily attributed to differences in methodologies. Many of the past studies used a case study approach, assembling and analyzing detailed data for a relatively small number of buildings. One of the problems associated with the case study approach is the lack of generalizability due to the uniqueness of the sample. For example, a sample containing only schools that have sophisticated energy accounting systems that track energy use and operating schedules each day, or samples with "clean" data sets and buildings, would be biased and not representative of the entire universe of schools. Moreover, because of the large range of energy use characteristics found in schools and the large range of potential ECMs, a large number of case studies must be performed if the results are to be reliably extrapolated beyond the limited case study sample. Conservatively, we believe that several hundred buildings must be examined for a national study of schools (e.g., a minimum of 6 different EUIs, for 10 different ECMs and combinations of ECMs, for 5 climates). Most of the studies we reviewed did not have large enough sample sizes for adequately comparing state results.

Another possible reason accounting for the differences between the Minnesota results and those found in past studies is the amount of emphasis given in this study to isolating and correcting for the amount of "noise" found in the energy data. As discussed earlier, there is a large amount of variation in energy usage within a building during its lifetime. Detailed data on each of the buildings must be available, and some form of analysis akin to a TA calculation would have to be performed to make the necessary corrections. After accounting for "external events" (e.g., changes in weather, operating schedules, and floor area), a relatively accurate calculation of energy savings can be made after retrofits of energy conservation measures have been installed. The extent to which this accounting has been done in other studies is unclear and, therefore, we are not confident in making direct comparisons of past studies with our analysis.

Based on our analysis of the Minnesota data and review of past studies, several conclusions can be drawn regarding the methodology needed for estimating aggregate savings for the ICP:

- The data that states are required to collect from ICP participants are not detailed enough to allow attribution of energy savings to the specific measures that ICP supported.
- Independent of the attribution problem, the required data are not available from an adequate number of states to allow estimates of national aggregate savings.
- Basing estimates of aggregate savings on monitored energy use data requires the adjustment of post-retrofit data to correct for external influences on energy use.
- Basing estimates of aggregate savings on monitored energy use data requires a relatively large sample of buildings (e.g., several hundred for schools) to avoid biases in sample selection. Past studies do not satisfy this condition.

In conclusion, the analysis of the Minnesota data base has provided valuable insight about the energy performance of schools, particularly the amount of year-to-year variation in consumption that occurs in these institutions. The performance of these schools can also be used as a yardstick to measure energy performance in other institutions for assisting the targeting of energy conservation programs. In addition, there is a need for more case studies with larger sample sizes and more detailed data that would allow a more precise determination of energy savings that could be generalized to schools at the national level. The case studies would also provide valuable data on how energy is actually used in school buildings, providing essential information for making informed decisions on future energy investments.

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## REFERENCES


Beling Consultants, Inc., "Evaluation of Effectiveness of FY 1980 and 1981 Energy Audits in Illinois." Prepared for the Illinois Institute of Natural Resources. Joliet, Ill., 1981.

Carroll, William L., Ronald Kammerud, Bruce Birdsall, Benoit Lebot, Brenda Hatfield, and Edward Vine, "Estimate of Aggregate Energy Savings Due to the ICP Program." LBL-24053. Lawrence Berkeley Laboratory, Berkeley, Calif., 1987.

Collins, Nancy, Linda Gaines, Phil Kier, and Ken Miller, "Nationwide Survey of Energy Conservation in Hospitals: Institutional, Organizational, and Technical Characteristics," Argonne National Laboratory, Argonne, Ill., 1987.

Collins, Nancy and Ronald Kammerud, "Institutional Conservation Program Evaluation Project: Review of Existing Data." LBL-22335, unpublished. Lawrence Berkeley Laboratory, Berkeley, Calif., 1986.

Gardiner, Betsy, Mary Ann Piette, and Jeffrey Harris, "Measured Results of Energy Conservation Retrofits in Non-Residential Buildings: An Update of the BECA-CR Data Base." In the Proceedings of the ACEEE 1984 Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy, Washington, D.C., 1984.

Griffin, Karen, "Energy Management in California's Public Institutions: An Assessment of the Schools and Hospitals Program." Report P400-85-012. Conservation Division, California Energy Commission, Sacramento, Calif. 1985.

Idaho Department of Water Resources, "Evaluation of the Schools and Hospitals Program, Cycles I and II." Boise, Idaho, no date.

Keating, Kenneth and Susan Blachman, "In Search of an Impact: An Evaluation of an Institutional Buildings Program." In the Proceedings of the 1987 Conference on Energy Conservation Program Evaluation: Practical Methods, Useful Results. Chicago, Ill., 1987.

Olle, Martin and JoAnn Howlett, "Energy Management in Wisconsin Schools and Hospitals: 1985 ICP Performance Review." Wisconsin Division of State Energy and Coastal Management, Madison, Wisc., 1986.

Quintrell, Josie, "Evaluation of the Institutional Conservation Program in Maine (Draft)." Office of Energy Resources, Augusta, Maine, 1985.

Rudy, John, H. Sigworth, Jr., and Art Rosenfeld, "Saving Schoolhouse Energy: Final Report." LBL-9106. Lawrence Berkeley Laboratory, Berkeley, Calif., 1979.

The Synectics Group, Inc., "An Evaluation of the Institutional Conservation Program: Results of the On-Site Analyses." DOE/CS/6457-1. Washington, D.C., 1983.

Vine, Edward, Ronald Kammerud, William L. Carroll, Brenda Hatfield, and B.K. Barnes, "Nationwide Survey of Energy Conservation in Colleges and Universities: Institutional, Organizational, and Technical Characteristics." LBL-23605. Lawrence Berkeley Laboratory, Berkeley, Calif., 1987.

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