DON'T NEGLECT THE BUILDING! EXAMINING THE ENERGY CONSERVATION POTENTIAL FOR INDUSTRIAL BUILDINGS

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ABSTRACT

Consumption of primary energy by the industrial sector in 1991 was 29.6 quad/year (1 quad = 10^{15} Btu). The manufacturing subset of this sector consumes approximately 25.3 quad of primary energy, with 20.3 quad consumed directly on-site. Traditional energy conservation efforts in industrial facilities tend to concentrate on process efficiency improvements, while impacts of building measures take on a secondary level of importance. Categories of end-use considered to be building-related include: combustion systems, steam systems, utility supply, and buildings and grounds.

End-use consumption in energy-intensive and non-energy-intensive manufacturing establishments is examined. Building-related consumption by non-energy-intensive manufacturers accounts for 25% of total consumption, while only 3.7% of the energy consumed by energy-intensive sites is building-related. Production and consumption growth rates are predicted to be higher for non-energy-intensive industries and exhibit a less energy efficient growth pattern than energy-intensive industries.

The data compiled from the Department of Energy's (DOE) Energy Analysis and Diagnostic Centers and Industrial Assessment Centers (EADC/IAC) include experiences with recommended and implemented building-related energy conservation opportunities in small- and medium-sized manufacturing facilities (<500 employees). Assessment data contains over 5,200 assessments of industrial manufacturing facilities with a total annual site consumption of 0.44 quad/year. The program recommended building-related conservation measures totaling 12.8 trillion Btu/year of site energy. Implementation of these recommendations reflected reductions in building-related site consumption of 5.9 trillion Btu/year, compared to an *overall* reduction in site consumption of 9.3 trillion Btu/year. This suggests that building-related conservation measures have been implemented more often than process and alternative source measures, in the small- and medium-sized facilities assessed. By extrapolating the efforts of the EADC/IAC program across the manufacturing sector, an optimistic estimation for building-related site energy savings is nearly 2.9%, or 0.59 quad/year.

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INTRODUCTION

The total consumption of primary energy by the industrial sector has grown from 15.7 quad per year (1 quad = 10^{15} Btu) in 1950 to 29.6 quad in 1991.[1] Within the industrial sector, manufacturing accounts for 85%, or 25.3 quad of this primary consumption, of which 20.3 quad are consumed directly on-site.[2] By definition, establishments using mechanical and/or chemical processes to convert raw materials into final products, are categorized into the manufacturing sector. This subset of the industrial sector does not include construction, mining, agriculture or fishing, and encompasses SIC's 20 through 39. On average, the energy consumption for the industrial sector, as a whole, is expected to have an annual growth rate of 1.2%.[3] Despite the potential attractiveness of reduced industrial utility rates from a newly deregulated market, efforts should continue to follow the intent of the Energy Policy Act of 1992 (EPACT) by increasing the energy efficiency of the industrial sector.

Traditionally, efficiency efforts in the manufacturing sector have concentrated on process improvements while impacts of building measures take on a secondary level of importance. This paper examines the potential for

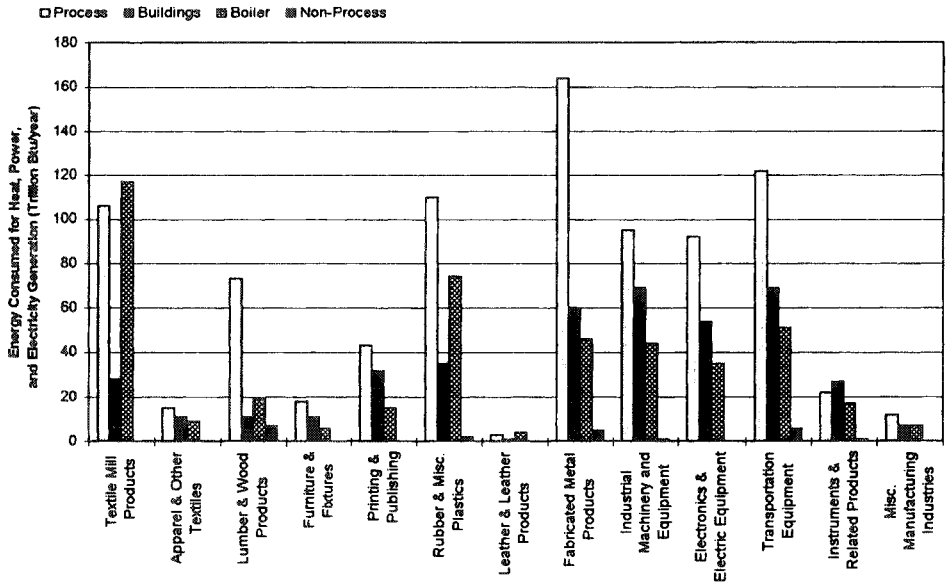
energy savings obtainable through building-related conservation measures. Such measures are defined here as improvements in boiler and steam systems, compressed air systems, lighting, HVAC, and the building envelope. Consumption patterns of non-energy-intensive manufacturers along with corresponding growth rates are studied to determine the influence of building-related consumption. Information gathered by the Department of Energy's (DOE) Energy Analysis and Diagnostic and Industrial Assessment Centers (EADC/IAC) is examined to determine retrofit recommendation and implementation trends for categories of building and process-related energy end-uses. Additionally, the higher implementation rates associated with building conservation measures, witnessed in the EADC/IAC program and elsewhere are explained. Finally, the success of the EADC/IAC program is projected across the entire manufacturing sector to determine potential sector-wide savings from similar efforts.

BUILDING-RELATED CONSUMPTION FOR ENERGY-INTENSIVE AND NON-ENERGY-INTENSIVE MANUFACTURERS

In U.S. manufacturing, 88% of the energy is consumed by energy-intensive industries.[4] Figures 1 and 2 provide a breakdown of reported end-use site energy consumption in energy-intensive, and non-energy-intensive industries.* These figures present the total inputs of energy for heat, power, and electricity generation consumed at the site and do not include the energy used directly in finished products.

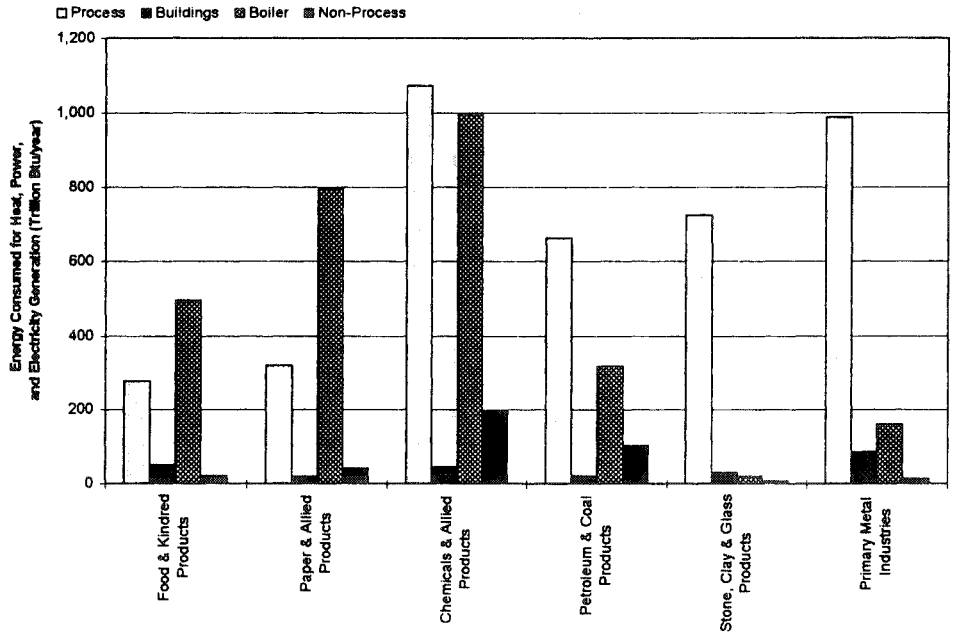
The categories of end-use are broken down into boiler fuel, process, building and non-process consumption. Boiler fuel is consumed in the transfer of energy into steam or other energy source. Direct process energy is consumed through the conversion of raw materials into final products. Building-related consumption, in this application, includes facility lighting, HVAC, and support. Finally, non-process consumption is composed of energy used for on-site transportation, conventional electricity generation, and other miscellaneous activities.

Figure 1. End-uses for non-energy-intensive industries in trillion Btu/year [2]
(note: 1 trillion Btu = 10^{12} Btu)



* Reported end-uses totaled 1,756 trillion Btu/year for non-energy-intensive manufacturers and 9,220 trillion Btu/year for energy-intensive manufacturers

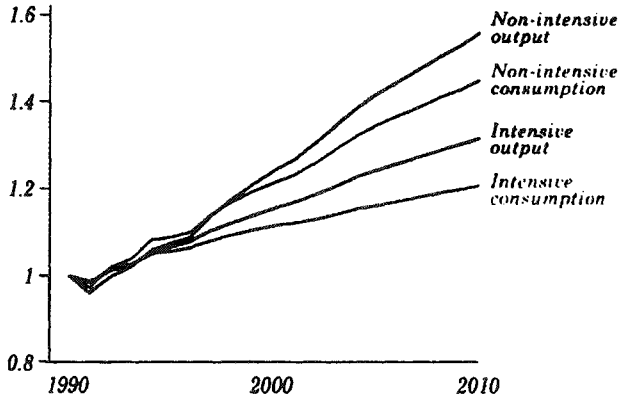
Figure 2. End-uses for energy-intensive industries in trillion Btu/year [2]



Upon examination of the distribution of end-uses in both energy-intensive and non-energy-intensive manufacturers, interesting variations in behavior are observed. Non-energy-intensive industries, on average, consume about 48% of end-use energy in direct processes, whereas in the energy-intensive establishments, this component accounts for 56% of the consumption. Similarly, boiler fuel consumption tends to be about 10 percentage points higher (at 36%) in the energy-intensive sites. The largest difference in consumption behavior, however, occurs in the buildings category. While building-related consumption only accounts for an average of 3.7% (250 trillion Btu/year) of the energy-intensive end-use, non-energy-intensive manufacturers use 25% (415 trillion Btu/year) of their energy for buildings. Upon closer examination of the composition of the non-energy-intensive industries, it is evident that those requiring larger amounts of energy for their buildings tend to have assembly-type environments.

While the magnitude of the energy consumed by the non-energy-intensive industries is considerably smaller than that consumed by the energy-intensive industries, growth in the production and consumption levels is predicted to be higher for the non-energy-intensive establishments through 2010. Figure 3 illustrates the expected trends in production and consumption growth for both categories of manufacturers. Using 1990 as a reference, 2010 production levels are expected to increase by 55% and 30% for non-energy-intensive and energy-intensive manufacturers, respectively. Corresponding energy consumption levels are predicted to increase by 42% and 21%. The ratios of production growth rates to consumption growth rates indicate that development in the non-energy-intensive industries will be less energy efficient than that anticipated in the energy-intensive industries.

Figure 3. Growth rates for energy-intensive and non-energy-intensive industries
Source: Annual Energy Outlook 1995, p. 18[3]



BUILDING-RELATED CONSUMPTION IN SMALL- AND MEDIUM-SIZED MANUFACTURERS

According to recent U.S. Census data, approximately 98% of U.S. manufacturers are considered to be small (<100 employees) or medium (100-500 employees) in size.[5] While small- and medium-sized manufacturers comprise a majority of the manufacturing population, they are responsible for consuming only 38%, or 7.7 quad of the total primary energy consumed by manufacturing facilities.[2] However, these small- and medium-sized manufacturers also pay an average of $1.15 more per million Btu's of energy than the larger firms.[2]

The Department of Energy has targeted these small- and medium-sized consumers for energy conservation efforts through its Energy Analysis and Diagnostics Centers and Industrial Assessment Centers (EADC/IAC). Thirty EADC/IAC's located at engineering colleges across the U.S. comprise the core of the DOE Program. Data collected by these centers, for over 5,200 site visits since 1981, include nearly 35,000 recommendations for improving energy efficiency. Overall, these recommendations reflect an annual site energy savings potential of 23.7 trillion Btu/year, with a source savings potential, converting for electricity, of 40.6 trillion Btu/year. Annual implemented site savings were 9.3 trillion Btu/year, indicating a 40% energy implementation rate.

Using the data from the EADC/IAC database, an overall understanding of the types of recommendations offered and the corresponding implementation rates can be developed. Two-digit categories of energy recommendations, referred to as assessment recommendation codes, or ARC's, are given in Table 1. In examining the 3- , 4-, and 5-digit subsets of these categories, it was evident that the division between building and process-related recommendations were at times abstract. The definition of building-related measures used here include ARC's involving several combustion, steam, heat recovery, cooling, and compressed air issues. These measures were incorporated into the building's category as 2.7(b), Building Utility Systems.

Table 1. Two-digit categories of energy ARC's[6]

Two-Digit Energy ARC	Description
2.1	Combustion Systems
2.2	Thermal Systems
2.3	Electrical Power
2.4	Motor Systems
2.5	Industrial Design
2.6	Operations
2.7(a)	Buildings and Grounds
2.7(b)	Building Utility Systems
2.8	Ancillary Costs
2.9	Alternative Energy Usage

The implementation status for each recommendation offered are also provided by the database. There are five status categories ranging from immediate implementation to recommendation rejection. Table 2 lists the distribution of recommendations, along with implementation status, for the 5,260 site visits recorded in the database. Of the 34,792 recommendations, 15,716 are reported as being implemented within the first two years following the site visit, and 19,076 were either rejected or not implemented within two years. For the purposes of this study, recommendations not implemented within two years of the assessment have been considered to be rejected.

Table 2 reveals some interesting information regarding the distribution of recommendations made across the ARC list. Over 50% of the recommendations made by assessment teams are building-related. Motor Systems follow with 15% of the total recommendations, and Thermal Systems with 11%. When examining the implementation rate of each individual category, however, the numbers are not as widely distributed. Neglecting Alternative Energy Use for the lack of recommendations, these rates are highest in the areas of Buildings, Operations, and Motor Systems. Overall, however, implementation rates for EADC/IAC recommendations tend to be high, at an average of 44%.

Table 2. Implementation status for recommendations, by two-digit ARC's

Two-Digit Recommendations	Status=1	Status=2	Status=3	Status=4	Status=5	Implementation Rate	Most Frequent Recommendations
Combustion	109	0	152	63	639	33.64	Fuel Switching
Thermal Systems	475	0	668	266	2,488	36.16	Process Heat Recovery & Containment
Electric Power	264	0	276	117	1,183	35.71	Demand Management
Motor Systems	860	0	690	752	3,000	43.42	Motors
Industrial Design	25	0	33	12	129	35.18	Systems
Operations	698	0	418	145	1,256	50.10	Maintenance
Ancillary Costs	128	0	108	35	382	41.50	Administration Costs
Alternative Energy Use	0	0	1	1	1	66.67	Solar Heating
Buildings & Grounds	1,955	0	1,715	1,458	6,110	45.63	Lighting
Building Utility Systems	2,257	0	1,587	448	3,888	52.47	Air-Compressors
Total	6,771	0	5,648	3,297	19,076		

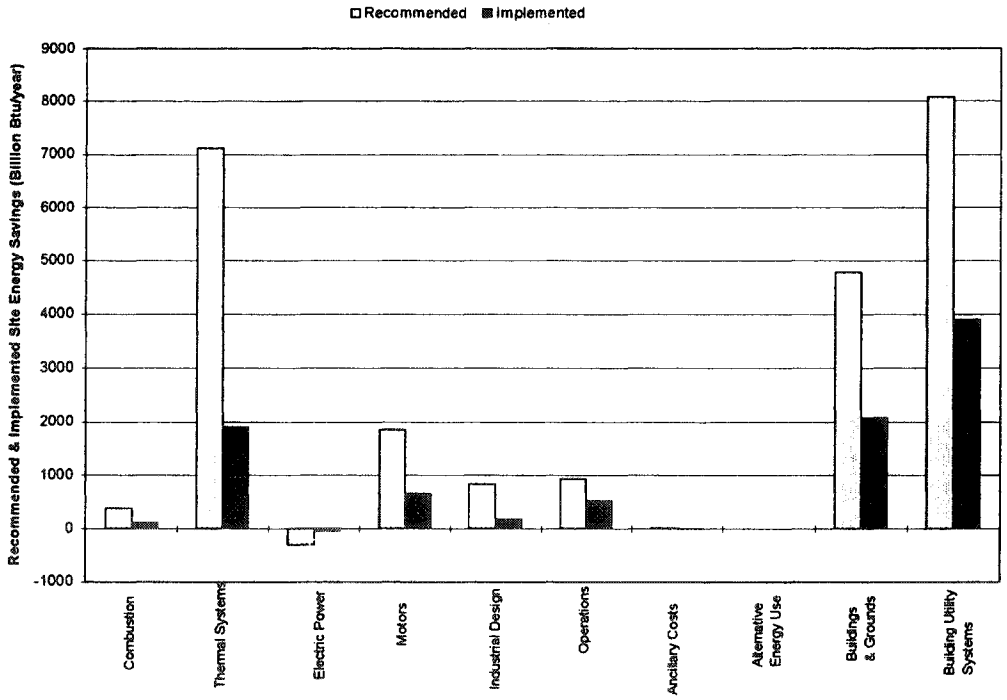
1 = Recommendation was completely implemented during the same calendar year as the assessment report
2 = Recommendation will be completely implemented during the same calendar year the assessment occurred
3 = Recommendation will be implemented by the end of the first calendar year subsequent to the assessment
4 = Recommendation will be completely implemented by the end of the second calendar year subsequent to the assessment
5 = Recommendation will not be implemented or will be implemented after the second calendar year subsequent to the assessment

Measures most frequently recommended are also given in Table 2. Lighting opportunities occurred most often in the Buildings category and, with 6,987 recommendations, also appeared most frequently for the entire database. Air-compressors were next with 4,384 occurrences, and motors ranked third overall, with 3,989. Measure implementation rates were found to coincide proportionately to these recommendation rates.

The trend in building-related opportunities cited by EADC/IAC assessment teams appears to be related to the structure of the program itself. Generally data required for building measures are easily gathered on-site, and savings calculations tend to be more familiar and less-involved to the students performing the assessments. Site visits only last for one day, which limits the amount of data that can be collected to quantify the savings for more complicated measures. Additionally, follow-up services offered by the program are highly limited, restricting customers from pursuing the more detailed information required to satisfy inquiries from upper-level management.

Average recommended site energy savings per measure were 680 million Btu/year, while total recommended energy savings were 23.7 trillion Btu/year (.024 quad) and total implemented savings were 13.1 trillion Btu/year (0.013 quad). The two-digit ARC distribution of recommended and implemented site-energy savings are given in Figure 4. Building-related savings are highest for both recommended and implemented measures, at combined values of 12.8 trillion Btu/year, and 5.9 trillion Btu/year, respectively. This corresponds to an implemented energy savings rate of 46%. Recall that Building Utility Systems include subsets of combustion, steam, heat recovery, cooling, and compressed air, issues which were considered to be neglected in the original category for Buildings and Grounds. Recommended and implemented savings from process-related Thermal Systems measures totaled 7.1 and 1.9 trillion Btu/year, with an implemented energy savings rate of 27%. These measures incorporate process-concentrated heating, heat recovery, and heat containment. The negative energy savings for Electric Power recommendations result from the conversion of energy into useful power via cogeneration.

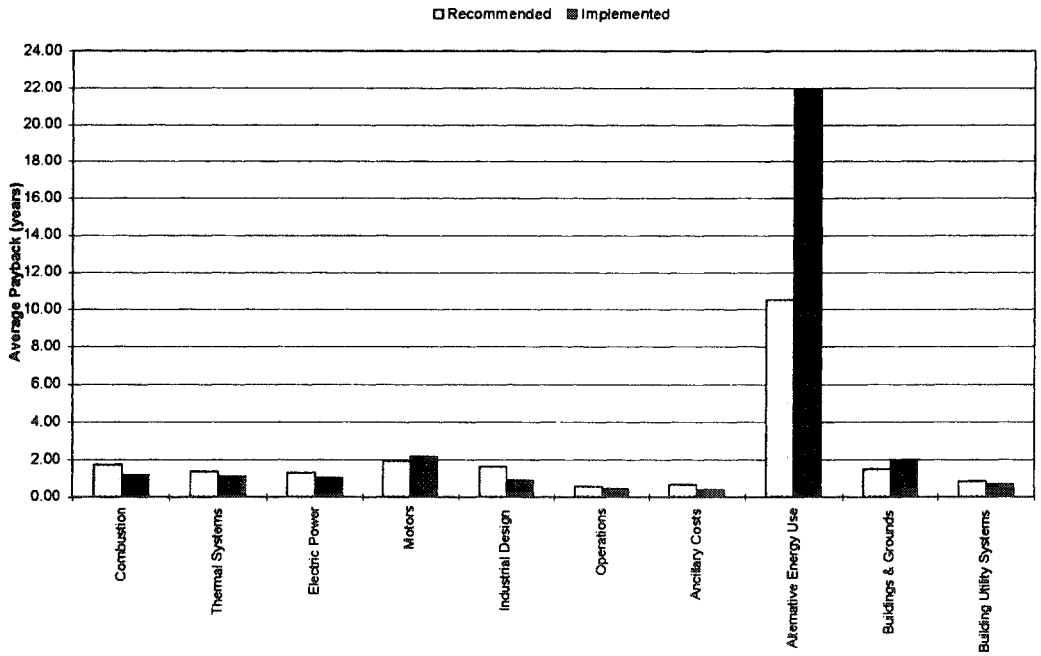
Figure 4. Two-digit distribution of recommended and implemented annual site-energy savings



Along with savings calculations for each recommended measure, EADC/IAC assessment reports include first-order estimates of measure implementation costs. Simple payback periods are used as a measure of the economic feasibility of a recommendation. Figure 5 illustrates average payback periods for each two-digit ARC category. Most categories exhibit average payback periods under two years, which historically are within the acceptable limit for industrial customers. Three recommendations made in the solar energy category had unexpectedly high payback periods and may be the result of specific customer inquiries regarding the technology. Overall average implemented payback periods are less than the average recommended payback periods, which indicates that EADC/IAC estimates tend to be conservative.

While average payback periods for most of the two-digit ARC categories are below 2 years, actual implementation rates were nearly 50%, indicating that short paybacks may not be the primary means used in decision making. A study performed by P. Sassone and M. Martucci on decision rationalization regarding industrial energy conservation found similar results.[7] Sassone and Martucci examined the response of 170 audited manufacturers to customized, detailed conservation recommendations and found that the most popular measures were building-

Figure 5. Average simple paybacks for two-digit ARC categories



related activities such as: boiler and steam system modifications, lighting systems, and consumption monitoring. These activities were prevalent because of their ability to be performed by the plant manager, while reducing higher-level management involvement, as higher-level management tends to reject small energy cost savings measures over revenue enhancements.

Extrapolating the results of the EADC/IAC program across the entire manufacturing sector allows an estimate of potential energy savings. The total annual energy consumed by the 5,260 sites visited by the program is approximately 0.44 quad/year. The total recommended site energy savings is 0.024 quad/year, reflecting a potential reduction in energy consumption by 5.0%. Similarly, a total implemented site energy savings of 0.0093 quad/year converts to an achievable reduction in energy consumption of 2.1%. By optimistically extending these savings across the entire manufacturing sector, a 5.0% recommended savings corresponds to a reduction in consumption of 1.02 quad/year. If implementation behavior across the sector were similar to that found with the EADC/IAC experience, implemented savings, at 2.1%, would be 0.43 quad/year.

Building-related conservation measures provided the majority of the energy savings experienced by the EADC/IAC. Under the combined categories of Buildings & Grounds and Building Utility Systems, 54% of the total recommended savings were made, for a reduction in total site energy consumption of 2.9% (0.013 quad/year). Correspondingly, 64% of the implemented site energy savings, or a 1.3% (0.006 quad/year) reduction in original consumption, were due to building-related measures. Across the sector, extrapolation leads to a potential in building-related energy savings of 0.59 quad/year and an achievable savings of 0.27 quad/year.

CONCLUSIONS

Increasingly, building-related conservation measures in industrial facilities are overlooked as a successful means of saving energy within the sector. A review of consumption and conservation behavior in non-energy-intensive industries, and in small- and medium-sized manufacturing industries shows that buildings efficiency issues are

substantive. Non-energy-intensive industries that consume approximately 25% of their energy through their buildings, are expected to experience a 42% increase in total consumption by 2010. Consumption growth in these industries is expected to be less efficient than that of the larger energy-intensive establishments.

Analysis of the database compiled from 14 years of EADC/IAC assessments provided background into the consumption and conservation efforts of 5,260 small- and medium-sized manufacturers. The recommendation list was reviewed and measures not directly listed under the category 'Buildings and Grounds' but qualifying as building-related, were re-categorized as 'Building Utility Systems'. Using the category definitions developed here, over 50% of the recommendations made by the EADC/IAC staff were found to be related to buildings. Implemented energy savings were also highest for these measures at 5.9 trillion Btu, or 46% of recommended energy savings. Average payback periods for most of the implemented recommendations were below 2 years, which has traditionally been the acceptable limit for economic feasibility.

The results of the EADC/IAC program were extrapolated across the entire manufacturing sector to estimate the potential and achievable energy savings from building-related retrofits. For the sites visited by the program, recommended building-related energy savings reflected a 2.9% (0.013 quad/year) reduction in total site consumption, while implemented energy savings reduced annual site consumption by 1.3% (0.006 quad/year). This translates to a sector-wide recommended site energy savings of 0.59 quad and an achievable site energy savings of 0.27 quad for building-related conservation measures.

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