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An Analysis of Buildings-Related Energy Use in Manufacturing

M. J. Niefer
W. B. Ashton

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Prepared for the U.S. Department of Energy
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Pacific Northwest National Laboratory
Richland, Washington 99352

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EXECUTIVE SUMMARY

This report presents research by the Pacific Northwest National Laboratory (PNNL) to develop improved estimates of buildings-related energy use in U.S. manufacturing facilities. The research was supported by the Office of Building Technology, State and Community Programs (BTS), Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy (DOE). The research scope includes only space conditioning and lighting end uses. In addition, this study also estimates the energy savings potential for application of selected commercial buildings technologies being developed by the BTS office to manufacturing and other industrial process facilities.

Research Methods

This research uses both published aggregate energy data and selected plant-level data from the 1991 Manufacturing Energy Consumption Survey (MECS), the most comprehensive source of national-level data on manufacturing energy-related information. MECS is administered by the Energy Information Administration (EIA) of the U.S. DOE. Data from the 1991 MECS (EIA 1994b) and other Bureau of Census surveys were used in this analysis to compile summary statistics on buildings-related energy consumption in U.S. manufacturing and on basic factors affecting buildings energy use such as manufacturing floorspace and employment. The plant-level MECS data provide a unique analytic resource for studies of manufacturing activities.

Findings

This study led to four major findings, including new estimates of buildings-related energy use and energy intensity that are comparable to previous estimates. The individual findings are presented below:

1. **Buildings-Related Energy Consumption in Manufacturing** -- On the basis of MECS data, the 1991 buildings-related energy use estimates in Table S-1 were developed in this research. They are compared to a key national-level energy consumption estimate produced in the 1980s (Hagler, Bailly & Co. 1987).

These results show differences in both the magnitude and pattern of energy consumption between 1983 and 1991. The changes may be due to a variety of factors, including differences in the data samples, in estimation methods and in definitions of energy consumed for HVAC and lighting. Nonetheless, a comparison of these estimates suggests several topics that may be of interest for buildings-related energy analysis.

The 1983 HBC estimate of 1.25 delivered (1.65 primary) quads was 15% of total industrial energy use in that year. The 1991 MECS estimate of 1.12 delivered (1.96 primary) quads is 7% of industrial energy consumed for heat, power and electricity generation in 1991. Despite an increase in total industrial energy consumption from 1983 to 1991, buildings-related energy use was apparently lower in 1991 than in 1983, based on the above numbers. End-use shares shifted as well, with lighting, ventilation and air conditioning all showing a larger share of the 1991 total and space heating showing a smaller share. However, in broad terms, the distribution patterns between end uses are similar.

Table S-1 Buildings-Related Energy Consumption in Manufacturing

Buildings-Related End Use	1983 HBC Estimates (Delivered Quads)	1983 HBC Estimates (Primary Quads)	1991 MECS Estimates (Delivered Quads)	1991 MECS Estimates (Primary Quads) ^(a)
Space Heating	1.05 (84%)	1.05 (78%)	0.77 (69%)	--
Ventilation & Air Conditioning	0.10 (8%)	0.30 (18%)	0.18 (16%)	--
Air Conditioning	--	--	0.09 (8%)	--
Ventilation	--	--	0.09 (8%)	--
Total HVAC ^(b)	1.15 (92%)	1.35 (82%)	0.95 (85%)	1.44 (73%)
Lighting	0.10 (8%)	0.30 (18%)	0.17 (15%)	0.52 (27%)
Total Buildings-Related End Use	1.25 (100%)	1.65 (100%)	1.12 (100%)	1.96 (100%)

(a) The 1991 MECS data did not report estimates of electricity consumed for space heating, air conditioning, or ventilation. The 1991 MECS data did, however, report electricity consumed for HVAC and lighting. Estimated electricity consumption was used to estimate primary energy consumed for HVAC and lighting. Delivered electricity was converted to primary electricity using a factor of 3.077.

(b) Heating, Ventilation and Air Conditioning (HVAC).

This research did not seek to explain changes in energy-use patterns between 1983 and 1991. However, in addition to differences in the data sources and analysis methods, the apparent changes in space heating, cooling, ventilation and lighting shares might be due to any of several factors. For example, compositional shifts among industries, growth in non-production worker share of employment, changes in energy prices, or the general relocation of manufacturing from "Rust Belt to Sun Belt" might explain these shifts.

Table S.2 presents this study's estimated buildings-related energy consumption for the manufacturing sector relative to the residential and commercial sector.

The data shown include total energy consumption as well as estimates of floor space, lighting intensity, heating intensity, and cooling intensity for all of manufacturing in 1991. Manufacturing consumed a total of 170 trillion Btu of energy for lighting in 1991 (Table 4.4) compared with 310 trillion Btu in the residential sector and 1150 trillion Btu in the commercial sector (manufacturing consumption is 12% of the residential and commercial total). The manufacturing industries consumed a total of 774 trillion Btu for heating (10% of the residential and commercial total), and 85 trillion Btu for cooling (11% of the residential and commercial total). The lower industrial totals are probably due in large part to the fact that manufacturing building floor space is only 6% of total commercial and residential floor space.

For lighting, the manufacturing sector is, on average, less intensive than the commercial sector, but considerably more intensive than the residential sector. However, the manufacturing sector is more heating intensive and more cooling intensive than both the commercial and residential sectors. These differences

**Table S.2 Buildings Energy Use Characteristics for
Manufacturing, Residential, and Commercial Sectors**

	Manufacturing	Residential	Commercial	Total Residential & Commercial
Energy for Lighting (delivered quads)	0.17	0.31	1.15	1.46
Energy for Space Heating (delivered quads)	0.77 ^(a)	5.61	1.84	7.45
Energy for Space Cooling (delivered quads)	0.09	0.48	0.55	1.03
Energy for Ventilation (delivered quads)	0.09	(b)	(b)	(b)
Total Energy for HVAC (delivered quads)	.95 ^(a)	(b)	(b)	(b)
Floorspace (billion sq ft)	15.5	181.2	70.0	248.2
Lighting Intensity (thousand Btu/sq ft)	11.0	1.7	16.4	--
Heating Intensity (thousand Btu/sq ft)	49.8	31.0	26.3	--
Cooling Intensity (thousand Btu/sq ft)	5.5	2.6	7.9	--

(a) Total includes energy consumed to raise steam used in space heating.

(b) Data are not available.

All energy totals are site totals rather than primary energy equivalent totals.

Sources:

Manufacturing - PNNL estimates based on 1991 MECS. Data for 1991.

Residential, Commercial - OBT Core Databook, 8/7/96. Data for 1994.

are probably due to the fact that manufacturing floor space is usually occupied for more hours per day than floor space in the residential and commercial sectors. Manufacturing plants with multiple shifts may operate 16 or 24 hours per day.

2. Characteristics of Manufacturing Buildings -- This research also produced new estimates of manufacturing buildings floorspace. As reported in Table 4.3, total floorspace in U.S. manufacturing in 1991 is estimated to be 15.5 billion square feet: 2.6 billion square feet in office space and 12.9 billion square feet in non-office space.

In addition, Table S.2 shows new estimates for building energy intensities for all manufacturing; lighting intensity is estimated to be 11,000 Btu per square foot, and HVAC intensity is estimated to be 60,900 Btu per square foot. There is significant variation across industries in total square footage as well as in lighting and HVAC intensity.

3. **Energy-Savings Potential** -- This research also produced estimates of the potential for reducing buildings-related energy use in manufacturing. Using the assumptions in the 1995 DOE/EE Quality Metrics process for commercial buildings, the energy savings potential for office space in manufacturing is roughly 43 TBtu or 22% of projected baseline energy use in 2020 (see Section 6.0).

4. **Industrial Buildings Technology Markets** -- Finally, this research suggests that attractive niche markets for some BTS technologies may exist in the manufacturing sector, but more work is needed to identify these markets and assess their potential. Example BTS technologies with potential industrial applications include high power S-lamps, thermally activated heat pumps (large commercial chiller), advanced desiccant technology and advanced refrigeration systems. Indoor air quality research may also have industrial sector payoffs.

Recommendation for Future Research

In contrast to the commercial and residential sectors, very few data exist on buildings-related energy consumption in the U.S. manufacturing sector; MECS provides nearly all there is, especially at the national level. This research used the best national level data currently available to develop improved estimates of manufacturing floorspace and energy consumed for HVAC and lighting. The results reveal significant differences between the residential, commercial and manufacturing sectors regarding the way energy is consumed for buildings-related purposes. In addition, there are significant differences in energy consumption patterns across the industries within the manufacturing sector. This research does not, however, offer any explanations for such differences. A fuller understanding of the determinants of manufacturing sector energy use for buildings purposes would require an examination of such factors as geographic location, shift work, types of workers on the plant floor, types of machinery on the plant floor, types of production processes used, and energy prices. Using data from the 1994 MECS, which is expected to be available in mid 1997, and a variety of other government sources, future research could be undertaken to explore these issues in more detail. A fuller understanding of these issues will permit analysts to estimate energy savings from emerging energy-efficient buildings technologies with greater confidence than has been possible to date.

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1.0 INTRODUCTION

This report presents research by the Pacific Northwest National Laboratory (PNNL) to develop improved estimates of buildings-related energy use in manufacturing facilities in the United States. The research was supported by the Office of Building Technology, State and Community Programs (BTS), Office of Energy Efficiency and Renewable Energy (DOE/EERE), U.S. Department of Energy (DOE). Analysis of buildings-related energy use data in manufacturing facilities from the Energy Information Administration's 1991 Manufacturing Energy Consumption Survey (MECS) has made it possible to update estimates of energy use in industrial buildings published during the 1980s.

According to the Energy Information Administration (EIA), the industrial sector consumed about 34 quads of primary energy in 1995 - slightly more than the 32 quads consumed by the residential and commercial sectors (EIA 1996b). This total consists of energy produced offsite and consumed as fuel or feedstocks, and energy produced onsite from non-energy inputs consumed as fuel or feedstocks. Some of the energy consumed by the industrial sector is not for manufacturing or process functions, but rather is for building-related purposes, such as lighting, space conditioning, and end uses. Previous estimates and anecdotal evidence have suggested that these end uses may consume as much as 1.25 quads of end-use energy (see, for example, Hagler Bailly & Company 1987).

The MECS-based estimates of buildings-related manufacturing energy use developed in this study are unique because plant-level MECS data are used to characterize energy use and energy intensity for different industries (i.e., for different types of plants). Emphasis in the research is on space conditioning and lighting end uses.

1.1 Objectives

The main objectives of this research are to 1) develop empirical estimates of buildings-related space conditioning and lighting energy use in the manufacturing sector based on 1991 MECS data, and 2) develop energy savings estimates from use of BTS commercial buildings technologies in manufacturing facilities. The energy use and savings potential estimates were developed in the following categories:

- end use (especially lighting; and heating, ventilating and air conditioning or HVAC)
- major industry type (based on the Standard Industrial Code or SIC; see Appendix A)

A final general objective in this research is to identify future research needs for better information on energy use and savings potential in buildings-related manufacturing markets.

1.2 Technical Approach

The technical approach in this study centered on statistical analysis of the MECS and other manufacturing energy and economic data from the Bureau of the Census (BOC). To begin, the literature review of previous studies of industrial building energy use permitted comparisons of the new estimates with other research in this area. Analysis of the MECS and related data was then completed to derive estimates of energy use and energy intensity for space heating, cooling and lighting. Improved estimates of both production and non-production manufacturing facility floorspace were developed as part of the energy intensity analysis. Where possible, comparisons with previous research results were also made.

The major data sources for this analysis were 1991 MECS aggregate and plant-level data and other BOC manufacturing data sources (the Annual Survey of Manufactures (ASM) and Census of Manufactures (CM) and Commercial Buildings Energy Consumption Survey (CBECS)). A combination of published aggregate data and unpublished plant-level data was used to derive buildings-related energy consumption estimates and energy intensities.

Finally, PNNL estimated the energy savings potential from applying the efficient commercial buildings technologies being developed by BTS to manufacturing. These estimates were based on the Quality Metrics (QM) process being used by DOE/EERE to evaluate its research and development (R&D) portfolio.

1.3 Non-Process Energy Use in Industry: Plant-Level MECS Data

EIA publishes the results of MECS in an aggregate form (EIA 1994). However, the BOC also maintains plant-level data from the 1991 MECS, as well as data from other BOC surveys, including the ASM and CM. The plant-level data are especially useful in assessing the energy performance of particular types of plants in the MECS sample, including the non-process use of energy in manufacturing. These data are made available to researchers through the Census Bureau's Center for Economic Studies (CES) which maintains a database containing individual responses to a variety of BOC surveys. Linkage of plant responses to the MECS with responses to other BOC survey data provides a rich set of energy- and production-related data at the plant level.

This section presents an overview of the types of non-process energy data available through CES.

1.3.1 Non-Process Energy Consumption Data

To estimate energy consumption by end use in manufacturing, the 1991 MECS asked survey respondents to estimate the percentage of their energy consumption attributable to various process and non-process uses by energy type.^(a) Estimates for the following 6 non-process uses were collected:

(a) The MECS Survey Form is reproduced in Appendix F of the final 1991 MECS report.

1. Facility HVAC
2. Facility lighting
3. Facility support (e.g., cooking, water heating, office equipment)
4. Onsite transportation
5. Conventional electricity generation
6. Other.

When coupled with estimates of energy consumption by fuel type also collected for MECS, these basic data permit energy consumption estimates by fuel type for each one of the 6 non-process use categories.

1.3.2 Related Non-Process Data

The 1991 MECS also collected other data which may be helpful for interpreting the plant-level lighting and HVAC consumption estimates. These data include the square footage of buildings at each respondent's plant, the percentage of square footage with controlled heating or cooling and the use of computer controls of building environment. Respondents were also asked to state whether or not their plants participated in a formal energy-management program and to identify the types of energy-efficiency activities at their plants. Finally, data on expenditures for and quantities of purchased electricity and fuels used for heat, power and electricity generation were collected, permitting construction of an average Btu price for all purchased energy by energy type.

1.3.3 Square Footage Estimates

Respondents were asked to check a box indicating the approximate total enclosed square footage category of buildings at their plant. The 10 categories ranged from "25,000 square feet or less," to "Over 25 million square feet." In addition, they were asked to check a box indicating the approximate percentage of total square footage using equipment designed to modify the internal building temperature. The five categories were 100%, 75%, 50%, 25%, and none. A related question asked respondents to check a box indicating whether their plants utilized computer control of their building environment (e.g., space heating or cooling equipment, lights).

1.3.4 Participation in an Energy-Management Program

Respondents were asked for a check-off response identifying whether or not their plant participated in a formal energy-management program (whether company, utility, or third-party sponsored) during 1989-1991.

1.3.5 Types of Energy-Efficiency Activities

The check-off box identifying whether or not plants participated in any of several energy-efficiency activities during 1989-91 including energy audits, electricity load control, equipment rebates, and equipment retrofits (which included retrofits for lighting and HVAC). The survey also asked whether

these activities were sponsored 1) by a utility or supplier, or 2) by the plant or some third party. In addition, respondents were asked to identify whether or not they participated in energy audits or took advantage of equipment rebates for the purpose of improving energy efficiency.

1.4 Other Plant-Level Census Data

Responses to other Census Bureau surveys, such as ASM and CM, can be linked with responses to the 1991 MECS to aid in interpreting the MECS-based HVAC and lighting energy use estimates. Plant-level data collected for other Census surveys include industry designation, value of shipments, investment, capital stock, plant age, ownership status, total employment, geographic location, and primary and secondary products.

While substantial buildings-related data are presented at an aggregate level in the 1991 MECS final report, using plant-level data allows simultaneous control of the many factors that might be expected to influence energy consumption or energy efficiency in HVAC and lighting and assess their relative importance. While the square footage data is categorical, it is possible to use the upper and lower bounds of square footage categories to estimate an upper and lower bound on energy use per square foot.

1.5 MECS Data Quality Issues

The 1991 MECS sample consists of about 13,000 manufacturing plants and is a subsample of the 1991 ASM. The probability of selection into the MECS sample is proportional to a plant's energy measure of size; plants consuming more energy are more likely to be included in the MECS sample. There were a total of 62 sampling strata: for 40 4-digit SIC industries, 2 3-digit SIC industries, and 20 2-digit SIC major groups. Aggregates were published for each of the 62 sampling strata. The 40 4-digit SIC industries consist primarily of the largest energy-consuming industries. For all but 3 of the 4-digit industries, the MECS sample consists of the full ASM sample.

CES requires that aggregates constructed from the plant-level responses to Census surveys meet certain requirements in order to avoid disclosing plant-specific data. Because the 40 4-digit industries along which the MECS is stratified are generally more heavily sampled than other industries, any analyses of these industries will generally meet disclosure requirements. For other 4-digit industries, however, where the sample may be quite thin, it may be difficult to conduct an industry-level analysis.

1.6 Organization of the Report

This document contains several sections to present the research process and results. Section 2.0 contains the literature review. Section 3.0 presents a summary of energy use in manufacturing based on MECS data. Manufacturing buildings-related energy use results are presented in Section 4.0. Section 5.0

gives the results of the manufacturing floorspace analysis and Section 6.0 discusses the market penetration analysis for use in the DOE/EE Quality Metrics analysis. The research findings from Sections 2.0 - 6.0 are drawn together and a recommendation is given in Section 7.0.

The Appendices contain background details relevant to the research process and results. Appendix A discusses the Standard Industrial Classification (SIC) system and Appendix B contains background on the research data sources and analysis methods used. A brief description of BTS programs is presented in Appendix C.

2.0 LITERATURE REVIEW

The literature on buildings-related energy use in industry is limited. Only a handful of studies have been completed, and the two most widely cited studies with national level estimates, completed in the mid-1980s, use the same basic source of data. A number of studies of industrial buildings exist for the state of California or some of its utility service areas; however, these each have a special focus and tend to draw on a mixture of specialized, diverse and possibly inconsistent data sources. Most of these efforts were also completed in the late 1980s or early 1990s. Moreover, there are also only a few studies of energy savings potential in industrial buildings. With few exceptions, this research focussed on aggregate estimates of the energy savings potential of new technologies.

The literature review identified the following major studies representing previous work in this area:

<u>Author</u>	<u>Year Published</u>	<u>Industry Scope</u>	<u>Building Services Covered</u>	<u>Type of Data Source</u>
Facas	1985	U.S.	HVAC, lighting	MIPD
Hagler, Bailly, & Co	1987	U.S.	HVAC, lighting	Facas, MIPD
Akbari and Gadgil	1988	California	HVAC, lighting	workshop
Akbari and Sezgen	1991	California	HVAC, lighting	2 case studies
Atkinson et al.	1995	U.S.	lighting	MECS, XENCAP
Abraham	1995	U.S.	HVAC, lighting	EADC/IAC
EIA	1994	U.S.	HVAC, lighting	1991 MECS

2.1 Summary of Individual Studies

The purpose, methods, data sources and findings from these studies are summarized in this section.

1. **Facas, G.N. June 1985. *Analysis of Industrial Space Heating and Air Conditioning*. Masters Thesis - Drexel University. Philadelphia, PA.**

The Facas study covered space heating and cooling and appears to be the first study to complete a detailed empirical analysis of energy use in industrial buildings. To complete the analysis, Facas developed an industrial building space heating model to estimate the percent of fossil fuel used for space heating at a typical plant site for 37 separate manufacturing segments. The model was driven by variables like heating degree days, production employees, and the ratio of total electric to total fossil fuel use at the plant site.

Data Sources and Analysis

In this study, data on fossil fuel use for space heating were obtained from 5,512 industrial plant sites in the United States for 1983. These data were from the Major Industrial Plant Data Base (MIPD)

developed by Dun and Bradstreet Economic Services, which is based on a mixture of original data sources, including a telephone survey of 20,000 plants, plant buildings engineering models, trade association sources and engineering expert systems. The MIPD database contains in-depth locational, process and site energy use information for each plant, including information on the fraction of fossil fuel and electrical energy expended at the plant site for space heating and cooling.

Facas statistically analyzed the MIPD data with other data sources such as utility audit data to estimate correlations between data sources for each industry SIC. He then used the correlations and the MIPD data in his industrial building space heating model to estimate both space heating and space cooling shares of total SIC energy consumption. He also developed estimates for lighting energy use using the MIPD data, but the method used is not described.

Findings

The study produced estimates for space heating (as a fraction of fossil fuel use), cooling (as a fraction of electricity use), and lighting (as a fraction of electricity use) energy consumption by SIC. The space heating estimates indicated that 9.2% of the total national industrial (SIC 20-39) fossil fuel (including waste fuel) or 1.195×10^{15} Btu (delivered) were used in 1983. This can be disaggregated into the major industrial sectors as shown in Table 2.1.

Table 2.1 Summary of Industrial Non-Process Delivered Energy Consumption - 1983

Industry Segment (SIC)	Total No. of Plants ^(a)	Estimated Space Heating Energy Consumed in 1983 (Trillion Btu)	Estimated Cooling Energy Consumed in 1983 (Billion Btu)	Estimated Lighting Energy Consumed in 1983 (Billion Btu)
20	3,015	135.8	1.90	2.95
21	25	0.7	0.02	0.05
22	1,466	34.0	1.88	1.41
23	601	24.1	0.10	0.03
24	823	13.4	0.13	0.39
25	291	26.0	0.14	0.05
26	1,379	76.0	1.25	8.51
27	503	44.5	0.58	0.08
28	1,428	90.1	4.07	8.68
29	329	27.2	0.38	1.41
30	847	50.3	1.15	0.42
31	107	5.9	0.03	0.03
32	747	81.5	0.81	1.40
33	1,345	111.4	1.57	11.95
34	2,063	74.5	1.19	1.42
35	2,041	134.7	5.06	2.52
36	1,483	87.7	5.84	2.00
37	1,246	129.7	3.55	5.20
38	460	26.9	0.89	0.27
39	512	20.6	0.13	0.01
Total	21,001	1,195.0	30.66	48.75

(a) Number of plants in the MIPD.

Source: Facas 1985.

Facas estimated that natural gas supplied the largest percentage (65%) of space heating fuel, followed by oil (16%), coal (14%) and other fuels (5%).

Analysis of other building services indicated that 5.6% or 0.0307×10^{12} kilowatt hours per year (KWh/yr) of the total electric use were used for space cooling, and 8.8% or 0.0488×10^{12} KWh/yr were used for lighting in the industrial manufacturing sector.

2. **Hagler, Bailly & Company. February 9, 1987. *Industrial Buildings Energy Use*. Prepared for the Office of Buildings and Community Systems, Department of Energy. Washington, DC.**

This study represents the most comprehensive effort in the recent past to study energy use and savings potential in industrial buildings. The method employed to carry out this assessment consisted of a literature and data source review, segmentation of industrial buildings by size and function, characterization of industrial buildings-related energy use and estimation of the potential for industrial buildings energy conservation. The project also included an evaluation of the applicability of commercial and residential energy programs and measures to industrial buildings.

Data Sources and Analysis

The study is based on a number of data sources, but the analysis relies most heavily on the Facas results discussed above and the 1984 space heating energy consumption in the Dun & Bradstreet Major Industrial Plant Database (MIPD). Industry economic data and production indices from the Survey of Current Business, U.S. Department of Commerce, were used in conjunction with the MIPD energy use data.

The technical analysis approach for each building end use was to derive estimates of the percentage (i.e., share) of total industrial energy used in each SIC that could be assigned to the end-use category. The resulting percentage refers to the "average share of the relevant total energy demand for a particular SIC that is consumed for each building's energy service (e.g., space heating, lighting)." In the case of space heating, energy percentages were based on total fossil fuel demand, since industrial heating almost exclusively relies upon fossil-fired technologies (e.g., steam boilers, gas/oil-fired furnaces). Ventilation, cooling, and lighting systems rely almost totally upon electricity for their energy source, and therefore the percentages developed are applied to total industry electrical consumption.

Findings

Table 2.2 summarizes the delivered energy use for three building energy end uses in the major industrial SICs.

The industry with the largest non-process energy consumption is the Transportation Industry (SIC 37) with approximately 173 trillion Btu, or nearly 14% of the total non-process energy consumption. This is followed by the Non-Electric Machinery Industry (SIC 35), the Food Industry (SIC 20), and the Chemical Industry (SIC 28).

Table 2.2 Summary of Industrial Non-Process Delivered Energy Consumption - 1985

Industry Segment (SIC)	Total No. of Plants ^(a)	Estimated 1985 Space Heating Energy Consumption (Trillion Btu)	Estimated Cooling Energy Consumed in 1985 (Trillion Btu)	Estimated Lighting Energy Consumed in 1985 (Trillion Btu)	Total 1985 Buildings Energy Consumption (Trillion Btu)
20	6,975	139.8	6.7	10.4	156.9
22	2,529	33.7	6.4	7.7	47.7
23	4,873	23.8	0.3	0.1	24.2
25	2,624	26.9	0.5	0.9	28.3
26	2,246	77.0	4.1	7.3	88.4
27	8,448	46.6	2.1	0.7	49.4
28	3,445	93.0	14.6	20.2	127.8
30	3,620	51.6	4.0	1.5	57.1
31	17	5.4	0.1	0.1	5.6
32	4,000	83.7	2.8	4.9	91.4
33	254	1.4	0.0	0.4	1.8
34	11,734	78.1	4.3	5.1	87.5
35	12,952	138.8	17.8	8.9	165.5
36	5,220	86.0	19.6	6.7	112.3
37	2,700	140.6	13.1	19.3	173.0
38	2,427	27.3	3.1	0.9	31.3
39	3,349	3.2	0.4	0.3	4.0
<hr/>					
Total ^(b)	77,159	1,057.1	100.0	95.1	1,252.2

(a) Number of plants in the Dialog Trinet Database.

(b) Totals presented are those in the original study.

Source:

Hagler, Bailly, and Co., 1987.

The study results for the three main end uses analyzed--space heating, ventilating and air conditioning and lighting--are discussed further below:

Space Heating--The space heating results are based on an analysis that statistically correlates three dependent factors--heating degree-days, number of production employees, and electric-to-fossil ratio--to the reported 1984 space heating energy consumption in MIPD. Total industrial energy use for space heating was estimated by applying the results of the statistical analysis--in the form of percentages of total energy use--against the total estimated fuel consumption of each industry segment. These industry energy estimates were then updated to 1985 using industry production indices from the Survey of Current Business.

Ventilating & Air Conditioning (VAC)--The energy consumption estimates for building ventilation and air conditioning (VAC) were developed using a similar approach to the space heating analysis. However, the percentages of total energy use were based on total plant electric energy consumption rather than fossil fuels. On a national average, industrial building VAC is estimated to consume approximately 5.9% of total industrial electricity consumption.

These values differ significantly from those presented in the space heating analysis. Several factors help to explain this result. The first important factor is that not all industrial facilities require air conditioning either for employee comfort or to maintain a proper process environment. Second, since many industries rely heavily on electrically operated equipment (i.e., there are few processes using fossil-fired direct heat), total plant consumption of electric energy can be quite high and, as a result, the percent of electric energy consumed by VAC will be correspondingly small.

Lighting--In general, lighting accounts for a lower percentage of total electrical load in industrial facilities than in commercial facilities. Lighting of offices can account for 30-40% of total electrical load, while in other commercial establishments, such as retail stores, lighting can account for up to 50% of total electrical load. Lighting industrial facilities normally accounts for only about 10% of total electrical load. However, industrial lighting requirements often vary significantly throughout a single plant as well as between different industries. Base unit power density values (UPD) used as new design and retrofit guidelines can range from 0.6 watts/ft² to nearly 7.0 watts/ft², depending on the task or area being illuminated. Guidelines published by the Illuminating Engineering Society cite UPD design requirements of 5.0 to 6.8 watts/ft² for activities such as final assembly, inspection, and fine glazing (Clay Products and Cements Industry) while activities such as rough assembly, general operation areas, and welding normally require UPD design levels between 0.6 and 1.5 watts/ft².

Despite the variability in lighting levels over plants and industries, overall lighting loads comprise similar percentages of the total plant electric load for most industries. These percentages do not vary as much as those estimated for space heating and VAC largely because enclosed plants can expect to provide some minimal level of lighting regardless of the industry or process activities which take place within that industry.

3. Akbari H. and A. Gadgil. November 7, 1988. *Industrial Building Energy Use: Workshop Proceedings*. LBL-27658. Lawrence Berkeley Laboratory, University of California. Berkeley, CA.

This document summarizes a one-day workshop jointly sponsored by the University-wide Energy Research Group (UERG) and the Lawrence Berkeley Laboratory with invited participation from researchers, the California Energy Commission, and California utilities to discuss aspects of data base generation, and maintenance and technology impacts on energy demand in industrial buildings. Several issues were addressed, including determinants of energy demand, the availability of data on energy use in industrial buildings and the quality of data.

Regarding data, one estimate of energy use indicates that, nationwide, about 100 GWh (equal to 13.5% of delivered industrial electricity use) is consumed in providing industrial building services; however, this figure may not include all the shaft power for HVAC fans, pumps, and compressors. This share is likely to be higher in newer industries (i.e., light industries with high occupancy levels and/or special needs for environmental conditioning as is the case for many California industries). In discussing data quality, the participants found that current energy use in the building services of the industrial sector is often aggregated with industrial process load data. Moreover, data on non-process industrial energy use

are not readily available in the literature. The workshop focused attention on energy use in industrial buildings, summarized the existing knowledge in the field, and identified gaps in data of energy and peak forecasting, as well as for analysis of load-shaping and conservation strategies.

One of the key points discussed during the meeting was the fact that the ratio of energy use in building service to the total site energy use is a function of several factors, including the nature and schedule of industrial activity, building size and site climate. Energy use in building services is more responsive to weather and occupant schedules than the traditional "base-load" industrial process energy. It was concluded, however, that industrial buildings have been found to be similar to other non-residential buildings. For practical reasons, many light industrial buildings are designed and built to be physically similar to retail or office structures.

4. **Akbari H. and O. Sezgen. September 1991. *Analysis of Energy Use in Building Services of the Industrial Sector in California: Two Case Studies*. LBL-31351 Lawrence Berkeley Laboratory, University of California. Berkeley, CA.**

This study used informal field surveys, simulation studies, and analyses of utility commercial/industrial audit files to study the energy use of selected small and medium-sized industrial facilities in California. In these industrial subsectors, the energy required for building services (providing occupant comfort and necessities like lighting, HVAC, office equipment, computers, etc.) may be at least as important as the more familiar process energy requirements, especially for electricity and on-peak demand.

The case studies focussed on high-tech manufacturing firms that operate small and medium-sized buildings used simultaneously or interchangeably over time for commercial (office, retail, warehouse) and manufacturing activities. The case studies were 1) a manufacturer of microwave components whose schedules and space-use characteristics were similar to those of an office building and whose process equipment was used intermittently, and 2) a manufacturer of printed circuit boards, which operated its process equipment continuously. Both case studies occurred in buildings that are typical of industrial park buildings in California.

Data Sources and Analysis

The data collected included site interviews with owners, review of buildings drawings, use of utility bill data and a building/process equipment inspection. The following analysis procedure was used: 1) characterizing non-process building energy and power use in California industries, 2) identifying conservation and load-shaping opportunities in industrial building services, and 3) investigating industrial buildings and system design methodologies. Based on the information for the case studies, the design considerations for the industrial buildings, their energy use, and their conservation and load-shaping potentials were reviewed. DOE-2 computer simulation models of the building were run to identify conservation potential estimates.

Findings

The study concluded that the lighting and HVAC energy-use characteristics of the case studies (and other similar high-tech industry buildings) and their conservation potential are comparable to those of office buildings. The authors pointed out that, compared to other non-residential buildings, industrial structures may have higher thermal loads, higher air-change rates, longer operating hours and greater pollution control or environmental conditioning requirements. Regarding energy conservation potential, the researchers estimated that more than 50% of electricity and gas use for the building services in the two case-study facilities can be saved on the basis of the DOE-2 simulations of commonly used buildings conservation measures.

5. Atkinson, B.A. et al. 1995. "Modeling U.S. Industrial Lighting Energy Consumption and Savings Potential." *Proceedings: ACEEE Summer Study on Industrial Energy Efficiency*. ACEEE. Washington, D.C.

In this study, the Lawrence Berkeley National Laboratory (LBL), working with Regional Economic Research, Inc. (RER), synthesized two key industrial energy use data sources, MECS and XENCAP, to improve estimates of energy use in lighting as well as for projections of future energy use under different scenarios. These data sources were combined to create a Lighting Database Application (LIDA) database consisting of technical and economic lighting data.

Data Sources and Analysis

The 1991 MECS contains aggregate data on interior and exterior lighting consumption by industry SIC. The data indicate that lighting accounts for about 6% of electricity use or a consumption of about 50 billion kWh. The second data source, XENCAP, contains utility energy audits data for 2,700 industrial buildings; the data were aggregated by 3-digit SIC code and zip code for analysis of the 1990-1995 period. The percentage of delivered lighting provided by the following four major lighting types was calculated:

- High intensity discharge (metal halide, high pressure sodium and mercury vapor),
- Fluorescent (four-foot, eight-foot high output, and other),
- Incandescent, and
- Compact fluorescent.

Market penetration, lighting operating hours and footcandle levels were also estimated for each of these technologies. Saturations of lighting equipment for new construction and renovated lighting systems were projected by LBL using Bureau of Census data trends, research by the Lighting Research Institute, information from industry, and analysis by RER. These data were combined to form the LIDA data base, which contains existing energy consumption data and projections of lighting energy use and savings potential. Lighting data exist at both the system-type and fixture-type level and includes typical operating hours and sectoral footcandle level (lumens per square foot) calculations.

The LIDA database was used in the Electric Power Research Institute's (EPRI) COMMEND model, Version 4.0, to estimate current lighting energy use and to project future levels of lighting energy consumption for the period 2000 through 2030. The key forecast driver in the current analysis is manufacturing floorstock, and average lighting intensity was assumed to be 3.8 kWh/ft². The COMMEND forecasts use a base year of 1992. The ratio of 1992 industrial electricity sales to 1991 industrial sales was used to scale the 1991 floorstock value to 1992 electricity sales levels. Interior and exterior lighting associated with industrial buildings have been included in each building type and are analyzed separately.

Findings

The data sources indicate that both fluorescent and high intensity discharge (HID) lighting (metal halide, high pressure sodium and mercury vapor) are used extensively. Fluorescent systems tend to be used in support spaces such as offices, employee areas, and restrooms. HID sources are used in areas with high ceiling or high bay facilities. Metal halide is becoming increasingly popular for mixed-used areas, including space with machinery. High pressure sodium is used where color rendering and distortion of moving parts is not a concern. There is little incandescent lighting used in the industrial sector.

In the COMMEND analysis, the study projected industrial floorstock to grow from 13.99 billion ft² in 1996 to 14.98 billion ft² in 2030.

6. **Abraham, M.M. 1995. "Don't Neglect the Building: Examining the Energy Conservation Potential for Industrial Buildings." *Proceedings: ACEEE Summer Study on Industrial Energy Efficiency*. ACEEE. Washington, D.C.**

In this study, information gathered by the Department of Energy's (DOE) Energy Analysis 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. The DOE provides technical assistance to small and medium-sized companies for energy conservation efforts through the EADC/IAC program. EADC/IAC efforts are administered through thirty centers located at engineering colleges across the United States. Engineers from the EADC/IAC centers conduct energy and materials audits of local manufacturing plants and recommend cost-effective measures that can be implemented at the plants to save energy, materials and costs. This study analyzes the recommended building conservation measures and actual implementation rates for recommendations that have been observed in the EADC/IAC program. Also, the success of the EADC/IAC program is projected across the entire manufacturing sector to determine potential sector-wide savings from similar efforts.

Data Sources and Analysis

Data collected by the EADC/IAC staff, for over 5,200 site visits since 1981, include nearly 35,000 recommendations for improving energy efficiency. Building-related conservation measures are defined in the EADC/IAC system as improvements in boiler and steam systems, compressed air systems, lighting, HVAC, and the building envelope. The recommendation and implementation data were tabulated across industry SICs, compared to identify patterns and then extrapolated to develop national-level estimates of manufacturing energy savings potential.

Findings

Building-related conservation measures provided the majority of the recommended and implemented EADC/IAC energy savings. The combined categories of Buildings & Grounds and Building Utility Systems produced 54% of the total recommended savings for a reduction in total site energy consumption of 2.9% (0.0128 quad/year). Sixty-four percent of all implemented site energy savings, or a 1.3% (0.0059 quad/year) reduction in original consumption, involved building-related measures. Average payback periods for most of the recommended improvement categories are below 2 years and actual implementation rates were nearly 50%, indicating that short paybacks may not be the primary means used in decision making.

The distribution of end uses in both energy-intensive and non-energy-intensive manufacturers reveals interesting variations in energy use patterns. The largest difference in consumption behavior between these manufacturers 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. The composition of the non-energy-intensive industries shows that those requiring larger amounts of energy for their buildings tend to have assembly-type environments.

The above results were extrapolated across the entire manufacturing sector to estimate the total annual energy consumed by the 5,260 sites visited; this was approximately 0.44 quad/year. The total recommended site energy savings is 0.024 quad/year, or about a 5.0% potential reduction in energy consumption. 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. 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 non-energy-intensive establishments through 2010.

7. **Energy Information Administration. U.S. Department of Energy. December 1994. *Manufacturing Consumption of Energy 1991*. DOE/EIA-0512(91). U.S. Government Printing Office. Washington, D.C.**

The Energy Information Administration (EIA) periodically provides estimates on energy consumption in the manufacturing sector of the U.S. economy. The most recent estimates are based on data from the 1991 MECS, which is the most comprehensive source of national-level data on energy information for manufacturing establishments (EIA 1994b). The 1991 MECS was EIA's third manufacturing energy consumption survey, but the first to collect detailed national-level end-use energy consumption data. The next survey was done in 1994, with results expected to be available in early 1997.

Data Sources and Analysis

The 1991 MECS data were collected from a stratified sample of 16,000 establishments chosen from among the 350,000 United States manufacturing establishments existing in 1991. The MECS sample

represented 98% of energy use in the U.S. manufacturing sector, excluding 2% from the smallest manufacturing establishments. These data were subjected to a battery of statistical analyses to consistently tabulate energy consumption for several end uses in a form that permitted detailed comparisons among manufacturing establishments.

Since the MECS data are evaluated extensively in this study, further information on the MECS data source is presented in Sections 1.0, 3.0 and 4.0 of this document.

Findings

Manufacturers use energy sources in two major ways: 1) to produce heat and power and to generate electricity, and 2) as a raw material input to the manufacturing process or for some purpose not considered heat, power, and electricity generation. For item (1), a total of 9.7 quadrillion Btu (representing natural gas, electricity, coal, residual and distillate fuel oils, and LPG) was used for the three following manufacturing end uses:

- Boiler fuel (which is used to transform one source of energy into another, e.g., steam)
- Direct process uses (e.g., for use in motors, ovens, strip heaters, and kilns)
- Direct non-process uses (for facility heating, ventilation, and air-conditioning (HVAC); facility lighting, other facility support; on-site transportation; electricity generation; and other miscellaneous uses).

Over half (5.0 quadrillion Btu) of reported end-use consumption was used to transform raw material inputs into production outputs (process heating, process cooling/refrigeration, machine drive--motors, electro-chemical processes, and other unspecified processes). About one-third (3.3 quadrillion Btu) of the end-use consumption was for boiler fuel. Finally, only 1.2 quadrillion Btu, or 12 % of reported energy consumption, was designated for direct non-process uses (0.2 quads of the 9.7 total had no reported end use).

Less than 8% (0.75 quadrillion Btu) of energy consumption in manufacturing establishments was directly related to facility use. This direct non-process (facility) energy was consumed as follows (figures do not add due to rounding):

<u>Facility Energy End Use</u>	<u>1991 Delivered Energy Consumption^(a) (quadrillion Btu)</u>
HVAC	0.49
Lighting	0.16
<u>Other facility support</u>	<u>0.05</u>
Total Facility Energy	0.71

(a) These are reported totals only. In the following sections, these numbers are adjusted to account for energy consumed but not reported by end use.

In most industries, a relatively small percentage of total energy consumed is used for non-process end uses. However, for some assembly-type manufacturing which uses large, environmentally controlled buildings, this can represent a significant percentage of their total consumption. Examples of industries where the high percentages occur are furniture and fixtures industries (32%); transportation equipment industries, such as automobile plants (25%); and computer and office equipment industries (43%).

The 1991 MECS also included data on industry's efforts to improve the energy efficiency of their direct non-process operations through various demand side and other energy management programs. From 1989 through 1991, the reported activities and percent of participation were as follows: improving the efficiency of facility lighting (36%) and installing equipment to improve facility HVAC systems (23%). The percentage figures given are shares of the total input energy use represented by participating establishments.

2.2 Literature Review Findings

The review of previous literature relevant to this study led to the following findings:

1. Overall, only a limited amount of literature on buildings-related industrial energy use exists. There have been a number of specialized studies of buildings-related energy use in industry since the early 1980s, but these efforts are usually limited to a few end uses, regional coverage and site or utility-service area data sources. It appears that the only comprehensive data source in its national coverage and range of end uses is the MECS information collected by EIA.
2. Research prior to the 1991 MECS data resulted an estimate of 1.25 quadrillion delivered Btu (or 15% of total industrial energy use) for buildings-related energy use in manufacturing. This energy use was broken down into space heating - 84%; AC/ventilation - 8% and lighting - 8%.
3. Commonly used estimates for buildings-related energy use in manufacturing are based on data collected in the early-mid 1980s. The most widely cited national-level studies by Facas, and Hagler, Bailly, and Co. rely on data from the MIPD which were collected in 1983 and 1984.
4. With respect to conservation potential for buildings-related energy use, discussions with industrial facility managers and simulations with the DOE-2 Model have suggested that 20-50% of non-process energy could technically (and perhaps cost-effectively) be conserved.
5. Several studies suggest that industrial facilities of interest for improved energy management are likely to be very similar to other non-residential buildings.

3.0 OVERVIEW OF ENERGY CONSUMPTION IN MANUFACTURING, 1991

In 1991, the U.S. manufacturing sector consumed a total of 20.3 quadrillion Btu of delivered energy: 15.0 quadrillion Btu for heat, power, and electricity generation, and 5.3 quadrillion Btu for other purposes including use as raw materials (EIA 1994b).^(a) Natural gas accounted for 37% of energy consumed for heat, power, and electricity generation, electricity for 16%, coal for 8%, residual and distillate fuel oil for 4%; the remaining 35% of consumption was accounted for by liquefied petroleum gases (LPG), coke and breeze, steam, and various byproduct fuels (EIA 1994b).

The total cost of purchased energy consumed for heat, power and electricity generation was \$61 billion (EIA 1994b) in 1991. Energy costs were 4% of total cost of materials which totaled \$1.5 trillion in 1991 (BOC 1992); they were 2% of the value of shipments in manufacturing which totaled \$2.8 trillion in 1991 (BOC 1992).

In 1991, energy used for various process uses, including process heating, process cooling, and machine drive, accounted for 54% (8.1 quadrillion Btu) of total energy consumed for heat, power, and electricity generation; boiler fuel accounted for 36% (5.4 quadrillion Btu); heating, ventilation, and cooling for 3% (0.5 quadrillion Btu); lighting for 1% (0.2 quadrillion Btu); and other non-process uses, including energy used for cooking, office equipment, onsite transportation, and conventional electricity generation, accounted for 6% (0.9 quadrillion Btu).^(b)

Currently available end-use data do not allow one to determine the end uses of steam or hot water from boilers. To the extent that steam or hot water from boilers is used for non-process heating, the share of energy consumed for non-process heating reported in Figure 3.1 will be understated. As explained in Section 4.1, PNNL attempted to account for the use of steam and hot water from boilers for non-process heating in the space heating estimates.

Energy consumed for lighting and HVAC is a small share of total energy consumption in the manufacturing sector. Given the small share of lighting and HVAC in total energy consumption and the small share of energy in total materials costs, the costs associated with lighting and HVAC are also a small share of total manufacturing costs. Nevertheless, the lighting and HVAC end uses include an important potential for cost-effective energy savings through improved processes and new technologies.

(a) Unless otherwise noted, all energy consumption numbers in this report refer to site rather than primary energy consumption.

(b) PNNL estimates based on EIA (1994b). See Appendix B.3 for details.

**ENERGY CONSUMED
(DELIVERED QUADS)**

Boiler Fuel	5.4
Process Use	8.1
HVAC	0.5
Lighting	0.2
Other Non-Process	0.9
Total	15.0 (for heat, power and electricity generation)

Source:

PNNL estimates based on 1991 MECS

Figure 3.1 Manufacturing Energy End Uses, 1991

4.0 ESTIMATES OF BUILDINGS ENERGY USE IN MANUFACTURING

This section presents detailed estimates of energy consumed by individual manufacturing industries for lighting, heating, and cooling in the manufacturing sector. Data on several factors that might be expected to affect the amount of energy consumed, including floorspace and the number of employees, are also presented.

The industry-specific estimates presented below are organized by the Standard Industrial Classification of establishments (SIC). The SIC divides manufacturing into 20 major groups, numbered 20 through 39. The SIC was developed for use in the classification of establishments by type of activity in which they are engaged for purposes of facilitating the collection, tabulation, presentation, and analysis of data relating to establishments (OMB 1987). Appendix A describes the major SIC groups for manufacturing.

The estimates of floorspace, lighting, heating, and cooling presented below are given by SIC in order to make use of many of the statistics relating to manufacturing that are based on the SIC.

4.1 An Overview of Buildings Energy Use in Manufacturing

Table 4.1 presents an overview of estimated total energy consumed for lighting, space heating, and space cooling for all of manufacturing in 1991 by SIC to show the variation among industries. The data are presented in a format similar to that in Table 2.1 to permit comparisons of the pattern of energy consumption by industry. The numbers reported in Table 4.1 do not come directly from the MECS; rather, they were imputed based on "reported" totals from the MECS. The reported totals published in MECS represent only amounts that were reported by plants that responded to the survey end-use questions. Because some plants failed to respond to the MECS end-use questions, the reported MECS totals were adjusted to account for the non-respondents' energy use.

For lighting, the reported MECS total of 161 trillion Btu for electricity consumed was scaled up to 169.9 trillion Btu to include the non-responding plants. To set an accurate picture of HVAC energy use, it was necessary to scale up the MECS-reported HVAC energy consumed to account for both non-responding plants and non-reported fuels used in HVAC. Furthermore, it was also necessary to account for steam or hot water generated on-site that was used for non-process heating. Thus, the space heating energy use shown in Table 4.1 also includes estimates of the amount of boiler fuel used to raise steam for non-process space heating. These factors increased the MECS-reported total for HVAC of 500.0 trillion Btu to 946.3 trillion Btu. In addition, the MECS reports only a single total figure for HVAC; it was necessary to decompose this estimate into its three heating, ventilation, and cooling components as shown in Table 4.1. Details on the methods used to produce the numbers reported in Table 4.1 can be found in Appendix B.

Reviewing both Tables 2.1 and 4.1 shows that the 1983 estimates did not include SICs 21, 24, 29 and 33 (instead SIC 339 was used for 33). The total consumption for each end use is less in 1991 than in 1983. Moreover, for space heating, the largest consumers, SICs 20, 28, and 37 are consistent in both

Table 4.1 Summary of Manufacturing Non-Process (Delivered) Energy Consumption - 1991

SIC Major Group Number	Manufacturing Industry	Estimated 1991 Consumption by End Use (Trillion Btu)				
		Ventilation	Space Heating	Cooling	Lighting	Total
20	Food	10.9	110.8	11.4	12.5	145.6
21	Tobacco	0.5	5.9	0.6	(a)	7.0
22	Textiles	3.4	37.3	3.7	9.2	53.6
23	Apparel	1.7	13.5	1.6	3.6	20.4
24	Lumber	1.1	7.8	1.0	3.3	13.2
25	Furniture	1.5	12.8	1.4	2.1	17.8
26	Paper	5.1	53.9	5.4	9.2	73.6
27	Printing	5.4	27.9	4.2	8.2	45.7
28	Chemicals	7.9	76.9	8.1	15.4	108.3
29	Refining	1.5	15.5	1.6	4.0	22.6
30	Rubber	3.2	28.3	3.1	9.4	44.0
31	Leather	0.5	5.4	0.5	(a)	6.4
32	Stone, Clay, Glass	2.1	19.7	2.1	5.1	29.0
33	Prim Metals	4.9	51.0	5.2	16.3	77.4
34	Fab Metals	6.6	61.3	6.6	11.8	86.3
35	Ind Machinery	7.4	54.0	6.6	16.3	84.3
36	Electron Equip	6.0	44.6	5.4	13.7	69.7
37	Transport Equip	10.8	101.0	10.8	19.1	141.7
38	Instruments	5.2	39.6	4.8	8.4	58.0
39	Misc Mfg	1.0	7.2	0.9	2.2	11.3
Total		86.9	774.3	85.1	169.9	1116.2

(a) Lighting intensities not calculated for Tobacco and Food Industries. Data on lighting for these industries not published in 1991 MECS since estimated energy consumed less than 0.5 trillion Btu.

Source:

PNNL estimates based on 1991 MECS.

studies. SIC 35 is high in 1983, but is not as high in 1991. For space cooling, the three largest consumers are SIC 36, 35, and 28 in 1983, but are SIC 20, 37, and 28 in 1991. For lighting, the largest energy users in 1983 were SICs 28, 37, and 20, whereas in 1991, they were SICs 37, 35, 33, and 20.

Table 4.2 presents several comparisons of buildings-related energy use in manufacturing with comparable figures from residential and commercial buildings. The data shown include total energy consumption as well as estimates of floorspace, lighting intensity, heating intensity, and cooling intensity for all of manufacturing in 1991.^(a) Manufacturing consumed a total of 170 trillion Btu of energy for lighting in 1991 compared with 320 trillion Btu in the residential sector and 1,060 trillion Btu in the commercial

(a) Published data from the 1991 Manufacturing Energy Consumption Survey (MECS) provided control totals for heating, ventilation, and cooling combined. The shares going to each of the components were estimated. See Appendix B for details.

**Table 4.2 Buildings Energy Use in Manufacturing, Residential, and Commercial Sectors
(Delivered Quads)**

	Manufacturing (1991)	Residential (1994)	Commercial (1994)	Total Residential & Commercial (Mfg as Pct of Total Res & Comm)
Energy for Lighting (Quads)	0.17	0.31	1.15	1.46 (12%)
Energy for Space Heating (Quads)	0.77 ^(a)	5.61	1.84	7.45 (10%)
Energy for Space Cooling (Quads)	0.09	0.48	0.55	1.03 (10%)
Energy for Ventilation (Quads)	0.09	(b)	(b)	(b)
Total Energy for HVAC (Quads)	0.95 ^(a)	(b)	(b)	(b)
Floorspace (Bil Sq Ft)	15.5	181.2	70.0	251.2 (6%)
Lighting Intensity (Thou Btu/Sq Ft)	11.0	1.7	16.4	--
Heating Intensity (Thou Btu/Sq Ft)	49.8	31.0	26.3	--
Cooling Intensity (Thou Btu/Sq Ft)	5.5	2.6	7.9	--

(a) Total includes energy consumed to raise steam used in space heating.

(b) Data are not available.

All energy totals are site totals rather than primary energy equivalent totals.

Sources:

Manufacturing - PNNL estimates based on 1991 MECS. Data for 1991.

Residential, Commercial - OBT Core Databook, 8/6/96. Data for 1994.

sector. The manufacturing industries consumed a total of 774 trillion Btu for heating (10% of the residential and commercial total), and 85 trillion Btu for cooling (11% of the residential and commercial total).

Energy consumed for lighting in the manufacturing sector is only 12% of that consumed in the commercial and residential sectors. This is probably due in large part to the fact that manufacturing building floor-space is only 6% of total commercial and residential floorspace.

In terms of lighting intensity, the manufacturing sector is, on average, less intensive than the commercial sector, but considerably more lighting intensive than the residential sector. The manufacturing sector is more heating intensive and more cooling intensive than both the commercial and residential sectors. In comparing the manufacturing sector to the residential and commercial sectors, it is important to

recognize that manufacturing floorspace is probably occupied for more hours per day than floorspace in the residential and commercial sectors. In particular, a manufacturing plant running multiple shifts may be operating 16 or 24 hours per day.

While the industry aggregates for lighting, heating, and cooling are interesting in and of themselves, they obscure a great deal of heterogeneity across industries. Some industries consume a large amount of energy per square foot for lighting, heating, and cooling, and some consume a small amount of energy.

4.2 Floorspace

Table 4.3 depicts floorspace by industry in 1991.^(a) Total floorspace in the manufacturing sector was 15.5 billion square feet. Industrial Machinery, SIC 35, had the most floorspace (1,485 million square feet) among the manufacturing industries; Leather, SIC 31, had the least floorspace (53 million square feet). The six industries with the most floorspace (Industrial Machinery, Food, Fabricated Metals, Primary Metals, Lumber, and Transportation) accounted for 50% of total manufacturing floorspace in 1991. In general, industry floorspace is fairly highly correlated with industry employment; the simple correlation between industry employment and floorspace is 0.78.

Table 4.3 Floorspace, Estimates by 2-Digit SIC for 1991 (Million Square Feet)

SIC	Office Floorspace	Non-Office Floorspace	Total Floorspace
20 Food	202.5	1207.0	1,409.50
21 Tobacco	5.5	50.8	56.30
22 Textiles	41.5	581.1	622.60
23 Apparel	72.5	450.7	523.20
24 Lumber	52.5	1,134.5	1,187.00
25 Furniture	48.5	520.8	569.30
26 Paper	72.0	827.3	899.30
27 Printing	350.5	476.7	827.20
28 Chemicals	184.5	714.0	898.50
29 Refining	20.0	104.9	124.90
30 Rubber	96.5	768.4	864.90
31 Leather	8.5	44.1	52.60
32 Stone, Clay	56.5	807.5	864.00
33 Prim Metals	80.5	1,121.1	1,201.60
34 Fab Metals	182.0	1,174.8	1,356.80
35 Ind Machinery	336.5	1,148.7	1,485.20
36 Electron Equip	265.5	628.6	894.10
37 Transport	289.0	776.4	1,065.40
38 Instruments	224.5	170.2	394.70
39 Misc Mfg	51.5	190.2	241.70
All Mfg	2,641.0	12,897.6	15,538.60

Source:
PNNL estimates based on unpublished data from 1991 MECS.

(a) The methodology underlying these estimates is given in Appendix B.

In terms of office floorspace, Printing (SIC 27) had the most floorspace (351 million square feet) in 1991; Tobacco (SIC 21) had the least floorspace. The six industries with the most office floorspace (Printing, Industrial Machinery, Transportation, Electronic Equipment, Instruments, and Food) accounted for over 60% of the 2.6 billion square feet of office floorspace in manufacturing in 1991. These are all industries with a large number of nonproduction workers.

In terms of non-office floorspace, Food (SIC 20) had the most floorspace (1,207 million square feet) in 1991; Tobacco (SIC 21) had the least floorspace. The six industries with the most non-office floorspace (Food, Fabricated Metals, Industrial Machinery, Lumber, Primary Metals, and Paper) accounted for over 50% of the 12.9 billion square feet of total non-office floorspace in 1991.

The largest industries in terms of floorspace were also, in general, the largest consumers of energy for lighting, heating, and cooling.

4.3 Lighting

Table 4.4 shows energy consumed for lighting by industry in 1991. For all industries, energy consumed for lighting was 170 trillion Btu. Leather, Tobacco, and Furniture were the smallest consumers. Transportation, Industrial Machinery, and Primary Metals are the three largest consumers of energy for all lighting. As noted above, they are also among the industries with the largest floorspace. The simple correlation between industry lighting and floorspace suggests that they are fairly highly correlated (a correlation coefficient of 0.70); the simple correlation between industry lighting and industry employment (0.76) suggests they are also fairly highly correlated. Controlling for industry floorspace, it appears that the share of nonproduction workers in total employment is also positively correlated with industry energy for lighting.^(a) The positive correlation between nonproduction worker share of employment and lighting suggests that nonproduction workers may, on average, have greater lighting needs than production workers.

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- (a) A simple log-linear regression of industry energy for lighting on industry floorspace, industry employment, and the share of nonproduction workers in total employment yielded a positive and statistically significant sign on the coefficient for the nonproduction worker share. The estimated coefficient on the log of nonproduction worker share (0.79) suggests that a 10% increase in the nonproduction worker share, holding floorspace and employment constant, would lead to a 7.9% increase in energy consumed for lighting.

A simple log-linear regression of industry energy for HVAC on industry floorspace, industry employment and the nonproduction worker share of employment also yielded a positive and statistically significant sign on the coefficient for the nonproduction worker share. The estimated coefficient on the log of nonproduction worker share (0.95) suggests that a 10% increase in the nonproduction worker share, holding floorspace and employment constant, would lead to a 9.5% increase in energy consumed for HVAC.

Both of these results suggest that nonproduction workers have, on average, different lighting and HVAC needs than production workers.

Table 4.4 Energy Consumed for Lighting, Estimates by 2-Digit SIC for 1991
(Trillion Delivered Btu)

SIC	Office	Non-Office	Total
20 Food	4.7	7.8	12.5
21 Tobacco	0.1	(a)	(a)
22 Textiles	1.0	8.2	9.2
23 Apparel	1.7	1.9	3.6
24 Lumber	1.2	2.1	3.3
25 Furniture	1.1	1.0	2.1
26 Paper	1.7	7.6	9.2
27 Printing	8.1	0.1	8.2
28 Chemicals	4.3	11.2	5.4
29 Refining	0.5	3.6	4.0
30 Rubber	2.2	7.2	9.4
31 Leather	0.2	(a)	(a)
32 Stone, Clay	1.3	3.8	5.1
33 Prim Metals	1.9	14.4	16.3
34 Fab Metals	4.2	7.6	11.8
35 Ind Machinery	7.8	8.5	16.3
36 Electron Equip	6.1	7.5	13.7
37 Transport	6.7	12.5	19.1
38 Instruments	5.2	3.2	8.4
39 Misc Mfg	1.2	1.0	2.2
All Mfg	61.0	109.3	169.9

(a) Data for Tobacco and Leather industries suppressed in 1991 MECS because less than 0.5 trillion Btu consumed. Energy consumed for office lighting in these industries estimated based on employment of non-production workers (see Appendix B.5). No estimates made of energy consumed for lighting non-office space.

Source:

PNNL estimates based on 1991 MECS.

4.4 Heating

Table 4.5 shows energy consumption for heating by industry. Energy consumed for non-process heating in manufacturing totaled 774 trillion Btu. Food, Transportation, and Chemicals, were the three largest consumers of energy for heating; Leather, Tobacco, and Miscellaneous Manufacturing were the three smallest consumers.

4.5 Cooling

Table 4.6 depicts energy consumed for cooling by industry. Energy consumed for non-process cooling in manufacturing totaled 85 trillion Btu. Food, Transportation, and Chemicals were the three largest consumers of energy for heating; Leather, Tobacco, and Miscellaneous Manufacturing were the three smallest consumers.

**Table 4.5 Energy Consumed for Non-Process Heating, Estimates by 2-Digit SIC for 1991
(Trillion Delivered Btu)**

SIC	Office Heating	Non-Office Heating	Total Heating
20 Food	6.2	104.6	110.8
21 Tobacco	0.2	5.8	5.9
22 Textiles	1.3	36.1	37.3
23 Apparel	2.2	11.2	13.5
24 Lumber	1.6	6.2	7.8
25 Furniture	1.5	11.3	12.8
26 Paper	2.2	51.7	53.9
27 Printing	10.8	17.1	27.9
28 Chemicals	5.7	71.2	76.9
29 Refining	0.6	14.9	15.5
30 Rubber	3.0	25.3	28.3
31 Leather	0.3	5.1	5.4
32 Stone, Clay	1.7	18.0	19.7
33 Prim Metals	2.5	48.5	51.0
34 Fab Metals	5.6	55.7	61.3
35 Ind Machinery	10.3	43.7	54.0
36 Electron Equip	8.2	36.5	44.6
37 Transport	8.9	92.1	101.0
38 Instruments	6.9	32.7	39.6
39 Misc Mfg	1.6	5.6	7.2
All Mfg	81.1	693.2	774.3

Source:

PNNL estimates based on 1991 MECS.

Table 4.6 Energy Consumed for Cooling, Estimates by 2-Digit SIC (Trillion Delivered Btu)

SIC	Office Cooling	Non-Office Cooling	Total Cooling
20 Food	1.5	9.8	11.4
21 Tobacco	0.00	0.5	0.6
22 Textiles	0.3	3.4	3.7
23 Apparel	0.5	1.1	1.6
24 Lumber	0.4	0.6	1.0
25 Furniture	0.4	1.1	1.4
26 Paper	0.5	4.9	5.4
27 Printing	2.6	1.6	4.2
28 Chemicals	1.4	6.7	8.1
29 Refining	0.2	1.4	1.6
30 Rubber	0.7	2.4	3.1
31 Leather	0.1	0.5	0.5
32 Stone, Clay	0.4	1.7	2.1
33 Prim Metals	0.6	4.6	5.2
34 Fab Metals	1.4	5.2	6.6
35 Ind Machinery	2.5	4.1	6.6
36 Electron Equip	2.0	3.4	5.4
37 Transport	2.2	8.7	10.8
38 Instruments	1.7	3.1	4.8
39 Misc Mfg	0.4	0.5	0.9
<hr/>			
All Mfg	19.8	65.2	85.1

Source:

PNNL estimates based on 1991 MECS.

5.0 BUILDINGS ENERGY END USE AND FLOORSPACE INTENSITIES

Table 5.1 provides estimates of lighting and HVAC intensities per square foot of floorspace and per worker by industry; the table also provides estimates of floorspace requirements per worker and average plant size by industry. These data indicate that the average amount of building floorspace per manufacturing plant varies widely: from an estimated 14 thousand square feet in the Miscellaneous Manufacturing industry (SIC 39) to 494 thousand square feet in the Tobacco industry. The industry average square footage per plant is 41 thousand square feet.

In terms of square footage per worker, there again is wide variation across industries. The mean for all industries is 925 square feet per worker; the range across industries is from 438 square feet per worker in the Instruments industry (SIC 38) to 1,881 square feet in the Lumber industry (SIC 24). EIA (1994a) estimates that commercial buildings with some manufacturing taking place had an average of 1,250 square feet per worker in 1991. This estimate is considerably greater than the 925 square feet per worker reported in Table 5.1. This relatively large difference can be accounted for, in part, by the fact that EIA (1994a) accounts for main shift workers only; the square footage requirements reported in Table 5.1 take account of all workers on all shifts. Since many manufacturing plants run multiple shifts, the use of the number of main shift workers rather than total number of workers would serve to increase the estimates of Table 5.1 and bring them closer to estimates reported by EIA (1994a).

The mean lighting intensity for all industries is 10,900 Btu per square foot; lighting intensity ranges from 2,800 Btu per square foot in Lumber (SIC 24) to 32,300 Btu per square foot in Refining (SIC 29). Because the Refining and Chemicals industries tend to light large outdoor areas, and because the MECS data do not distinguish between indoor and outdoor lighting, the relatively large lighting intensities for these industries may be explained, in part, by their use of outdoor lighting.

In terms of HVAC intensities, the manufacturing mean is 60,900 Btu per square foot per year. Again, the variation across industries is large: from a minimum of 8,300 Btu in the Lumber industry (SIC 24) to a maximum of 148,300 Btu in the Refining industry (SIC 29).

The HVAC and lighting intensities in the Refining industry (SIC 29) appear to be exceptionally high. As noted, a plausible explanation for the high lighting intensity is the use of outdoor lighting in the industry. One possible explanation for both the high HVAC and lighting intensities is that building square footage for the Refining industry may be understated. We have no independent source of information on floorspace in the Refining industry against which to check the estimate reported here. The relative standard error associated with the floorspace estimate for Refining (reported in Table B.3) is in excess of 1, suggesting that the estimate is somewhat imprecise. The lighting and HVAC intensity estimates for the Refining industry should be treated with extreme caution. Finally, we note that the 1994 MECS will ask respondents to estimate building floorspace rather than asking them to check off a box for a range of floorspace estimates. The data from the 1994 MECS will provide estimates of floorspace against which to check the estimates reported here.

The variation in lighting and HVAC intensities, as well as floorspace per worker, suggest that the manufacturing industries are very heterogeneous in their use of building floorspace.

Table 5.1 Lighting, Heating, Ventilation, and Cooling Intensities, Square Footage Intensities, 1991

SIC	Energy Consumed per Square Foot (Thousand Delivered Btu)		Energy Consumed per Worker (Million Delivered Btu)		Floorspace	
	Lighting	HVAC	Lighting	HVAC	Per Worker (Square Feet)	Per Plant (Thousand Square Feet)
20 Food	8.9	94.4	8.5	90.2	956	67.8
21 Tobacco	(a)	125.0	(a)	176.0	1407	493.9
22 Textiles	14.7	71.4	15.4	74.4	1041	105.8
23 Apparel	6.8	32.1	3.7	17.5	545	22.7
24 Lumber	2.8	8.3	5.3	15.6	1881	33.1
25 Furniture	3.7	27.5	4.6	33.6	1222	49.0
26 Paper	10.3	71.6	14.9	103.6	1448	139.8
27 Printing	10.0	45.3	5.5	25.2	556	12.6
28 Chemicals	17.2	103.4	18.2	109.8	1062	74.6
29 Refining	32.3	148.3	35.7	164.0	1105	58.8
30 Rubber	10.9	40.0	11.2	41.2	1030	54.7
31 Leather	(a)	122.6	(a)	60.8	496	25.8
32 Stone, Clay	6.0	27.7	10.8	50.3	1815	53.1
33 Prim Metals	13.5	50.8	24.0	90.1	1775	182.9
34 Fab Metals	8.7	55.0	8.7	54.9	998	37.3
35 Ind Machinery	11.0	45.8	9.2	38.3	837	27.5
36 Electron Equip	15.3	62.7	9.6	39.3	627	52.7
37 Transport	18.0	115.1	11.7	75.1	652	94.6
38 Instruments	21.3	125.6	9.3	55.0	438	34.8
39 Misc Mfg	9.0	38.0	6.0	25.3	666	14.2
All Mfg	11.0	60.9	10.1	56.3	925	40.7

(a) Lighting intensities not calculated for Tobacco and Food Industries. Data on lighting for these industries not published in 1991 MECS since estimated energy consumed less than 0.5 trillion Btu.

Sources:

Lighting, HVAC, Square Footage - PNNL estimates based on 1991 MECS.

Total Number Workers - BOC (1992). Number Plants - Data for 1992 from BOC (1994).

6.0 ENERGY SAVINGS POTENTIAL FROM USE OF ENERGY EFFICIENT BUILDINGS TECHNOLOGIES IN THE MANUFACTURING SECTOR

Based on the floor space and energy consumption estimates reported above, primary energy savings from the use of BTS-supported technologies in offices within the U.S. manufacturing sector were estimated using the Quality Metrics (QM) methodology developed by BTS (see Hostick, et al. 1995).^(a) Energy savings through the year 2020 were estimated by first forecasting baseline buildings-related energy consumption through 2020. Energy consumption was then estimated assuming BTS technologies penetrate office space in the manufacturing sector as they penetrate commercial office floor space. Because there is not any direct evidence on the comparability of commercial office floor space and manufacturing office floor space, commercial office space was assumed to be similar to manufacturing office space. While crude, this assumption is probably not unreasonable: many of the management-type activities that take place at a manufacturing facility are probably similar to activities in commercial office floor space. The difference between the baseline and BTS-technology cases represents energy savings resulting from the adoption of BTS technologies.^(b)

Table 6.1 reports primary energy savings by BTS program.^(c) On a primary basis, BTS programs reduce primary energy consumed for heating, lighting, and cooling in manufacturing office space by 30% in the year 2020; total savings amount to 87 trillion Btu. As can be seen in table 6.1, the Energy Savers Partnership program, a program designed to increase the penetration of advanced, energy-efficient equipment for lighting and appliances, accounts for nearly half of all energy savings accruing from BTS programs in the year 2020.

It should be noted that in one sense, these numbers are conservative. There can be little doubt that many of the BTS programs apply to non-office as well as office space in the manufacturing sector. As we have accounted for the impact of BTS programs only on office space, our energy savings totals probably understate total savings from BTS programs. We do not, however, have enough information about the characteristics of non-office space in the manufacturing sector to be able to ascertain the impact of BTS programs on non-office space very accurately. With further research related to the characteristics of non-office space in manufacturing, it may be possible to develop estimates of the impact of BTS programs on the manufacturing sector as a whole.

Figure 6.1 depicts both the baseline forecast and the forecast assuming BTS office technologies gradually penetrate the manufacturing sector. Based on assumptions for the 1995 QM analysis, a potential savings of 87 TBtu (31% of the projected baseline) in 2020 was estimated for building-related end uses in manufacturing.

(a) Hostick, D.J., S.A. Shankle, S.K. Douglas, J.A. Johnson, C.J. Hostick, H.E. Seely, and D.B. Belzer. 1995. "Draft: Documentation of the FY 1997 Quality Metrics Estimates for the Office of Building Technologies, Volumes 1 and 2 and Appendixes." Pacific Northwest National Laboratory, Richland, WA.

(b) See Appendix B for details on the baseline forecast.

(c) See Appendix C for details on each of the BTS programs.

Table 6.1 Annual Primary Energy Savings in Manufacturing Office Space by BTS Program

Program	1998	2000	2010	2020
Commercial Buildings				
Commercial/Multifamily R&D	0	0	0.9	3.1
Best Practices				
Design for Best Practice: Energy Tools	0	0	3.6	7.9
Passive Solar	0	0	1.3	4.2
Indoor Air Quality	0	0	0	1.3
Technology Transfer Information and Outreach	0	0	0	0.5
Space Conditioning R&D				
Large Commercial Chiller	0	0	0	0.2
Fuel Cell Building Microgeneration	0	0	1.4	2.8
Advanced Refrigeration/Component Technology	0	0	0.5	4.7
Lighting & Appliance R&D				
Advanced Light Sources & Electronics:	0	0	0.2	0.8
Low Power S-lamps				
Lighting Collaborative	0	0	2.4	6.2
Energy Savers Partnership	0	0.8	15.4	40.4
Materials & Structures R&D				
Roofs, Walls and Foundations	0	0.1	4.2	8.1
Urban Heat Islands/Highly Reflective Surfaces	0	0	0	0.1
Windows and Glazings				
Electrochromic Research	0	0	0.3	1.4
Superwindows Technologies/Collaborative	0	0	0.2	0.6
Advanced Glazing	0	0	0.2	0.9
Lighting & Appliance Standards				
Commercial Appliances: Test Procedures	0.1	0.4	2.4	4.0
Total	0.2	1.4	33.4	87.2

Source:
PNNL estimates.

**Figure 6.1 QM Energy Savings Estimates -
Lighting, Heating, and Cooling for Manufacturing Office Space**

7.0 FINDINGS AND RECOMMENDATIONS

This research was designed to develop improved estimates of buildings-related energy use in the manufacturing sector. The study was based on unique energy consumption data from the 1991 MECS at both industry aggregate and plant levels.

This research produced four major findings, including new estimates of buildings-related energy use and energy intensity that are comparable to previous estimates. The individual findings are presented below.

1. **Buildings-Related Energy Consumption in Manufacturing** -- On the basis of MECS data, the 1991 energy use estimates are compared to a key national-level energy consumption estimate produced in the 1980s (Hagler, Bailly & Co 1987):

These results show differences in both the magnitude and pattern of energy consumption between 1983 and 1991. The changes may be due to a variety of factors, including differences in the data samples, in estimation methods and in definitions of energy consumed for HVAC and lighting. Nonetheless, a comparison of these estimates suggests several topics that may be of interest for buildings-related energy analysis.

Table 7.1 Buildings-Related Energy Consumption in Manufacturing

Buildings-Related End Use	1983 HBC Estimates (Delivered Quads)	1983 HBC Estimates (Primary Quads)	1991 MECS Estimates (Delivered Quads)	1991 MECS Estimates (Primary Quads) ^(a)
Space Heating	1.05 (84%)	1.05 (78%)	0.77 (69%)	--
Ventilation & Air Conditioning	0.10 (8%)	0.30 (18%)	0.18 (16%)	--
Air Conditioning	--	--	0.09 (8%)	--
Ventilation	--	--	0.09 (8%)	--
Total HVAC ^(b)	1.15 (92%)	1.35 (82%)	0.95 (85%)	1.44 (73%)
Lighting	0.10 (8%)	0.30 (18%)	0.17 (15%)	0.52 (27%)
Total Buildings-related End Use	1.25 (100%)	1.65 (100%)	1.12 (100%)	1.96 (100%)

(a) The 1991 MECS data did not report estimates of electricity consumed for space heating, air conditioning, or ventilation. The 1991 MECS data did, however, report electricity consumed for HVAC and lighting. Estimated electricity consumption was used to estimate primary energy consumed for HVAC and lighting. Delivered electricity was converted to primary electricity using a factor of 3.077.

(b) Heating, Ventilation and Air Conditioning (HVAC)

As previously discussed, the 1983 HBC estimate of 1.25 delivered (1.65 primary) quads was 15% of total industrial energy use in that year. The 1991 MECS estimate of 1.12 delivered (1.96 primary) quads is 7% of industrial energy consumed for heat, power and electricity generation in 1991. Despite an increase in total energy consumption from 1983 to 1991, buildings-related energy use was apparently lower in 1991 than in 1983 based on the above numbers. End-use shares shifted as well, with lighting and A/C ventilation both showing a larger share of the total and space heating showing a smaller share. However, in broad terms, the distribution patterns are similar.

This research did not seek to explain changes in energy-use patterns between 1983 and 1991. However, in addition to differences in the data sources and analysis methods, the apparent changes in space heating, cooling, ventilation and lighting shares might be due to any of several factors. For example, compositional shifts among industries, growth in non-production worker share of employment, changes in energy prices, or the general relocation of manufacturing from Rust Belt to Sun Belt might explain these shifts.

Table 7.2 presents this study's estimated buildings-related energy consumption for the manufacturing sector relative to the residential and commercial sector.

Table 7.2 Buildings Energy Use Characteristics for Manufacturing, Residential, and Commercial Sectors

	Manufacturing	Residential	Commercial	Total Residential & Commercial
Energy for Lighting (delivered quads)	0.17	0.31	1.15	1.46
Energy for Space Heating (delivered quads)	0.77 ^(a)	5.61	1.84	7.45
Energy for Space Cooling (delivered quads)	0.09	0.48	0.55	1.03
Energy for Ventilation (delivered quads)	0.09	(b)	(b)	(b)
Total Energy for HVAC (delivered quads)	0.95 ^(a)	(b)	(b)	(b)
Floor space (billion ft ²)	15.5	181.2	70.0	248.2
Lighting Intensity (thousand Btu/ft ²)	11.0	1.7	16.4	--
Heating Intensity (thousand Btu/ft ²)	49.8	31.0	26.3	--
Cooling Intensity (thousand Btu/ft ²)	5.5	2.6	7.9	--

(a) Total includes energy consumed to raise steam used in space heating.

(b) Data are not available.

All energy totals are site totals rather than primary energy equivalent totals.

Sources:

Manufacturing - PNNL estimates based on 1991 MECS. Data for 1991.

Residential, Commercial - OBT Core Databook, 8/7/96. Data for 1994.

The data shown include total energy consumption as well as estimates of floorspace, lighting intensity, heating intensity, and cooling intensity for all of manufacturing in 1991. Manufacturing consumed a total of 170 trillion Btu of energy for lighting in 1991 compared with 310 trillion Btu in the residential sector and 1150 trillion Btu in the commercial sector (manufacturing consumption is 12% of the residential and commercial total). The manufacturing industries consumed a total of 774 trillion Btu for heating (10% of the residential and commercial total), and 85 trillion Btu for cooling (11% of the residential and commercial total). The differences between buildings and industrial totals are probably due in large part to the fact that manufacturing building floorspace is only 6% of total commercial and residential floorspace and the fact that manufacturing floorspace is usually occupied for more hours per day than floorspace in the buildings sectors. Manufacturing plants with multiple shifts may operate 16 or 24 hours per day.

2. Characteristics of Manufacturing Buildings -- This research also produced new estimates of manufacturing buildings floorspace. As reported in Table 4.3, total floorspace in U.S. manufacturing in 1991 is estimated to be 15.5 billion square feet: 2.6 billion square feet in office space and 12.9 billion square feet in non-office space.

In addition, Table 5.1 shows new estimates for building energy intensities for all manufacturing; lighting intensity is estimated to be 11,000 Btu per square foot and HVAC intensity is estimated to be 60,900 Btu per square foot. There is significant variation across industries in total square footage as well as in lighting and HVAC intensity.

3. Energy-Savings Potential -- This research has also produced estimates of the potential for reducing buildings-related energy use in manufacturing. Using the assumptions in the 1995 DOE/EE Quality Metrics process for commercial buildings, the energy savings potential for office-space in manufacturing is 43 TBtu or 22% of projected baseline energy use in 2020 (see Section 6.0).

4. Buildings Technology Markets -- Finally, this research suggests that attractive niche markets for some BTS technologies may exist in the manufacturing sector, but more work is needed to assess this potential. Example BTS technologies with potential industrial applications include high power S-lamps, thermally activated heat pumps (large commercial chiller), advanced desiccant technology and advanced refrigeration systems. Indoor air quality research may also have industrial sector payoffs.

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Appendix A

Description of Major SIC Groups

APPENDIX A: A Description of Major SIC Groups

This appendix provides background information on the Standard Industrial Classification (SIC) of establishments used by the U.S. federal government for industrial statistics. The SIC divides the manufacturing sector into 20 major groups, numbered 20 through 39. The SIC was developed for use in the classification of establishments by type of activity in which they are engaged for purposes of facilitating the collection, tabulation, presentation, and analysis of data relating to establishments.

A general summary of the products and characteristics of each major SIC industry is given in this appendix to assist readers in understanding the pattern of energy consumption presented in this report. The descriptions are obtained from OMB (1987).

SIC 20-Food and Kindred Products: This major group includes establishments manufacturing foods and beverages for human consumption and certain related products such as manufactured ice, chewing gum, vegetable and animal fats and oils, and prepared feeds for animals and fowls.

SIC 21-Tobacco Products: This major group includes establishments engaged in manufacturing cigarettes, cigars, smoking and chewing tobacco, snuff, and reconstituted tobacco; and in stemming and redrying tobacco.

SIC 22-Textile Mill Products: This major group includes establishments engaged in performing any of the following operations: 1) preparation of fiber and subsequent manufacturing of yarn, thread, braids, twine, and cordage; 2) manufacturing broadwoven fabrics, narrow woven fabrics, knit fabrics, and carpets and rugs from yarn; 3) dyeing and finishing fiber, yarn, fabrics, and knit apparel; 4) coating, water-proofing, or otherwise treating fabrics; 5) the integrated manufacture of knit apparel and other finished articles from yarn; and 6) the manufacture of felt goods, lace goods, nonwoven fabrics, and miscellaneous textiles.

SIC 23-Apparel and Other Textile Products: This major group, known as the cutting-up and needle trades, includes establishments producing clothing and fabricating products by cutting and sewing purchased woven or knit textile fabrics and related materials, such as leather, rubberized fabrics, plastics, and furs.

SIC 24-Lumber and Wood Products: This major group includes establishments engaged in cutting timber and pulpwood; merchant sawmills, lath mills, shingle mills, cooperage stock mills, planing mills, and plywood and veneer mills engaged in producing lumber and wood basic materials; and establishments engaged in manufacturing finished articles made entirely or mainly of wood or related materials.

SIC 25-Furniture and Fixtures: This major group includes establishments engaged in manufacturing household, office, public building, and restaurant furniture; and office and store fixtures.

SIC 26-Paper and Allied Products: This major group includes establishments primarily engaged in the manufacture of pulps from wood and other cellulose fibers, and from rags; the manufacture of paper and paper board; and the manufacture of paper and paperboard into converted products, such as paper coated off the paper machine, paper bags, paper boxes, and envelopes.

SIC 27-Printing and Publishing: This major group includes establishments engaged in printing by one or more common processes, such as letterpress, lithography (including offset), gravure, or screen; and those establishments which perform services for the printing trade, such as bookbinding and platemaking.

SIC 28-Chemicals and Allied Products: This major group includes establishments producing basic chemicals, and establishments manufacturing products by predominantly chemical processes. Establishments classified in this major group manufacture three general classes of products: 1) basic chemicals, such as acids, alkalies, salts, and organic chemicals; 2) chemical products to be used in further manufacture, such as synthetic fibers, plastics materials, dry colors, and pigments; and 3) finished chemical products to be used for ultimate consumption, such as drugs, cosmetics, and soaps; or to be used as materials or supplies in other industries, such as paints, fertilizers, and explosives.

SIC 29-Petroleum Refining and Related Industries: This major group includes establishments primarily engaged in petroleum refining, manufacturing paving and roofing materials, and compounding lubricating oils and greases from purchased materials.

SIC 30-Rubber and Miscellaneous Plastics Products: This major group includes establishments manufacturing products, not elsewhere classified, from plastics, resins, and from natural, synthetic, or reclaimed rubber, gutta percha, balata, or gutta siak.

SIC 31-Leather and Leather Products: This major group includes establishments engaged in tanning, currying, and finishing hides and skins, leather converters, and establishments manufacturing finished leather and artificial leather products and some similar products made of other materials.

SIC 32-Stone, Clay, Glass, and Concrete Products: This major group includes establishments manufacturing flat glass and other glass products, cement, structural clay products, pottery, concrete and gypsum products, cut stone, abrasive and asbestos products, and other products from materials taken principally from the earth in the form of stone, clay, and sand.

SIC 33-Primary Metal Industries: This major group includes establishments engaged in smelting and refining ferrous and nonferrous metals from ore, pig, or scrap; in rolling, drawing, and alloying metals; in manufacturing castings and other basic metal products; and in manufacturing nails, spikes, and insulated wire and cable.

SIC 34-Fabricated Metal Products: This major group includes establishments engaged in fabricating ferrous and nonferrous metal products such as metal cans, tinware, handtools, cutlery, general

hardware, nonelectric heating apparatus, fabricated structural metal products, metal forgings, metal stampings, ordnance (except vehicles and guided missiles), and a variety of metal and wire products, not elsewhere classified.

SIC 35-Industrial Machinery and Equipment: This major group includes establishments engaged in manufacturing industrial and commercial machinery, and equipment and computers.

SIC 36-Electronic and Other Electric Equipment: This major group includes establishments engaged in manufacturing machinery, apparatus, and supplies for the generation, storage, transmission, transformation, and utilization of electrical energy.

SIC 37-Transportation Equipment: This major group includes establishments engaged in manufacturing equipment for transportation of passengers and cargo by land, air, and water.

SIC 38-Instruments and Related Products: This major group includes establishments engaged in manufacturing instruments (including professional and scientific) for measuring, testing, analyzing, and controlling, and their associated sensors and accessories; optical instruments and lenses; surveying and drafting instruments; hydrological, hydrographic, meteorological, and geophysical equipment; search, detection, navigation, and guidance systems and equipment; surgical, medical, and dental instruments, equipment and supplies; ophthalmic goods; photographic equipment and supplies; and watches and clocks.

SIC 39-Miscellaneous Manufacturing Industries: This major group includes establishments primarily engaged in manufacturing products not classified in any other major group.

Appendix B

Data Sources and Analysis Methods

APPENDIX B: Data Sources and Analysis Methods

This appendix documents the construction of baseline estimates of building floor space, and energy consumed for lighting, heating, and cooling for the year 1991. A baseline forecast of energy consumed for lighting, heating, and cooling in manufacturing office floorspace through the year 2020 was made using employment growth rates.

B.1 BUILDING STOCK

Total Square Footage by Industry, 1991

Data collected for the 1991 Manufacturing Energy Consumption Survey (MECS) were used to construct square footage estimates by two-digit Standard Industrial Classification (SIC) major groups. The MECS is a triennial survey that collects data related to energy consumption from a sample of U.S. manufacturing plants.

The 1991 MECS asked each respondent to the survey (the person filling out the MECS questionnaire for a manufacturing plant) to check off a box indicating the approximate total enclosed square footage of buildings located at the plant site. Each box represented a range of estimated square footage. Using the plant-level responses to the MECS, an estimate of a plant's square footage in 1991 was made by taking the midpoint of the range of the box checked off by the respondent. Table B.1 gives the square footage categories from the MECS and the midpoints used to estimate a plant's square footage. Since the uppermost range does not contain an upper bound, an arbitrary estimate of plant square footage was used in place of a midpoint.

Table B.1 Square Footage Categories and Continuous Values Used to Estimate Floorspace (Square Feet)

MECS Category	Minimum	Mid-Low	Midpoint	Mid-High	Maximum
25,000 or less	5,000	10,000	12,500	20,000	25,000
25,001 to 100,000	25,000	43,750	62,500	81,250	100,000
100,001 to 200,000	100,000	125,000	150,000	175,000	200,000
200,001 to 500,000	200,000	275,000	350,000	425,000	500,000
500,001 to 750,000	500,000	562,500	625,000	687,500	750,000
750,001 to 1 million	750,000	812,500	875,000	937,500	1,000,000
1,000,001 to 5 million	1,000,000	2,000,000	3,000,000	4,000,000	5,000,000
5,000,001 to 10 million	5,000,000	6,250,000	7,500,000	8,750,000	10,000,000
10,000,001 to 25 million	10,000,000	13,750,000	17,500,000	21,250,000	25,000,000
Over 25 million	25,000,000	32,500,000	40,000,000	47,500,000	55,000,000

The MECS is based on a sample of manufacturing plants; each sampled plant is assigned a weight that is used to construct industry aggregate statistics. Sample weights are proportional to an energy measure of size such that smaller plants receive a larger sample weight than larger plants.^(a)

Square footage estimates by two-digit SIC were constructed by taking the MECS-weighted sum of plant square footage estimates:

$$SF_{i,1991} = \sum_{j=1}^{n_i} MECSWT_{ij,1991} \cdot SF_{ij,1991} \quad (B.1)$$

where $SF_{i,1991}$ is estimated 1991 total square footage of buildings in industry I, n_i is the number of plants in industry I sampled for the 1991 MECS, $MECSWT_{ij,1991}$ is the 1991 MECS sample weight for plant j in industry I, and $SF_{ij,1991}$ is estimated 1991 square footage of plant j in industry I.

Respondents to the survey were given the option of checking off a box if they didn't know the approximate square footage of buildings at their plant. Approximately 3% of those responding to the survey indicated they did not know the square footage of buildings at their plant. In addition, approximately 3% of those responding to the survey did not respond to the square footage question. Since neither of these categories of responses could be used to estimate building square footage, values were imputed. Table B.2 gives the total number of plants in the MECS sample, the number of plants providing usable responses, and the number of plants for which responses had to be imputed.

The imputation method for plants with unusable records was straightforward: first, the two-digit SIC to which a plant belonged was identified; second, the mode of usable responses to the square footage question for each two-digit SIC was identified; third, the mode of the appropriate two-digit SIC was used to impute a response for plants originally supplying an unusable response.^(b)

In order to get some idea of how precise the estimates of floorspace by industry are, standard errors were calculated.^(c) In addition, square footage estimates based on five possible values for each range were calculated. The five values included the midpoint of the ranges, the minimum and the maximum of each range from the MECS questionnaire, as well as a mid-low and a mid-high value of the ranges. Table B.1 gives the actual values used to compute the range of estimates. Table B.3 gives floorspace estimates based on each of these values.

Table B.3 also shows that the relative standard errors for several of the industries are in excess of 50%, the level at which the Energy Information Administration (EIA) generally suppresses data in its publications because of concern about the quality of the estimate. Particular caution should be exercised in

(a) See EIA (1994b) for a description of the MECS sample and the construction of sample weights.

(b) This is a relatively ad hoc method of imputing values for unusable responses. See Sande (1982) for a brief discussion of alternative imputation methods.

(c) The formula for the standard error, and a discussion of its use, is given in EIA (1994b).

**Table B.2 Counts of Usable and Unusable Responses to 1991 MECS Building
Square Footage Question**

SIC	Total Number of Observations	Number of Usable Observations	Number Imputed Because Missing	Number Imputed Because Didn't Know
20 Food	1803	1670	61	72
21 Tobacco	46	46	0.00	0.00
22 Textiles	810	786	20	4
23 Apparel	367	337	24	6
24 Lumber	397	342	23	32
25 Furniture	313	305	8	0.00
26 Paper	794	733	20	41
27 Printing	447	421	21	5
28 Chemicals	1655	1455	80	120
29 Refining	337	294	12	31
30 Rubber	780	753	23	4
31 Leather	232	218	12	2
32 Stone, Clay	1011	939	35	37
33 Prim Metals	867	817	24	26
34 Fab Metals	914	880	24	10
35 Ind Machinery	882	848	28	6
36 Electron Equip	666	654	11	1
37 Transport	652	636	12	4
38 Instruments	446	433	12	1
39 Misc Mfg	308	299	7	2
Total Sample	13727	12866	457	404

Source:

PNNL calculations based on unpublished data from 1991 MECS.

using those estimates with standard errors in excess of 50%. For the manufacturing sector as a whole, there is a large difference between the low-mid (11.9 billion square feet) and high-mid (19.5 billion square feet) floorspace estimates. The relative standard error for manufacturing as a whole, however, is 28%.

Office Square Footage by Industry, 1991

Using the midpoint estimate of floorspace, total square footage by industry in 1991 was broken out into office and non-office categories. It was assumed that each manufacturing nonproduction worker occupied 500 square feet, the median reported by EIA (1994) for square footage per worker in office buildings. The number of nonproduction workers in each industry from the Annual Survey of Manufactures (BOC 1992) was multiplied by 500 square feet to arrive at an estimate of office square footage by industry:

Table B.3 Relative Standard Errors & Range of Floorspace Estimates

SIC	Relative Standard Error Associated With Mid Estimate (%)	Range of Square Footage Estimates (Millions Square Feet)				
		Minimum	Low-Mid	Mid	High-Mid	Maximum
20 Food	43	743	1079	1409	1751	2087
21 Tobacco	7	27	41	56	71	86
22 Textiles	43	361	492	623	755	886
23 Apparel	134	251	393	523	676	818
24 Lumber	301	648	924	1187	1478	1755
25 Furniture	73	306	439	569	706	839
26 Paper	30	471	686	899	1115	1330
27 Printing	151	395	629	827	1098	1332
28 Chemicals	60	466	684	898	1118	1336
29 Refining	105	66	97	125	157	188
30 Rubber	42	441	657	865	1089	1305
31 Leather	27	26	40	53	67	81
32 Stone, Clay	53	471	674	864	1079	1282
33 Prim Metals	23	641	916	1202	1467	1742
34 Fab Metals	42	695	1036	1357	1717	2058
35 Ind Machinery	80	742	1134	1485	1919	2311
36 Electron Equip	91	465	682	894	1117	1334
37 Transport Equip	22	533	801	1065	1338	1606
38 Instruments	28	203	300	395	494	591
39 Misc Mfg	61	119	184	242	312	376
All Mfg	28	8069	11888	15539	19524	23343

Source:

PNNL calculations based on unpublished data from 1991 MECS.

$$SF_{i,1991}^O = NPW_{i,1991} \cdot 500 \quad (B.2)$$

where $SF_{i,1991}^O$ is estimated 1991 square footage of office space for industry I, $NPW_{i,1991}$ is total number of nonproduction workers in industry I in 1991, and 500 is estimated square footage of office space per non-production worker in the manufacturing sector.

This method may result in an overestimate of office floor space in the manufacturing sector because of differences in the definition of number of nonproduction workers by BOC (1992) and the definition of number of workers by EIA (1994a) used in construction of floor space per worker. For purposes of constructing estimated floor space by worker by EIA, the number of workers in a building is defined as the number of workers in a building during the main shift on a typical workday during the year. The number of nonproduction workers defined by BOC includes all nonproduction employees on all shifts. The number of main shift nonproduction workers would be a more desirable number to use in estimating office space.

While it seems likely that the number of nonproduction workers working second or third shifts in manufacturing is small compared to the number of production workers working second or third shifts, the failure to account for second and third shift nonproduction workers biases estimated office floor space upward. For industries that routinely operate two or three shifts (such as the steel, paper, aluminum, glass, cement and other continuous process industries), the bias seems likely to be larger. Second and third shifts often require that medical and other nonproduction personnel be present. It seems likely that these personnel utilize office space that is occupied during the main shift.

Another potential source of bias arises as a result of the BOC definition of nonproduction workers. Nonproduction workers includes sales delivery workers such as highway truck drivers and their helpers, and cafeteria workers. Square footage per worker for these nonproduction workers is likely to differ from that for office workers. Unfortunately, BOC does not provide any additional detail on the composition of nonproduction workers by industry.^(a)

Non-Office Square Footage by Industry, 1991

Non-office square footage by industry in 1991 was estimated by taking the difference between estimated total square footage and estimated office square footage:

$$SF_{i,1991}^{NO} = SF_{i,1991} - SF_{i,1991}^O \quad (B.3)$$

where $SF_{i,j,1991}$ is estimated 1991 square footage of plant j in industry I , $SF_{i,1991}^O$ is estimated 1991 square footage of office space for industry I , and $SF_{i,1991}^{NO}$ is estimated 1991 square footage of non-office space for industry I .

Forecast Square Footage, 1992-2020

An industry-by-industry forecast of office floorspace for 1992-2015 was made by applying industry-specific total employment growth rates from EIA's base case forecast for the 1996 Annual Energy

(a) One possible source of detail on the types of nonproduction workers by industry is the occupational employment data for manufacturing industries collected by the U.S. Bureau of Labor Statistics. See BLS (1994).

Outlook (AEO) to the benchmark 1991 estimates of floor space.^(a) A forecast of office floorspace for 2016-2020 was made by applying the average annual growth rates of employment during 2005-2015 from the EIA forecast to estimated 2015 office floorspace. Table B.4 details employment growth rates from the 1996 AEO for selected subperiods.

B.2 ELECTRICITY FOR LIGHTING

Total Electric for Lighting by Industry, 1991

Electricity consumed for lighting in 1991 by two-digit SIC industry was taken from the 1991 MECS (EIA 1994b).^(b) These data do not distinguish between indoor and outdoor lighting; instead, the total includes both indoor and outdoor lighting.

Electric for Office Lighting by Industry, 1991

Total electric for lighting in 1991 was broken out into office and non-office categories for each industry. Electric for office lighting in 1991 was estimated by multiplying estimated office floor space by an estimated lighting intensity for office space. Lighting intensity for office space was assumed to be 23.1 thousand BTU per square foot office space; this is the end-use intensity for lighting in office buildings reported by EIA (1994b). Thus electricity consumed for office lighting was computed as:

$$L_{i,1991}^O = SF_{i,1991}^O \cdot 23.1 \quad (B.4)$$

where $L_{i,1991}^O$ is electric used for lighting in industry i in 1991 in thousands Btu, $SF_{i,1991}^O$ is office space square footage in industry i in 1991, and 23.1 is estimated office lighting intensity. While lighting intensity was assumed constant over industries, total electric for lighting varies as total office space varies by industry.

As noted above, estimated office floor space is likely to be biased upward. Because office floor space is used to estimate office lighting, estimates of office lighting will be biased upward as well.

(a) The employment forecast for the 1996 AEO was supplied by T. Crawford Honeycutt, Energy Demand and Integration Division, Office of Integrated Analysis and Forecasting, Energy Information Administration.

(b) Because respondents often failed to estimate the amount of electricity used for non-process lighting, it was necessary to impute the amount of electricity consumed for lighting for non-responding plants. Electricity consumed for lighting by nonresponding plants was accounted for by scaling up reported electricity for lighting by the share of total electricity consumed by nonresponding plants.

Table B.4 Average Annual Growth Rates of Employment for Selected Time Periods

SIC	1991-95	1995-97	1998-2000	2001-05	2006-10	2011-15	2016-20	1991-2020
20 Food	0.023	-0.013	-0.012	-0.036	-0.054	-0.056	-0.060	-0.006
21 Tobacco	-0.163	-0.073	-0.079	-0.143	-0.133	-0.115	-0.117	-0.021
22 Textiles	0.004	-0.042	-0.044	-0.067	-0.069	-0.068	-0.073	-0.012
23 Apparel	-0.011	-0.044	-0.038	-0.062	-0.068	-0.076	-0.076	-0.012
24 Lumber	0.060	-0.003	-0.012	-0.015	-0.038	-0.019	-0.029	-0.004
25 Furniture	0.086	0.000	0.037	0.058	0.028	0.017	0.025	0.007
26 Paper	0.017	0.001	0.020	0.039	0.000	-0.008	-0.004	0.002
27 Printing	0.028	0.032	0.050	0.078	0.040	0.023	0.036	0.010
28 Chemicals	0.010	0.006	0.010	0.020	0.000	-0.006	-0.003	0.001
29 Refining	-0.075	0.000	-0.020	-0.028	-0.043	-0.038	-0.046	-0.007
30 Rubber	0.128	0.000	0.034	0.060	0.008	0.000	0.005	0.008
31 Leather	-0.040	-0.101	-0.084	-0.133	-0.129	-0.139	-0.135	-0.021
32 Stone, Clay	0.027	-0.009	-0.008	-0.011	-0.029	-0.020	-0.026	-0.005
33 Prim Metals	-0.028	-0.046	-0.001	0.007	0.003	-0.004	0.000	-0.004
34 Fab Metals	0.052	-0.017	-0.010	-0.005	-0.028	-0.025	-0.029	-0.003
35 Ind Machinery	0.023	-0.032	0.036	0.057	0.035	0.009	0.026	0.004
36 Electron Equip	-0.016	-0.051	-0.017	0.005	-0.069	-0.082	-0.079	-0.010
37 Transport Equip	-0.076	0.015	0.038	0.032	-0.004	-0.012	-0.008	-0.003
38 Instruments	-0.084	-0.016	-0.021	-0.004	-0.037	-0.046	-0.044	-0.009
39 Misc Mfg	0.077	-0.020	-0.021	-0.003	-0.048	-0.042	-0.048	-0.004
All Mfg	0.008	-0.014	0.007	0.014	-0.014	-0.021	-0.019	-0.002

Source:

Detail for Annual Energy Outlook 1996 (EIA 1996a), supplied by T. Crawford Honeycutt, EIA.

Electric for Non-Office Lighting by Industry, 1991

Electric non-office lighting by industry in 1991 was estimated by taking the difference between total electric for lighting and estimated electric for office lighting:

$$L_{i,1991}^{NO} = L_{i,1991} - L_{i,1991}^O \quad (B.5)$$

where $L_{i,1991}^{NO}$ is estimated 1991 electricity consumed for lighting non-office space in industry I, $L_{i,1991}$ is estimated 1991 electricity consumed for lighting in industry I, and $L_{i,1991}^O$ is estimated 1991 electricity consumed for lighting office space in industry I.

Forecast Electric for Office Lighting, 1992-2020

An industry-by-industry forecast of electricity consumed for lighting in office space for 1992-2015 used industry-specific total employment growth rates from EIA's base case forecast for the 1996 Annual

Energy Outlook (AEO). It was assumed that lighting intensity (Btu per square foot) in office space would decline by 25% between 1995 and 2020. Lighting intensity was assumed to remain constant between 1991 and 1995. The product of forecast office floorspace and projected lighting intensity yielded forecast lighting for office floorspace.

B.3 ENERGY FOR NON-PROCESS HEATING, VENTILATION AND AIR CONDITIONING

Total Energy for Non-Process HVAC by Industry, 1991

Energy consumed for non-process HVAC in 1991 by two-digit SIC industry was taken from the 1991 MECS and adjusted to account for energy consumed as boiler fuel for non-process HVAC.^(a) The non-process HVAC totals from the MECS exclude steam or hot water generated onsite that is used for non-process heating. The Energy Information Administration has estimated the share of steam consumption that is used for non-process heating in the manufacturing sector by two-digit SIC industry (EIA 1994c). The shares are reported in Table B.5. These shares were applied to total energy consumed in boilers in order to estimate the total amount of boiler fuel used to raise steam for non-process heating.

Energy for Office HVAC by Industry, 1991

Total energy for HVAC in 1991 was broken out into office and non-office categories. HVAC intensity for office space was assumed to be 49.5 thousand BTU per square foot office space; this is the sum of end-use intensities for space heating (30.7 thousand BTU), cooling (7.5 thousand BTU), and ventilation (11.3 thousand BTU) reported by EIA (1994a). Estimated square footage of office space was multiplied by this HVAC intensity to arrive at an estimate of total energy consumed for HVAC in offices:

$$H_{i,1991}^O = SF_{i,1991}^O \cdot 49.5 \quad (B.6)$$

where $H_{i,1991}^O$ is energy used for HVAC in offices in industry I in 1991 in thousands Btu, $SF_{i,1991}^O$ is office space square footage in industry I in 1991, and 49.5 is estimated office lighting intensity.

While HVAC intensity was assumed constant over industries, energy for office HVAC varies as total office space varies by industry.

(a) Because respondents often failed to estimate the amount of energy consumed for non-process HVAC, it was necessary to impute the amount of energy consumed by non-responding plants. In addition, the MECS reports energy consumed only for selected fuels; it was necessary to impute the amount of non-reported fuels consumed for non-process HVAC. These imputations were carried out with the aid of EIA estimates for missing data supplied by T. Crawford Honeycutt.

Table B.5 Percent of Steam Consumption Used for Non-Process HVAC

SIC	
20 Food	20
21 Tobacco	24
22 Textiles	22
23 Apparel	75
24 Lumber	11
25 Furniture	84
26 Paper	4
27 Printing	100
28 Chemicals	4
29 Refining	1
30 Rubber	14
31 Leather	100
32 Stone, Clay	0
33 Prim Metals	0
34 Fab Metals	64
35 Ind Machinery	43
36 Electron Equip	50
37 Transport Equip	82
38 Instruments	77
39 Misc Mfg	50

Source:
EIA (1994c).

Energy consumed for HVAC was broken out into its three components for office space: heating, cooling, and ventilation. Heating in office space was estimated using the heating intensity of 30.7 thousand BTU per square foot; cooling in office space was estimated using the heating intensity of 7.5 thousand Btu per square foot; ventilation in office space was estimated using the ventilation intensity of 11.3 thousand Btu per square foot.

Energy for Non-Office HVAC by Industry, 1991

Energy for non-office HVAC by industry in 1991 was estimated by taking the difference

$$H_{i,1991}^{NO} = H_{i,1991} - H_{i,1991}^O \quad (B.7)$$

between total energy for HVAC and estimated energy for office HVAC:

where $H_{i,1991}^{NO}$ is estimated 1991 energy consumed for non-office HVAC in industry I, $H_{i,1991}$ is estimated 1991 energy consumed for HVAC in industry I, and $H_{i,1991}^O$ is estimated 1991 energy consumed for office HVAC in industry I.

Energy used for heating, cooling, and ventilation in non-office space was estimated based on a crudely estimated intensity for each end use. DOE (1994a) reports estimated end-use intensities for heating, cooling, and ventilation for buildings primarily used for assembly and for buildings that are used

primarily as warehouses. These are the two types of buildings reported in DOE (1994a) that are most similar to manufacturing. The intensities reported in DOE (1994a) for assembly were: 32.9 thousand Btu per square foot for heating, 3.7 thousand Btu per square foot for cooling, and 3.7 thousand Btu per square foot for ventilation. The intensities reported for warehouses were 23.9 thousand Btu per square foot for heating, 0.6 thousand Btu per square foot for cooling, and 0.4 thousand Btu per square foot for ventilation.

A weighted average of intensities for the assembly and warehouse types was constructed for heating, cooling, and ventilation, using a weight of 0.67 for assembly and 0.33 for warehouse.^(a) This yielded intensities of 29.9, 2.7, and 2.6 thousand Btu per square foot for heating, cooling, and ventilation respectively; a total HVAC intensity of 35.3 thousand Btu per square foot. The heating, cooling, and ventilation shares of this intensity (0.85, 0.08, and 0.07) were applied to the total HVAC intensity for each 2-digit SIC industry to estimate heating, cooling, and ventilation intensities. Given these intensities, energy consumed for heating, cooling, and ventilation was calculated using each industry's non-office square footage.

Forecast Energy for Office Heating and Cooling, 1992-2020

An industry-by-industry forecast of energy consumed for heating and cooling of office space for 1992-2015 was made by applying industry-specific total employment growth rates from EIA's base case forecast for the 1996 Annual Energy Outlook (AEO). A forecast of energy consumed for heating and cooling of office space for 2016-2020 was made by applying the average annual growth rate of employment during 2005-2015 from the EIA forecast (Table B.4).

(a) These weights were chosen somewhat arbitrarily. It does seem likely, however, that some share of total manufacturing floor space should look like assembly floor space and some should look like warehouse floor space. The heavier weight was given to assembly because the reported HVAC intensity in DOE (1994a) (40.3 thousand Btu per square foot) was closer to our estimated HVAC intensity for all non-office manufacturing floor space (40.7 thousand Btu per square foot); it also seems probable that space for assembly-like activity is larger than that for warehouse-like activity.

Appendix C

Description of BTS Programs

APPENDIX C: DESCRIPTION OF BTS PROGRAMS

This appendix contains a brief description of the BTS programs included in the Quality Metrics analysis discussed in Section 6.0

Commercial/Multifamily R & D

The overall objective of this program is to improve O&M practices and to develop advanced retrofit technologies, including commercial building controls and automation systems, to be deployed through the Rebuild America and Affordable Housing activities. Advanced retrofit technologies, including commercial heating & cooling mechanical systems, building system controls and performance monitoring systems, building commissioning, and building operation and maintenance.

Design for Best Practice: Energy Tools

The objective of this program is to develop easy-to-use design and analysis tools capable of modeling state-of-the-art solar technologies, including applicable efficiency measures, and algorithms that properly model advanced solar technologies. The program promotes a more sensitive approach to site planning and building design. Energy design tools that facilitate optimal energy performance in the design and operation of buildings.

Passive Solar

The objective of this program is to promote buildings that use passive solar strategies, combined with efficiency, to provide on average, 75% of the building's heating, cooling, and lighting needs, and 50% reduction for renovated buildings in heating, cooling, and lighting needs. The program promotes a more sensitive approach to site planning and building design: smaller HVAC systems and new approaches to meeting auxiliary needs, e.g., integrated systems. Passive solar design strategies, proper sizing of efficient equipment, photovoltaics or wind for electric loads and solar hot water systems, and their control.

Roofs, Walls & Foundations

The objective of this program is to address application of advanced materials and techniques to the development and characterization of building envelope components. Improve thermal performance of existing buildings using insulation, develop roof with R-30 and 30 year life.

Electrochromic Research

The objective of this program is to support development and commercialization of windows with dynamically controllable optical transmittance properties that allow for optimal control of daylighting and improved energy performance in both heating and cooling climates. Develop electrochromic windows.

Superwindows Technologies/Collaborative

The objective of this program is to develop advanced window assemblies (glazing and frame) having high thermal resistance and spectral selectivity tailored to specific climate regions and performance requirements. Support development of high-performance superwindow and spectrally selective window technologies.

Advanced Glazing

The objective of this program is to conduct performance and simulation research for design tools, develop advanced glazing technologies, and provide research and support for a window energy rating system. Develop advanced window glazing technology; double the average thermal performance of windows installed or being installed from R-2 to R-5 by 2000.

Indoor Air Quality

The objective of this program is to reduce the energy liabilities associated with the intentional and unintentional air flows in buildings while maintaining or improving indoor air quality, comfort, health, and worker productivity. Near term objectives focus on general building tightening. Longer term objectives focus on advanced ventilation strategies. Ventilation and infiltration systems.

Large Commercial Chiller

The objective of this program is to speed up the development and commercialization of a large commercial chiller using the Double Condenser Coupled (DCC) concept having a cooling COP of 1.4 or better. Develop a DCC cycle commercial chiller using LiBr/H₂O and having a cooling COP of 1.4 or better.

Advanced Refrigeration/Component Technology (HP)

The objective of this program is to develop and commercialize an advanced Air-to-Air Heat Pump with a system of 20 SEER and 13 HSPF. Complete modeling of alternate refrigerant blends for electric heat pump applications.

Advanced Refrigeration/Component Technology (Refrig)

Develop a 1 kWh/day refrigerator.

Fuel Cell Building Microcogeneration

The objective of this program is to develop and demonstrate technologies, up to 50 kW in size, which are unique to the building applications and are not being addressed by other fuel cell programs. Develop a PEM fuel cell that is suited for cogeneration, and a high temperature membrane that will improve the cogeneration, and a high temperature membrane that will improve the cogeneration potential of the fuel cell.

Adv. Light Sources & Electronics: Low Power S-lamps

The purpose of this technology is to continue development of a low-power S-lamp source, completing the development of the VHF electronics design, and work on new light distribution systems utilizing light pipes. Develop low power sulfur lamp.

Lighting Collaborative (CFL)

The objective of this technology is to continue the development of dedicated compact fluorescent fixtures. Continue efforts to replace incandescent lamps with dedicated CFLs.

Energy Saver Partnerships

The objective of this program is to achieve energy savings by increasing the market penetration of advanced, energy-efficient equipment for lighting and appliances. Technologies include high-efficiency clothes washers, sulfur lamps, hot wastewater recycle systems, packaged terminal AC, dedicated CFLs, residential electric HP water heaters, dish washers, refrigerators, and other high-efficiency equipment.

Commercial Appliances: Test Procedures, Standards, and Labeling

The objective of this program is to continue research to develop, maintain, simplify, and improve test procedures for appliances; and to continue the support of voluntary efficiency rating and labeling programs for commercial office equipment and luminaires.

Urban Heat Islands/Highly Reflective Surfaces

The objective of this program is to reduce the heat island effect in urban areas by researching and developing building surface materials that minimize heat transfer. Model community wide cooling effects of light surfaces and vegetation in urban communities, adopt standardized measurement and product labeling of light color products.

Technology Transfer Information & Outreach

Monitor and analyze technical advances and research developments to develop and disseminate results through training of architects, builders, engineers, developers, and trades people.

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